LPM2007

8th International Symposium on Laser Precision Microfabrication

April 24 - 28, 2007, University of Vienna, Austria

Main Building, Dr.-Karl-Lueger-Ring 1, A-1010 Vienna

Program & Abstracts

Local Chairmen

Wolfgang Kautek (University of Vienna)
Dieter Schuöcker (Vienna University of Technology)

Editors

Wolfgang Kautek, Günter Trettenhahn
Claudia Weber, Christian Zafiu

Homepage

http://cms.univie.ac.at/lpm2007/

Foreword

Prof. Dr. Wolfgang Kautek
Local Chair, LPM 2007

Laser micro-fabrication has become a fast growing field of science and technology. This trend was triggered by relying on a highly directional light beam, easily focused into a close to diffraction-limited spot size. With the development of pulsed lasers with progressively shorter pulse durations, the field of laser material processing emerged. The thorough understanding of the physical and chemical mechanisms of light–matter interactions and ablation at high irradiance became the prerequisite of a widening number of scientific and industrial applications.

Particularly ultrashort (subpicosecond) lasers have expanded the field of material processing into the real three-dimensional (3D) domain. Ablation can be used to fabricate 3D microstructures on the one hand, however, highly nonlinear light–matter interaction made possible by the ultimate light intensities achieved by ultrashort pulses allows real 3D structuring of materials from the "inside" (bulk). Thus, even nanomicro-structuring is provided in the irradiance range of more than 10^{14} Wcm^{-2} Combined with modern mechanical micro-technological technologies, this makes the ultrashort pulse approach attractive in terms of its “green”, environmentally friendly, high precision and effective single-step procedure.

The "8th International Symposium on Laser Precision Microfabrication", LPM 2007, provides a forum for discussion on the fundamental aspects of laser/material interaction, the state of the art of laser materials processing and in the germination of next-generation ideas that arises from collaborating scientists, end users and laser manufacturers. LPM 2007 is based on a series of yearly held symposia in Omiya / Japan (2000), Singapore (2001), Osaka / Japan (2002), Munich / Germany(2003), Nara / Japan (2004), Williamsburg / USA (2005), and Kyoto / Japan (2006).

A major special session is being jointly organized together with the "3rd European Conference on Applications of Femtosecond Lasers in Materials Science", FemtoMat 2007. This looks back on a recent tradition of two events in Visegrád / Hungary (2002) and Bad Kleinkirchheim / Austria (2004).

The LPM 2007 is organized as a four-day event with a plenary session providing a thorough introduction into up-to-date laser processing and laser chemistry followed by micro- and nano-fabrication. There are two parallel oral sessions which will be interrupted around noon by so-called Poster Lunch Sessions characterized by poster presentations and Viennese buffet catering. A permanent table-top exhibition neighbouring the poster locations is allowing steady insight into recent product programmes and communication with modern laser and optics companies.

World authorities have been involved in the scientific planning of each session. My local co-chair, Dieter Schuöcker, and I would like to thank particularly them for their invaluable suggestions and support in the preparation of the program and the invitation of top-level invited speakers. We would like to acknowledge the steady help by the JLPS secretary Ms. Hiromi Teraoka, the general LPM chair Isamu Miyamoto, and the co-chairs, Koji Sugioka, Friedrich H. Dausinger, Henry Helvajian, Kazuyoshi Itoh, and Seiji Katayama.

There has been a broad interest and sponsoring support by Austrian public authorities both on the federal and the local city community level, by international organizations, but also by international and Austrian companies. Their contribution has been crucial for the realization of LPM 2007.

Last but not least we have to express our thanks to our local organizing committee, Magdalena Forster, Gerhard Humenberger, Günter Trettenhahn, Claudia Weber, and Christian Zafiu, without their help the preparation of LPM 2007 would not have been possible.

We hope that LPM 2007 and Austrian hospitality will serve as a platform of intensive scientific and technological communication which may yield progress in laser nanomicro fabrication technologies world-wide, and may eventually also lead to friendships between scientists.

Vienna, April 2007

Wolfgang Kautek (University of Vienna)
Dieter Schuöcker (Vienna University of Technology)

Sponsors

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Email: office@goech.at; http://www.goech.at/

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Dr.-Karl-Lueger-Ring 1, A-1010 Vienna
http://www.univie.ac.at

Vienna University of Technology
Karlsplatz 13
1040 Wien
http://www.tuwien.ac.at

Austrian Laser Association
Arbeitsgemeinschaft für Lasertechnik (ARGELAS)
Arsenal, Obj.207, Franz-Grill Str. 1, A-1030 Wien
E-Mail: sekretariat+e345@tuwien.ac.at; Internet: http://www.argelas.org

European Office of Aerospace Research & Development (EOARD)
EDISON House, London, UK

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Internet: http://www.bmwf.gv.at

Stadt Wien
Kulturabteilung (Magistratsabteilung 7)
Friedrich-Schmidtplatz 5, A-1080 Wien (Rathaus)
E-Mail: post@m07.magwien.gv.at; http://www.wien.gv.at/kultur/abteilung/

Vienna Convention Bureau
Untere Augartenstrasse 38 / Top 5, A-1020 Wien
E-Mail: convention@vienna.info; http://www1.vienna.convention.at

Erwin Schrödinger Society for Nanosciences
Schmiedlstrasse 6, A-8042 Graz
E-Mail: ruth.prassl@oeaw.ac.at; http://www.ibr.oeaw.ac.at/esgnano/en/index.html

Austrian Society for Microsystem Technology (OGMS)
Floragasse 7/2, A-1040 Wien
E-Mail: office@ogms.at; http://www.ogms.at/default_e.htm

High Q Laser Production GmbH
Kaiser-Franz-Josef-Str. 61, A-6845 Hohenems
E-Mail: sales@highqlaser.at; http://www.highqlaser.at

Time-Bandwidth Products AG (TBP)
Technoparkstrasse 1
CH-8005 Zürich
E-mail: info@tbwp.com; http://www.tbwp.com/

Coherent Inc.
5100 Patrick Henry Drive
Santa Clara, CA 95054 USA
http://www.coherent.com/

LASER 2000 in cooperation with 3D MICROMAC

3-D Micromac AG
Annaberger Straße 240
D-09125, Chemnitz
http://www.3d-micromac.com/

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FEMTOLASERS Produktions GmbH

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A - 1100 Vienna
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Auenstraße 3 - 5, D-98529 Suhl
E-Mail: info@erothitan.com; http://www.erothitan.com/

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University of Vienna

Botanical Garden of the University of Vienna
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email: botanik@univie.ac.at; http://www.botanik.univie.ac.at/hbv/english/hbv.htm

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Maps

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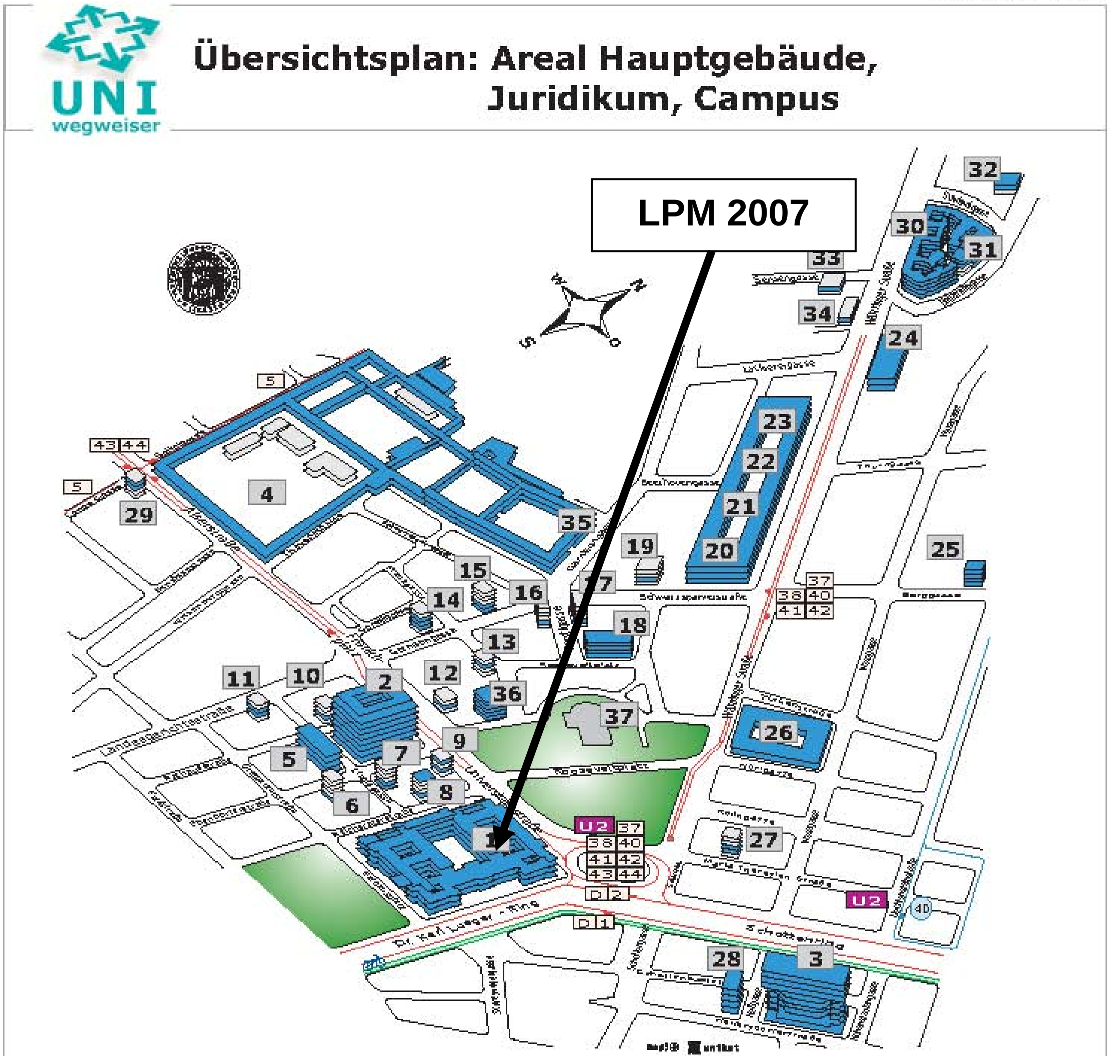

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2 Neues Institutsgebäude (NIG), 1. Universitätsstraße 7
3 Juridikum, 1. Schottenbastei 10-16
4 Universitätscampus (Campus), 9. Spitalgasse 2
5 1. Liebiggasse 5
6 1. Ebendorferstraße 10
7 1. Liebiggasse 4
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12 9. Universitätsstraße 2
13 9. Frankgasse 1
14 9. Garnisongasse 10
15 9. Garnisongasse 7
16 9. Ferstlgasse 7
17 9. Ferstlgasse 6
18 9. Rooseveltplatz 10
19 9. Schwarzspanierstraße 15
20 9. Schwarzspanierstraße 17
21 9. Währinger Straße 13
22 Institut f. Pharmakologie, 9. Währinger Straße 13a
23 9. Währinger Straße 17
24 9. Währinger Straße 28
25 9. Berggasse 11
26 9. Währinger Straße 10
27 9. Maria Theresien Straße 3
28 Juristische Institute, 1. Heßgasse 1
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30 Universitätszentrum Boltzmanngasse
9. Währinger Straße 38
9. Währinger Straße 42
9. Boltzmanngasse 1
9. Boltzmanngasse 5
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31 9. Boltzmanngasse 3
32 9. Boltzmanngasse 9
33 9. Sensengasse 8
34 9. Währinger Straße 25
35 9. Garnisongasse 13
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Hochparterre

Raised Ground Floor

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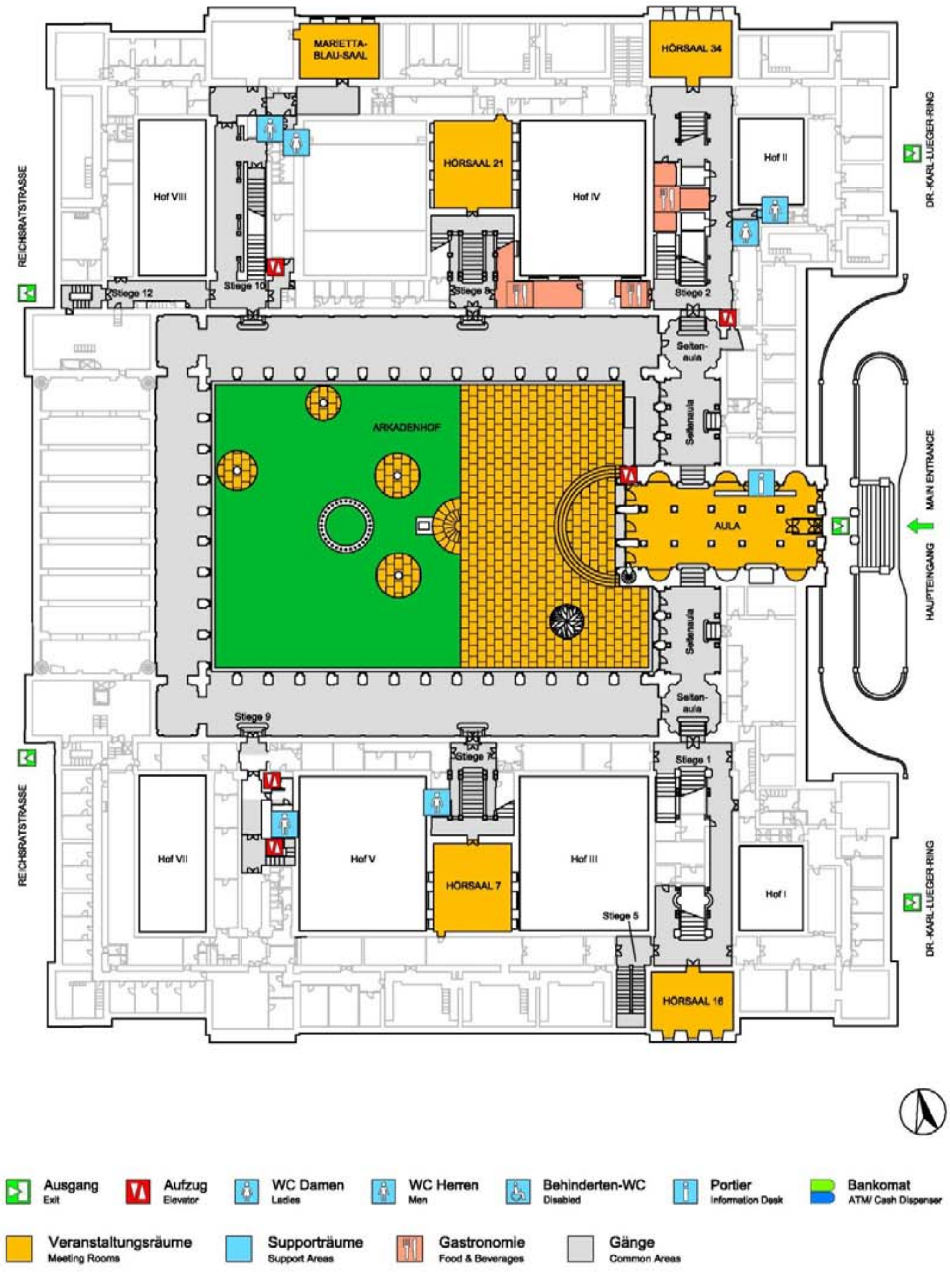

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1. Stock 1st Floor

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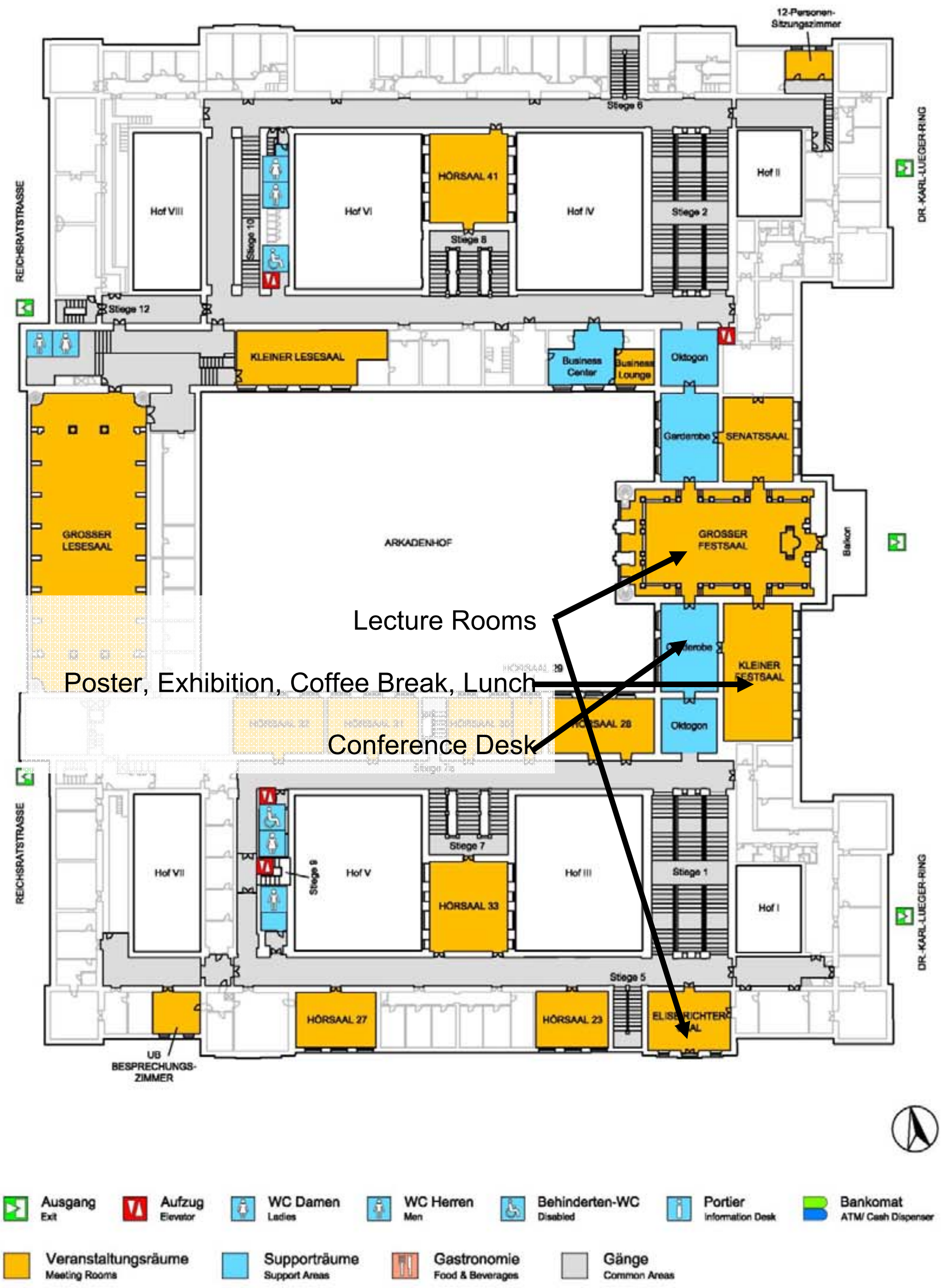

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Special Events

Table-Top Exhibition

From Tuesday afternoon, April 24, until Friday evening, April 27.

Kleiner Festsaal

Poster Lunch Sessions

From Wednesday, April 25, until Friday, April 27

Kleiner Festsaal and Reception Hall

Complimentary Viennese Buffet served (Sponsors indicated)

Coffee Breaks

Everyday

Kleiner Festsaal and Reception Hall

Femtolasers Company Reception

Thursday, April 26, 19:00h

Bus service to Femtolasers provided. Dinner Buffet offered.

LPM Conference Dinner

Friday, April 27, 19:00h

Bus service provided.

Grinzing

LPM Committee Meeting

(Invited members)

Wednesday, April 25, 19:00h

Hotel Regina

ONLINE LPM2007 PROCEEDINGS

Submission Due Date (on-site): April 24, 2007

CD-R media with both PDF and Word files and one hardcopy should be delivered on April 24, 2007 on-site at the conference office desk. The LPM2007 Proceedings will be published online after the event. Full Registration will include the access to the online LPM2007 Proceeding.

Manuscript Guidelines and Copyright Transfer Form:
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Program:

Tuesday, April 24
11:00-15:00 **Registration Time**
15:00-15:30 **Opening Remarks**
15:30-16:30 **Plenary Talk** **Bäuerle** (Inv.) Laser processing and chemistry: Fundamentals and applications in micro- and nano-fabrication
Coffee Break 16:30-17:00
Session 4-1 17:00 We 4-01 **Forsman** (Inv.) Advanced double pulse format for increasing the speed and quality of high aspect ratio laser micromachining
17:30 We 4-02 Veiko Nonlinear Nd:YAG laser-induced optical blooming of glass-ceramics
17:50 We 4-03 Ito Fabrication of an OLED display using an ultra-short fiber laser
18:10 We 4-04 Haglund Electronic properties of thin polymer films deposited by resonant infrared laser ablation
18:30-20:00 **3D-Micromac Welcome Reception**

Wednesday, April 25	
Großer Festsaal	Elise Richter Saal
Session S1-1 9:00 **We S1-01** **Nakata** (Inv.) Nano-sized and periodic structures generated by interfering femtosecond laser processing	**Session S3-1** 9:00 We S3-01 **John** (Inv.) Optical Lithography of Photonic Band Gap Materials
9:30 We S1-02 Reif Control parameters for self-organized nanostructure formation upon femtosecond laser ablation	09:30 We S3-02 Bekesi Grating interferometers for efficient generation of large area grating structures via laser ablation
9:50 We S1-03 Zhao Periodic structuring of metals by femtosecond laser pulses	9:50 We S3-03 Ganser Fabrication of Nd:Gd3Ga5O12 planar waveguide laser by pulsed laser radiation
10:10 We S1-04 Sun Standing electron plasma wave mechanism of void array formation inside glass irradiated by femtosecond laser pulses	10:10 We S3-04 Maerten Trouble Shooting and Optimization of Laser Beam Parameters for Precision Micro Fabrication by Beam Analysis
Coffee Break 10:30-11:00	
Session S1-2 11:00 We S1-05 **Boneberg** (Inv.) Focussing fs-pulses with optical near-fields	**Session S3-2** 11:00 We S3-05 Katayama In-Process Monitoring and Adaptive Control during Micro Welding with CW Fiber Laser
11:30 We S1-06 Stoian Energy coupling and material removal from metallic surfaces irradiated by temporally-shaped and ultrashort laser pulses	11:20 We S3-06 Brockmann Latest Disk Laser for Industrial Applications
11:50 We S1-07 Izawa Ultra low energy crystallization process for Si by femtosecond laser irradiation	11:40 We S3-07 Weiler Ablative laser micro processing with short and ultrashort pulses

<table>
<tr><th colspan="2">Wednesday, April 25</th></tr>
<tr><th>Großer Festsaal</th><th>Elise Richter Saal</th></tr>
<tr><td>12:10 We S1-08
Horn
Investigations onmelting and welding of glass by ultra-short pulsed laser radiation</td><td>12:00 We S3-08
Hoenninger
Millijoule high-repetition rate femtosecond laser amplifier</td></tr>
<tr><td colspan="2">12:30-14:30
Time Bandwidth Products AG
Poster Lunch Session</td></tr>
<tr><td>Session S2-1
14:30 We S2-01
Rode (Inv.)
3D write-read-erase memory bits by femtosecond laser pulses in photorefractive LiNbO3 crystal</td><td>Session 6-1
14:30 We 6-01
Howard
Mechanisms of water assist for overcoming the self-limiting effects of high aspect ratio machining of silicon and for minimising particulate redeposit</td></tr>
<tr><td>15:00 We S2-02
M. Hong
Multi-lens array fabrication and its applications in laser precision engineering</td><td>14:50 We 6-02
Zhigang
The Hydrodynamic theory and Simulation of Liquid Phase for Laser shock Process</td></tr>
<tr><td>15:20 We S2-03
Misawa
Three-Dimensional Femtosecond Laser Microfabrication</td><td>15:10 We 6-03
Komatsu
Self-organized growth of sp3-bonded 5H-BN electron-emitter micro cones prepared by plasma-assisted laser chemical vapor deposition: experiments and modeling</td></tr>
<tr><td>15:40 We S2-04
Neumeister
3-D micro fabrication of mechanical systems using laser based stereo lithography</td><td>15:30 We 6-04
Boehme
Laser-induced writing of submicron surface relief gratings in fused silica on-the-fly</td></tr>
<tr><td>16:00 We S2-05
Passinger
Two-Photon Polymerization System for Research and Industrial Applications</td><td></td></tr>
<tr><td colspan="2">Coffee Break 16:30-17:00</td></tr>
</table>

Wednesday, April 25	
Großer Festsaal	Elise Richter Saal
Session S2-2 17:00 **We S2-06** **LeHarzic** (Inv.) Nanostructuring with Nanojoule Femtosecond Laser Pulses	**Session 11-1** 17:00 We 11-01 Delmdahl VUV laser technology for nanostructuring
17:30 We S2-07 Gonzalo Optical and vibrational properties of self organized silver nanocolumns	17:20 We 11-02 Baek Organic layer direct patterning using a DUV excimer laser
17:50 We S2-08 Miyamoto Characteristics of internal melting of glass for fusion welding using ps laser pulses with average power up to 8W	17:40 We 11-03 Cefalas Dynamics and VUV laser processing of functional polymeric surfaces
18:10 We S2-09 Zh. Wang Femtosecond laser direct fabrication of 3D microoptical components buried inside of photosensitive glass	
19:00 LPM Committee Meeting	

Thursday, April 26	
Großer Festsaal	**Elise Richter Saal**
Session S1-3 9:00 Th S1-09 **M. Schmidt** (Inv.) Non-thermal micro adjustment using ultrashort laser pulses	**Session 4-2** 9:00 Th 4-05 **Kim** (Inv.) A Experimental Study on Raising the Efficiency of Production for Industrial SFF system
9:30 Th S1-10 Miyazaki Nanostructuring with femtosecond laser pulses on patterned DLC surface	09:30 Th 4-06 Fukuda Development of dry-etching system with Q-switched DPSS lasers for flat panel display
9:50 Th S1-11 Mizoshiri Silica-based nonplanar structures fabricated by femtosecond laser lithography and plasma etching	9:50 Th 4-07 Molpeceres UV laser microprocessing of photovoltaic devices based on thin film a-Si:H
10:10 Th S1-12 Ko Lithography-free, high resolution polymer transistors by conductive polymer laser ablation	10:10 Th 4-08 Zoppel Selective Laser Ablation of Photoresists for MEMS Devices
Coffee Break 10:30-11:00	
Session S1-4 11:00 Th S1-13 **Papazoglou** (Inv.) Micro-filamentation induced permanent structural modifications in fused silica with intense sub-picosecond ultraviolet laser pulses	**Session 4-3** 11:00 Th 4-09 Arnold Rapidly tunable Bessel beam and pattern generation for laser microprocessing
11:30 Th S1-14 Baumert Tailored femtosecond pulses for nanoscale laser processing of wide band gap materials	11:20 Th 4-10 Gaspard Laser induced foaming and chemical modifications of gelatine films
11:50 Th S1-15 Solis Structural transformation dynamics below and above the ablation threshold in fused silica upon single pulse femtosecond laser irradiation	11:40 Th 4-11 Zhou Fabrication of Surface-enhanced Raman Scattering Substrate on Ag-doped Silicate Glass Using Femtosecond Laser

Thursday, April 26	
Großer Festsaal	Elise Richter Saal
12:10 Th S1-16 Mauclair Dynamic correction of optical aberrations during ultrafast laser photoinscription of waveguides in bulk transparent materials	12:00 Th 4-12 Pique Laser Fabricated Microelectronic Circuits on Flexible Substrates
12:30-14:30 **Hi-Q-Laser** **Poster Lunch Session**	
Session S2-3 14:30 Tu S2-10 **Cheng** (Inv.) Integration of multifunctions in glasses using 3D femtosecond laser microfabrication	**Session 5-1** 14:30 Tu 5-01 Meunier «Green» processing of stable and ultra-pure nanoparticles using femtosecond laser-induced supercontinuum generation in water
15:00 Tu S2-11 Anderson Femtosecond-laser induced negative refractive index shift in thin film $Ge_{0.23}Sb_{0.07}S_{0.70}$ chalcogenide glass	14:50 Tu 5-02 Hahn Influences on nanoparticle production during pulsed laser ablation
15:20 Th S2-12 Nishiyama Microfabrication of nonplanar surface structures by femtosecond laser lithography	15:10 Tu 5-03 Makimura Silica Nanomachining Using Laser Plasma Soft X-rays
15:40 Th S2-13 Nakamura Femtosecond Laser Direct Writing of Optical Waveguides in Silicone Film	15:30 Tu 5-04 Kobe Growth of bi-phase crystalline/amorphous Sm-Fe-Ta-N magnetic nano-droplets fabricated by PLD
16:00 Th S2-14 Noh Fabrication of a rainbow color logo (diffraction grating) using the picosecond laser	15:50 Tu 5-05 Guo Extensive laser nanopatterning by micro-particle lens arrays
Coffee Break 16:30-17:00	

Thursday, April 26	
Großer Festsaal	Elise Richter Saal
Session S2-4 17:00 Th S2-15 **Perrie** (Inv.) NUV and NIR Femtosecond Laser Modification of PMMA	**Session 9-2** 17:00 Th 9-06 Dickmann Laser micro-perforation “on-the-fly“ as an essential step of a novel process combination for micro-sieve production
17:30 **Th S2-16** **V. Schmidt** (Inv.) Two-photon 3D lithography: A versatile fabrication method for complex 3D shapes and optical interconnects within the scope of innovative industrial applications	17:20 Th 9-07 Michalowski Melt Dynamics and Burr Formation during Drilling with Ultrashort Pulses
18:00 Th S2-17 Ohmura Internal Modification of Ultra Thin Silicon Wafer by Permeable Pulse Laser	17:40 Th 9-08 Naeem Laser percussion drilling of aerospace materials with a 20KW peak power fiber delivered pulsed ND: YAG laser
18:20 Th S2-18 Tomita TEM observation of structural changes under 4H-SiC single crystal surface irradiated by femtosecond laser pulses	18:00 Th 9-09 Fortunato 3D modelling of LASER hardening and tempering of hypo-eutectoid steels

19:00	**Femtolasers Company Reception**

Friday, April 27	
Großer Festsaal	**Elise Richter Saal**
Session S1-5 9:00 Fr S1-17 **Obara** (Inv.) Overview of laser micro/nanoprocessing mediated with near field - the state of the art and future perspective	**Session 8-1** 9:00 Fr 8-01 **Bellec** (Inv.) Femtosecond irradiation of a photosensitive zinc phosphate glass containing silver
9:30 Fr S1-18 Audouard Ultrafast laser processing of metals: New tools and new results	9:30 Fr 8-02 Lippert Laser-Induced Forward Transfer (LIFT) of Sensitive Materials Using a Photolabile Dynamic Release Layer
9:50 Fr S1-19 **Hoeche** (Inv.) Pulsed Laser Deposition using Femtosecond Laser Radiation and Plasma Filtering	9:50 Fr 8-03 Glushkov Laser photoionization and photodissociation method and technologies for cleaning the semiconductor materials and preparing the films of pure composition at atomic level
	10:10 Fr 8-04 Ueta Micro-Marking Using Violet Laser Diode with Dyestuff and Pigments on Plastic Surfaces
Coffee Break 10:30-11:00	
Session 7-1 11:00 Fr 7-01 **Wintner** (Inv.) Ultra-Short Pulse Laser Ablation of Biological Hard Tissue and Biocompatibles	**Session S3-3** 11:00 Fr S3-09 **Nolte** (Inv.) Fiber lasers and amplifiers: Novel avenues to real world applications of ultrashort lasers
11:30 Fr 7-02 Ooie Laser-controlled pico-injector for nano-biodevices	11:30 Fr S3-10 Mai Fundamental and Beam Propagation Behavior of a Microjet® and Recent Applications using Laser MicroJet Technology
11:50 Fr 7-03 Baersch Ultrafast-laser-processed zirconia and its adhesion to dental cement	11:50 Fr S3-11 Tu On The Mechanism of Laser-Matter Interaction in Laser Drilling and Spot Welding

Friday, April 27	
Großer Festsaal	Elise Richter Saal
12:10 Fr 7-04 Yousif Investigation on Laser Dental Implants Decontamenation	
12:30-14:30 **Poster Lunch Session**	
Session 7-2 14:30 Fr 7-05 **Stoiber** (Inv.) Application of Femtosecond Lasers in Ophthalmology	**Session 9-1** 14:30 Fr 9-01 Arai Micromachining with a High Repetition Rate Femtosecond Fiber Laser
15:00 Fr 7-06 Chollet UV excimer laser ablation of RGD peptide grafted onto PET: Impact on cell attachment	14:50 Fr 9-02 Okamoto Fine Micro-welding of Thin Stainless Steel Sheet by High Speed Laser Scanning
15:20 Fr 7-07 Farsari Surface functionalization of 2D and 3D structures using biomolecules	15:10 Fr 9-03 Kraus Microdrilling in steel with frequency-doubled ultrashort pulsed laser radiation
15:40 Fr 7-08 Strassl Scanning of Ultra-Short Laser Pulses in Dental Applications	15:30 Fr 9-04 Demir Precision drilling of Ti6Al4V titanium alloy using pulsed Nd:YAG laser
16:00 Fr 7-09 Miyashita Autofluorescence of electrophoresis chip grooved by excimer laser	15:50 Fr 9-05 Ashkenasi Comparing DPSSL Micro Drilling and Cutting Applications at Different Wavelengths
Coffee Break 16:30-17:00	

Friday, April 27	
Großer Festsaal	Elise Richter Saal
Session 7-3 17:00 Fr 7-10 Stampfl Biofunctional Photopolymers for micro-stereolithography	**Session 10-1** 17:00 Fr 10-01 **Newaz** (Inv.) Miniaturized Samples for Bond Strength and Hermetic Sealing Evaluation for Transmission Laser Joints
17:20 Fr 7-11 Serra Laser-induced forward transfer of liquids for miniaturized biosensors preparation	17:30 Fr 10-02 Sari Laser Transmission Bonding and Welding of Silicon, Glass and other Brittle-Rigid Materials for Microsystems
17:40 Fr 7-12 Hanada Bio-microchips fabricated in transparent materials by femtosecond laser	17:50 Fr 10-03 Moalem Laser micro welding in silicon solar module manufacturing
18:00 Fr 7-13 Guillermot Infra-red (1064 nm) laser printing of biological elements: preliminary results	18:10 Fr 10-04 Richter Pulsed laser beam welding with filler wire
18:30-19:00 **Closing Remarks**	
19:00 **LPM Conference Dinner**	

Sessions

Special Session 1 (LPM-S-1)

Joint session with the "3rd European Conference on Applications of Femtosecond Lasers in Materials Science" - **FemtoMat 2007**:

Applications of Femtosecond Lasers in Materials Science
(Fundamentals, new processes, pulse shaping, etc.)

Session Organizers:
Eric Audouard (Université Jean Monnet, France), Ingolf Hertel (Max Born Institut, Germany), Xavier Solis (Consejo Superior de Investigaciones Científicas - CSIC, Spain), Xianfan Xu (Purdue University, USA)

Special Session 2 (LPM-S-2): 3D Micro- and Nanomachining

(Ultrafast Laser processing, buried optical circuits, photonic bandgap materials etc.)

Session Organizers:
Boris Chichov (Laser Zentrum Hannover, Germany), Minghui Hong (DSI-Data Storage Institute, Singapore), Alberto Piqué (Naval Research Laboratory, USA), Yoshiro Ito (Nagaoka University of Technology, Japan)

Special Session 3 (LPM-S-3): Advanced Laser Systems and Optics

(New Laser concepts and beam delivery systems, etc.)

Session Organizers:
Eric Fogarassy (Ecole nationale supérieure de physique de Strasbourg, France), Tino Petsch (3D-Micromac AG, Germany), Andreas Stingl (Femtolasers Produktions GmbH, Austria)

Session 4 (LPM-4): Micromachining and Processing

Session 5 (LPM-5): Nanotechnology and Nanomaterials

Session 6 (LPM-6): Laser Hybrid and Media-Assisted Processes

Session 7 (LPM-7): Biomedical and Analytical Applications

Session 8 (LPM-8): Photochemistry

Session 9 (LPM-9): Micro-Drilling and Cutting

Session 10 (LPM-10): Micro-Welding and Bonding

Session 11 (LPM-11): Deep UV Laser Application

Plenary Lecture

Tu Plenary Talk

Invited

Laser processing and chemistry: Fundamentals and applications in micro- and nano-fabrication

Dieter Bäuerle[1]

[1]Institut für Angewandte Physik, Johannes-Kepler-Universität Linz

Micro- and nanopatterning of various substrate materials by means of laser-direct writing and projection [1-3], by near-field optical techniques (SNOM), and by 2D lattices of microlenses [4] will be presented. The possibility of focused anomalous transmission through metal-coated microspheres with subwavelength apertures is discussed as well [5,6].

[1] D. Bäuerle: Laser Processing and Chemistry, 3rd ed. (Springer, Berlin, Heidelberg, 2000)
[2] S. Gigan et al.: Nature 444, 67 (2006)
[3] H.R. Böhm et al.: Appl. Phys. Lett. 89, 223101 (2006)
[4] D. Brodoceanu et al.: Appl. Phys. A 86, 313 (2007)
[5] L. Landström et al.: Appl. Phys. A 83, 271 (2006)
[6] G. Langer et al.: Appl. Phys. Lett. 89, 261104 (2006)

Special Session 1 (LPM-S-1)

Joint session with the "3rd European Conference on Applications of Femtosecond Lasers in Materials Science" - **FemtoMat 2007**:

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We S1-01

Invited

Nano-sized and periodic structures generated by interfering femtosecond laser processing

Yoshiki Nakata[1], Noriaki Miyanaga[1], Tatsuo Okada[1]

[1]Institute of Laser Engineering, Osaka University Grad. School of ISEE, Kyushu University

Nanotechnology based on nano-sized structures will innovate the next industrial revolution. Those structures have been produced by bottom-up techniques such as plasma process, CVD, laser ablation etc.. These methods have advantages in generation of quite small structures, but have difficulties in yield, versatility in kind of material, size and structure control, and alignment. On the other hand, material processing using femtosecond (fs) laser beam has been utilized to generate nano-sized structures on and in materials. We advanced the technique to use interfering fs laser beams in wide region, and nano-sized and periodic structures could be generated. When thin films are processed, nano-sized structures of nanobump array, nanomesh, nanobelt, dual periodic structure etc. can be generated. They have characteristic structures and allow us to promote new phase of nanotechnology. In this presentation, recent results of the generation of new nano-sized structures will be shown.

[1] Y. Nakata, T. Okada, and M. Maeda, Appl. Phys. Lett. 81, 4239 (2002).
[2] Y. Nakata, T. Okada, and M. Maeda, Jpn. J. Appl. Phys. 42, L1452 (2003) .
[3] Y. Nakata, T. Okada, and M. Maeda, Appl. Phys. A 79, 1481 (2004).
[4] Y. Nakata, N. Miyanaga, and T. Okada, to be published on Appl. Surf. Sci. (2007).

We S1-02

Control parameters for self-organized nanostructure formation upon femtosecond laser ablation

Juergen Reif[1], Olga Varlamova[1], Florenta Costache[1]

[1]Brandenburgische Technische Universitaet Cottbus and JointLab Cottbus

In self-organized nanostructure formation upon femtosecond laser ablation, it has been observed that the laser polarization is an important control parameter for the type of order achievable. Experiments on CaF2, using circular and elliptical polarization study this influence in more detail. For circular polarization spherical nanoparticles of about 100 nm diameter are formed, while with increasing ellipticity longer and longer ordered linear structures are generated, oriented perpendicular to the long axis of the polarization ellipse. A similar effect occurs when, instead, for circular polarization the angle of incidence is varied from normal to 45°. Here, the in-plane component of the incident beam appears to play the same control function as the long axis before. It determines length and orientation of the ordered ripples. For elliptical or linear polarization no such dependence on the angle of incidence has been observed. Varying the input polarization of the quarter wave plate, used to generate circular/elliptical polarization, a sharp phase transition in the ripples direction occurs at a rotation of the input by 90°. When the large axis of the ellipse is rotated behind the quarter wave plate, the ripples orientation rotates correspondingly. Further, surface defects like scratches or the edge of deeper craters tend to exert a stronger influence on the ripples orientation than the polarization, resulting in curved structures bending from polarization controlled to defect controlled orientation. For modelling the self-organization process, we still do not have clear evidence about the actual control mechanisms, since the laser field is no longer present when the structure formation seems to occur. Experiments superimposing the field of a weak cw-laser did not show any influence. Another approach may be the generation of surface plasmons surviving much longer which may influence the diffusion properties which plays an important role in the self-organization.

We S1-03

Periodic structuring of metals by femtosecond laser pulses

Q. Z. Zhao[1], S. Malzer[1], and L. J. Wang[1]

[1]Institute of Optics, Information and Photonics,Max-Planck Research Group and University Erlangen-Nuremberg

Periodic micro-/nano-scale structuring of metals, tungsten, copper, and stainless steel, etc., have been investigated by using single beam 800 nm femtosecond (fs) laser pulses irradiation. Ripple-like periodic structures are formed when the product of the pulse energy and the pulse numbers meets the threshold condition. The orientation of ripples is aligned perpendicularly to the direction of laser polarization for linearly polarized light, while +45 degree for left circularly polarized light and -45 degree for right circularly polarized light with respect to the incident plane of the beam. The period of ripple can be controlled by adjusting the pulse energy, the pulse numbers, and the incident angle. The experimental results do not follow the conventional prediction. We discuss a possible mechanism based on the interference between the incident light pulses and the excited plasma density wave. Our observation has potential application in large-area structuring of metals. Finally, under special pulse energy and pulse number conditions, mushroom-like nano-needles are formed on both the ridge and the valley of the ripple structures.

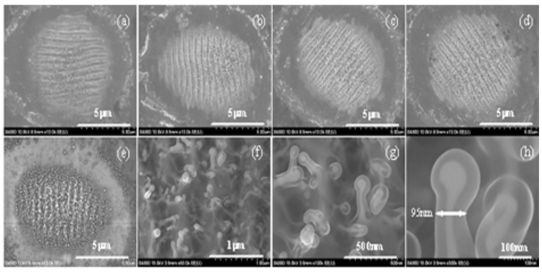

Fig. 1: Ripple structures on tungsten surface induced by (a) vertical and (b) horizontal linearly polarized fs pulses, and (c) left and (d) right circularly polarized fs pulses, respectively, and Mushroom-like nano-needles formed on both the ridge and the valley of ripples induced by fs pulses; (e) lower magnification and (f) to (h) increasing magnification.

We S1-04

Standing electron plasma wave mechanism of void array formation inside glass irradiated by femtosecond laser pulses

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The interaction of ultrashort laser pulses with transparent dielectrics has attracted much attention since the advent of the femtosecond (fs) laser, because it can lead to many interesting phenomena [1,2], such as filamentation, birefringence, formation of periodic void array, and so on. Among these phenomena, the formation of periodic void array in the direction of laser propagation is one of the most puzzling phenomena because of the lack of a good physical understanding. In this paper, we theoretically analyzed the formation mechanism of the void array. A regenerative amplified Ti: sapphire laser at wavelength of 800 nm that emits 120 fs, 1 kHz pulses was used in our study. We focused the pulses inside silica and BK7 glasses using a 100× objective lens (NA=0.9), and the induced characteristic structure is shown in Fig.1. In particular, we focus our study on the dependence of the period of the void array on the laser parameters, including pulse energy, pulse number and the focal depth. The results show that the period of each void array is not uniform along the laser propagation direction, and the average period of the void array decreases with increasing pulse number and pulse energy. Based on these experimental phenomena, we propose that a mechanism in which a standing electron plasma wave created by the interference of a fs-laser-driven electron wave and its reflected wave is responsible for the formation of the periodic void arrays. Reasonable agreement between the experimental results and the theoretical analysis was obtained.

1. S. Kanehira, J. Si, J. Qiu, K. Fujita, K. Hirao, Nano Letters 5, 1591 (2005).
2. E. Toratani, M. Kamata, M. Obara, Appl. Phys. Lett. 87, 171103 (2005).

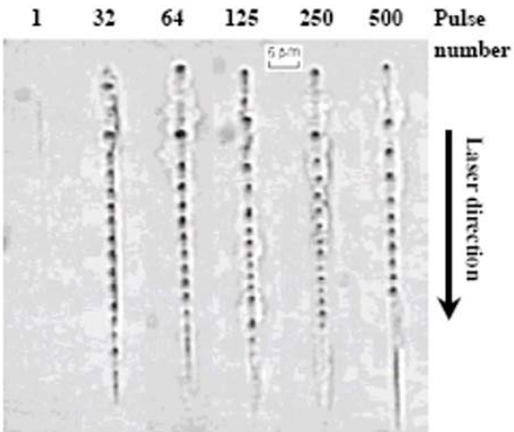

Fig. 1: Side views of BK7 glass when irradiate with an average single-pulse energy of 26.1 μJ focused 400 μm beneath the sample surface by a 100× object lens

We S1-05

Invited

Focussing fs-pulses with optical near-fields

Johannes Boneberg[1] and Paul Leiderer[1]

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The presentation will show how fs-laser pulses can be used to modify surfaces on a scale well below the diffraction limit. For that purpose the application of spherical particles as well as the use of optical near-fields of metallic nanostructures will be discussed. Spherical particles are easily applied to surfaces e.g. by spin coating. Nevertheless their usage with respect to dimensions well below the diffraction limit is restricted due to Mie scattering. There, the intensity enhancement decreases with particle size. At the same time the field distribution changes from one focus behind the particle to two foci at the side of the particle as the particle size decrease below the $\lambda/2$. For metallic particles or metallic nanoantennas these limitations do not exist. Field enhancements can be very high, thus very small features (<25nm for λ=800 nm) can be written. Nevertheless other complications exist as there are complicated near-fields and interference effects at higher particle densities.

We S1-06

Energy coupling and material removal from metallic surfaces irradiated by temporally-shaped and ultrashort laser pulses

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[2] CEA/DAM Ile de France, Département de Physique Théorique et Appliquée, 91680 Bruyères-le-Châtel, France
[3] Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, 12489 Berlin, Germany

We discuss the efficiency of energy coupling in laser-irradiated aluminium surfaces by ultrashort laser pulses with different intensity envelopes. The approach allows to test particle ejection from materials subjected to different heating rates. Ion and neutral emission from the excited sample is used to probe the efficiency of energy deposition in the material. Subsequently, we examine probable thermodynamic paths for material ejection under the laser action. With support from numerical simulations of the hydrodynamic advance of the excited matter, consequences of optimized energy coupling relevant for applications in material processing are revealed. The overall absorption efficiency can be elevated if the proper conditions of density and temperature are met for the expanding material layers. We show that, in particular irradiation regimes, laser energy delivery extending on several picoseconds leads to significant superheating of the superficial layers as compared to femtosecond irradiation and to a swift acceleration of the emitted particles. Subsequently, the lifetime of the post-irradiation liquid layer is diminished, which translates into a reduction in droplet ejection. Adaptive control of ion ejection from metallic samples via laser-generated supercritical states allows a certain degree of control in nano-droplets formation from the liquid phase. In contrast, short pulse irradiation at moderate fluences generates a higher quantity of removed material that is ejected in a dense mixture of gas and liquid-phase particulates.

We S1-07

Ultra low energy crystallization process for Si by femtosecond laser irradiation

Yusaku Izawa[1], Masayuki Fujita[2], Shigeki Tokita[1], Takayoshi Norimatsu[1], Yasukazu Izawa[1]

[1]Institute of Laser Engineering, Osaka University
[2]Institute for Laser Technology

We investigated laser wavelength dependences of crystallization process for Si by femtosecond laser irradiation, at room temperature in air. The near infrared light above 1100nm is almost transparent for Si. The absorption coefficient for 800 nm light, which is the fundamental wavelength of Ti: sapphire laser, is about 0.0001 nm-1. This value corresponds to 10 mm as light penetration depth. The absorption coefficient of Si increases with decreasing the laser wavelength. It is also expected that the laser fluence required in processing is smaller for the shorter wavelength lasers. In our experiments, we used the second and third harmonic generation by BBO crystal to convert the near infrared light of Ti: sapphire femtosecond laser into the shorter wavelengths. The fundamental wavelength of 800 nm and the frequency-converted wavelengths of 400 nm and 267 nm laser pulses [100 fs pulse width, 1000 Hz repetition rate] were focused on a thin amorphous Si layer [8 nm thickness] sputtered on a crystalline Si wafer [P type, (100) surface orientation, 99.999 % purity]. To confirm the crystallization process, we performed a high resolution transmission electron microscope observation. The change of the surface reflectivity was observed by means of laser scanning microscope. In three cases, the crystallization occurred below the ablation thresholds, the number of pulses required for sufficient crystallization was about 100. The fluences required for crystallization of 800 nm, 400 nm and 267 nm femtosecond laser irradiation were 100 mJ/cm2, 30 mJ/cm2, and 16 mJ/cm2, respectively. Ultra violet femtosecond laser is suitable for the fast crystallization of thin amorphous Si layer.

We S1-08

Investigations on melting and welding of glass by ultra-short pulsed laser radiation

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[1]Lehrstuhl für Lasertechnik der RWTH-Aachen, Germany

The interaction of laser radiation with pulse durations between 300 fs and 3 ps and wavelength λ = 810 nm with glass like BK7 or D263 glass is detected by pump&probe techniques. Even with femtosecond laser radiation melt ejection dynamics can be observed in the time-range of 100 ns to 1.4 μs by irradiating a glass on the surface using time-resolved shadowgraphy. Using ultra-short pulsed laser radiation glass plates are welded together. The pump beam is focussed by a microscope objective (2ω_0  1 μm) into the glass. After partial absorption of the optical energy the glass is heated. Due to the large intensities in the focus using high NA objectives multi-photon absorption gets the dominant process and due to large repetition rates heat is accumulated and meting of the glass is induced. By setting the intensity of the laser radiation below the ablation threshold glass can be melted inside and on the surface without cracking making welding of glass possible. The modification of a technical glass (D263 Schott) induced by ultra-short pulsed laser radiation with large repetition rates up to 5 MHz is observed during welding by time-resolved quantitative phase microscopy using ultra-short pulsed white-light continuum as probe beam. The change in refractive index induced by heating and by compression of the glass is detected.

Th S1-09

Invited

Non-thermal micro adjustment using ultrashort laser pulses

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[1]Bayerisches Laserzentrum gGmbH

In the field of micro technology highest accuracies have to be attained regarding position, angles and distances. To achieve this task within reasonable expenses roughly tolerated assembly followed by high-precision adjustment is often applied. As the final tolerances tend to get smaller in the same manner as the dimension of the devices common adjustment processes are reaching limits rapidly. To provide a better solution for this discrepancy the Bavarian Laser Center investigates a new process of highly accurate, contact-free and time-efficient micro adjustment for a wide variety of materials using ultrashort laser pulses. Basic researches have already been accomplished and actual efforts regard process limits, possible actuator materials, actuator geometry, process robustness, long term stability and industrial applicability. The process mechanism is based on the effect that an ultrashort laser pulse of high intensity is able to produce plasma on the surface of the absorbing bulk material in nearly isochoric manner. The following expansion of the plasma into the confining medium excites shock waves propagating into the bulk material due to recoil effects. These shock waves, which rapidly decay to compressional waves, induce near-surface plastic deformation which results in bending the actuator's free end away from the laser beam. Using suitable actuators this can be used for highly accurate adjustment. Results of previous investigations show that the bending angle can achieve accuracies in the scale of a few 10 µrad while allowing maximum deflections of a few degrees. Up to now copper, steel, silicon and pyrex-glass have been successfully deformed with this process.

Th S1-10

Nanostructuring with femtosecond laser pulses on patterned DLC surface

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[1]Institute of Advanced Energy, Kyoto University

Recent laser ablation experiments have shown that superimposed fs-laser pulses at low fluences can produce periodic nanostructures as small as 1/10 of laser wavelength on hard thin films such as TiN and diamond-like carbon (DLC) [1], suggesting a potential nano-processing technology with fs lasers. We report a preliminary experiment to demonstrate our proposal for the origin of nanostructuring on the thin film surface. The target was fabricated on Si substrate. Using electron-beam lithography and liftoff process, the Si surface was patterned with parallel lines of 200-1600 nm in interval, each of which is 100-500 nm in width, 50 nm in height, and 4500 nm in length. DLC of 900 nm in thickness was deposited on the patterned Si surface. This target was irradiated with multiple shots of linearly polarized, 100-fs, 800-nm laser pulse at low fluence, and the surface morphology was observed with a scanning electron and/or probe microscopes. The results have shown that the nanostructure oriented to the direction perpendicular to the laser polarization is formed on both of the patterned and non- patterned surface areas. However, we have found a significant difference between structures on the patterned and non-patterned areas. The mean spacing of nanostructure on the latter was about 100 nm or less, being in accordance with the previous observations [1]. On the other hand, much larger and deeper structure was created near and on the parallel lines, as if the patterned area were irradiated at higher fluence. This characteristic structure was observed only in the vicinity of the lines perpendicular to the laser polarization. This observation demonstrates that the nanostructure is created with nano-scale local fields enhanced around the surface pattern, as proposed in our study [2]. [1] N.Yasumaru, K.Miyazaki, and J.Kiuchi, Appl. Phys. A 76, 983 (2003); 81, 933 (2005). [2] G.Miyaji and K.Miyazaki, Appl. Phys. Lett. 89, 1919002 (2006).

Th S1-11

Silica-based nonplanar structures fabricated by femtosecond laser lithography and plasma etching

Mizue Mizoshiri [1], Hiroaki Nishiyama[1], Junji Nishii[2], Toshio Kawahara[3], Tomoji Kawai[3], Yoshinori Hirata[1]

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[2]National Institute of Advanced Industrial and Science Technology
[3]The Institute of Scientific and Industrial Research, Osaka University

Silica-based diffractive optical elements (DOEs) were widely used in many applications such as optical pickups. The nonplanar elements such as blazed gratings and micro-Fresnel lens were useful for high diffractive efficiencies. However, it is rather difficult to fabricate silica-based nonplanar microstructures by conventional semiconductor technology including lithography and plasma etching processes. In our study, silica-based micro-Fresnel lenses were fabricated on silica substrates by femtosecond laser lithography followed by plasma etching. Resist patterns of micro-Fresnel lens were written in a chemically amplified negative-tone photoresist KMPR-1050 on silica substrates utilizing multi-photon absorption induced by femtosecond laser. We utilized filamentation induced by femtosecond laser pulses for the resist patterning to reduce the scanning sequences. Then, resist patterns were transferred to the silica substrate by plasma etching with CHF3 and O2 mixed gas. Figure 1 shows a silica-based micro-Fresnel lens. The diameter and the height were 280 um and 5 um, respectively. The micro-Fresnel lenses with smooth surfaces were obtained. We are now trying to fabricate a silica-based diffractive/refractive hybrid lens by the combination process of femtosecond laser lithography and plasma etching. The preparation and characterization of the hybrid lens will be reported in detail.

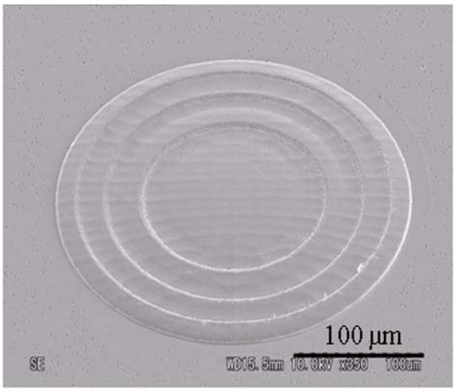

Fig. 1: SEM image of silica based micro Fresnel lens fabricated by femtosecond laser lithography followed by plasma etching

Th S1-12

Lithography-free, high resolution polymer transistors by conductive polymer laser ablation

Dr. Seung Hwan Ko[1], Heng Pan[1], Prof. Costas, P. Grigoropoulos[1], Prof. Dimos Poulikakos[1]

[1]University of California at Berkeley, USA ETH at Zurich, Switzerland

OFETs (organic field effect transistors) with air stable carboxylate-functionalized polythiophene semiconducting polymer as active layer were fabricated and characterized. Conductive polymer was used as electrodes. After depositing the conductive polymer, focused pulsed laser was applied to define high resolution channel with micron to submicron critical feature resolution in a fully maskless sequence, eliminating the need for any lithographic processes. All processing and characterization steps were carried out at plastic-compatible low temperatures and in air under ambient pressure.

Th S1-13

Invited

Micro-filamentation induced permanent structural modifications in fused silica with intense sub-picosecond ultraviolet laser pulses

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[3]National Technical University of Athens, Physics Department, Iroon Polytexneiou 9, 15780 Zografou, Athens, Greece

We report on the temporal dynamics of sub-picosecond ultraviolet laser pulse micro-filamentation in the bulk of fused silica. Using a high resolution pump-probe imaging technique we monitor the formation of plasma micro-filaments. Interestingly, single shot permanent structural modifications are observed only in areas where the electron density exceeds a threshold value of ~ 4×1019 cm-3. The length of the permanent modifications increases with pulse accumulation while saturates after a few hundreds of pulses. From this saturation we can extract a lower limit of the electron density. Applications in photonic devices will also be discussed.

Th S1-14

Tailored femtosecond pulses for nanoscale laser processing of wide band gap materials

L. Englert[1], B. Rethfeld[2], L. Haag[1], C. Sarpe-Tudoran[1] and T. Baumert[1]

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[2]Gesellschaft für Schwerionenforschung,
Planckstr. 1, D-64291 Darmstadt, Germany

Lasers delivering ultrashort pulses have emerged as a promising tool for processing wide band gap materials for a variety of applications ranging from precision micromachining on and below the wavelength of light to medical surgery [1]. It is the transient free-electron density in the conduction band of the dielectric that plays a fundamental role in addition to various propagation and relaxation mechanisms that in the end lead to phase transitions or the creation of voids. A large number of experiments devoted to the study of the microscopic ionization processes makes use of the threshold of observed damage as experimental evidence for exceeding a certain critical electron density after the laser interaction. These involve pulse duration measurements [2] and recent pulse-train experiments [3] all showing a strong dependence of the damage threshold on pulse duration and on pulse separation. In our work we make use of temporally asymmetric femtosecond pulses of identical fluence, identical spectral distribution and identical pulse duration in order to control photoionization and electron-electron impact ionization. Control leads to different final electron densities as the direct temporal profile and the time inverted profile address the two ionization processes in a different fashion. This results in observed different thresholds for material modification in fused silica ans sapphire as well as in reproducible lateral structures being an order of magnitude below the diffraction limit. [1] H. Misawa and S. Juodkazis, 3 D Laser Microfabrication WILEY-VCH Verlag GmbH & Co. KGaA, 2006. [2] A. C. Tien, S. Backus, H. C. Kapteyn, M. M. Murnane, and G. Mourou, Phys. Rev. Lett. 82, 3883-3886 (1999). [3] R. Stoian, M. Boyle, A. Thoss, A. Rosenfeld, G. Korn, I. V. Hertel, and E. E. B. Campbell, Appl. Phys. Lett. 80, 353-355 (2002).

Th S1-15

Structural transformation dynamics below and above the ablation threshold in fused silica upon single pulse femtosecond laser irradiation

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[2]Present address: Max-Born-Institut fuer Nichtlineare Optik und Kurzzeitspektroskopie,
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[3]Present address: Laboratoire de Spectrometrie Ionique et Moleculaire, Universite Claude Bernard Lyon 1- CNRS (UMR 5579), 43 Boulevard du 11 Novembre 1918,
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We have used time-resolved microscopy in order to investigate the temporal and spatial evolution of the ablation process in fused silica upon irradiation with single femtosecond laser pulses at 800 nm. Images of the surface reflectivity at 400 nm have been recorded at different delays, covering a time span from ~ 100 fs up to 20 ns. The quantitative analysis of the image sequence allows to determine the ultrafast evolution of the reflectivity of the surface at different local fluences. The observed reflectivity changes have been correlated to the density and spatial extension of the free-electron plasma formed upon laser exposure. The results show that an annular transient plasma region is formed outside the ablating region for fluences in a narrow window below the ablation threshold. This outer region is spatially coincident with a subtle structural transformation observed with light microcopy after irradiation. The material in this annular zone is structurally modified after irradiation and shows a reflectivity increase of app. 3% with respect to the non irradiated material. This is consistent with a refractive index change of 0.01, similar to the values reported upon fs laser irradiation inside bulk fused silica for the production of optical waveguides. To the best of our knowledge, this effect, being common inside bulk silica, has not been reported before in surface irradiation experiments. This structural modification below the ablation threshold would play a major role in the results induced upon multiple pulse laser exposure and help in understanding the role of incubation effects.

Th S1-16

Dynamic correction of optical aberrations during ultrafast laser photoinscription of waveguides in bulk transparent materials

C. Mauclair[1], A. Mermillod-Blondin[1], N. Huot[1], E. Audouard[1], and R. Stoian[1]

[1]Laboratoire Hubert Curien (UMR 5516 CNRS), Université Jean Monnet, 18 rue Prof. Benoit Lauras, 42000 Saint Etienne, France

The quality of a laser beam as well as the flexibility in tailoring intensity envelopes is becoming important in material processing applications in view of the demands of accuracy in the machining process. When 3D processing of structures with optical functions in bulk transparent materials is concerned, the linear and nonlinear propagation of the processing light beam is affected by its own spatial characteristics. For example, spatial beam distortions are often detrimental for the process of laser photoinscription of wave guiding elements in bulk transparent materials. Consequently, the axial redistribution of energy depends on the spatial characteristics of the incoming laser beam upon focusing in the bulk material, influencing therefore the dimensions and the nature of the laser-induced material modification. Spherical aberrations are usually induced during refraction at air-dielectric interfaces, creating a dependence of the deposited energy density on the depth of writing. We present in the following a procedure of dynamic correction of optical aberrations during longitudinal photoinscription in BK7 optical glass. The procedure involves the adaptive control of the spatial phase of the incoming beam using programmable spatial shaping of ultrafast laser pulses and relies on a positive feedback loop based on phase-contrast microscopy detection of laser-induced modifications.

Fr S1-17

Invited

Overview of laser micro/nanoprocessing mediated with near field - the state of the art and future perspective

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In this talk, we will experimentally and theoretically overview the laser micro and nano-processing mediated with near field and then describe the future perspective of the near field laser processing. The precise nanostructuring of various materials attracts a growing interest in recent years. This is related to the need for development of new optical, photonic and tribology components for micro and nano devices, and also related to the new effects and phenomena at such dimensions. Various methods and techniques are proposed and developed for producing nanostructured materials by means of electron and ion beam lithography, laser lithography, and direct laser write 2D and 3D structuring. Among the developed methods a promising technique would be to use a near-field of the dielectric particles due to Mie scattering, and a low dimension of the resonant plasmon field produced in metal nanostructures. If the diameter of the dielectric particle is smaller than the wavelength, a light enhancement effect may occur due to the near field scattering cross section based on the Mie's theory. The effect of the laser fluence, polarization, particle size and arrangement, on the nanohole properties is studied. Transparent spherical particles are placed on various substrate surface and nanoholes are fabricated at the original position of the particle using femtosecond laser. In the meantime, due to the effective coupling of the incident laser to the plasmon oscillation a significant enhancement of the field in vicinity of the metal structure can be produced. The main advantage of the two techniques is that the size of the field enhanced zone is governed not by the wavelength and polarization of the incident radiation, but by the size of the illuminated metal and dielectric structures. Finally we will focus on the promising prospective of the near field laser nanostructuring in photonics, electronics and tribology.

Fr S1-18

Ultrafast laser processing of metals: New tools and new results

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Ultrafast laser sources are considered as a promising tool for new micromachining applications. In the case of metals, a deep understanding of the main laser matter interaction mechanisms is now reached and relevant simulations can be done. At the same time, new application fields are reaching the industrial step. We will show also that increasing the repetition rate of laser sources can lower the processing time, by the use of sources based on a single non-cryogenic regenerative amplifier which produces after compression up to 350-µJ and 60-fs pulses at a 10 and 15 kHz repetition rate.A detailed model of the ultrashort response to reproduce ablation process is presented, describing dynamical electronic properties such as temperature, pressure and energy. To simulate the interaction between the laser and the metallic target, these theoretical models are inserted inside a 1D Lagrangian hydrodynamic code. We point out to the role of strong isochoric heating as a mechanism for producing highly non-equilibrium thermodynamic states. In the case of metals, the conditions of material ejection from the surface are discussed in a hydrodynamic context, allowing correlation of the thermodynamic features with ablation mechanisms. An estimation of the amount of material exceeding the specific energy required for melting is reported for copper and aluminium and a theoretical value of the limit-size of the recast material after ultrashort laser irradiation is determined. A specific application will be shown in the field of microtexturation of metallurgical surfaces and coatings. The objective is to reduce friction and wear in various lubrication regimes. The use of femtosecond laser pulses improves the achievable quality of the microstructures on any kinds of materials, in comparison to nanosecond laser pulses because of the minimized heat affected zone. Under rolling–sliding conditions, the film thickness distribution is modified, and specific effects can be point out.

Fr S1-19

Invited

Pulsed laser deposition using femtosecond laser radiation and plasma filtering

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When femtosecond lasers became available, huge expectations in regard of their utilisation for pulsed laser deposition (PLD) were raised. This was due to their ability to ablate all solid matter (via multiphoton absorption), the extraordinarily high pulse power (together with very short interaction times leading to mainly electronic excitations), and the highly ionised ablation plasma. It was believed that a high degree of ionisation would allow to deposit high-quality thin films without impairment by particulates. However, browsing through current literature reveals that PLD using femtosecond lasers is not yet widely used. This is related to two facts. First, due to small pulse energies, deposition rates are very low and second, and more importantly, in the very dense plasma, a large number of condensation droplets with a few 100 nm diameter is formed. In the end, the latter particulates are so dominating that thin-film quality is inferior. We have designed and build a UHV PLD workstation (currently operated in combination with a chirped-pulse amplification 775 nm Ti:sapphire laser, 130 fs pulse length, 1 kHz repetition rate) to study the mechanism of femtosecond laser deposition in greater depth. With this experimental setup, we have been investigating ultrathin-layer deposition of various rare metals as well as complex nitrides. Three general principles for particulate suppression were evaluated, including filtering by a transverse magnetic field, a bias supplied to the substrate, and scattering at a background gas. All of those methods proved viable, however, on the expense of the already very small deposition rate. Therefore, we are currently designing and testing a dedicated high-throughput plasma filter and first results of this development will be presented. Our PLD chamber equipped with a dedicated plasma filter will become a very valuable extension for preexisting ultrashort-pulse laser workstations enabling the generation of high-quality thin films.

Special Session 2 (LPM-S-2):

3D Micro- and Nanomachining
(Ultrafast Laser processing, buried optical circuits, photonic bandgap materials etc.)

Session Organizers:
Boris Chichov (Laser Zentrum Hannover, Germany), Minghui Hong (DSI-Data Storage Institute, Singapore), Alberto Piqué (Naval Research Laboratory, USA), Yoshiro Ito (Nagaoka University of Technology, Japan)

We S2-01

Invited

3D write-read-erase memory bits by femtosecond laser pulses in photorefractive LiNbO3 crystal

Eugene Gamaly[1], Saulius Juodkazis[2], Vygantas Mizeikis[2], Hiroaki Misawa[2], Andrei Rode[1], Wieslaw Krolikowski[1]

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We present results of experimental and theoretical studies of the formation of refractive index voxels in photorefractive crystals with high power femtosecond laser pulses. We used 150fs pulses at 800nm wavelength (energy 6-130nJ) tightly focused inside the iron-doped lithium niobate crystal in a single shot regime [1]. This resulted in a formation of a micrometer size (2xx2yx8z ?m3) region of elevated refractive index which may be used as memory bits in information storage/retrieval application [2]. The index contrast as high as 10-3 has been obtained with an average light intensity of ~Tw/cm2 that is close to the breakdown threshold in dielectrics [see Fig.1(a-b)]. The writing process is independent of the polarization of the laser beam and is fully reversible. Once written local modulation of the refractive index can be removed (erased) by the action of a low intensity broad beam and induced again at the same place (re-written) by using a tightly focused pulse. Up to 20 same-spot rewriting cycles have been performed without any deterioration of the recorded bits. Moreover, by moving the crystal in vertical direction few independent layers of bits have been recorded [see Fig.1(c)]. In this talk we discuss various aspects of the recording/erasing process including mechanisms of laser absorption, electron excitation and recombination, formation of charge separation field, as well as methods for control of the size and longevity of the refractive index changes. The analysis shows that the photovoltaic effect [3] is mainly responsible for these changes. The presented results suggest the possibility of suitability of properly chosen femtosecond pulses for fast 3D write-read-erase optical memory application.

We S2-02

Multi-lens array fabrication and its applications in laser precision engineering

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Slow processing speed is one of technical bottlenecks in laser precision engineering, especially as the processing resolution reduces down to sub-micron or even nanometer scale. Laser micro- & nano-fabrication of multi-lens array (MLA) is investigated by both laser direct writing approach and interference lithography, following with thermal reflow and reactive chemical etching. It is found that a large area (up to 1 cm2) MLA can be made uniformly on the transparent substrate with the lens diameter from 500 nm to 500 µm. The fabricated MLAs are used in the optical microscope and laser beam shaping to enhance imaging quality and tune laser beam profile for the top flat beam surface processing. With the special design of MLA scanning directions with the MLA orientation, surface multiplexing can be achieved. Meanwhile, different laser sources from UV to IR spectra and different pulse durations from 100 fs up to dozens of ns are used to fabricate different sub-micron/nanometer resolution surface structures in parallel. With the laser irradiation through a MLA on a sample surface immersed inside a chemical solution, high speed and large area sub-micron structure deposition under laser induced photo-chemical reactions is studied for micro/nanostructure fabrication as well.

We S2-03

Three-dimensional femtosecond laser microfabrication

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Three-dimensional (3D) structuring of glasses, ceramics, crystals, and polymers by tightly focused femtosecond laser pulses is a promising technique for microfluidic, micro-optical, photonic crystal and micro-mechanical applications [1-4]. The 3D laser micro-structuring of resists is demonstrated by direct laser writing [1] and holographic recording using phase control of interfering pulses [2]. Flexibility of the phase control method is demonstrated by forming a log-pile photonic template out of a tetragonal body centered structure by interference. 3D photonic crystal templates with stopband at a shorter than 1 micrometer wavelength have been achieved in resist by modified direct laser writing. Tightly focused laser pulses can reach dielectric breakdown irradiance without self-focusing when sub-1 ps pulses are used inside dielectric. The mechanism of void formation [3] has been explained. The absorption in the plasma at focus is localized within a skin depth of tens-of-nanometers. This defines an ultimate localization of the energy delivery by a laser pulse. The high temperature and pressure buildup can be large enough to generate a shock wave (strong micro-explosion). A single 100 nJ laser pulse forms a void under tight focusing conditions even in the high strength sapphire (Young modulus of 400 GPa). This opens new material processing routes for inert dielectrics [4]. Altered chemical properties of shock-affected regions inside silica glass, quartz, and sapphire were revealed by wet etching of “shocked” regions in aqueous solution of hydrofluoric acid. The achievable resolution limits and potential of the fabricated 3D patterns in photonics, microfluidics, and sensor applications are discussed.

[1] K. K. Seet et al., Adv. Mat. 17, 541, 2005.
[2] T. Kondo, et al., New J. Phys. 8, 250, 2006.
[3] S. Juodkazis, et al., Phys. Rev. Lett. 96 166101 2006.
[4] S. Juodkazis, et al., Adv. Mater. 18 1361 2006.

We S2-04

3-D micro fabrication of mechanical systems using laser based stereo lithography

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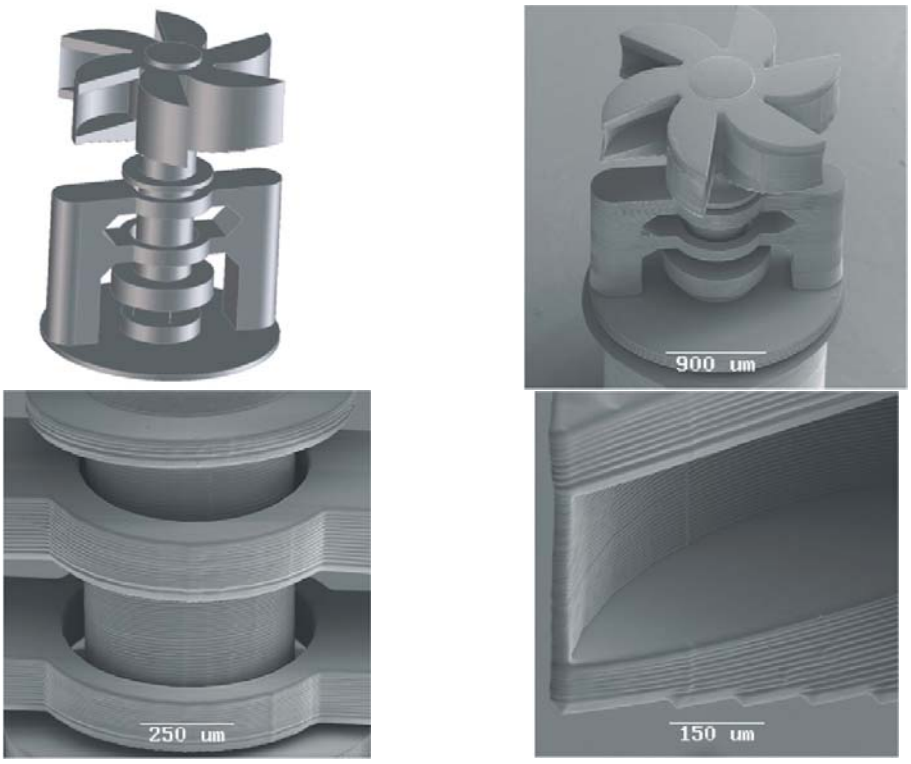
Within the presented work, we demonstrate the fabrication of micro mechanical systems by using laser based stereo lithography. For that aim, a high resolution machining setup for the creation of three-dimensional precision components from a UV-curable photo-resin has been developed. Functional micro-mechanical devices that include movable components are fabricated within a one step production without the need of assembling individual parts. The layer-by-layer fabrication process is directly based on user defined CAD data that will be sliced at a constant increment. For illumination purpose, a frequency-converted diode-pumped solid-state laser is applied, providing high structural surface quality due to a repetition rate of 100 MHz. Specially designed materials from the type Ormocere b59 offer a high process resolution up to 10 µm in both lateral and vertical dimension. In particular, we present the modification of the resin material and the consequences on the process resolution to achieve the suitability for micro stereo lithography.



We S2-05

Two-photon polymerization system for research and industrial applications

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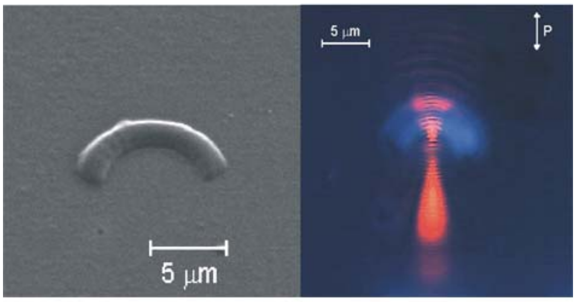
Two photon polymerization (2PP) is a very promising technique offering new possibilities in micromechanical, microoptical, and biomedical applications. In this contribution, the development of a 2PP system for industrial applications is reported. The topic of surface plasmon polaritons is taken as an example for the application of 2PP. Waveguides, Bends, Splitters, Couplers and other plasmonic structures are fabricated by two-photon induced polymerization of a high refractive index in-organic-organic hybrid polymer. The SPP structures are investigated in the far-field by a leakage radiation setup for their plasmon-excitation and -guiding properties. As an example Fig. 1 shows on the left a SEM image of a curved structure fabricated by 2PP. On the right the plasmon excitation is observed in a leakage radiation setup. Quality of 2PP structures fabricated with different writting speeds are compared and a high speed, high quality, and large area 2PP structuring is demonstrated.



We S2-06

Invited

Nanostructuring with nanojoule femtosecond laser pulses

R. Le Harzic [1,2], H. Schuck [1], F. Bauerfeld [1], D. Sauer [1], T. Velten [1], P. Becker [1], E. Lai [1], M. Stark [1], K. König [1]

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Sub-wavelength multiphoton nanoprocessing of silicon wafers, direct nanowriting of metals or polymers, laser processing for nanofluidics applications as well as 3D maskless lithography by two two-photon polymerization in combination with five-dimensional (x,y,z,□,□) multiphoton analysis have been performed using several compact near infrared MHz femtosecond lasers as tuneable turn-key, one-box Chameleon (coherent) and Mai-Tai (spectra physics) oscillators as well as a special femtoTrain system (High Q laser). The lasers were coupled with scanning microscopes as the FemtOcut (JenLab GmbH) device as well as a modified ZEISS LSM510-NLO system. Nanostructuring of silicon wafers was based on NIR laser-induced periodic surface structures (LIPPS) likely due to self-organization processes. Periodic structures of less than 400 nm were performed at a wavelength of 1035 nm in air. For the first time, periodic 70nm nanogrooves have been generated in wafers using oil immersion objectives which is one order below the 800 nm [1]. Nanogrooves of 150-200nm can be achieved by UV direct writing at 345 nm. Three-dimensional two-photon polymerization in SU-8 photoresists at allowed rapid prototyping with sub-200 nm precision. MHz femtosecond laser pulses with nanojoule photon energies can be considered as novel tools for nanoprocessing in material science, nanobiotechnology and nanomedicine.

[1] R. Le Harzic, H. Schuck, D. Sauer, T. Anhut, I. Riemann, T. Velten, K. König, “Sub-100 nm nanostructuring of silicon by ultrashort laser pulses”, Optics Express, 13, 6651-6656 (2005).

We S2-07

Optical and vibrational properties of self organized silver nanocolumns

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The optical properties of silver nanostructures are determined by the absorption at the surface plasmon resonance (SPR) wavelength which depends on their morphology. The vibrational properties also depend on the morphology and are particularly interesting for SERS applications. Further tuning of the SPR can be achieved through the synthesis of complex nanoparticles with taylored sizes and shapes. Among possible ways for achieving a control on the morphology, we have recently produced self aligned nanocolumns in the direction perpendicular to the substrate. The aim of this work is to explore the interaction between surface plasmons and vibrational modes in such “nanodesigned” composites formed by oriented metal nanocolumns embedded in a dielectric host. In a previous work, we have successfully used pulsed laser deposition to produce silver nanoparticles in an amorphous Al2O3 host. The nanoparticles are located within layers whose separation can easily be controlled. This technology has been extended to produce self-assembled nanocolumns by reducing the distance between consecutive layers. The analysis of nanocolumn morphology shows that they have a diameter of 2.7 nm and a height of 6.7 nm, which corresponds to an aspect ratio around 2.5. The non-spherical shape of the nanoparticles is evidenced in the optical absorption spectra through the presence of the longitudinal and transverse SPRs located respectively at lower and higher wavelength than that of spherical nanoparticles. Under resonant excitation of the longitudinal surface plasmons a low frequency band is observed in the Raman scattering spectra, which is assigned to the spheroid-like vibration mode (l=2, m=+2,-2)of the nanocolumns. The corresponding vibration frequency calculated using molecular dynamics simulations agrees well with the experimentally measured frequency. The reported results shed light on the plasmon-phonon interaction in metal nano-objects.

We S2-08

Characteristics of internal melting of glass for fusion welding using ps laser pulses with average power up to 8W

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Glass is an attractive material for devices such as MEMS, μ-TAS, electronics and biomedicals due to its excellent optical, mechanical and chemical properties. It is required to develop reliable and high-throughput joining technique without pre- and post-heating and inter layers. Picosecond laser is an excellent tool for fusion welding of glass, which enables joining of glass plates very efficiently by selective melting of the interface of the glass plates [1]. This paper discusses characteristics of internal glass melting using10ps laser with high pulse repetition rates up to 1MHz and high average power of 8W from Lumera Laser GmbH. The effects of pulse energy, repetition rate, lens NA and focus position on the nonlinear absorptivity, melt dimensions are extensively determined at a velocity range of 1-500mm/s for different glass materials (fused silica, pyrex glass, crown glass and display glass (Shott D263)) having different band gap energies. The melt dimensions are analyzed based on thermal conduction model [1]. The threshold energy of the nonlinear absorption was nearly constant ~0.2μJ despite of large difference in band gap energy, except for D263 of somewhat larger value of 0.3μJ, as is shown in Fig. 1. Local melting of fused silica was obtained without cracking at high average power level of 6W, while cracks are easily developed at low average power. Figure 2 shows the laser- melted cross-sections of fused silica between 500kHz and 1MHz at 6W. It is interesting to see that the melted regions in 500kHz are larger than 1MHz, indicating that lower pulse repetition rate provides larger melting region.

[1] I. Miyamoto et al: Local melting of glass material and its application to direct fusion welding by ps-laser pulses, JLMN, Vol. 3, No.1 (2007) to be published

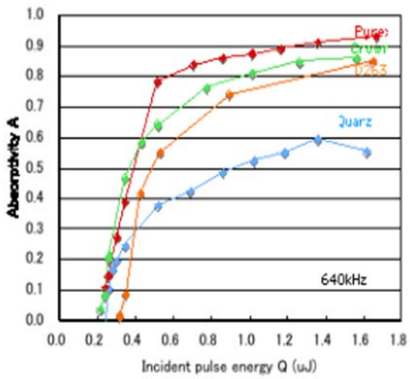

Fig. 1: Nonlinear absorptivity vs. pulse energy at pulse repetition rate of 640 kHz

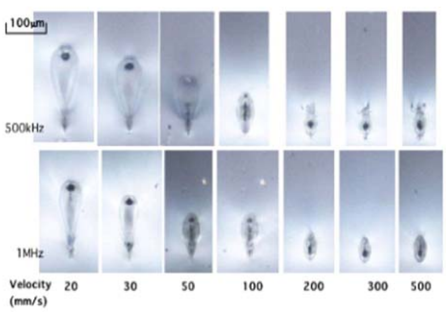

Fig. 2: Melt cross-section at different travelling velocities at 500 kHz and 1 MHz in fused quartz

We S2-09

Femtosecond laser direct fabrication of 3D microoptical components buried inside of photosensitive glass

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Recent years, microchip devices are of great interests and have received the much attention for highly efficient performance of chemical analysis, biosensing, medical inspection, etc. with great ease of use. As a result, these demands have drived the significant progress in the fabrication and incorporation of microoptical circuits into microfulidic circuits inside the bulk of a transparent material using femtosecond laser micromaching [1]. With the developing in application, the enhanced functionality of these microchips has put out more and more the requirements of a wide variety of optical structures in the construction of fluidic photonic integrated devices, for example, the integrated light collimating system with microlens and slits for a highly efficient and sensitive absorbance detection in a capillary electrophoresis microchip [2], etc. In this work, we demonstrate the fabrication of the cylindrical microlens and hemispherical plane-convex microlens embedded inside of bulk Foturan photosensitive glass using fs laser direct writing followed by programmed thermal treatment and successive wet etching. Fabrication of the cylindrical and hemispherical plane-convex microlenses made of the Foturan glass by the fs laser processing has been reported [3]. In this case, however, these microleses were gouged out from the bulk. In the meanwhile, in this paper, the microlenses which consist of hollow structures are truly embedded inside of the Foturan glass. The functionality of the fabricated microlenses and the integration with mirror and waveguide will be shown in detailed in this presentation.

Th S2-10

Invited

Integration of multifunctions in glasses using 3D femtosecond laser microfabrication

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Integrating multifunctions into a common substrate poses a formidable challenge to micro- and nano-fabrication. Generally, micro-components of different functions need to be fabricated on different substrate materials by different technical approaches. Integration of the micro-components into a fully functional micro-device requires cumbersome assembly and packaging processes. Recent advances in femtosecond laser microfabrication provide a potential solution to this tough issue. In this paper, we describe the formation of optical, fluidic, electronic, and plasmonic elements on either photosensitive or non-photosensitive glasses as well as their integrations using femtosecond laser microfabrication. Particularly, we highlight the integration of microfluidics and microoptics in glass chips which leads to a series of key elements such as tunable optical waveguides and microfluidic lasers for lab-on-a-chip application. Shown in Fig. 1 is a single mode microfluidic optical waveguide fabricated on a microscope cover glass slip. In this waveguide, refractive-index-optimized liquid is fed into a microfluidic channel fabricated by femtosecond laser direct writing, which serves as the core of the waveguide. Lastly, we comment on several technical barriers currently existing, and suggest the potential solutions to them.

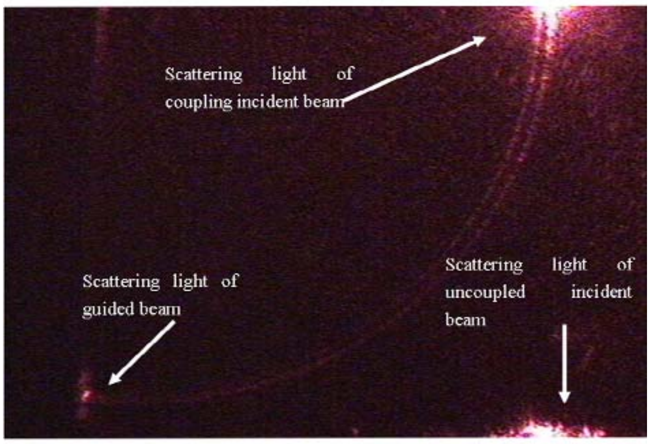

Fig. 1: Demonstration of microfluidic optical waveguide using a He-Ne Laser

Th S2-11

Femtosecond-laser induced negative refractive index shift in thin film $Ge_{0.23}Sb_{0.07}S_{0.70}$ chalcogenide glass

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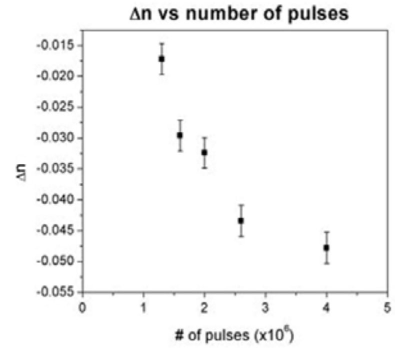
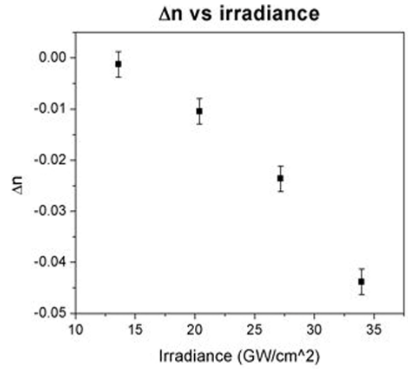
We present a study of the response of thin film Ge_{0.23}Sb_{0.07}S_{0.70} chalcogenide glass to 800nm femtosecond laser irradiation. Lasers with 1kHz (Spitfire, Spectra Physics) and 80MHz (Ti:sapphire oscillator, KMLabs) repetition rates are used to investigate the response of the material to femtosecond pulses. The laser was focused using a 0.25NA 10X microscope objective and defect lines were created in the films by translating the glass through the focal region. Films fabricated using both thermal evaporation and pulsed laser deposition were irradiated with irradiances below the ablation threshold. The glass exhibited photo-expansion as a result of irradiation that was a function of both the laser irradiance and the translation speed of the sample. The height of the photo-expansion, measured with a Zygo NewView 6300 white light interferometer, was ~4nm for irradiation with kHz repetition rate pulses and ~40nm for irradiation with MHz repetition rate pulses, indicating that the response of this glass composition is sensitive to cumulative effects. Irradiation with the MHz repetition rate laser induces a negative shift of the refractive index of the films (Δn ~ - 0.03). The dependence of Δn on the number of pulses incident on the sample per focal spot and the irradiance is shown in the figure. The Δn was measured using both an interferometric technique and the Swanepoel method. Using the interference technique, the refractive index change was seen as a shift in an interference pattern created between a reference flat and the back surface of the film. The Swanepoel method was used to calculate the refractive index of the film through an analysis of the interference fringes of the transmission spectrum before and after irradiation. The bond structure of the glasses before and after irradiation as measured by micro-Raman spectroscopy is also discussed. The authors acknowledge Barry Luther-Davies and CUDOS for the film deposition using the PLD technique.





Th S2-12

Microfabrication of nonplanar surface structures by femtosecond laser lithography

Hiroaki Nishiyama [1], Mizue Mizoshiri [1], Tomohiro Iba [1], Junji Nishii [2], Toshio Kawahara [3], Tomoji Kawai [3], and Yoshinori Hirata [1]

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[2] AIST, Japan
[3] ISIR, Japan

Femtosecond laser polymerization has received much attention because this technique is a powerful tool for three-dimensional patterning of photosensitive resin with subdiffraction-limit spatial resolution. In this study, silica-based nonplanar surface microstructures were created by femtosecond laser lithography followed by plasma etching for integrated optical components. The center wavelength, pulse duration, and repetition rate of femtoseond fiber laser used are 800 nm, 68 fs, and 50 MHz, respectively. Figure 1 shows a SEM image of silica-based line patterns on the step structures. First, a chemically amplified negative-tone photoresisit were spin-coated on the silica-based step structures which were fabricated by conventional semiconductor technology in advance. Then, the line patterns were written directly inside the photoresist using femtosecond laser induced multiphoton absorption. Here, we utilized the filamentation of the femtosecond laser pulses in the resist. Finally, the patterns were transferred to the step structures by CHF3/O2 plasma. The smooth surfaces of the structures were successfully obtained, and no crack and thermal damages were observed. We also used not only negative-tone resist but also a chemically amplified positive-tone resist for easier removal of the residual resist after plasma etching process. Figure 2 shows a silica-based blazed grating, which were created using direct laser writing of the patterns inside the positive-tone resist. The size and period are 500 um x 500 um and 10 um, respectively. The combination process of femtosecond laser lithography and plasma etching is useful for fabrication of nonplanar microstructures on inorganic optical materials.

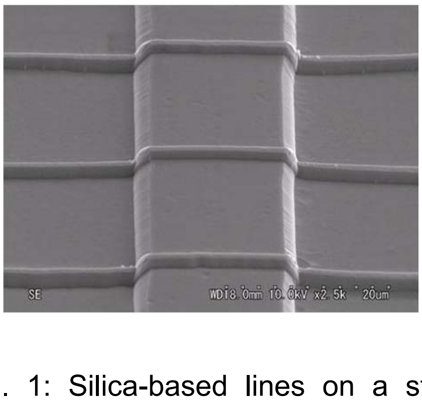

Fig. 1: Silica-based lines on a step structure

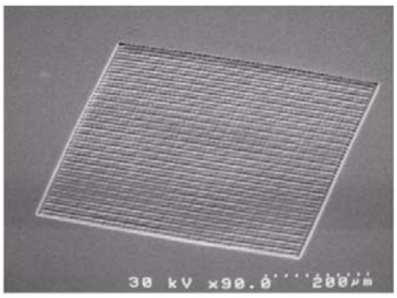

Fig. 2: Silica-based blazed grating fabricated using positive resist

Th S2-13

Femtosecond Laser Direct Writing of Optical Waveguides in Silicone Film

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Polymeric optical waveguides have attracted wide interest for potential applications as optical interconnects and other micro-optical systems in portable digital equipment and the access network field. Recently, Okoshi et al. reported direct writing of silica optical waveguides on the surface of silicone rubber by F2-laser induced photochemical reactions.[1] The high 7.9-eV photon energy was instrumental here in transforming silicone into carbon-free silica waveguides, thereby defining a new means for creating flexible optical circuits. This paper reports an extension of silicone waveguide formation to nonlinear femtosecond laser direct writing. An amplified Yb-doped fiber laser (IMRA FCPA µJewel) provided 280-fs pulses at 1044-nm wavelength. Frequency doubling in LBO to 522 nm was used to enhance the nonlinear absorption and potentially drive similar photochemical processes – generation of O(1D) and silicone photodissociation – as the 157-nm F2 laser. The light was focused (0.55-NA aspherical lens) into silicone film (Quantum Silicone, QSIL216), spun uniformly (~30-µm thick) on a glass substrate. Samples were scanned at variable fluence, focal depth, and scan speed and then inspected by optical microscopy, SIMMs, and waveguide-firing diagnostics to assess the waveguide formation. We report a permanent modification of refractive index inside the silicone by the nonlinear femtosecond laser interactions. Single-mode waveguides were observed at both red (633-nm) and infrared (1560-nm) wavelengths. Figure 1 shows a microscope image (top) and the near-field mode profile at 1560-nm (bottom) for a 5-µm wide silicone waveguide. This waveguide was formed 6-µm below the silicone surface with 2-nJ pulse energy and 10^5 overlapping pulses at 1-MHz repetition rate. This paper will present optimal waveguide processing parameters and assess the underlying photochemical processes driving the refractive index change. [1]M.Okoshi, J.Li, P.R.Herman: Opt. Lett., 30, 2730(2005)

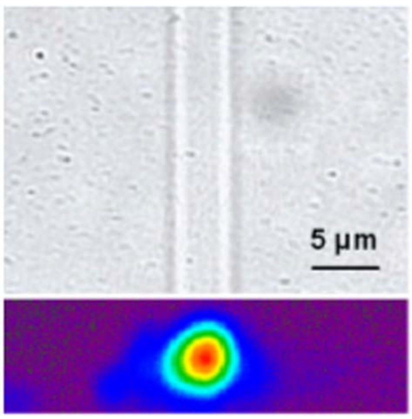

Fig. 1: Microscope image (top) and near-field mode profile (bottom) of a silicone waveguide guiding at 1560 nm wavelength light

Th S2-14

Fabrication of a rainbow color logo (diffraction grating) using the picosecond laser

Jiwhan Noh[1] , Hyonkee Sohn[1] , Jung Suh[1] , Dongsig shin[1] , Jae-Hoon Lee[1]

[1]KIMM (Korea Institution of Machinery & Material)

A rainbow color logo mold (diffraction grating) was fabricated by using the picosecond laser. In this paper, a metallic mold for diffraction gratings was fabricated with a mode-locked 12 ps Nd:YVO4 laser. Laser pulses with a wavelength of 355nm were irradiated on the surface of NAK 80, a mold material, to generate line patterns and dot patterns. In order to minimize the line width, laser power was set just above the ablation threshold of NAK 80. The dot pattern in the rainbow color logo mold was brighter than the line pattern. Results show that the spectrum from the fabricated mold was good enough for some industrial application. For the mass production, injection molding was performed using the rainbow color logo mold.

Th S2-15

Invited

NUV and NIR Femtosecond Laser Modification of PMMA

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Significant refractive index changes in clinical grade poly(methyl methacrylate) (PMMA) with both femtosecond NIR (800 nm) and NUV (387 nm) laser pulses are demonstrated, enabling volume gratings and waveguides in bulk PMMA. In the NIR, temporal pulse duration is shown to be very critical, with modification efficiency increasing rapidly as pulse duration decreases below 200 fs. On the other hand, in the NUV, efficient index modification can be accomplished with longer, 200 fs pulses. The modification of ultra-pure, clinical grade PMMA demonstrates that doping to increase sensitivity is unnecessary. Grating diffraction efficiency and refractive index profile measurements infer a maximum positive refractive index change of Δn(max) = 3x10-3 in exposed regions. Chemical analysis of the modified structures in the NUV suggests direct polymer back bone cleavage and monomer production as photo-modification pathway. Holographic writing at 387 nm with a high NA objective produced weak periodic features of period Λ= 0.42 µm. The combined results in the NIR and NUV demonstrate the importance of peak intensity for inducing non-linear absorption and sugggest that three and two photon absorption are responsible for modification of pure PMMA at 800 nm and 387 nm, respectively.

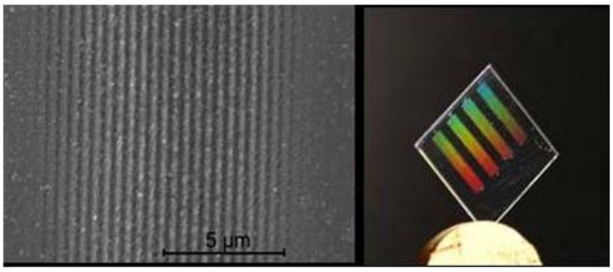

Fig. 1: Holographically produced sub-micron structure on stainless stell (left, SEM picture) and inside PMMA (right, photograph of white light diffraction)

Th S2-16

Invited

Two-photon 3D lithography: A versatile fabrication method for complex 3D shapes and optical interconnects within the scope of innovative industrial applications

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Laser material processing using intense laser pulses, which are provided from ultrafast laser systems, enable sophisticated structuring methods such as the two-photon 3D lithography. This method is based on the simultaneous absorption of two photons in a photosensitive material that is transparent for the laser wavelength. The non linear laser-matter interaction induces material changes that are tightly confined around the laser focus and build up a structure in the volume of the material. These intrinsic 3D capabilities allow easy fabrication of a physical structure from a CAD design. In combination with suitable materials, it is possible to realize complex 3D structures and photonic micro- and nano-systems. We introduce our experimental setup comprising laser source, three axes sample stage and 3D registration of the sample. We present two distinct applications of the versatile two-photon 3D lithography on organic photosensitive materials: first, the fabrication of complex arbitrarily shaped 3D micro-structures and second, the fabrication of direct laser-written, embedded multimode waveguides that are aligned relative to preconfigured printed wiring boards (PWBs). In the first case, the high resolution aspect of the method is addressed, while in the latter case, the lithographic method is combined with astigmatic beam focusing for a larger interaction volume as required for writing multimode waveguides. Due to the sample registration prior to the waveguide fabrication, the alignment of the waveguides becomes an intrinsic part of the fabrication process itself. A single organic-inorganic hybrid material is used for both, the waveguide core and its cladding, because the material exhibits a sufficiently large increase of the refractive index upon laser irradiation. The function of such waveguides is demonstrated (optical loss, etc.). The ultimate goal of this approach is the large scale fabrication of leading-edge PWBs with an integrated optical communication layer.

Th S2-17

Internal modification of ultra thin silicon wafer by permeable pulse laser

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When a permeable nanosecond pulsed laser is focused into the interior of a silicon wafer and is scanned in the horizontal direction, a belt-shaped high dislocation density layer including a partially polycrystalline region is formed at an arbitrary depth in the wafer. By applying tensile stress perpendicularly to this belt-shaped modified-layer, the silicon wafer can be separated easily into individual chips without creating any damage to the wafer surface compared to the conventional blade dicing method, because the internal cracks spread from the modified layer up and down to the surfaces. This technology is called “stealth dicing” (SD), and attracts attention as a novel dicing method in semiconductor industries. The formation mechanism of this modified layer has been investigated theoretically for a relatively thick wafer in previous studies and it has been concluded that the modified layer and the internal cracks are generated due to propagation of a thermal shock wave caused by laser absorption. In this study, SD was applied to ultra thin wafers 50 um in thickness (Fig. 1). A coupling problem composed of focused laser propagation in single crystal silicon, along with laser absorption, temperature rise and heat conduction was analyzed by considering the temperature dependence of the absorption coefficient as in our previous studies. When the depth of the focal plane is too shallow, the laser is also absorbed at the surface as the thermal shock wave reaches the surface. As a result, not only is an internal modified layer generated but ablation occurs at the surface as well (Fig. 2(b)). When the laser is focused at the surface, strong ablation occurs (Fig. 2(c)). Ablation at the surface is unfavorable because of the debris pollution and thermal effect on the device domain. It was concluded that there is a suitable depth for the focal plane so that the thermal shock wave propagates inside the wafer only (Fig. 2(a)).

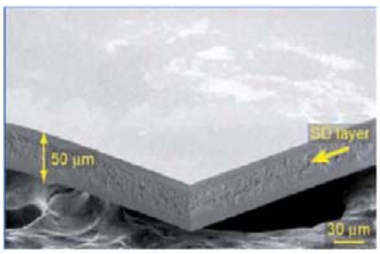

Fig. 1: Stealth dicing of silicon wafer of 50 µm thick

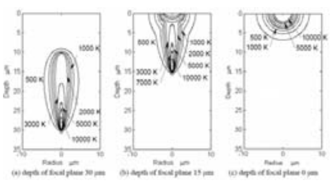

Fig. 2: Maximum temperature distribution during one pulse irradiation of 1064 nm laser to a silicon wafer of 50 µm thick. Contour lines show 500, 700, 1000, 1500, 2000, 3000, 5000, 7000 and 10000 K (pulse energy 2.74 µJ, pulse width 150 µs, spot radius 485 µm)

Th S2-18

TEM observation of structural changes under 4H-SiC single crystal surface irradiated by femtosecond laser pulses

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A number of studies have been conducted on the formation of laser-induced ripple structures on the semiconductor surface irradiated by femtosecond laser pulses because the ripple structures may be applied to nano-scale surface machining. The purpose of the present study was to examine the cross-sections of fine and coarse ripples formed on 4H-SiC single crystals by transmission electron microscopy (TEM). Femtosecond laser pulses were irradiated onto the (0001) surface of 4H-SiC single crystals to form ripple structures. The wavelength, energy, width and number of pulses were 800 nm, 6 microJ/pulse, 130 fs and 50 shots, respectively. Cross-sectional TEM samples perpendicular to the ripples were prepared by focused ion beam (FIB) micromachining. Cross-sectional TEM images for fine and coarse ripples are presented in Fig. (a) and (b), respectively. The dark area in the micrographs is the tungsten layer deposited on the surface prior to the FIB machining. The periods of fine and coarse ripples are about 200 nm and 500 nm, respectively. Although the morphology is totally different, microstructural features are similar. Along the surface undulation, there exists a thin layer approximately of 50 nm. Probably, this topmost layer corresponds to amorphous detected by micro Raman spectroscopy.[1] Beneath the topmost layer, another thin layer appears dark. This second layer is accompanied by strain because its appearance changes with the diffraction vector g. In some areas, we observed crystallographic defects such as dislocations and stacking faults introduced by the strain. Such defects did not penetrate the topmost layer because the layer was not crystalline. So far, we found that the microstructural features are common to any ripple structures irrespective of their morphology. This suggests that the formation mechanisms are also common for both fine and coarse ripples.

[1] M. Yamaguchi et al.: Proc. of 4th Int. Cong. on Laser Advanced Materials, p.117, Kyoto, 2006.

Special Session 3 (LPM-S-3):

Advanced Laser Systems and Optics
(New Laser concepts and beam delivery systems, etc.)

Session Organizers:
Eric Fogarassy (Ecole nationale supérieure de physique de Strasbourg, France),
Tino Petsch (3D-Micromac AG, Germany), Andreas Stingl (Femtolasers Produktions GmbH, Austria)

We S3-01

Invited

Optical lithography for photonic band gap materials

Sajeev John[1]

[1]University of Toronto,

Photonic band gap (PBG) materials are three-dimensional (3D) periodic microsctructures that enable the localization of light. These materials and their 2D counterparts have applications to optical information processing, lighting, energy conversion, optical sensing, and clinical edicine. In the past, it has been considered very challenging to micro-fabricate 3D PBG materials, out of high refractive index materials such as silicon, with diamond crystal symmetry, for guiding and trapping light in the near-infrared to visible wavelength regimes. This situation is now changing as a result of optical lithography methods. I describe the development of optical phase mask architectures capable of creating diamond-symmetry PBG architectures based on illumiation by a single laser beam. This is a significant simplification to previously proposed methods based on multi-beam optical interference. The optical phase mask method may be combined with direct laser writing techniques and photoresist-to-silicon replication methods to create circuits for light on a 3D optical micro-chip.

We S3-02

Grating interferometers for efficient generation of large area grating structures via laser ablation

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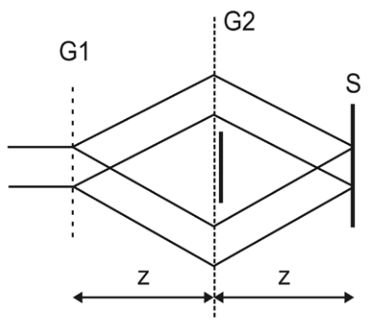
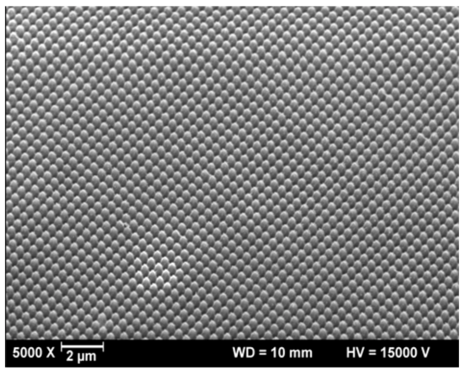
Generation of large area grating structures by laser ablation is a challenging task if the whole area must be patterned with a high definition submicron-period line structure in perfect registry. A Two-Grating-Interferometer set up is described for producing large area grating structures via laser ablation with UV pulses. Phase grating pairs on fused silica substrates with high damage threshold and diffraction efficiency were illuminated with non-collimated (convergent) laser beams to generate a periodic intensity distribution with high energy density and high contrast on the sample surface. Large line numbers without phase distortions were reached by applying cylindrical focusing perpendicular to the plane of diffraction. Scanning with the illuminating laser beam in the direction parallel to the grating lines enabled the fabrication of cm-scale grating size with multiple shot ablation, while keeping the whole line structure in phase. Complex patterns are possible by applying multiple exposures. Experimental results demonstrating the capability of the method to generate laser ablated grating structures with submicron periods down to ~300 nm are presented.





We S3-03

Fabrication of Nd:Gd3Ga5O12 planar waveguide laser by pulsed laser radiation

Dimitri Ganser[1], Herbert Horn-Solle[1], Leonid Moiseev[1], Larisa Starovoytova[1], Ion Vasilief[1], Dirk Wortmann[1], Jens Gottmann[1]

[1]Lehrstuhl für Lasertechnik, RWTH Aachen, Steinbachstr. 15, 52074 Aachen, Germany

Pulsed laser radiation is used as well for the deposition of the laser active thin films of Nd:Gd3Ga5O12 as for micro structuring to define wave guiding structures for fabrication of a waveguide laser. Laser active films with thickness up to 5 µm of Nd:Gd3Ga5O12 on YAG (Y3Al5O12) and sapphire single crystalline substrate are fabricated by pulsed laser deposition using a KrF eximer laser (µ = 248 nm, τ = 25 ns). By variation of PLD-parameters such as temperature and pressure of processing gas amorphous and single crystaline thin films are produced. X-ray diffraction using θ-2θ scans in Bragg geometry with Cu kα radiation (µ = 0,15406 nm) is used to determine the structural properties of the deposited films. By coupling the radiation of a diode laser (µ = 808 nm) into the polished edge of the film the optical properties of the films are determined. The emission spectrum of an amorphous film is broadened inhomogeneously and the spectrum of a crystalline film is similar to that of the bulk Nd:GGG crystal used as a target material for the deposition. A planar wave guiding structure is generated between two parallel grooves micromachined using laser radiation from a femtosecond CPA-Laser-System with µ = 800 nm and pulse duration of 100 fs. The structural properties on the films and the extinction losses of the structured waveguide are determined. For the first time a structured planar waveguide laser of an amorphous Nd:Gd3Ga5O12 thin film on YAG (Y3Al5O12) single crystalline substrate is achieved.

We S3-04

Trouble shooting and optimization of laser beam parameters for precision micro fabrication by beam analysis

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[1]PRIMES GmbH, Max-Planck-Str. 2, 64319 Pfungstadt

Precision laser micro fabrication processes have strong requirements on beam parameters in the focus because of their influence on processing speed and quality, e.g. drilling speed and hole geometry, cutting speed and kerf shape, milling speed and contour accuracy as well as surface roughness. These beam properties are not only determined by the power density distribution at the laser but also by the propagation properties of the beam as well as by the optical performance and quality of the beam train and focusing system. (e.g. telescopes, polarization filters, attenuators, masks, diffractive beam shapers, lens systems, etc.) Focus analysis at real process conditions reveals the resulting beam parameters of the spot: beam shape in the focus, focus diameter, Rayleigh length, beam propagation ratio, focus position, and far field divergence. In the case that the measured focus parameters differ from the specs, the causes for deviations have to be identified. Effects from laser, beam train, and focusing system have to be distinguished. Here beam propagation analysis at different positions in the beam path is required. We will show the influence of optical component properties and alignment on beam propagation and beam parameters in the focus. Furthermore we will demonstrate methods for the optimization of beam parameters using beam propagation analyzers and focus analyzers.

We S3-05

In-process monitoring and adaptive control during micro welding with CW fiber laser

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Fiber laser has an excellent beam quality enough to be applied for micro welding of electronics or automobile parts, and thus is regarded as a promising heat source for adaptive control since the laser peak power can be changed within sub-micro-second period. Laser micro welding of sheets can be influenced by the surrounding heat transfer conditions. This study was therefore undertaken with the objective of developing a new laser system with in-process monitoring and adaptive control for the stable production of sound welds in thin sheets. The bead-on–plate welding of 0.1 mm-thick stainless steels was performed with a 75 W fiber laser beam of 1,090 nm in wavelength. The stability of bead widths of laser welds made with or without monitoring and adaptive control was investigated in welding the sheet with or without heat exchanger plate. It was revealed that the heat radiation signal was sensitive to the increase in the bead width when the heat transfer process was changed to the heat-insulated process. Moreover, the peak power was controlled in the minimum 50 ms-short period in order to produce stable weld bead width regardless of the existence of the heat transfer plate, and the limit cycle time of the adaptive control was investigated by comparison with the bead widths of welds made without adaptive control. It was consequently confirmed that the fiber laser was an excellent oscillator for the adaptive control in laser micro welding.

We S3-06

TRUMPF Disklaser, TruDisk

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Todays development of new laser beam sources is dominated by the new generation of diode pumped solid state lasers. The TRUMPF disk laser offers a unique variety of features, which assure the success of industrial applications. The power range from several hundred watts up to 8 kW enables both, micro material processing as well as welding of thick metal sheets.
Actual applications of the TRUMPF disklaser vary from welding and remote scanner welding to cutting, ablation and structuring of surfaces. The beam quality and output power of the TRUMPF disklasers are geared to its application, whereat no limits are reached today. The potential of the TRUMPF disk technology was demonstrated in several prototypes, where 25 kW output power or a beam quality of 4.5 mm*mrad @ 5 kW were provided. Furthermore, the potential of cost reduction will be successively opened up. The price per kW was reduced to a level of 60% within the last three years, and will be reduced further on in the next years. By these means the cost-effectiveness of laser processes is increased and new applications will be established.
The presentation will show the design of the TRUMPF disklaser, gives an overview of actual industrial applications and will point out future developments in technology and cost.

We S3-07

Ablative laser micro processing with short and ultrashort pulses

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[1]TRUMPF Laser GmbH + Co. KG, Aichhalder Strasse 39, 78713 Schramberg, Germany

Ablative laser-micro-processing can be achieved by using a wide range of pulse durations. The demands on quality and throughput do vary when the pulse duration changes from low µs over several tens of ns to the < 10 ps range. Micro-machining with short ns-pulses has become well established and widespread for industrial usage. TRUMPF Laser has developed advanced solid-state q-switched lasers, designed to specifically meet the requirements of industrial micro-processing. If short is not short enough, i.e. no mechanical and thermal modification of the surrounding material is required (cool processing), then the laser-material-interaction-time has to be reduced by shortening the pulse duration. Due to the fact that cool material processing is still possible by using ps pulses, the technological approach to create these pulses can be dramatically simplified. We present a CPA-free, diode-pumped all-solid-state laser, delivering pulses as short as 6 ps with an average power of 50 W at a repetition rate of 200 kHz. The corresponding pulse energy of up to 250 µJ provides the basis for efficient material-processing. Precise switching or attenuation of the amplified pulses is provided by an external modulator. The laser output beam is diffraction limited, with an $M^2 < 1.2$ and a roundness of > 95 %. If burr formation and heat affected zone are acceptable or the material properties (melting temperature, vaporization temperature and thermal conductivity) allow for it, then the productivity of the laser ablation process can be maximized by turning to longer (several hundreds of nanoseconds to one microsecond) pulse durations. Here the free space beam delivery, a drawback of the ns and ps lasers, can be overcome by fiber coupling. Using the q-switched disk-technology, pulse durations in the order of 1 µs with an average power of 400 W at a repetition rate of up to 20 kHz can be realized. The beam delivery is implemented by a step index fiber.

We S3-08

Millijoule high-repetition rate femtosecond laser amplifier

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Inka Manek-Hönninger [2]

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We demonstrate millijoule-level pulse energy extraction from a high-repetition rate diode-pumped Ytterbium-doped femtosecond laser amplifier. The extracted pulse energy exceeds 1 mJ for pulse repetition rates up to 5 kHz and remains above 0.1 mJ for repetition rates as high as 100 kHz. In order to minimize nonlinear effects and avoid damage to optical components, we applied chirped pulse amplification using a grating-based stretcher prior to amplification and a grating-pair com-pressor. After compression we measured a pulse duration of 480 fs. The M² value was better than 1.2. These parameters result in a versatile high-energy laser source that can be operated in a wide range of pulse repetition rates matching the requirements of numerous high precision machining ap-plications. The complete laser system fits into a compact footprint of 750x500 mm².

Fr S3-09

Invited

Fiber lasers and amplifiers: Novel avenues to real world applications of ultrashort lasers

Andreas Tuennermann[1], Jens Limpert[1], Stefan Nolte[1]

[1]Friedrich-Schiller-University Jena Fraunhofer Institute for Applied Optics and Precision Engineering

Fiber lasers and amplifiers: Novel avenues to real world applications of ultrashort lasers Rare-earth-doped fiber lasers are one of the most promising solid-state laser concepts due to the outstanding thermo-optical properties of an actively doped fiber. The large ratio of surface to active volume of such a fiber ensures excellent heat dissipation, furthermore the beam quality is defined by the refractive index profile of the active core and is therefore independent on the pump power. Fiber lasers and amplifiers offer a very high single-pass gain and therefore low laser thresholds and efficient diode-pumped operation approaching the kW-level based on the double-clad design. Ytterbium-doped fibers provide also several key advantages regarding the amplification of short optical pulses. The gain bandwidth supports pulses as short as ~30 fs, the huge saturation fluence allows for the generation of millijoule pulses and high optical pumping efficiencies (up to 80%) even for ns-pulses, make an ytterbium-doped fiber amplifier to an outstanding gain medium. However, power and energy scaling of ultrafast single-mode fiber amplifiers is restricted due to nonlinear pulse distortions, which are enforced by the large product of intensity and interaction length inside the fiber core. This limitation can be overcome by sufficient pulse stretching in the time domain and the enlargement of the mode-field diameter of the fiber to reduce the nonlinear effects such as stimulated Raman scattering (SRS) and self-phase modulation (SPM). The application of this technique leads to a chirped-pulse amplification (CPA) system based on large-mode-area fibers (LMA), where power scaling is limited by the maximum acceptable phase distortion due to self-phase modulation. An ytterbium-doped ultrafast fiber CPA system what generates 100 µJ pulses at repetition rates above 100 kHz is reported. The application of this system in advanced laser micro-machining of metals and semiconductors is discussed.

Fr S3-10

Fundamental and beam propagation behavior of a microjet® and recent applications using laser microJet technology

Dr. Tuan Anh Mai[1], Dr. Bernold Richerzhagen[1]

Synova SA

The innovative water jet-guided laser technology (also called as Laser MicroJet® LMJ) is relatively new. However, due to a number of unique advantages, it has quickly and successfully matured into many applications such as dicing and slotting of silicon wafers, cutting of coronary stents, drilling of stencil and OLED masks, as well as the cutting of hard materials for tool inserts. This cold, clean machining technology allows the precision fabrication of intricate structures, providing exceptional aspect ratios. In this paper, the fundamental behavior of a hair-thin water jet such as jet velocity, jet breakup and interruptions are studied. A well-rounded understanding of the jet stability characteristics is very important to enhance the performance of the LMJ technology. The propagation and the intensity distribution of a laser beam coupled in the low pressure, laminar water jet at various coupling conditions are theoretically and experimentally investigated as well. The final part of this paper will highlight some recent micromachining examples of the LMJ technology.

Fr S3-11

On the mechanism of laser-matter interaction in laser drilling and spot welding

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Dept. of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC, USA, 27695 Division of Materials and Manufacturing Science, Osaka University, Osaka, Japan

The mechanism of laser ablation is investigated both experimentally and theoretically for microsecond laser ablation using a 300W, single-mode CW fiber laser. Pulses of 1 microsecond and longer are used to achieve laser ablation and those longer than 100 microseconds are used to produce spot welding. Control methods are developed to exploit the use of an initial spike of about 1.5 kW in power that lasts approximately 1 microsecond and then falls to its steady output level at 300 W. The laser can then be controlled to generate a pulse duration between 1 microsecond to 1 ms. Experimental results, based on high speed photography, in-process plasma measurements, and cross-section etching, reveal that, for a 1 microsecond pulse, the primary mechanism of ablation is seen to be evaporation with a small amount of melt ejection. For longer pulse durations, the lower steady state power contributes only to further heating and melting of the material to widen the molten pool. There is experimental evidence of boiling that occurs in the melt pool for long pulse up to 1 ms. These experimental results are used to refine a theoretical model which simulates details of the keyhole creation at the beginning of the pulse and the keyhole collapsing at the end of the pulse. The simulation results show that the laser beam is mainly absorbed via multiple reflections of the laser and as the keyhole depth increases, absorption in the bottom of the keyhole increases, providing the energy for the boiling mechanism seen in the experimental investigation. At the end of a long pulse, spot welding is formed because the keyhole collapses quickly by the surrounding large molten pool. The melt quickly fills the keyhole and solidifies to form a bump on the surface with either large or very fine voids inside.

Session 4 (LPM-4):

Micromachining and Processing

Tu 4-01

Invited

Advanced double pulse format for increasing the speed and quality of high aspect ratio laser micromachining

A. Forsman[1], A. Dodell[1], M. Armas[1], E. Lundgren[1], A. M. Komashko[1]

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The speed and quality of laser machining has been improved by using a train of pairs of 4 ns laser pulses rather than a train of single laser pulses. The first laser pulse in each pair generates an ablation plasma and other ablation debris which is allowed to dissipate for a prescribed period of time. After the debris has partially dissipated the second pulse of the pair strikes, and heats the remaining debris to cause more efficient ablation and inhibit redeposition. The use of pairs of laser pulses therefore uses debris and plasma to enhance machining performance. Material removal rates have been significantly improved, by factors of three to ten times while reducing redeposition and reducing or eliminating heat affected zones. Percussion drilling using this double pulse format has also been used to produce small (< 10 um diameter), high aspect ratio (> 30:1) holes that are straight and reproducible. In addition to improvements in machining speed and quality, measurements of the laser-target interaction and results of numerical modeling will be presented. These, together with the results of laser machining trials, are used to develop a phenomenological model to account for the improvements in performance that are offered by the double pulse format.

Tu 4-02

Nonlinear Nd:YAG laser-induced optical blooming of glass-ceramics

V.P. Veiko[1], B.Yu. Novikov[1]

[1]St.Petersburg State University of Information Technologies, Mechanics and Optics

There are class of glass-ceramics (GC) materials which are not transparent in a visible range due to a high light scattering by their polycristalline structure. Laser action can localy modify crystalline phase of those materials to the amorphous. Usually a popular laser for such kind of transformations is a CO2-laser (10.6 mkm). As initial (crystalline) as final (amorphous) phase have a strong absorption in a middle infrared (IR) range. Different situation have place when near-IR radiation acts on to these matereals. From one hand absorption of initial GC in this case is little bit less but enough to lead to laser melting followed by hardening and finally to amorphization of initial structure. From the other hand amorphous GC is a kind of glass which is highly transparent for near IR-radiation. This phenomenon produce new situation which we call as nonlinear optical blooming. Optical blooming has been investigated in this work on the example of ST-50 GC experimentally and theoretically. Some examples of Nd:YAG-laser (1.06 mkm) amorphization of ST-50 GC for different applications are demonstrated. Nd:YAG-laser provides smaller size (higher resolution) and bigger deepness of bloomed area than CO2-laser.

Tu 4-03

Fabrication of an OLED display using an ultra-short fiber laser

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Organic light emitting diode (OLED) is now in practical use and also a subject of active research and development. In industrial production of OLED displays, one of the key technologies is patterning of electrodes, especially a metal electrode, which is usually made on a thin layer of organic compounds. Laser machining of the electrode is one of the possible techniques. We have developed a selective patterning technique of a thin top electrode of aluminum using an ultra-short fiber laser. OLED sample used has indium tin oxide (ITO) anode of about 150 nm thick at the bottom. The organic electro-luminescence material of less than 200 nm is deposited on it and the top is aluminum cathode of 100 to 150 nm thickness. An ultra-short fiber laser at 1560 nm with a repetition rate of 198 kHz is used to the patterning of the aluminum electrode and a display panel of the OLED is fabricated successfully. Benefits of our system will be described. It is found that the underlying layers affect much to the machinability of top metal electrode. The ITO layer seems to enhance the machining efficiencies of aluminum electrode. Its machining threshold fluence becomes lower and the ablated size becomes larger for that on ITO than that without ITO, even though the laser energy is kept constant. These phenomena cause some difficulties in the laser fabrication process of the OLED. To investigate the phenomena in detail, we have constructed two ultra-fast imaging systems using an ultra-fast Ti:Sapphire laser at 785 nm with 1 kHz repetition rate, one of which has a time-resolution of one picosecond and the other has five nanoseconds, and carried out time-resolved imaging observations of the process. Even though we use two different types of lasers as machining tools, the observed effects of ITO layer seems quite parallel. The results suggest that the change of the threshold energy might be due to the change of relevant machining mechanisms.

Tu 4-04

Electronic properties of thin polymer films deposited by resonant infrared laser ablation

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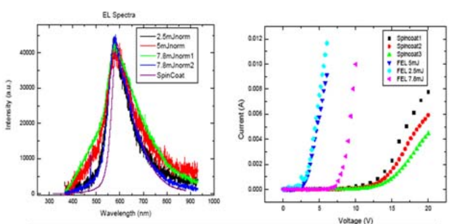
Current liquid-phase techniques for fabricating polymer-based electro-optic devices — e.g., ink-jet deposition, spin coating — face significant challenges of material deposition efficiency, solvent bleedthrough and decomposition, and lifetime degradation due to electro-chemical activity. While resonant infrared pulsed laser deposition (RIR-PLD) has been successfully used to deposit many different kinds of polymers, maintaining electro-optic functionality from device-compatible polymers such as MEH-PPV and PEDOT:PSS has proven to be a stringent test of this process. We have recently been able to deposit both conductive and electro-luminescent polymers by RIR-PLD, in some cases using matrix- or co-matrix-assisted ablation, and have compared the electronic properties of the RIR-PLD films with those obtained by conventional spin coating. In this paper, we present results of these experiments on both PEDOT:PSS and MEH-PPV thin films, including transport measurements by standard four-point probe techniques, and spectral characterization of electroluminescence and photoluminescence. The results suggest that the polymer films prepared by RIR-PLD exhibit a level of performance compatible with device requirements for electro-optic applications, such as organic light- emitting diodes. By correlating these measures of the electronic properties of the film with variations in the operating parameters of a picosecond, tunable free-electron laser (FEL), we are able to identify specific effects of laser fluence and wavelength on the electronic properties of the deposited films. These comparative studies are providing new insights into the mechanism of infrared laser ablation of intact polymers in the regime of picosecond pulses and very high pulse-repetition frequencies. We will also discuss the potential for the use of more conventional laser systems, such as amplified, frequency-shifted ultrafast solid-state lasers, to reproduce these results.



Electroluminescence spectra and I-V curves for polymer light-emitting diodes prepared by spin-coating and RIR-PLD

Th 4-05

Invited

A Experimental Study on Raising the Efficiency of Production for Industrial SFF system

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A Solid Freefrom Fabrication (SFF) system using selective laser sintering (SLS) is currently recognized as a leading process and SLS extends the applications to machinery and automobiles due to the various materials employed. Especially, accuracy and processing time are very important factors when the desired shape is fabricatied with selective laser sintering (SLS), one of Solid Freeform Fabrication (SFF) system. In the converntional SLS process, laser spot size is fixed during laser exposing on the sliced figure. Therefore, it is difficult to accuracy and rapidly fabricate the desired shape. In this paper, to deal with those problems a SFF system having abilty of changing spot size is developed. The system provides high accuracy and optimal processing time. Specifically, a variable beam expander is employed to adjust spot size for different figures on a sliced shape. Finally, design and performance estimation of the SFF system empoying a variable beam expander are achieved and the mechanism will be addressed to measure the real spot size generated from the variable beam expander.

Th 4-06

"Dry-Etching System" with Q-switched DPSS laser for flat panel displays

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Hitachi Zosen Corporation

Flat panel displays (FPDs) are used in many electrical products, such as cellular phones, car-navigation systems, personal computers, slim profile televisions and so on. With the popularization of these productions, the market of FPDs has expanded rapidly. The current industry trends for FPD productions are: increase in picture quality and multifunction capabilities. Other factor also includes pursuit of the cost reduction, environmental conservation and so on. An etching process of thin film for FPDs is usually performed by a wet etching method. By replacing the wet etching method with the laser-dry-etching method, there is an enormous cost reduction. And the product is made under a clean and chemical-free manufacturing environment. Moreover, the laser-dry-etching method can exchange product patterns quickly. This method has attracted a great deal of interest in industry because it has many potential benefits. The laser-dry-etching for FPDs have the ability to process large areas with minute detail and at high speed. However, the laser-dry-etching method requires that a large amount of energy to be concentrated for small areas. Therefore, it takes a long time to process a large area due to lack of energy source. A sufficient power is needful to process a huge area on a large-scale substrate. On the other hand, it is clear that the laser beam with huge power oscillators is more unstable and produce lower quality results because of thermal lens effect and lens degradation. Moreover, it is crucial to keep making high-quality processing, in the mass production lines, which operate 7 days per week, 24 hours per day. The authors have developing various laser-dry-etching system for large-scale FPDs. All these system tries to balance between processing speed to processing quality. In this paper, these needed elements for the FPD manufacturing are discussed.

Th 4-07

UV laser microprocessing of photovoltaic devices based on thin film a-Si:H

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Laser ablation of individual layers in Glass/TCO/Thin-film silicon/Metal structures is essential for cell isolation and monolithic interconnection in thin-film photovoltaic technologies. In these processes laser technology appears as a very competitive alternative both in quality and running costs and, taking into account the importance of controlled material removal process in photovoltaic industry, is remarkable the scarce academic research in this field. On the other hand, suppliers of laser machinery have been working in the development of potential applications of this technology for film ablation and patterning during years, obtaining promising results using excimer lasers for annealing and ablation, and excellent results with solid state pulsed lasers sources for direct writing and backscribing techniques in cells and modules production. More recently, the potential application of laser scribing techniques for the development of photovoltaic matrix position sensors based on a-Si has generated much activity. This work gives an approach to the characterization of ablation process in thin film a-Si based devices using ns laser sources, determining potential parametric windows and an giving an approach to the quality assessment based on the morphological analysis of the generated tracks. The study is focussed on direct writing techniques using UV sources, taking into account that backscribing techniques at 532 nm are well developed and are fully integrated in industrial production. Moreover only laser sources in the ns regime has been considered, bearing in mind that thin film based photovoltaic technologies are still demanding further reduction in production costs and, nowadays, ultrafast sources are beyond the scope of these technologies due to their investment and running costs. ACKNOWLEDGMENTS: Work financed by the Spanish National R&D Plan Ref. NTS (ENE2004-07376-C03)

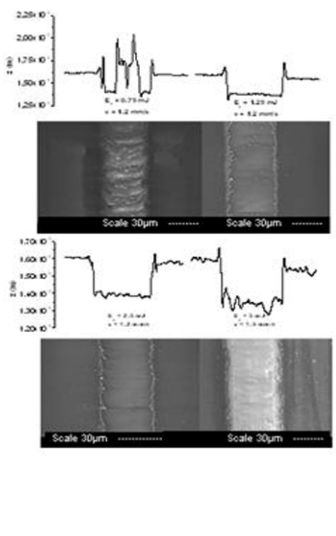

Fig. 1: LSCM profiles and SEM images (x1.5k) of ablated a-Si under different irradiation condition at 248 nm. SEM images have been sized in order to fit groove width in measured profiles

Th 4-08

Selective laser ablation of photoresists for MEMS devices

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We present recent results on selective laser ablation of thick photoresists (KMPR, SU-8, AZ-Types) from dielectric and metallic substrates as a process step in MEMS fabrication, capitalizing on different ablation mechanisms with ultrashort pulsed Yb:Glass and CO2 laser systems, respectively. By employing pulses with a duration of 300 fs we were able to structure thick photoresist selectively on a glass wafer without damaging the substrate. Subsequent sputter and micro-electroplating steps permit the fabrication of metallic structures of micrometer size. The removal of the remaining photoresist was performed by quasi-cw CO2 laser radiation. While femtosecond pulse durations permit structuring almost free of any heat load to the material, the thermal nature of the CO2-laser ablation of polymers is well suited for resist removal. In particular, thick resists like KMPR or SU-8 used for UV-LIGA can be removed from high-aspect ratio structures by solvents only with difficulty. The CO2 radiation at 10.6 microns is highly absorbed by the polymer material, yet completely reflected by the subjacent sputter layer. Although this method does not allow process speeds comparable to conventional lithography, it is a valuable and highly versatile (because maskless) option as for rapid prototyping in R&D.

Th 4-09

Rapidly tunable Bessel beam and pattern generation for laser microprocessing

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Rapid shaping of an incident Gaussian laser beam enables local control and spot-to-spot modifications over material properties in pulsed and CW applications. In this study, we present a novel approach to beam shaping and Bessel beam formation using a Tunable Acoustic Gradient Index of Refraction (TAG) lens. Bessel beams have the unique properties of nondiffracting and self-healing behavior with a characteristically different intensity profile compared to a focused Gaussian. These features can be beneficial in a variety of laser processing applications such as deep hole drilling, waveguide fabrication, micromachining on non-planar substrates and 3-d manufacturing. Bessel beams are typically created using axicons, diffractive elements, or holographic methods all of which present fundamental limitations to high throughput, tunable operation. In our approach, an amplified ultrasonic signal is used to establish a steady-state density fluctuation within a liquid causing an oscillatory variation in local index of refraction. Light propagating through this liquid produces a Bessel-like beam whose properties primarily depend on driving amplitude, frequency, geometry and liquid properties. The theory behind the lens operation, its degrees of control, experimental results, and applicability to laser-materials processing will be presented.

Th 4-10

Laser induced foaming and chemical modifications of gelatine films

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This paper investigates the microfoaming [1, 2] and accompanying chemical modifications following single pulse laser irradiation at 248 nm (KrF excimer laser, 20 ns fwhm) and at 266 and 355 nm (Nd:YAG laser 4th and 3rd harmonic, 6 ns fwhm) of films of gelatine. It was earlier anticipated that the foaming mechanism can be viewed as a cold boiling phenomena mainly induced by the laser launched tensile wave at the film surface. Therefore spectroscopic investigations are expected to confirm that the material does not degrade because of a high temperature. Fluorescence emissions from the films were studied by spectrofluorimetry and laser induced fluorescence and the emission lifetimes were measured by time-correlated single photon counting. This approach opens up the possibility to gain information on the molecular structure of the new nano-foamy material, as well as on its microscopic distribution with emerging fluorescence-based confocal systems allowing high spatial resolution. The main fluorofores responsible of the observed emissions are aromatic aminoacids like tyrosine and its derived crosslink products, possibly formed during the laser foaming. It is observed that laser irradiation with a single ns UV pulse induces modifications on the relative intensity of emisions depending on the wavelength of irradiation and the type of film. The observed chemical changes are related /discussed in terms of the structural modifications induced by foaming and have important consequences for the laser processing of biopolymers of interest in biomedical applications since the obtained laser foam exhibits interesting properties close to that of the natural extracellular matrix ones.

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Th 4-11

Fabrication of surface-enhanced raman scattering substrate on ag-doped silicate glass using femtosecond laser

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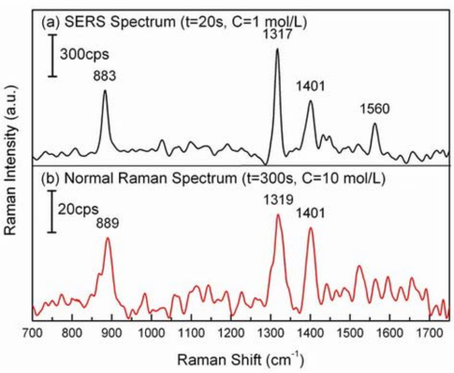
Detecting molecules in solution with high sensitivity and molecular specificity is of great scientific and practical interest in many fields. Raman spectra, which can provide a structural "fingerprint" of the molecules, can be enhanced greatly by surface-enhanced Raman scattering (SERS) for the detected molecules close to metal nanoparticles, which makes itself an important tool in the biomedical detection. In this paper, we report the fabrication of a new kind of substrate on Ag-doped glass for SERS using ultrashort pulse laser. Silver nanoparticles are formed in the fs laser scanned areas by electroless plating the laser-irradiated sample in the solution of AgNO3 at proper temperature. After this, a rough silver film is deposited on the glass which can be used for SERS. The normal and SERS spectra of glycine are detected individually. The results compared in Fig.1 clearly show the enhanced Raman signal measured on the substrate deposited with silver-nanoparticles. The enhancement factor of this substrate for glycine is about 2500 in our experiment. The enhancement factor may be improved further for the polar molecules which can be absorbed more close to the substrate. Furthermore, the substrate fabricated by the ultrashort pulse laser scanning followed by the electroless plating makes it possible to construct SERS-based microsensor inside a microfluidic channel because the fabrication of embedded microfluidic hollow structures in Foturan glass has already been demonstrated so far. Keywords: Surface-enhanced Raman scattering; Ag-doped glass; Chemical plating Fig.1 Normal and SERS spectra of glycine. 2500-fold enhancement was demonstrated. (note that different registration time and concentration were used for two spectra).



Th 4-12

Laser fabricated microelectronic circuits on flexible substrates

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The use of laser-based direct-write techniques might revolutionize the way microelectronic components such as interconnects, passives, IC's, antennas, sensors and power sources are designed and fabricated. The Naval Research Laboratory has developed a laser-induced forward transfer process for direct-writing the materials required for the fabrication and assembly of the above components. The laser direct-write (LDW) system used for these applications is capable of operating in subtractive, additive, and transfer mode. In subtractive mode, the system operates as a laser micromachining workstation. In additive mode, the system utilizes the laser forward transfer process for the deposition of metals, oxides, polymers and composites under ambient conditions onto virtually any type of surface. Finally, in transfer mode, the system is capable of transferring a single device, such as a semiconductor bare die, inside a trench or recess in a substrate, thus performing the same function of the pick-and- place machines used in circuit board manufacture. The use of this technique is ideally suited for the rapid prototyping of microelectronic components and systems on plastic substrates for flexible electronics applications. This presentation will discuss several examples of the types of electronic devices fabricated using LDW processes on flexible substrates. This work was sponsored by the Office of Naval Research.

Session 5 (LPM-5):

Nanotechnology and Nanomaterials

Th 5-01

«Green» processing of stable and ultra-pure nanoparticles using femtosecond laser-induced supercontinuum generation in water

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There is a need to produce nanoparticles using only environmentally benign reducing agent and non-toxic materials for the stabilization of the nanoparticles which can be dissolved in water. However, due to the very mild synthesis condition, processes based on «green» chemistry are characterized by a long reaction time (20-120h) and result usually in a relatively size and shape dispersed nanoparticles distribution. We propose to use a two-step laser-assisted method for the synthesis of small and low-dispersed colloidal nanoparticles, all performed in only deionized water at room temperature, rendering this process very environment friendly. As an example, we developed this process for producing gold nanoparticles. As the first step, laser ablation from a gold target is used to fabricate relatively large (few tens of nanometers) and size-dispersed colloids. As the second stage, self-modification of the femtosecond laser pulse into a white-light supercontinuum is used to perform the secondary ablation of colloids. The fragmented species then re-coalesce to form smaller, less dispersed and much more stable nanoparticles in the solution. The size of the nanoparticles after the treatment is independent of initial characteristics of colloids, but depends strongly on laser parameters. Being prepared in pure deionized water, the colloidal nanoparticles are stable and free of any impurities, making them unique for Surface Enhanced Raman Scattering (SERS) and bio-imaging in vivo applications.

Th 5-02

Influences on nanoparticle production during pulsed laser ablation

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The generation of nanoparticles using pulsed laser ablation is already a well-known technique. This method allows the generation of nanoparticles from a variety of materials and has inherent advantages compared to the conventional methods, for example in the purity of the fabricated nanoparticles due to the lack of precursors. But there are still no data on the influence of the media and laser parameters on the characteristics of nanoparticle production (e.g. size distribution, productivity). In this study we demonstrate the impact of pulse duration (nanosecond, picosecond, and femtosecond) on the particle size distribution. Additionally, general differences between the laser ablation in air compared to the ablation in liquids will be discussed. Our results indicate that the size distribution depends stronger on the irradiated area or spot size, as compared to the laser pulse energy. Furthermore, comparison of both media is investigated regarding influence of laser pulse duration on the particle size distribution and productivity for a variety of metal and ceramic materials. In this report, we present an overview of parameters influencing the generation of nanoparticles by pulsed laser ablation in air and liquids.

Th 5-03

Silica nanomachining using laser plasma soft x-rays

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Hiroyuki Niino[2], and Kouichi Murakami[1]

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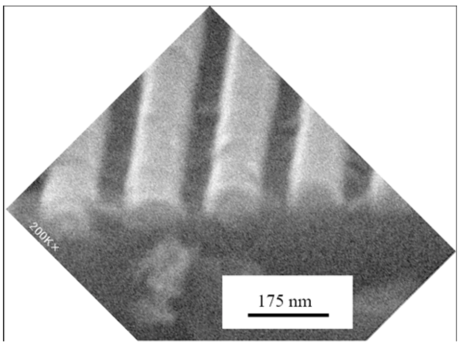
Silica micromachining at high precision is required for (a) mold fabrication in nanoimprint, (b) nanometric chemical analyzers and chemical reactors in medicine and biotechnology, and (c) optical devices. For these applications, it is required to machine silica at high precision at low cost. We have investigated silica nanomachining using laser plasma soft X-rays at around 10 nm [Appl. Phys. Lett. 89, 101118 (2006); 86, 103111 (2005); 85, 1274 (2004)]. Soft X-rays were generated by irradiation of Ta targets with 532 nm Nd:YAG laser light with a pulse duration of 7 ns, at an energy density of about 10 kJ/cm2. Under the condition, Ta plasma emit light with energies of 10-500 eV, in addition to soft X-rays at around 100 eV (10 nm). The soft X-rays were focused on samples with a spot size of 400 micrometers, using an ellipsoidal mirror that we designed so as to focus soft X-rays at around 10 nm efficiently. The samples were irradiated with soft X-rays through contact masks. We found that silica glass can be machined by irradiation with laser plasma soft X-rays. Furthermore, it is remarkable that surface roughness is about 1 nm after 10 shot irradiation with soft X-rays at 50 nm/shot. Ablation rate can be controlled by the fluence of soft X-rays in a range of 0.2-150 nm/shot. In addition, we found that the ablation observed here requires high fluence beyond the threshold, which have not been achieved by synchrotron radiation etching. In order to investigate lateral resolution, we fabricated a WSi mask with 175-nm-pitch line-and-space patterns on a silica glass plate. After irradiation with laser plasma soft X-rays, the WSi mask was selectively removed by reactive ion etching. As shown by Figure, we found that a series of trenches with a width of 50 nm can be fabricated on silica glass. With further development of imaging optics, slilica nanomachining should be achieved by direct irradiation with laser plasma soft X-rays without any contact mask.



Th 5-04

Growth of bi-phase crystalline/amorphous Sm-Fe-Ta-N magnetic nano-droplets fabricated by PLD

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The magnetic properties of rare earth–iron intermetallic alloys in the form of thin films mainly depend on the crystal structure and size and the stochiometry of the nano-(micro)-composites [1]. The amount of deposited material in the form of amorphous (non-magnetic) droplets of nano dimensions sets the upper limit of film magnetism achieved after further annealing and nitriding. However, even without annealing and nitriding, the coercivity will appear in droplet-like film structures if the crystal (nitride) phase starts to grow within the amorphous nano-droplet. We report that growth of magnetic nano-crystal islands within the amorphous phase depends on the target composition and on processing parameters, such as background pressure, energy, and distance between substrate and target. Sm2Fe17-xTaxN3-σ magnetic nano-droplets were fabricated in situ under nitrogen background pressure from the Sm13.8Fe82,2Ta4,0 target by pulse laser deposition using a molecular fluorine laser at 157 nm [2]. In contrast, nano-droplets fabricated from an Sm13.8Fe86,2 target under similar experimental conditions but with a high vacuum or He background atmosphere were non-magnetic in the absence of further annealing and nitriding. Using analytical electron microscopy and a vibrating sample magnetometer, we found that the magnetism of the nano-droplets originated from Sm2Fe17-xTaxN3-σ crystal dots. The crystals were 5–10 nm wide, encapsulated within ~50–100-nm amorphous spherical droplets . The crystal phase was formed during the cooling of the original amorphous liquid droplets in the plume.

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Th 5-05

Extensive laser nanopatterning by micro-particle lens arrays

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Laser-induced surface nanopatterning cross a large surface area is a challenging task. Compared with electron beam and focused ion beam lithography techniques, laser process has an advantage of simple setup, fast speed and massive processing. In this paper, a near-field technique was developed to overcome the diffraction limit for direct laser surface nanopatterning. For the first time, it was demonstrated that different nano-features can be written on the substrates in a large surface area. By using an angular incident laser beam with a self-assembled particle-lens array, millions of nanostructures can be accomplished by a few laser pulse exposure.

Session 6 (LPM-6):

Laser Hybrid and Media-Assisted Processes

We 6-01

Mechanisms of water assist for overcoming the self-limiting effects of high aspect ratio machining of silicon and for minimising particulate redeposit

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UV DPSS laser micromachining has emerged as a tool that is widely used for high aspect ratio machining of features in semiconductor materials. For machining of through-trenches in silicon, the machining rate reduces as the depth increases. For high aspect ratio trenches, it is considered that the retention and re-deposition of laser generated particulate in the trench is significant in impacting the machining rate. A water assist process can be utilised to prevent this reduction in machining rate and the mechanisms of this assist process have been studied. A review is presented of the possible mechanisms outlined in the literature for such water assist processes. In the initial stages of machining a trench, water assisted and non-assisted machining rates are the same – it is found that the machining rates only begins to differ at a particular trench depth where the aspect ratio reaches a certain critical value. This indicates that contrary to other theories on water assist, that the water assist does not necessarily enhance the actual ablation mechanism but increases the overall machining rate through efficient removal of the laser generated particulate for high aspect ratio features. Comparing cross sectional profiles for non-assisted and assisted machining and looking at the particulate dissolved in the water assist provides further evidence to support this theory.

We 6-02

The hydrodynamic theory and simulation of liquid phase for laser shock process

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[1]Huazhong University of Science & Technology

Laser shock processing can improve the anti-fatigue and anticorrosion performance of metal use d for micro-device. The theory model is given to investigate a target with transparent confining medium and painting coating layer irradiated by pulse laser considering potential melting liquid phase of the target. The mechanics model is established, its initial conditions adopt the modified model by Zhang wenwu etc, as according the basic equations of mass continuity, momentum conservation and energy conservation. Matlab is used to research in detail and analyze the issue. Special attention is paid to the influence of liquid phase on peak pressure of shock waves at laser intensity of I_0=2GW/cm^2 - 4GW/cm^2 using CFD (Computational fluid dynamics) soft to make simulation computation. Some referential interesting results for future experiences are obtained.

We 6-03

Self-organized growth of sp3-bonded 5H-BN electron-emitter micro cones prepared by plasma-assisted laser chemical vapor deposition: experiments and modeling

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Here we propose a repetitive photochemical-reaction and diffusion model for the fractal pattern formation of sp3-bonded 5H-BN micro cones in laser-assisted plasma chemical vapor deposition, which was observed experimentally and reported previously. This model describing the behavior of the surface density of precursor species, gave explanations to (1) the “line- drawing” nature of the patterns, (2) the origin of the scale-invariant self similarity (fractality) of the pattern , and (3) the temperature-dependent uniform to fractal transition. The results have implications for controlling the self-organized arrangements of electron-emitter cones at the micro- and nano-scale by adjusting macroscopically the boundary condition (Lx, Ly) for the deposition, which will be very effective to improve the electron field emission properties.

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We 6-04

Laser-induced writing of submicron surface relief gratings in fused silica on-the-fly

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The high quality etching of transparent materials is still a challenge for laser processing. The hybrid laser processing method LIBWE (laser-induced backside wet etching [1]) allows the defined microstructuring of transparent materials like fused silica at low laser fluences and with high quality. The etch process is based on the pulsed laser irradiation of backside of a transparent material that is in contact with an absorbing substance. Usually organic solvents or solutions (hydrocarbons) are applied as absorbing liquid for LIBWE. The etching is characterized by a high surface quality and small etch rates [1,2]. Otherwise, the decomposition of the organic liquids can distinctly alter the materials surface with respect to their chemical and structural properties, which will be responsible for the observed incubation effects at LIBWE [3]. Recent results show the application of liquid metals such as gallium for etching instead of organic solvents or solutions [4]. Liquid-metal-LIBWE features negligible incubation effects and very large etch rates (100 600 nm/pulse) while the surface quality is as high as for hydrocarbon LIBWE. For the etching of periodically sub-micron structures on a solid surface interfering laser beams are used generated by projection of diffraction masks. In conjunction with the backside etching approach, submicron surface relief gratings with regular line or dot patterns can be realized on planar fused silica substrates in a one-step direct fabrication process [5]. The large etch rates at LIBWE by means of the liquid metal enable a high-speed processing; gratings with a period of ~ 700 nm and a height of more than 100 nm can be etched onthefly with one laser pulse.

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Session 7 (LPM-7):

Biomedical and Analytical Applications

Fr 7-01

Invited

Ultra-short pulse laser ablation of biological hard tissue and biocompatibles

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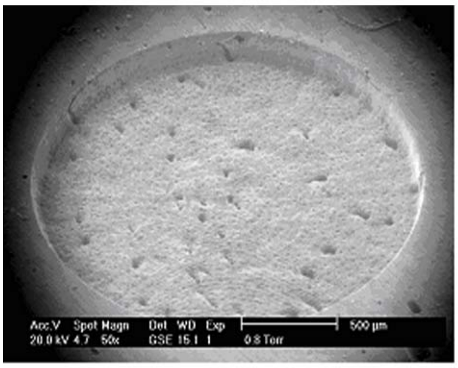
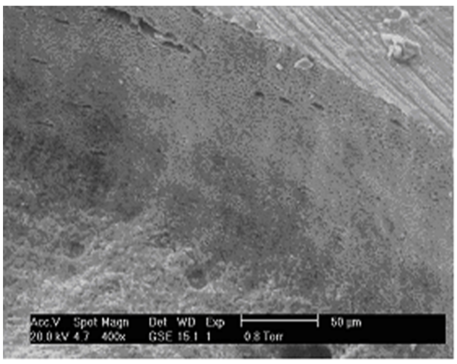
The application of ultra-short pulse lasers (USPLs) to biological hard tissue and compatible materials (like for dental restoration) in order to process cavities and more complicated structures is not yet a routine technique which can soon be implemented into practice. Its advantages, however, cover the feasibility of avoidance of collateral damage (i.e. thermal and shock wave), the creation of geometrically fully versatile and precise structures, and the option of spectroscopic feedback. In this paper, new data are presented concerning ablation rates and ablation thresholds of human and bovine dental hard tissue, dental composites and bone, i.e. compacta, spongiosa and cartilage, being ablated by various scanned USPLs with different pulse durations. The data give evidence that even ps pulses yield very useful results, and selective ablation may be beneficial for practical application. The morphology of the cavities yielded by different scanning techniques is analyzed via environmental scanning electron microscopy. Fig.: Bovine compacta ablated by Ti:S laser pulses scanned according to an Archimedic spiral. Laser parameters: $\tau\pi$ = 700 fs and F = 0.65 J/cm², PRR = 1 kHz, 20 roundtrips. a) overall view, b) magnification of the rim.





Fr 7-02

Laser-controlled pico-injector for nano-biodevices

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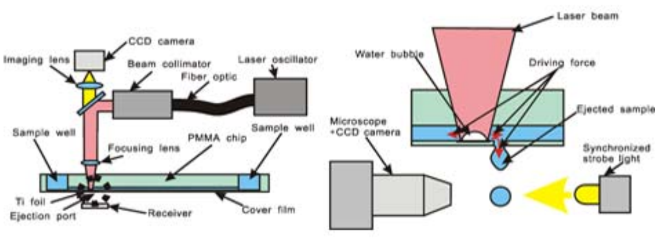
Micro fluidic devices are powerful tools for the analysis of DNA, protein and other biopolymer samples. However, they have no fraction function that enables further analysis and/or the use of separated samples. For plastic-based disposable chips, complex systems such as piezoelectric actuators, micro valves and micro heaters are not suitable because of their costs. We developed a laser controlled injector, which has a laser unit outside and minimum additional parts in chip, a piece of metal foil as a beam absorber and an ejection port. Explosive vapor bubbles formed on a thin metal foil in a channel during laser irradiation effectively ejected biopolymer samples of the water solution from the channel to outside. The samples before and after ejection were analyzed by SELDI-TOF MS. The laser controlled pico-fraction unit successfully ejected protein samples without the change of their mass spectra.



Fr 7-03

Ultrafast-laser-processed zirconia and its adhesion to dental cement

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All-ceramic dental crowns from yttrium-stabilised tetragonal zirconia polycrystal (Y-TZP) are the cutting-edge solution for dental restorations, with regard to cosmetic aspects as well as mechanical durability. The material in its final hot-isostatically pressed constitution can be machined with femtosecond lasers as the most precise, damage-free, and wear-free tool for micromachining. The exact geometry shall be generated according to CAD data from patients' dentitions. A processing station, including a 300 fs laser system, has been designed based on previous investigations that have narrowed down optimal laser characteristics and necessary processing dynamics. These requirements have led to a modular machine concept with five-stage machining and high dynamics that will be presented. Fixation between crowns and cement remains a weak point. Regarding its adhesion to dental cement, Y-TZP naturally comes off worse than dentin. This is due to mechanical bonding to dentin tubules - hollow perpendicular tubes travelling from the pulp to the enamel undersurface - to which cements are mechanically locked at the surface of a dental stump. We have investigated whether the fixation between cement and Y-TZP surfaces can be improved similarly by artificial microstructures. Such structures can be added to the inner surface of laser-processed dental crowns in a final step after ultrafast-laser-based manufacturing. The investigations include basic studies on surface machining of Y-TZP with femtosecond pulses and evaluate possible microstructures with regard to structure sizes and process efficiency. Achieved practical values of adhesion between ceramic and cement are compared to estimations from numeric simulations. Measurements for similar applied microstructures turn out to be constricted by side effects. Still, the results demonstrate that microscopic structuring does in fact enhance the adhesion and can therefore contribute to the overall reliability of dental crowns.

Fr 7-04

Investigation on laser dental implants decontamenation

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During the last decades, the use of dental implants for replacement of missing or extracted teeth became more and more state of the art in dental prosthetic therapy. One of the most probable reasons for failure cases nowadays is periimplantitis. This type of inflammation is associated with increased probing depth, mobility, bleeding and suppuration for the implant representing the clinical symptoms of periimplantitis. Implant failure may be the result of one or several pathogenic factors such as infection, implant contamination, trauma during surgery, impaired healing and/or premature loading during the healing process. Conventional surgical treatment of periimplantitis lesions can be performed in cases with considerable pocket formation (pocket depth larger than 5 mm) and bone loss after the acute infection has been resolved and proper oral hygiene has been instituted. Numerous methods for implant surface decontamination have been suggested as part of the surgical treatment of periimplantitis. Actually, decontamination of infected implant surfaces can be achieved very easily and effectively by application of laser radiation. In several studies bactericidal effect of high-power microsecond pulse laser irradiation on contaminated dental implant surfaces already has been demonstrated. As most of these studies were undertaken under the aspects of medical needs, the view on the driving physical parameters was mostly not sufficiently reported. Hence, the purpose of our study was to evaluate suitable parameters for laser decontamination of titanium implant surfaces by employing pulses in the range of microseconds generated by different laser systems. For this, special consideration had to be taken on heat deposition and surface changes to prevent bone necrosis and stimulate reattachment of tissue. In our presentation, we will report the results for temperature development and surface morphology of different laser parameters and their clinical relevance and limitations

Fr 7-05

Invited

Application of femtosecond lasers in opthalmology

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Lasers with ultrafast pulses have been developed to decrease the energy necessary to incise tissues and to decrease damage to surrounding tissues. In ophthalmology, femtosecond lasers have so far been used for corneal surgery. The fs-laser uses infrared light to precisely cut the tissue by photodisruption. The specialized software is focusing the laser beam into tiny, 2-3 micron spots of energy. The beam passes harmlessly through the outer layers of the cornea until it reaches its exact focal point within the corneal stroma. Upon reaching this focal point, the beam forms microscopic bubbles of carbon dioxide and water vapor. Thousands of these bubbles are placed at a precisely controlled depth to define a dissection plane. By interconnecting the bubbles very tightly, a corneal flap is created with remarkable precision and accuracy. The technology enables the surgeon to precision-design the cuts in terms of diameter, depth, edge angle, and morphology. At present, the main application in ophthalmology is the creation of lamellar flaps for laser in situ keratomileusis (LASIK), a procedure to correct myopia (nearsightedness), hyperopia (farsightedness), and astigmatism, and therefore to reduce patients' dependency on contact lenses and glasses. When used during LASIK, the fs-laser replaces the handheld microkeratome blade traditionally used during surgery. Clinical studies show that the flaps are uniformly of good quality with no flap complications. The flexibility of this system allows for intrastromal corneal surgery and may make it useful also for other refractive and corneal procedures. Further applications are the creation of pre-cut channels for intra-corneal ring segments and cuts for lamellar and perforating corneal transplantation, which represents an entirely new approach for the correction of various corneal disorders.

Fr 7-06

UV excimer laser ablation of RGD peptide grafted onto PET: Impact on cell attachment

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Introduction: Poly (ethylene terephthalate) (PET) has been most widely used as biomedical implant because of its desirable properties, such as strength and modulus. In order to favor osteoblast cells adhesion onto PET, our work deals with grafting of RGD peptides on surface. Indeed, the RGD peptide is well known to be the active sequence of adhesive proteins of the extracellular matrix[1]. When hybrid biomaterials are produced, the current consens is now to distribute the bioactive ligands in a controlled fashion in the form of nanoscale-clusters or nanodomains, and no longer in a homogeneous or statistically based way. As a result the aim of our study is to be able to produce nanostructured surfaces which will present variable densities and distributions of peptides on the surface and monitor both qualitatively and quantitatively cell adhesion[2]. Materials and methods: PET sample used is a commercial film obtained from Good Fellow . The four subsequent steps for RGDC grafting are: Hydrolysis with NaOH + water/acetonitrile; Oxidation with KMnO4 in H2SO4; NHS, EDC grafting; RGD grafting [3]. Ablation was performed by laser onto the graft surface. It is composed by KrF excimer laser (Lambda Physik LPX 220i) with µ= 248nm [4]. X-Ray photoelectron spectroscopy (XPS), Optical profilometry, SEM and radiolabelling techniques are applied to characterize the surfaces. Cell attachment studies were performed with MC3T3 cell line. Conclusions: XPS results shown that RGD peptides were covalently grafting to PET surfaces and peptide density was evaluated by high resolution µ-imager. Cell adhesion on different materials (homogeneous and patterned) were studied by vinculin and actin labelling (immunogold labelling/SEM and fluorescent staining/confocal).

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Fr 7-07

Surface functionalization of 2D and 3D structures using biomolecules

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Bio-micro-array fabrication and biological molecule patterning has been the focus of much research in recent years, as they are envisaged to play an important part in genomic studies, drug discovery and screening, protein identification and scaffolding development for tissue engineering. However, there are still several issues remaining regarding biomolecules malfunction in harsh environments, as these materials are chemically and structurally very complex and heterogeneous and they easily lose their structure and biochemical activity due to denaturing, dehydration or oxidation. A number of different approaches have been examined for fabricating patterned biological surfaces. Almost in all cases, biomolecules patterning has been two-dimensional. We demonstrate both 2D and 3D biomolecules patterning using techniques which enable the construction of arbitrary two and three dimensional shapes, not restricted to array-based shapes. For the 2D printing, Laser Induced Forward Transfer (LIFT) is employed to deposit controlled and viable micro-patterns of a variety of biomaterials. The activity and the functionality of the transferred materials is shown. For the 3D printing, firstly micro-structures are made employing multi-photon polymerization. Biotin is subsequently immobilized on the surface of the structures by excimer laser photo-activation of photobiotin and further exposed to fluorescently labelled avidin. The specificity of the binding is demonstrated. The methods allow not only prototyping but also direct device construction.

Fr 7-08

Scanning of Ultra-Short Laser Pulses in Dental Applications

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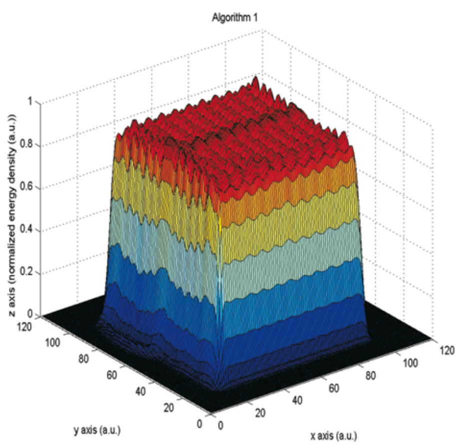
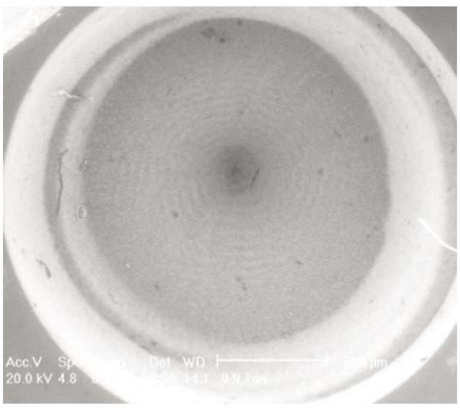
In the last years ultra-short laser pulses have proved their potential for application in medical tissue treatment in many ways, especially for the most sensitive dentinopulpal com-plex in teeth. In hard tissue ablation their aptitude of material ablation with negligible collat-eral damage brings many advantages. Up to now it was shown by many authors that the application of picosecond or femtosec-ond pulses allows to perform an ablation to the physiological requirements. Beside the short interaction time with the irradiated matter, scanning of the ultra-short pulses turned out to be crucial for ablating cavities in the required quality. One reason for this can be seen in the fact that during scanning the time period between two pulses falling repetitively on the same spot is so long that no accumulation effects occur and each pulse can be taken as a first one. In our talk we present the actual results of our investigations on optimizing different pulse durations and scanning patterns. They allow to create cavities without collateral damage by a constant irradiation of the scanned area and to avoid any irritation to the pulp being one of the most important prerequisites for pain free dental treatment. In simulation and experi-ments the theoretical energy distribution and the practical ablation behaviour are compared and discussed. Figure Caption: Left: Simulation of the energy distribution of an x/y-scan. A flat top shaped energy distribution is preferred to yield constant ablation quality and depth. Right: ESE micrograph of a cavity prepared by an r/phi scan. The rotational geometry has the advantage to allow the simulation of a conventional drill. Furthermore, this shape is insensitive against translational move-ments in any direction.





Fr 7-09

Autofluorescence of electrophoresis chip grooved by excimer laser

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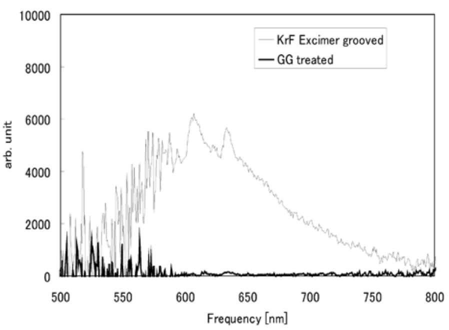
[1]National institute of Advanced Industrial Science and Technology,
Health Technology Reseach Center

The spectra of autofluorescence from the grooves of electrophoresis chip machined by a KrF excimer laser were measured by a fluorophotometer equipped with the 2nd harmonic of Nd:YAG laser as excitation source. Acrylic plastics (PMMA) were used as the specimen. Total fluorescence of laser machined groove in a wavelength range between 580and 750nm strongly depended on the fluence of laser and could be reduced by the optimization of the fluence. However, the intensity of fluorescence was still high at the best condition compared with an electrophoresis chip formed by injection molding. For further reduction of autofluorescence of laser machined groove, we used a solvent, GG developer that contains 60 wt% of 2-(2-n-butoxyetoxi) ethanol and 20 wt% of morpholine and 5 wt% of 2-aminoethanol. Etched by the solvent, the autofluorescence of the grooves was dramatically improved as to applicable for practical electrophoresis. The electrophoresis signals of the chip formed by the combination of laser grooving and solvent etching were compared to that of the chip by conventional injection molding. The spectra of autofluorescence from acrylicplastic specimen excited by green laser (532nm) after laser irradiation is shown by thin line in the Figure. After laser irradiation and etching the spectra of autofluorescence from the groove is shown by heavy line in the figure.



Fr 7-10

Biofunctional photopolymers for micro-stereolithography

J. Stampfl[1], M. Schuster[1] ,R Inführ[1] , F. Varga[2] , C. Turecek[2] , R. Liska[2]

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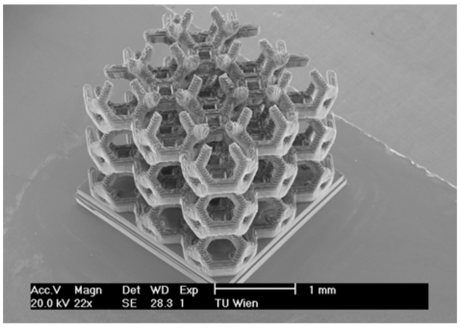
Micro-Stereolithography (μSL) is a computerized fabrication technique that has gained increasing interest in tissue engineering applications because of its ability to produce objects with complex geometry and inner structure, like cellular structures as they appear in natural bone. In these investigations we aim at the development of a new polymers for tissue engineerign, that can be formed by μSL and fulfills the requirements from the medical point of view. For that an acrylate-based monomer formulation has been developed by testing several commercially available acrylic compounds concerning photoreactivity, mechanical properties and biocompatibility. By use of a modified gelatin as a photoreactive crosslinker biodegradability can be introduced into the polymer. Further components of such a formulation are appropriate photoinitiators and filler materials to further improve the mechanical properties and to act as Ca source in the body in the case of bone replacement.



Fr 7-11

Laser-induced forward transfer of liquids for miniaturized biosensors preparation

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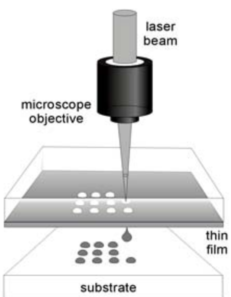
The high focusing power of lasers makes them adequate for the development of direct writing techniques for micropatterning purposes. Although most laser direct writing techniques are essentially subtractive, lasers can also be used as additive tools in several ways. One of the most common configurations is the corresponding to laser-induced forward transfer (LIFT). In this approach, a small amount of material is directly transferred from a donor thin film to a receptor substrate placed parallel and in close proximity to the film. Transfer is induced by a laser pulse focused on the film through its transparent support. In traditional LIFT, the donor thin film is solid, and the fraction of transferred material is completely vaporized by the laser pulse; deposition takes place through recondensation of the laser-generated vapor on the receptor substrate. This transfer mechanism makes this technique feasible for the deposition of some inorganic materials, like metals and oxides, but useless for more complex materials which structure is irreversibly damaged after vaporization, like polymers or biological molecules. However, it is also possible to induce material transfer from liquid films; in this case the process takes place through direct ejection of droplets from the film, with no significant phase change (see the scheme in the figure). This makes feasible the deposition of complex materials through their previous suspension in a liquid solution, since the material of interest is then dragged by the solvent during transfer instead of being vaporized, thus preventing it from decomposition. Under these conditions, transfer occurs in a way very similar to ink-jet printing. The capability of LIFT of transferring complex materials without degradation makes this technique adequate for miniaturized biosensors preparation: patterns of biomolecules can be accurately deposited with a high degree of spatial resolution (see droplets of 10 µm diameter in the figure) and without loss of their biological activity. In this work we investigate the physical processes and parameters determining the characteristics of the micrometric patterns deposited through LIFT for the preparation of minitaturized biosensors.



Fr 7-12

Bio-microchips fabricated in transparent materials by femtosecond laser

Yasutaka Hanada[1], Koji Sugioka[1], Ikuko Ishikawa[1], Hiroyuki Kawano[1], Katsumi Midorikawa[1]

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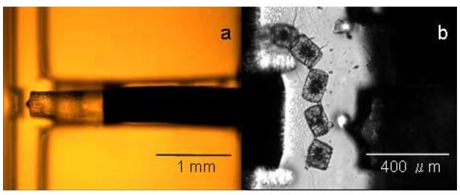
Observation and analysis of living cells and microorganisms are currently important subjects for biologists due to the pursuit of origin of life and bio-motor applications. Their common tool for this study is an optical microscope with a high numerical aperture (NA) objective lens. They strongly demands to three-dimensionally confine the living cells and microorganism in an area as small as possible for easier observation since the high NA objectve lens limits both the field of view and the depth of focus. We applied our technique fabricating three-dimentional (3D) hollow microstructures inside photosensitive glass by fs laser for manufacture of a microchip, in which a simple microchannel was embedded in the glass, for observation of Euglena. In the meanwhile, to integrate some functions to the microchip is required for some other applications. In the present paper, we attempt to integrate a mechanical component into the microchannel to investigate mechanism of information transmission in living Pleurosira. The procedure for fabricating the 3D hollow microstructures consists of (1) 3D direct writing by fs laser (775nm, 150fs, 1kHz),(2) baking to form the modified regions at the laser exposed regions, (3) wet etching in dilute HF solution to selectively remove the modified regions, and (4) post annealing to smooth the etched surfaces. Figure 1 shows a microscope image of the fabricated microchip in which a movable microneedle is integrated into the microchannel. Motion of the microneedle is controlled by a Cu tube connected to the miconeedle. When the tip of miconeedle is stuck to one of the cells of Pleurosira, its information is transmitted to other cells successively. As a result, it is observed that Chloroplast gather to the center of each cell as shown in Fig. 2. This Phenomena is considered to be similar to the information transmission in neuronal cells and thereby is of great use for understanding neuron network mechanism.



Fr 7-13

Infra-red (1064 nm) laser printing of biological elements: preliminary results

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Considering microarrays generation, biomaterials surface treatment or else tissue engineering, laser printing of biological elements such as proteins, enzymes and cells is called to become an important tool in the future. In this aim, many processes have been described under the names MAPLE-DW, LIFT or AFA-LIFT considering if the biological elements are embedded in an absorbing matrix or/and placed onto an metallic absorbing layer. Principle works have involved pulsed UV lasers: Nd:YAG laser tripled in frequency (l = 355 nm) or excimer lasers (l = 193 and 248 nm) and thermal and thermo-mechanical mechanisms have been proposed considering nanosecond lasers. In this study, we focus on laser printing of cells and peptides for biomaterial applications. Experimental set-up included a Nd:YAG laser (1064, 30ns), a galvanometric scanner, a gold (20-30 nm) absorbing layer and a 30-50µm thick hydrogel matrix layer containing above-mentioned biological elements. Peptides patterning were performed on a pre-functionalized poly(ethylene terephthalate) (PET) using radiolabeled peptides ([3H]-lysine) and observed by means of a high resolution beta-Imager. In the other hand, human endothelial cells (EaHy926 cell line) were printed on a glass slide varying fluence conditions. Short and long term viability of endothelial cells were determined by live/dead assays. According to these preliminary studies, infra-red laser printing seems to be an effective alternative to UV processes. However, deepest studies should concern heat shock proteins expression in relation to optical parameters.

Session 8 (LPM-8):

Photochemistry

Fr 8-01

Invited

Femtosecond irradiation of a photosensitive zinc phosphate glass containing silver

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We report on exposing a photosensitive zinc phosphate glass containing silver to infrared femtosecond pulses. The used laser source is a directly diode-pumped high energy Yb:KYW oscillator delivering pulse energies up to 1 µJ and pulse durations down to 430 fs, thus pulse peak powers exceeding the MW level. The pulse repetition rate is 9 MHz and the average power is on the 10-W-level. . This laser source is hence well suited for various micro- and nanostructuring applications. By focusing such a laser beam inside the zinc phosphate glass containing silver glass, we can induce microstructures below the diffraction limit. Indeed, following exposure, we observed the formation of chemically stable silver clusters (Agnx+ with n<10). Several linear and nonlinear optical and spectroscopic time resolved techniques allows probing the dynamic of the formation of these clusters. The mechanism of the photoreaction is discussed. Following a thermal treatment, controlled creation of precious metal nanoparticles inside glass could be achieved. Some applications should be considered due to local modification of refraction index such as waveguides, gratings, photonic crystals or 3D-microstructures.

Fr 8-02

Laser-induced forward transfer (LIFT) of sensitive materials using a photolabile dynamic release layer

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Laser-induced forward transfer (LIFT) is one possible method to transfer materials or material layers with micrometer resolution from a transparent transfer substrate to a receiver. This technique utilizes laser to achieve the transfer and lateral resolution, and can be performed “solvent-free” with the pure material. As lasers near-infrared or UV laser can be applied, but in the case of sensitive materials, such as biomaterials or electroactive polymers, thermal load or UV photons can be detrimental to the properties of these materials. We have therefore developed and tested photosensitive dynamic release layers (DRL) which absorb the laser photons and protect in this way the transfer layer. The DRL functions also as pressure generator upon decomposition which enables the LIFT process (shown in scheme 1). It is of course important that the decomposition products will not contaminate the transferred layer. The utilization of photopolymers, which completely decompose into gaseous fragments, is the basis for this approach, while metallic DRL tend to contaminate the transfer material. The DRL polymers are based on triazene functional groups that decompose into nitrogen while the other structural units of the triazene polymers are utilized to obtain specific properties, e.g. solubility in certain solvents, including water, surface polarity, or biocompatibility. We have studied and optimized the triazene-based DRL with regard to film forming, optimum thickness for the transfer at a given laser wavelength and fluence, optimum laser fluence. The optimized DRL system was then tested for the transfer of sensitive materials, such as cells, water-soluble polymers, nanocrystals and in most detail electroactive polymers, e.g. MEH-PPV (poly(2- methoxy,5-(2’-ethylhexyloxy)-1,4-phenylene vinylene). The functionality of the transferred materials have been tested in detail, e.g. in the case of MEH-PPV by observing light emission. The application of the DRL allows also the transfer of more than one layer in one step, i.e. the MEH-PPV with an electrode.

Fr 8-03

Laser photoionization and photodissociation method and technologies for cleaning the semiconductor materials and preparing the films of pure composition at atomic level

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Method of laser photoionization and dissociation of molecules is very perspective method for cleaning semiconductor materials from admixtures. Laser cleaning of mono-silan represents a great interest for technology of obtaining a poor Si in the semiconductor industry. The paper is devoted to the search and modeling optimal schemes of laser technologies for control and cleaning the semiconducting substances. Here at first we construct the optimal scheme of laser photoionization technology for preparing the films of pure composition on example of creation of the 3-D hetero structural super lattices (layers of Ga(1-x)Al(x)As with width 10Å and GaAs of 60Å). It includes at first step an excitation of atoms by laser field and their transition into Rydberg states and then ionization by electric field [2]. A creation of the films of pure composition (our problem is creation of the 3-D layers of Ga(1-x)Al(x)As with width 10Å and GaAs of 60Å) is directly connected with using photoion pensils of Ga, Al, As. Similar pensils are created by means of the selective ionization method. Then electromagnetic focusing and deflecting systems will provide a creating 3D supper lattices. Besides, we present a new multi-level optimized model for definition of maximal effectiveness of laser action in process of photodissociation of molecules. Model is based on the Focker-Plank type equation for density of molecules [2]. Parameters for optimal excitation for molecules of HCl (PH3,SiH4)are defined. In fig. we present the data of computer testing optimized model for HCl molecules (T=300K) and dependence (number of particles) of functional: I(u)=Int.{f(x1,t1;x2,t2)h(x)dx} in vibration energy interval x~[15,21] (in units of kT)upon x1, wavelength of laser radiation.

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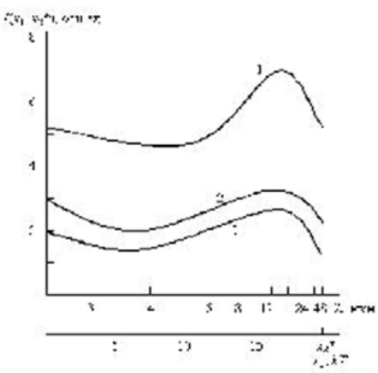
2. A.Glushkov,L.Ivanov, J.Phys.B 26,L376(1993); A.Glushkov et al, Int.J.Quant.Chem. 104, 562 (2005).



Fr 8-04

Micro-marking using violet laser diode with dyestuff and pigments on plastic surfaces

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Laser Diode (LD) is very excellent light source with advantages in high efficiency, small size and lightweight and so on. Jitsuno et al. in Institute of Laser Engineering, Osaka University corrected the wavefront distortion of a infrared LD (wave length 940nm) to provide a precise spot, and tried to use the beam to direct processing. Because wavelength of Violet Laser Diode (VLD: Wave length 405nm) is shorter than that of infrared LD, VLD is expected to obtain smaller beam spot. The wavefront distortion of a beam from a single-mode VLD with a collimator lens was measured and corrected to provide a precise focal spot. And using the precise beam, we tried to print color marking on plastics. Figure 1 shows process of color marking on plastics such as PET, PMMA, and PC. Disperse Dye (or pigment) was mixed into stock paste, and this color paste was coated on plastics and dried. The output beam of this VLD was focused on a plastic plate to which dyestuff or pigments were added to enable color micro-marking without an absorbent. The part irradiated by the laser was marked, and unfixed dyestuff or pigments were removed with ethyl alcohol. Using this focusing VLD, color micro-marking of 100μm font size on the plastic plate was achieved. Figure 2 shows micro-markings of 100μm and 200μm font size.

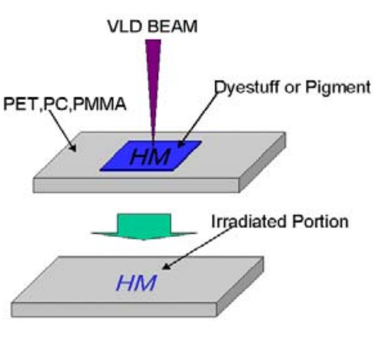

Fig. 1: Color marking process

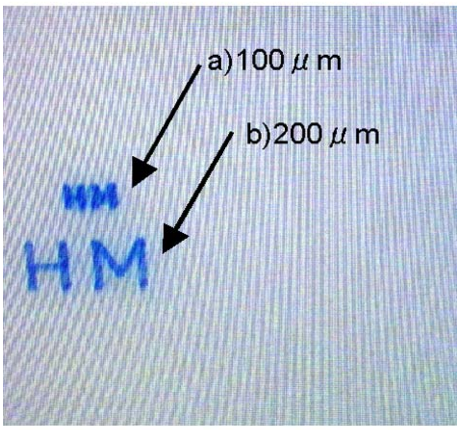

Fig. 2: Micro-marking on PET. a)100 μm b)200 μm

Session 9 (LPM-9):

Micro-Drilling and Cutting

Fr 9-01

Micromachining with a high repetition rate femtosecond fiber laser

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Industrial micromachining applications with ultrashort pulse lasers are often difficult to make practical due to the lack of robustness of the laser and the slow processing speed resulting from the low repetition rate. In the past, amplified, femtosecond lasers produced high pulse energies, but at a slow pulse repetition rate of around a kHz. The high repetition rate oscillators did not have enough pulse energy for micromachining of most industrial materials. Fiber Chirped Pulse Amplification (FCPA) is bridging these two performance regimes, producing relatively high pulse energies (compared to oscillators) and relatively high repetition rates (compared to amplifiers) in a robust and reliable package. The FCPA µJewel D-1000 has a flexible performance range that includes 10-µJ pulses at 100 kHz and 1-µJ pulses at 1 MHz. The µJ pulses at MHz repetition rates enable some interesting micromachining processes, particularly with transparent dielectric materials where thermal accumulation begins to play an important role in the process. This paper expands on previously reported work on micromachining of transparent materials using a high repetition rate, femtosecond fiber laser.

Fr 9-02

Fine micro-welding of thin stainless steel sheet by high speed laser scanning

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Recently, since the size of component becomes smaller, then the welding of thin metal sheet has been required. Besides, the flexibility of process is important according to the accessibility in the case of small component. Fraunhofer Institute for Laser Technology had developed the SHADOW® welding technology, in which the high speed joining with small distortion is possible using pulsed Nd:YAG laser by a non-contact process. On the other hand, Prof. Miyamoto had reported the possibility of high speed and high quality welding by single-mode fiber laser. The combination of micro beam and high speed laser scanning has the benefits for welding of thin metal sheet. Therefore, the characteristics of micro-welding for thin stainless steel sheet were investigated by high speed laser scanning, in which the welding was carried out by high speed scanner system with single-mode fiber laser and pulsed Nd:YAG laser. The absorption condition of laser power at the start point of irradiation had a great influence on the welding seam, because the heat conductivity immediately progressed to the surface direction. Besides, large distortion was observed at the start and end point of laser irradiation even under low laser power and high scanning speed conditions. Then, the controllability of welding depth was discussed, and welding seams were also evaluated under various laser irradiation conditions. Welding depth of 25 μm sheet can be controlled widely by smaller spot diameter of fiber laser and high scanning speed compared to larger spot diameter of pulsed Nd: YAG laser. It was difficult to weld two sheets of 25 μm stably in long length by larger spot laser beam, while smaller spot laser beam makes it easy to weld two sheets of 25 μm even in long length. Therefore, the small diameter of laser beam is effective in the welding of thin sheet by the combination of high speed scanning.

Fr 9-03

Microdrilling in steel with frequency-doubled ultrashort pulsed laser radiation

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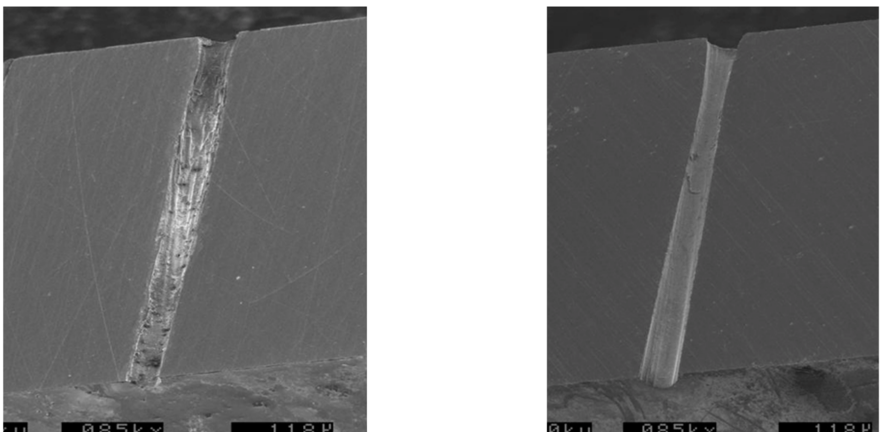
It is shown in a wide variety of papers that microstructures of outstanding quality can be manufactured by means of ultrashort laser pulses. Limiting the pulse energy with the objective of melt reduction and enhancement of accuracy, however, leads to insufficient productivity. Thus, the principle object of current research, particularly in the field of microdrilling, is to raise the process efficiency, whilst maintaining the required precision. Today, prototype solid-state lasers not only provide ps-pulses at repetition rates up to several 100 kHz, combined with adequate pulse energies, but also feature harmonic generation units. These units convert the fundamental infrared wavelength into the second, third or even fourth harmonic by frequency doubling and sum frequency generation in nonlinear crystals. The frequency-doubled radiation exhibits better focusability as well as reduced widening and distortion of the beam profile in a laser induced gas break down. The investigations discussed in this article are focused on drilling at 1064 nm and 532 nm in austenitic CrNi-steel. Fundamental research concerning the breakthrough time and the average drilling rate was carried out on the basis of percussion as well as helical drilling. The main part of the experiments, though, dealt with the fabrication of microholes with a diameter less than 100 µm, utilizing a helical drilling process without core. Fig. 1: Microholes in 1 mm CrNi-steel. Left side: 1064 nm. Right side: 532 nm. Manufactured with fully automated FGSW Helical Drilling Optic at equal process parameters. Fig. 1 depicts two holes manufactured at 1064 nm and 532 nm, respectively, in a 1 mm steel sample. By drilling with frequency-doubled radiation, the hole quality improves considerably. The drilling generated at 532 nm shows a regular shape, smooth hole walls and an absence of recast. On top of this, the frequency-doubled radiation widens the outlet to the predetermined diameter more efficiently and steadily.



Fr 9-04

Precision drilling of Ti6Al4V titanium alloy using pulsed Nd:YAG laser

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Since the introduction of titanium and titanium alloys in the early 1950s, these materials have in a relatively short time become backbone materials for the aerospace, energy, and chemical industries, because of their physical qualities of high strength, low weight. The most important components of the aircraft gas turbine is made by titanium alloys due to its high melting point (1677 ºC). In aircraft large numbers of effusion holes with small diameters are required for improving the cooling capacity of turbine components. Because of laser can be focused very small area, most useful techniques for microholes drilling.
In this study, 150-250 micron diameter holes drilled on Ti6Al4V titanium alloys using pulsed Nd:YAG laser. The effects of the laser parameters are investigated. In order to understand the physical process during the drilling process laser pulse duration, energy, and pulse to pulse time were changed systematically. And also the laser-material interaction was monitored using speed camera. The micro structures were analyzed using optic microscope.

Fr 9-05

Comparing DPSSL micro drilling and cutting applications at different wavelengths

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New strategies in laser micro processing are being developed with increasing interest and intensity using diode pumped solid state laser (DPSSL) systems generating short or ultra-short pulses at good beam quality. Outside the traditional laser guided micro machining of metals and - more recently – semiconductors, less versatile candidates for laser machining such as ceramics, crystals and technical glass are coming into focus. Hence, questions concerning the right choice of laser wavelength are addressed with great concern. However, by using short (ns) pulsed laser light with sufficient peak power, additional non-linear absorption channels are utilized to induce a material reaction even at under classical aspects non-favorable wavelength conditions. To be able to “dial” between IR (1064 nm), green (532 nm) and UV (355 nm) laser pulses, a newly designed diode-pumped q-switch Nd:VO4 laser system by Azura Laser AG was implemented at the laser laboratory. The Mesa-15V is a compact and air-cooled system with off-resonator frequency conversion crystals, yielding ca. 10 W in the IR, 4.5 W in the green and 2 W in the UV (at 15 kHz) simply by “polarization tuning” using two different lambda/2 plates inside ultra-flat opto-mechanical units. This study reports on different laser drilling and cutting application near experiments performed at these three different wavelengths using the identical DPSSL system MESA-15V. For example, results on laser scribing, dicing and cutting of technical glasses such as B33 and D263T will be compared for 1064, 532 and 355 nm at <30 ns pulse width in TEM00 at average powers up to 10W and discussed in respect to potential applications in display technology, micro electronics and optics.

Th 9-06

Laser micro-perforation "on-the-fly" as an essential step of a novel process combination for micro-sieve production

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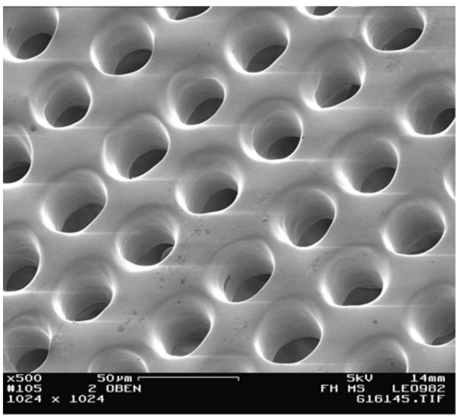
A novel two-step technique, capable of performing large pore matrices (100 pores/mm2) in thin stainless steel foils (10 µm < foil thickness < 300 µm) is maintaining high processing rates and pore widths < 5 µm. This process combination is initiated by high-speed single-pulse perforation "on-the-fly" with use of a brilliant fibre laser. This laser source combines ample output power with an excellent beam quality (M2 = 1.1). The high drilling rate (5000 drillings/second) which can be achieved by use of this technique makes it an attractive option for the creation of large bore matrices and widths smaller than 15 µm (fig. 1). The second step consists in cold-roll forming of the previously laser micro-perforated foil. This mechanically induced plastic deformation leads to a pore size reduction (in one dimension) perpendicular to the rolling direction. However, in filtration applications (e. g. separation of spherical particles) the minimum pore width determines the filtration parameters. Thus, many separation applications benefit from this special pore shape with a minimum pore width of less than 5 µm. Applications can be found in the fields of bio-medical applications and life sciences. High-precision laser single-pulse perforation represents the basis of this process combination. As a result of the micrometer dimensions and high processing rate even sophisticated high-speed camera systems fail to give insight into the laser-material interaction and liquid ejection process. At present, process results are optimised by experimental studies. In order to determine the influence of the independent parameters on the overall thermal and drilling efficiency FEM analysis of the single-pulse "on-the-fly" perforation is carried out. Fig. 1 SEM image of high-speed laser-micro perforated stainless steel foil (50 µm thickness, 1.4301, electro-polished) with a drilling rate of 2500 drillings/second. Up to now a maximum drilling rate of 5000 drillings/second was achieved.



Th 9-07

Melt Dynamics and Burr Formation during Drilling with Ultrashort Pulses

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On the fast growing market of precision micro-machining of metals there are not only lasers which compete with other methods of drilling, but strong competition is also observed among different laser-processing strategies. For processes which are in need of highest productivity, e.g. drilling of cooling holes in turbine blades, drilling with a long single pulse is typical. In that case the material removal is nearly completely performed by melt ejection. For better quality of holes, a reduction of energy density and pulse duration is needed which leads to percussion and helical drilling strategy. Although the fraction of evaporated material increases in that case, there is still material removal due to melt ejection during material processing, even for femtosecond pulse durations. Highest precision without detectable material recast requires very small pulse energies and therefore seems to defeat productivity needed in most cases. Significant advances in productivity of drilling imply deeper understanding of melt dynamics, which can be obtained by diagnostics of the process. The difficulties are the short timescales of the physical processes activated by ultrashort laser pulses and a small scale of the objects under investigations, which are difficult to resolve optically. Because the high aspect ratios of laser drilled holes does not allow in general direct observation of the interior during processing, helpful information can also be obtained by examining droplet ejection, hole formation and accumulation of recast.

Th 9-08

Laser percussion drilling of aerospace materials with a 20kW peak power fiber delivered pulsed Nd:YAG Laser

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[1]GSI Group, Laser Division

Fibre optic delivery of high powered Nd-YAG laser light for material processing is now well developed with respect to laser welding, surface treatment or laser cutting. The application of optical fibres technology to laser drilling has been at a much slower pace due to a number of technical problems. The two main problems are the relative low damage threshold of optical fibres and the preservation of beam quality. The drilling parameters for aerospace components usually use pulse widths in the millisecond range. Though laser damage thresholds in optical materials have been extensively reviewed, unfortunately the available data relates generally to nanosecond laser pulses and very little systematic data has been published in the microsecond and macrosecond regimes. The other problem is that as the fibre diameter is increased the beam quality deteriorates. An M2 of 25 or better, given the right pulse parameters should produce an acceptable hole. The aerospace industry would like to move to a fiber delivery system because laser drilling via an optical fiber can offer a number of advantages i.e. • An optical fiber laser beam delivery system offers the option of standardising the beam path for all CNC machines. • Optical fibres homogenise the power distribution across the laser beam giving a top hat profile. • An optical fibre allows the use of beam sharing optical components so that an aerospace component of the right geometry can be drilled in either of two configurations. This paper investigates laser percussion drilling with a high peak power pulsed Nd: YAG laser (up to 20kW) fitted a 300µm fiber. Holes were drilled with various laser and processing parameters on coated and uncoated nickel based superalloy to quantify laser drilling times, recast layer, taper, oxidized layer and cracking

Th 9-09

3D modelling of laser hardening and tempering of hypo-eutectoid steels

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Laser hardening of steels gained an undoubted interest in today's manufacturing technology thanks to its direct applicability on the production line. The possibility to deal with small, circumscribed and complex surfaces makes possible to obtain highly localized and cost-effective heat treatments. According to this consideration a accurate process set up, together with the determination of technological process parameters, are primary aims to be achieved in order to obtain the desired results. This work presents a full featured software utility which starts from a customizable ferrite-pearlite distribution and simulates the resulting microstructure due to laser heat treatment, taking into consideration every possible phase such as martensite, bainite and residual austenite. It also takes into consideration the tempering effect due to overlapping beam trajectories. These forecasts can be applied to any 3D geometry, both simple and complex, thanks to the exploitation of an advanced 3D mesh generator and to the possibility to implement Laser beam path through a standard CN ISO format. A wide experimental campaign performed on a complex 3D surface is described as a mean of validation of the above mentioned software simulator.

Session 10 (LPM-10):

Micro-Welding and Bonding

Fr 10-01

Invited

Miniaturized samples for bond strength and hermetic sealing evaluation for transmission laser joints

Golam Newaz[1], Taslema Sultana[1] and Hans Herfurth[1]

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Localized joining and hermetic sealing of dissimilar materials (metals, non-metals and polymers) are critical requirements in miniaturized microelectronics, biomedical implants and telecommunications/optoelectronic devices. These devices can combine components made of a variety of materials including silicon, polymers, glass, ceramics and metals. Micro joining and hermetic sealing of dissimilar materials can be achieved by localized laser joining. The controlled heat input decreases the possibility for thermal damage to the highly sensitive components with very precise heat affected zone (HAZ). To improve the performance and reliability of the existing laser joining technology- a better understanding is needed about the effect of material properties in successful laser joining, the impact of the joint mechanism on the materials, and a reiable way of evaluating the integrity of the joints.The efficacy of miniature bond strength samples utilizing pressure induced bond separation and samples for hermeticity using miniature helium bomb test were developed evaluated for laser bonded titanium coated glass/polyimide samples. Sample configurations are given in Fig. 1. Successful results from these tests and meaningful failure modes establish these tests with miniature samples as good methods to determine the integrity of transmission laser joints. The paper will describe in detail these results and provide the technical basis for utilizing these tests for reliable assessment of quality of laser joints.

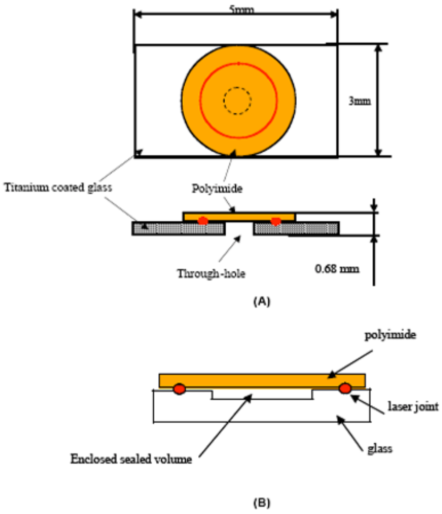

Fig. 1: Schematic of miniaturized samples designed for (A) bond strength evaluation and (B) hermeticity testing (sample has square configuration, 5 mmX3mmX0.68mm). The laser joints are shown in red

Fr 10-02

Laser transmission bonding and welding of silicon, glass and other brittle – rigid materials for micro systems

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Laser assisted transmission bonding with continuous wave (cw) Nd:YAG Laser by linear absorption of optical energy and laser induced transmission welding with ultra short pulsed laser radia-tion by non-linear absorption of optical energy are suitable methods for joining of hybrid microsys-tems made of silicon, glass and other brittle-rigid materials. Two different technologies have been investigated for joining glass and other materials. The non-melting process, laser induced selective bonding of silicon and borosilicate glass is based on the thermo-chemical principles building direct oxygen bridges between the joining partners. Experimental results e.g. the determination of the me-chanical properties and the leak tightness using different functional intermediate layers at the inter-face between silicon and glass will be shown. An overview about possible application on other ma-terial combinations to assemble complex hybrid systems will be given. With the second technique using IR-ultra-short pulsed laser radiation with pulse durations between 300 fs and 3 ps and large repetition rates up to 5 MHz, technical glass plates (D263 SCHOTT) are welded together. Due to the very large intensities in the focus using high NA objectives multi-photon absorption gets the dominant process and due to large repetition rates heat is accumulated and melting of the glass is induced. The mechanical stress within the welding zone is investigated by quantitative phase mi-croscopy and by optical microscopy of cross-sections the dimension of the interaction zone is measured.

Fr 10-03

Laser micro welding in silicon solar module manufacturing

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During the last years, the photovoltaic solar cell industry has experienced enormous growth. However, for solar cells to be competitive on the longer term, both an increase in their efficiency as well as a reduction in their cost is necessary. One opportunity for cost reduction that laser technology can offer is laser micro welding as a substitute for conventional soldering methods in solar module manufacturing where single solar cells are interconnected to solar strings. The advantages of laser micro welding are a shorter processing time and the abolishment of fluxing agent that forms an ageing risk. The challenge of this welding application is to join parts with important differences in their thicknesses and consisting of different metals. In the developed laser process a tin plated copper joiner with a thickness of 100µm is welded on a silver metallization with a thickness of 10µm. To allow proper handling of the solar strings, the welding zone has to withstand a peeling force of 10 N/cm. Furthermore, damage of the silicon in the surrounding area has to be avoided. Results show that with laser micro welding the electrical contact resistance of the joining zone can be reduced by more than 90% compared to conventional soldering methods. Theoretical investigations considering the temperature distribution and strategies for the laser power deposition by pulse forming are described, in order to reduce the variance in durability and to achieve repeatable welding results.

Fr 10-04

Pulsed laser beam welding with filler wire

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Today many laser beam welding processes already use the opportunity to work with additional materials for example filler wire within the laser hybrid welding process. The use of filler wire can be advantageous in aspects of metallurgical (i. e. for crack sensitive materials) and geometrical reasons like gap bridging of butt joints or fillet welds. This process is already well established in the “macro – industries” like automotive or shipbuilding industry utilizing continuous wave lasers. However, for micro welding applications the use of a pulsed laser with filler wire is less common. Its potential is investigated in this work. Therefore a laser source with a free pulse shaping capability and the wire feeding system “Mini Drive” is used. This allows to transport the wire in a continuous and pulsed manner in addition to an actively controlled welding process which includes the melting of the wire and the base material respectively, the welding phase and the cool down phase. This paper will give an overview about the opportunities with a new welding concept targeted at critical weldments.

Session 11 (LPM-11):

Deep UV Laser Application

We 11-01

VUV laser technology for nanostructuring

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[1]Coherent GmbH

The capability of producing ever more dense and complex structures is pivotal for the production of faster generations of microchips, increasingly capable micromechanical and microoptical systems (MEMS) as well as for downscaling biotechnological devices. Both quality and longevity of the microstructures acting e.g. as sensors, actuators, bioreactors or information transmitters strongly depend on the degree of accuracy achieved in the manufacturing process. Emitting at the shortest commercially available wavelength of 157nm F2-lasers by nature are the laser source enabling the highest optical resolution. At the same time, F2-lasers deliver the highest commercially available photon energy of nearly 8eV. This allows even optical transparent compounds to be efficiently processed. In addition, heat transfer into neighboring substrate which facilitates melting or micro crack formation is virtually eliminated by the interaction of material with high energy photons. As a consequence, F2-lasers are the source of choice to manufacturing microsystems with unsurpassed quality. Recent progress in F2-laser technology in terms of output power and also long-term operation of laser tube, resonator optics and gas lifetime makes today’s F2 laser a reliable tool in pushing the envelop in nanotechnological developments.

We 11-02

Organic layer direct patterning using a DUV excimer laser

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In this study, the pentacene patterning is performed using DUV excimer laser and mask projection technique. The pentacene, organic material is used as an active layer of Organic Thin Film Transistor(OTFT) because of their high carrier mobility (>1.5cm2/Vs) characteristic and OTFT is an operating device for the backplane of flexible display. Conventional fabrication process of pentacene pattern is vacuum plating using mask. It has limitation for the fine pattern. However, excimer laser patterning can make more fine pattern than conventional process and minimize solvent damage for the plastic substrate by elimination of developing and stripping. The process parameters are energy density and pulse shot numbers on target substrate and the homogenizing optics is used to improve beam profile quality. Surface morphology after laser ablation is observed by Scanning Electron Microscope (SEM) and the pattern profile and residue after patterning are measured by Atomic Force Microscope (AFM) and Atomic Emission pectrometer (AES).

We 11-03

Dynamics and VUV laser processing of functional polymeric surfaces

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The physical principles and the advantages of using laser light in the Vacuum Ultraviolet (VUV) region of the spectrum to fabricate micro/nano-structures and thin films on organic surfaces is presented. A number of novel approaches have been developed during the last years in the area of processing methodologies for micro-fabrication of devices. New materials have been designed and efficient patterning methods have been proposed for the fabrication of modern multi-analytic devices The 157 nm F_2 laser is enhancing photo-chemical processing during patterning and is improving the resolution. The high value of the absorption coefficient and the process of molecular photo-dissociation, in organic molecules at 157 nm, allows atomic resolution depth control during laser ablation on the organic films, with major applications in surface preparation of DNA films, preservation of cultural heritage artifacts, biology and fabrication of bio-arrays [1, 3]. The common denominator for all these applications is the fact that nano-fabrication and control at VUV wavelengths allows atomic resolution depth control with localized chemical changes under certain conditions on organic substrates. The aim of this article is to present the physical principles, methodologies of polymer patterning based on self-assembly, surface localized etching and controlled functionalization by VUV laser ablation.

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[3] E. Sarantopoulou,_Z. Kollia, I. Gomoiu, Appl. Phys. A83, 663-668 (2006).

Poster

P-01

Femtosecond laser surface modifications of stainless steels and their consequences on the corrosion point of view

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P-02

Production of nanoparticles with high repetition rate picosecond laser

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P-03

Excimer Laser Processing of CNT Backlight Unit

C.M. Chen

ITRI

P-04

Laser micro-machining on the single crystal diamond using Nd-YAG laser

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P-05

DEBRIS-FREE ITO SURFACE MICROFABRICATION USING AN ECONOMIC 532nm LASER – VISIBLE LIBWE

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P-06

TRANSPARENT CELL CULTURING DEVICE WITH INTEGRATED HEATER

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P-07

Excimer laser assisted growth and dehydrogenation of Silicon/Germanium thin film multilayers

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P-08

Burst pulse ablation of metals and dielectrics using a Ti:Sapphire femtosecond laser

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P-09

Pulsed Laser Deposition - UV Lasers and Applications

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P-11

Optimizing and pulse compression of a 200-nJ chirped pulse Ti:sapphire oscillator

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P-12

A Monte Carlo Model of Light Propagation in Tissue

Simona Dontu, Sorin Miclos, Dan Savastru, Vasile Babin

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P-14

Photoresponsive Polymer Structures

M. Farsari, J. Catherine, E. Tsiranidou, S. H. Anastasiadis, M. I. Lygeraki, M. Varda, A. Athanassiou, C. Fotakis

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P-15

The influence of plasma plume in laser milling for mold manufacturing

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P-16

Characterization of different fiber cleavage methods for Optimend(TM), a new mechanical splice.

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P-17

Formation of gratings by self-organization of chromium thin film on the glass substrate under irradiation with laser pulses

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P-18

Theory of interaction of intense laser radiation with atoms, nuclei and femto-second laser plasma at surface and atomic dynamics with non-rectangular laser pulses

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P-19

A search of possible high power source of monochromatic gamma radiation and discharge of the metastable nuclei during negative muon capture

Alexander V. Glushkov

Odessa University

P-20

New cooperative laser-electron-nuclear effects in atomic and molecular systems in the strong laser field

Alexander V. Glushkov Svetlana V. Malinovskaya

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P-21

Direct writing of polymethyl-methacrylate and polycarbonate with ultrashort pulses for rapid prototyping applications.

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P-22

PRODUCTION OF MICRO-PATTERNED AMORPHOUS Si/Ge BILAYERS AND THEIR CRYSTALLIZATION TROUGH LOW THERMAL BUDGET LASER ASSISTED TECHNIQUES

F.Gontad, E. López, S. Chiussi, J.Serra, P. González, B. León

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P-23

Nonlinear optical properties of heavy metal oxide film glasses produced by pulsed laser deposition

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P-24

Optical Near-field Interaction Between Neighboring Micro/Nano-particles

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P-26

Microfluidic waveguides fabricated on glass chips using femtosecond laser pulses

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P-27

FS-time-resolved phase contrast microscopy in dielectrics

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P-28

Low-debris, efficient laser-produced tin plasma extreme ultraviolet source for the next generation lithography

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P-29

Quality glass processing using LIBWE method

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P-30

3D Micro/Nano-structure Fabrication of Phase-change Film

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P-32

Micro-drilling of ceramic using pulsed Nd:YAG laser

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P-34

Laser photoionization method detecting of single atoms and products of nuclear reactions

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P-35

The generation of ultra-short VUV and X-ray pulses in atomic, molecular and cluster systems in a strong laser field

Olga Khetselius, Alexander Glushkov, Alexander Fedchuk

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P-36

Femtosecond laser microdrilling of Alumina (Al2O3) ceramic

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P-37

Influence of Laser Beam Irradiation Condition on Low Temperature Poly-Silicon Crystallization using a High-power Diode Pumped Solid State Laser

Dae-Jin Kim, Gun-Seop Go, Hyun-Jung Kim, Seung-Hwan Eum, Gwang-Jae Lee, Doh-Hoon Kim

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P-40

Nano-patterning by Diffraction Mask-Projection Laser Ablation

Marisa Mäder, Thomas Höche, Jürgen W. Gerlach, Klaus Zimmer, Rico Böhme and Bernd Rauschenbach

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P-41

Microstructure studying of laser pulse irradiating metal targets in water

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P-42

Light diffraction on modulations of solid surface relief and low threshold IR multi-photon laser-molecular dissociation on surface. Laser microscopy

Andrey Malinovsky, Alexander Glushkov, Sergey Ambrosov, Andrey Svinarenko

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P-43

Estimation of pulsed laser Ablated Polyimide Sizes

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P-44

Pulsed Laser-Induced Surface Modification of Silicon in Liquids

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P-45

Femtosecond laser induced forward transfer (LIFT) process for skutterudite thin film patterning

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P-46

Formation of Graded Band Gap in CdZnTe by Nd:YAG Laser Radiation

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P-47

Laser-Shaping of Hexagonal Ordered Triangular Gold Nanoparticles with Nanosecond Pulsed Laser Light

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P-48

Fabrication of DOE using Laser Direct Write Lithography System

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P-49

Direct Laser Marking on CD ROM for Identification

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P-51

Process of glass-ceramics reverse crystallization under Nd:YAG laser action

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P-52

Thin metal sheet bending and residual stresses relaxation by ns-pulse lasers in MEMS manufacturing

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P-53

Laser-assisted micromachining of Fe-alloys using a novel thermochemical etching technique with an optical fiber

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P-54

Aligned Growth of ZnO Nanowire by Catalyst-Free Nano-Particle Assisted Laser Deposition

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P-55

Formation of Graded Band-gap in CdZnTe by YAG:Nd Laser Radiation

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P-56

Interferometric femtosecond patterning of metals

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P-57

Nano-particle generation from Femtosecond laser ablation of materials

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P-58

Modification of phase change memory materials during interaction with excimer laser pulses

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P-59

Enhancement of sensing properties of thin poly(methyl methacrylate) films by VUV surface modification

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P-60

MICRO/NANO SELF-ASSEMBLED STRUCTURES FROM BLOCK COPOLYMER/SAMARIUM-IRON NANOPARTICLES HYBRID MATERIALS INDUCED BY VUV LIGHT

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P-61

Laser assisted delamination of paint by inductive heating

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P-62

Correction of ditch-shaped defects during KrF excimer laser ablation using a mask projection

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P-63

Temperature Dependent Heat Generation by Optically Active Rare Earth Ions for Full Body Cutting of LCD module

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P-65

Laser micro-welding of dissimilar materials using femtosecond laser pulses

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P-66

Dynamics of the shock wave accompanied by nanoparticle formation in the PLA processes

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P-67

Fabrication of microstructures on cemented tungsten carbide by a femtosecond laser

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P-68

Surface morphology-dependent formation of ripples on Si, SiC, and HOPG substrates

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P-71

Laser Surface Nanotexturing and Applications

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P-72

Amorphous structure of ripple on SiC studied by micro Raman spectroscopy

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P-73

Tribological property of DLC films with femtosecond-laser induced nanostructure

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P-74

Femtosecond laser fabrication of metamaterials for high frequency devices

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P-75

Ultra-short pulse laser processing of Galium Nitride semiconductor epitaxial layers: theoretical modeling.

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P-76

The Second-order Doppler Error of Laser Dual-frequency Interferometer

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P-77

Quality and Yield Enhancement of IR-Laser Ablation by Harmonics Seeding

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P-01

Femtosecond laser surface modifications of stainless steels and their consequences on the corrosion point of view

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To allow the identification and the traçability of surgical tools as well as prostheses, marking is of prime interest in the field of biomaterials industry. Such kind of materials is subjected to extreme conditions during sterilization or decontamination processes and justify the choice of stainless steels. Nowadays, marking is often achieved by means of laser beam. Such kind of marking may involve modifications into the characteristics of the surfaces treated. These modifications may be critical concerning the initial functions of the surfaces. Nd:YAG laser delivering microsecond pulses are used in the laser marking industry. The aim of this work is to study the behavior of the irradiated area in terms of corrosion resistance when the marking is performed with femtosecond pulses compared to microsecond industrial devices. Experiments have been performed on martensitic Z30C13 and austenitic 316L stainless steels. Electrochemical measurements (cyclic polarization curves) were carried out to determine the passive state of samples before and after laser marking. Corrosion rate and their susceptibility to localized corrosion were also measured. Femtosecond laser marking is shown to provide an electrochemical ennoblement. Moreover, the chemical composition is not affected so that the passive character of noth stainless steels is maintained, even improved if we consider the susceptibility to localized corrosion.

P-02

Production of nanoparticles with high repetition rate picosecond laser

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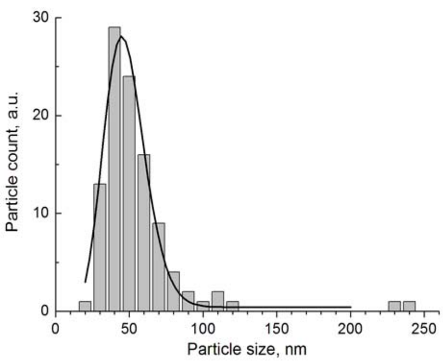
Due to their size-specific and unique properties, nanoparticulate materials and composites became increasingly popular, promising a breakthrough in the development of novel methods in bioimaging, biosensing, and medical therapeutics. Chemical processes for nanoparticle production have huge production capacities, but purity of nanoparticles is still a very big problem, because they contain impurities from chemical agents and other additives used in chemical reactions. Nanoparticle production by pulsed laser ablation of solid materials provides high purity nanoparticle colloids, which purity depends only on the purity of the solid. But, with respect to commercial applications, the production rate of nanoparticles is limited by the average power and repetition rate of the applied laser systems. Compared to femtosecond lasers, high repetition rate picosecond lasers show high ablation rate and low thermal impact to the material, thus they have a great potential for the fabrication of nanoparticles at high rate. Laser ablation in liquid produces charged nanoparticles and they form a shell from dipole molecules (zeta potential), which protects them from agglomeration. The ablation process in liquid is strongly affected by thermal distortion of the laser beam and formation of bubbles. These effects increase with higher power and higher repetition rate. We present a flow chamber in which a high liquid flow rate across the sample surface allows the successful solution of this problem. The generation rate of the silver nanoparticles in water was 8.6 µg/s using 5.5 W laser power and 50 kHz repetition rate. The production rate of gold nanoparticles using the same laser was up to 3.7 µg/s. The particle size distribution was obtained from the SEM pictures. Nanoparticle sizes vary from 20 to 125 nm, and most probable dimension of the nanoparticles is in the range of 40 to 60 nm.



P-03

Excimer Laser Processing of CNT Backlight Unit

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Compared to conventional backlight technologies such as CCFF and LED, Carbon Nano-Tube Backlight Unit (CNT-BLU) have a number of key advantages, including a flatter design, a lower power consumption, no optical films (i.e. reflectors or diffuser films), and a reduced cost. Display Technology Center (DTC) of Industrial Technology Research Institute (ITRI) in Taiwan has developed a novel planar reflective CNT-BLU using a screen-printing method. The term “planar” here indicates that the cathode and the gate are horizontal with respect to the anode plane, in marked departure from the conventional “vertical” structure in which the cathode and the gate are vertical with respect to the anode plane. The planar reflective design keeps higher transmittance for luminescence and reduces the thickness of the backlight unit. Therefore, it is suitable for use in backlight unit of LCD-TVs. Although screen printing is a low cost manufacturing technique, its resolution and uniformity are poor. Therefore, this study will investigate how to apply excimer lasers for processing the carbon nanotubes on the CNT-BLU emitter. The goal is to control the density and height of the carbon nanotubes, so that the electrical properties of the emitter can be improved. Screen printed CNT cathodes were irradiated by KrF (248 nm) excimer laser with fluence from 80 to 150 mJ/cm2. The irradiation was made in air by a single shot for the same spot (see Fig.1). After laser irradiation, a diode structure was used for electron emission measurement. The anode was 95Í32 mm2 phosphor patterned on the ITO/glass substrate (see Fig.2). The 300 mm spacer was put between the anode and cathode. The emission characteristics were measured in a vacuum chamber with a pressure of 10-4 Pa. The emission characteristic is shown in Fig.3. The CNT surface morphology was investigated by scanning electron microscopes (see Fig.4).

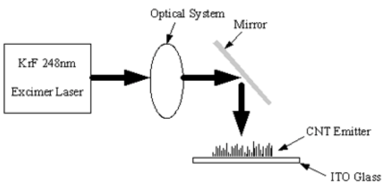

Fig. 1: Excimer laser processing of CNT

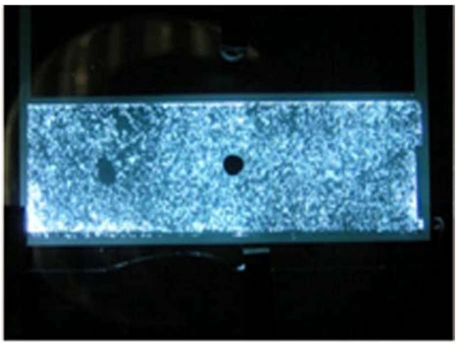

Fig. 2: Image of CNT after laser irradiation in 150mJ/cm²

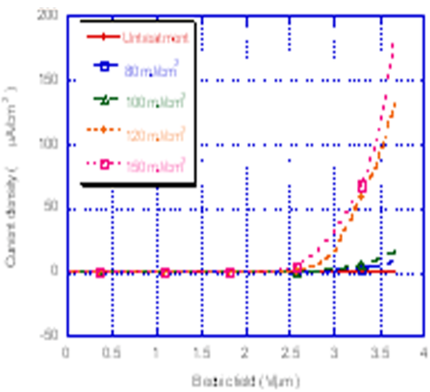

Fig. 3: Field emission

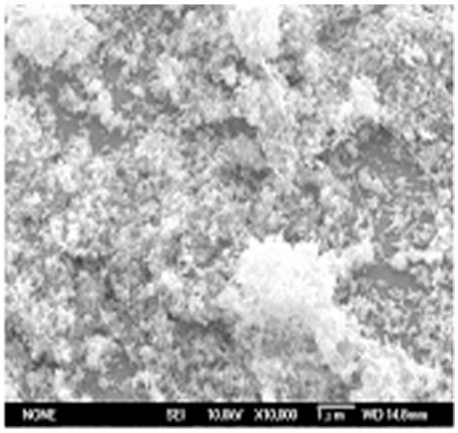

Fig. 4: SEM of CNT after laser irradiation in 150mJ/cm²

P-04

Laser micro-machining on the single crystal diamond using Nd-YAG laser

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In this work, we report a laser-direct writing method to micro-machine the single crystalline diamond. We will demonstrated that three-dimensional geometric features with high dimensional accuracy and high material integrity (such as minor thermal damage surface and burr-free surface) on the diamond substrate can be machined using this proposed method. The diamond is laser ablated as a two-step method. The first step employs a laser-induced transformation of the crystalline diamond structure to the layered graphite at a temperature around 1500K (called the graphitization process) using the laser heat. It is then followed by the laser-induced sublimation of the layered graphite at a temperature around 4000K (called the sublimation process). To engineer the laser ablation mechanism of diamond as a reliable and high precision machining technique, precise control of the laser energy is the critical part. The laser energy should be high enough to heat the diamond surface to the graphitization or sublimation temperature but avoid thermally over-loading on the brittle diamond substrate. Therefore, a 3-D thermal analysis model has been established to predict the temperature distribution of the laser machining process. In this thermal analysis model, the laser energy is modeled as moving and pulsed Gaussian volume heat sources. The time-variant and spatial-variant temperature distribution of the diamond surface is then calculated by the thermal analysis model. Through the thermal analysis model, the laser irradiance thresholds for the graphitization and sublimation steps were theoretically calculated as 0.367 J/mm2 and 1.105 J/mm2 which had been experimentally verified by about 18% and 3% errors differed from the 0.45 J/mm2 and 1.14 J/mm2 of experiments. Finally, we will demonstrate that a diamond micro-nozzle with 3D geometric shape can be fabricated with clean and low HAZ (heat affected zone) surface appearance using the Nd-YAG laser of 170 ns pulse width and 1064 nm wavelength. The laser-treated diamond substrate were examined by a Raman spectroscopy. The result confirms that the residual graphite layer on the diamond is not significant. The substrate surface remained as single crystalline diamond state after the laser processing.

P-05

DEBRIS-FREE ITO SURFACE MICROFABRICATION USING AN ECONOMIC 532nm LASER – VISIBLE LIBWE

Ji-Yen Cheng[1], Meng-Hua Yen[1,2], Wen-Chih Hsu[1], Tai-Horng Young[2]

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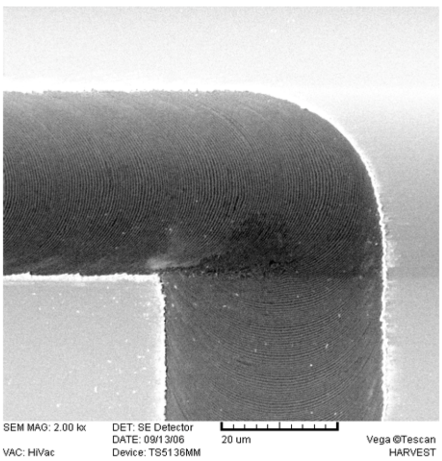
Indium tin oxide (ITO) coated glass has been widely used in optoelectronics because of its good optical transmission. ITO patterning is usually done by wet chemical etching or selective ion etching. Photolithography that requires photomask generation and tedious dry/wet etching is needed. In this work a method to achieve debris-free ITO ablation by an economic green is presented. ITO is transparent in visible region and hence does not absorb 532 nm laser energy. Laser induced back-side wet etching (LIBWE) has been used for etching transparent glass substrate but only UV laser has been utilized before. In this work we utilized our newly developed “visible LIBWE” technology to perform surface micromachining of ITO thin film by laser direct-writing. No photomask is needed using this laser direct-writing method. This method can be used for debris-free ITO micropatterning and device fabrication, such as microheater and micro flow sensors. Desired surface pattern on ITO was drawn by AutoCAD and then transferred to a laser machining system for surface ablation on ITO coated glass. The laser machining system consists of a Q-switched 532 nm laser and an X-Y CNC stage. 3~10 mW laser power at repetition rate of 2 kHz was used for ITO ablation. The cleanness of ITO removal was first examined by SEM. Further inspection on surface element distribution of Indium was observed by energy dispersive X-ray spectroscopy (EDS). Thermally affected zone (TAZ) is crucial for subsequent application of the patterned ITO layer. The distortion of the ITO near the ablated region was examined by a surface profiler. TAZ and surface debris resulted by our visible LIBWE was compared to that from UV laser ablation, direct green laser ablation, and near-IR laser ablation. We have already applied this method for fabricating transparent cell-culturing device.



P-06

TRANSPARENT CELL CULTURING DEVICE WITH INTEGRATED HEATER

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*Research Center for Applied Sciences, Academia Sinica Taiwan
**Institute of Biomedical Engineering, National Taiwan University, Taiwan

Real-time observation of cell growth provides essential information for studies such as of cell migration and chemotaxis. Conventional cell incubation device is usually too clumsy for these applications. Here we report a transparent microfluidic device that has integrated heater. ITO glass was ablated by our newly developed visible LIBWE (laser induced backside wet etching) so that transparent heater strips were prepared on the glass substrate. A microfluidic chamber was fabricated by CO2 laser and assembled with the ITO heater so that the chamber temperature can be controlled for cell culturing. Successful culturing was performed inside the device. Continuous long-term observation on cell growth is thus achieved. In this presentation, the development and the performance of the independent cell culture device is elaborated.

P-07

Excimer laser assisted growth and dehydrogenation of Silicon/Germanium thin film multilayers

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The demand of thin amorphous or crystalline Silicon/Germanium layers and alloys with tailored hydrogen content on micro-patterned as well as on thermo-sensible substrates implies the development of new processing technologies avoiding high substrate temperatures. Elevated temperatures smudging or destroying the lateral extensions of micro-patterned structures on biomedical or nano-electronic devices, softening polymers for flexible electronic or photovoltaic devices and deteriorating the interface quality of multilayers have to be avoided. Conventional thermal processing techniques have already demonstrated the advantages of such SiGe based devices, but are usually of no use when substrate temperatures below 300ºC are needed. It has been shown that an alternative processing strategy based on UV-Excimer Laser assisted deposition and crystallization techniques can satisfy these demands and produce high quality SiGe thin films at low substrate temperatures[1]. This contribution presents an integrated UV-Excimer laser assisted process that combines the growth of thin amorphous hydrogenated Si and Ge multilayers on large areas as well as in micro-patterned regions with their subsequent in depth controlled dehydrogenation. Composition of the low temperature grown and laser annealed multilayer structures have been followed-up through H-Effusion measurements and several spectroscopic techniques in depth profiling mode for studying both the dehydrogenation process and segregation effects as a function of the applied laser pulse energy density. Surface morphology and crystalline structure have been characterized through electron microscopy and interferometric techniques. The experimental results allowed estimating the temperature gradient in the multilayer and demonstrating that tailoring of the degree of dehydrogenation can be achieved through fine control of the laser pulse energy density.
[1]S.Chiussi, E.López, J.Serra, P.González, B.León, Thin Solid Films 508 (2006)48-52

P-08

Burst pulse ablation of metals and dielectrics using a Ti:Sapphire femtosecond laser

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College of Optics & Photonics CREOL & FPCE, University of Central Florida, Orlando, FL, USA

Femtosecond laser micromachining based on ablative process has potentially many applications in areas of technology for microelectric devices, micro-fluidics, sensor technology and for the development of advanced complex devices on a single chip. The low throughput of femtosecond laser machining because of the shallow penetration depths in many materials of interest has been a major obstacle against the industrial use although it has distinct advantages over conventional laser micromachining . A simple method to increase the ablation rate by increasing the pulse energy soon becomes counterproductive when the peak intensity exceeds the air ionization threshold. In this paper, we present our approach using multiple pulse bursts that can be an alternative to overcome the limit of increasing the per-pulse energy. Our prior work on burst ablation has been performed using high-power lasers at KHz repetition rate and significant increases were observed . We are now investigating the ablation rates of metals and dielectrics using a custom designed long-path, low frequency Ti:Sapphire oscillator producing bursts of pulse at MHz repetition rates. These two modalities will then be compared.

P-09

Pulsed Laser Deposition - UV Lasers and Applications

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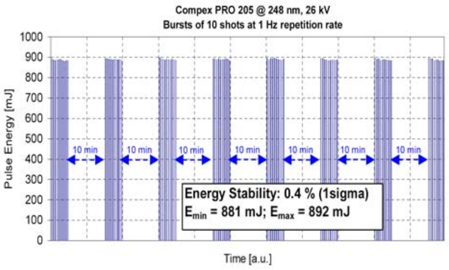
Coherent GmbH, Goettingen, Germany

Ongoing progress in material research and processing industry is fueled to a large extent by the technique of pulsed laser deposition (PLD). With this powerful and versatile approach, multi-component target materials can be ablated and deposited onto a substrate to form stoichiometric layers which exhibit the desired properties. Monitoring of growth parameters such as thickness and surface roughness is frequently in-situ monitored via electron diffraction or other diagnostic tools. High energy excimer lasers lend maximum flexibility to the PLD technique since virtually every material is amenable to excimer laser ablation and subsequent deposition on account of their record high photon energies. Spectral properties, temporal pulse and laser beam parameters of state of the art excimer lasers will be compared with frequency converted flash-lamp pumped Nd:YAG lasers with regard to advanced pulsed laser deposition requirements.



P-11

Optimizing and pulse compression of a 200-nJ chirped pulse Ti:sapphire oscillator

Péter Dombi (1,2) Péter Antal (1) Róbert Szipöcs (1) Júlia Fekete (1) Zoltán Várallyay (3)

(1) Research Instiute for Solid-State Physics and Optics, Budapest, Hungary
(2) Institut für Photonik, Technische Univerität Wien
(3) FETI Ltd., Budapest, Hungary

Merging Ti:sapphire oscillator technology with the long cavity, chirped-pulse oscillator concept brought significant advances in recent years. As a result the energy of pulses directly available from femtosecond oscillators reached several 100s of nJs. Development efforts to combine this oscillator construction with the cavity dumping technique hold promise of exceeding the microjoule frontier. State-of-the-art lasers of this type deliver 30-60 fs pulses. Shorter durations could not be demonstrated due to some inherent limitations in this technology that set a boundary to the spectral content of the laser output. In our experiments we optimized such a laser oscillator by investigating limiting effects (especially intracavity dispersion) on the width of the laser output spectrum. By optimizing the cavity length as well, we could achieve pulse energies exceeding 200 nJ at a repetition rate of 3.6 MHz with a relatively compact setup. The inherent lengthening of the outcoupled, highly chirped picosecond pulses was compensated by a 4-prism compressor to reduce the pulse width to the transform limit determined by the spectral content of the oscillator output. For another application we also investigated further extracavity compressibility of the pulses achieved in such a way. We focussed negatively chirped, 150-fs pulses (generated by overcompensating the chirp with the 4-prism compressor) in a single-mode fibre with an achromatic objective. This way optical damage on the fibre input face could be avoided. The resulting fibre output supercontinuum corresponds to a pulse length of 7-8 fs in the transform-limit. The observed highly efficient spectral broadening process of negatively chirped pulses in the fibre are also supported by simulation data.

P-12

A Monte Carlo Model of Light Propagation in Tissue

Simona Dontu, Sorin Miclos, Dan Savastru, Vasile Babin

National Institute of R&D for Optoelectronics INOE 2000

The Monte Carlo method is rapidly becoming the model of choice for simulating light transport in tissue. The paper aims to obtain an analytical model to describe light transport in tissue based on Monte Carlo simulation. Flowchart for the variable stepsize simulation is discussed. The Monte Carlo method began by launching a photon into tissue. Various techniques are used to reduce the number of required photons to achieve the desired accuaracy for a Monte Carlo calculation. The convolution equations for finit flat and Gaussian beams are applied taking into account the internal reflection of photons at boudaries. The results proved that Monte Carlo method can be efficiently applied for the complex tissue modeling leading to estimation of reflection, transmission and fluence rates in tissue.

P-14

Photoresponsive Polymer Structures

M. Farsari, J. Catherine, E. Tsiranidou, S. H. Anastasiadis, M. I. Lygeraki, M. Varda, A. Athanassiou, C. Fotakis

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A photochromic molecule, spiropyran, has been doped into photopolymers in order to construct 2D and 3D structures whose shape, volume and wetting characteristics can reversibly respond to irradiation with light of appropriate wavelength. The reversible conformational change is induced upon UV laser irradiation, where the embedded non-polar spiropyran molecules convert to their polar merocyanine isomers; this is reversed upon green laser irradiation. The construction of 3D structures has been done using multi-photon polymerization, a powerful technique which allows the fabrication of fully three-dimensional polymer structures with submicron resolution. The 2D micropatterning of the photochromic-polymer films has been done using soft lithography and visible-light interferometry. It has been found that surface patterning affects their wettability towards a more hydrophobic or more hydrophilic behaviour depending on the dimensions of the patterned features and on the hydrophilicity-hydrophobicity of the substrate. The light-induced wettability variations of the structured surfaces are substantially enhanced compared to those on uncoated surfaces. This enhancement is attributed to the photoinduced reversible volume changes of the imprinted gratings, which additionally contribute to the wettability changes due to light-induced photochromic interconversions.

P-15

The influence of plasma plume in laser milling for mold manufacturing

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Laser milling is a manufacturing technology characterized by the possibility of creating small and complex shapes with good accuracy even in hardened alloys. The short working times, if compared to the ones concerning EDM, and the possibility to integrate the laser source directly on the manufacturing system, determined the great interest of today's industry towards this technology. The great number of parameters involved in the process makes optimization quite difficult and time expensive especially if performed through a trial-and-error technique. According to this the possibility to exploit a reliable and accurate numerical model to simulate the process is a time and cost-effective topic. This paper deals with the fine tuning of a 3D transient numerical model which also takes into consideration the interaction of the plasma plume with the laser beam and the target material. In particular a large number of simulations were performed aimed at investigating the variation of target material reflectivity and plasma plume diffusivity with respect to temperature. These physical phenomena are of basic importance in order to obtain accurate and reliable process simulations.

P-16

Characterization of different fiber cleavage methods for Optimend(TM), a new mechanical splice.

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Phasoptx inc. Institut national d'optique (INO)

The use of laser micro machining for fabrication of optical components has grown significantly over the past few years. In particular, CO2 lasers have proved their capabilities for optical fiber cleaving. The roughness of the endfaces obtained by this method is better than the ones obtained by conventional mechanical cleaving methods and is equivalent to those obtained by the best mechanical polishing methods. Although laser systems are more costly and bulky than conventional cleaving devices they have the advantage of being less operator and tool dependant which can be and advantage when yield has to be taken into account. In this article, the two cleaving methods are compared using a new kind of mechanical splice, OPTIMEND, developed by Phasoptx Inc. The advantages and disadvantages of the inherently less flat surface of the laser cleaves will be evaluated for both monomode and multimode fibers. Since this new mechanical splice also allows to auto align two fibers, fusion splices with a CO2 laser will also be discussed. The results of these laser splices have been compared with common electric arc fusion splices.

P-17

Formation of gratings by self-organization of chromium thin film on the glass substrate under irradiation with laser pulses

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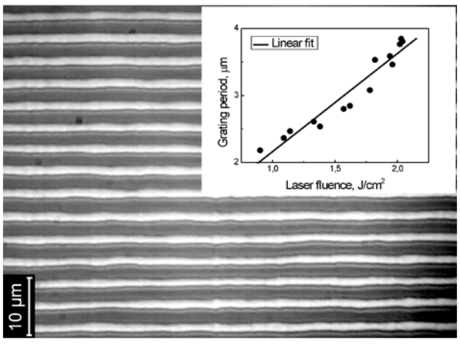
In addition to lithography, laser ablation is a typical process of making masks in the chromium layer on the glass substrate. Different types of lasers have been applied to spatially confined evaporation of the metal from the substrate. In this report we present new features in metal removal that were observed when the laser beam was focused into a long and narrow stripe. The infrared Nd:YVO4 laser with the nanosecond pulse duration was used in experiments. The laser beam was focused through the glass substrate into chromium film with the thickness of 50 – 200 nm using an acylindrical lens. The elliptical spot with the aspect ratio of 1:1000 was formed on chromium in order to remove a strip-like area of chromium by a laser pulse. The film removal threshold by a single laser pulse was 1.5 J/cm2 for the 100 nm thick layer. Ridges of melted material formed nearby the evaporated area prevented complete removal of the chromium film with the same fluence. Moreover, the partially overlapped laser pulses with the fluence up to three times exceeding the threshold caused complex self-organization of remaining part of the metal. Formation of regular gratings of ripples was observed in a certain range of laser fluences and beam overlap. Ripples were orientated perpendicular to the orientation of the beam stripe and their length increased with every shifted pulse. The periodic gratings with the unlimited line length could be implemented by using this technique. The grating was irradiated with the HeNe laser and the diffraction image was investigated. The results showed that the grating period varied depending on the local laser fluence applied. The grating period linearly changed with the laser fluence. The grating period slightly decreased with increasing the shift between pulses. Small period fluctuations caused extension of the non-zero order diffraction maxima in the diffraction image. The period of the chromium grating on the glass substrate can be varied from 4 to 2.5 µm.



P-18

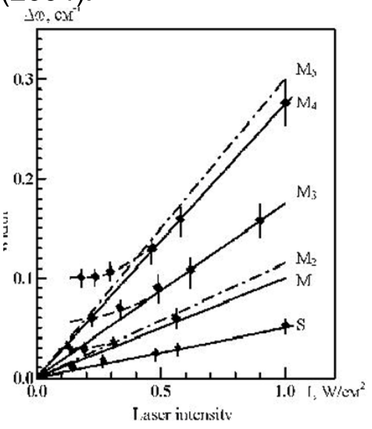
Theory of interaction of intense laser radiation with atoms, nuclei and femto-second laser plasma at surface and atomic dynamics with non-rectangular laser pulses

Alexander V. Glushkov, Olga Khetselius

Odessa University

At first, QED theory is presented to describe interaction of atoms,nuclei with intense laser pulses (LP). Method bases on a description of system in field by k-photon emission and absorption lines moments [1], which are defined within Gell-Mann & Low approach. Calculation for multi-photon and ATI ionization in H,Na,Mg,Cs is carried out.As example, in fig.we present multi-photon resonance width for transition 6S-6F in Cs in dependence on LP intensity I: S- for Lorentz LP; M1, M3, M4-for multi-mode Gauss LP with line band 0.03, 0.08, 0.15 1/cm; M2, M5- for soliton-type LP with line band 0.03,0.15 (+experiment).Atomic dynamics with non-rectangular LP is studied and results of calculation of population kinetics of resonant levels for atoms in non-rectangular LP field on basis of the modified Bloch equations are presented. The equations describe an interaction of 2-level atom ensemble and LP with account of dipole-dipole interaction. A new result is discovery and adequate explanation of the optical bi-stability effect. At second, we carried out the modelling of the femto-second laser plasma (FLP) forming in the porous materials on the basis of the energy balance equations and Green's function method for non-ordered materials.Using super short LP changes principally a character of interaction of a laser radiation with surface and may result in forming FLP. Special attention is surface of which there is a great number of bonds with H, OH groups. In a case of D-and OD group's one can wait for realization of cluster explosion process and reaction D+D-alpha+n (3,8MeV). One can wait for appearance of powerful flow of neutrons for LP intensity ~10(16)W/cm2. We carried out modeling excitation of the low lying isomers by means of channels: photoexcitation by X-ray plasma radiation, electron conversion etc.

1.A.Glushkov etal,Int.J.Quant.Ch.99, 889,936(2004);104,496,512,562(2005); J.Phys.CS.35,420,425(2006);A.Glushkov,L.Ivanov,Phys.Lett.A 170,33(1992); Nucl.Phys.A 734,e21(2004).



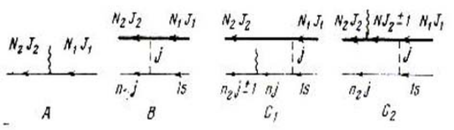
P-19

A search of possible high power source of monochromatic gamma radiation and discharge of the metastable nuclei during negative muon capture

Alexander V. Glushkov

Odessa University

We propose optimal conditions of realization of high power source of monochromatic gamma radiation. For a sample with a sufficiently high density of metastable nuclei and a sufficiently intense muon beam the process of discharge of metastable nuclei during negative muon capture can result in a sharp increase of gamma radioactivity of the sample and may be used as the basis of operation of a high power source of gamma radiation. A negative muon captures by a metastable nucleus may accelerate the discharge of the latter by many orders of magnitude [1,2]. For a certain relation between the energy range of the nuclear and muonic levels the discharge may be followed by ejection of muon, which may then participate in the discharge of the other nuclei. We present a new quantitative theory for high power gasers and discharge dynamics of a nucleus with emission of gamma quantum and further muon conversion, which initiates this discharge. Within an energy approach [2] the intensities of transitions are linked with Im part of energy for the "nuclear core+ proton +muon" system. Three channels should be taken into account (fig.): 1). Radiative purely nuclear 2j -poled transition (probability P1); 2). Non-radiative decay, when proton transits to the ground state and a muon leaves nucle (P2); 3). A transition of proton into the ground state with excitation of muon and emission of gamma quantum (P3). As example we considered the nucleus of Sc28. The probabilities of decay for different nuclear transitions are: P2(p1/2-p3/2)=3,93.10(15), P2(p1/2-f7/2)=3,15.10(12),P2(p3/2-f7/2)=8,83.10(14). The dipole transition 2p-1s occurs with probability: P3=1.9.10(13)1/s. 1. V.I.Gol'dansky, V.Letokhov,JETP.67,513(1974); L.Ivanov, V.Letokhov, JETP.70,19(1976); A.V.Glushkov, L.N.Ivanov,Phys.Lett.A 170,33(1992). 2.A.Glushkov etal, Int.J.Quant.Chem. 99, 936(2004); Nucl.Phys.A. 734, e21 (2004); Rec.Adv.in Theory of Phys.Chem.Syst.15, 301 (2006).



P-20

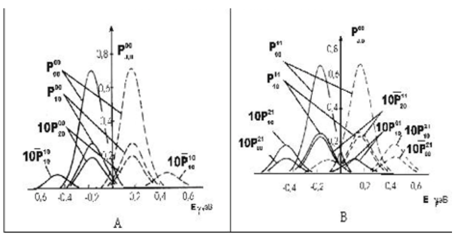
New cooperative laser-electron-nuclear effects in atomic and molecular systems in the strong laser field

Alexander V. Glushkov Svetlana V. Malinovskaya

Odessa University

A great progress in development of laser technique resulted to new class of problems in laser physics. Great interest attracts the co-operative dynamical phenomena [1] due the interaction between electron shells and nuclei nucleons in a strong laser field. We propose new QED theory to calculation the electron satellites in spectra of the electron-nuclear gamma -transition of nucleus in atoms and molecules. As example, the nuclear transitions in the isotopes Fe, Ne etc. are considered for O-and F-like ions of Fe, Ne. The electron-nuclear lines in spectra of emission or absorption can be experimentally observed in plasma of the O-and F-like multicharged ions. Due to the emission or adsorption of nuclear gamma-quantum in molecular system there is changing the electron vibration-rotation molecular states. We at first develop a new, consistent, quantum theory to calculation of electron-nuclear gamma transition spectra (set of vibration satellites in molecule) of nucleus in atom and molecule, based on the energy approach (S-matrix formalism of Gell-Mann and Low) [2]. Decay and excitation probability are linked with imaginary part of the molecule-field system. Calculation results of the electron-nuclear gamma-transition spectra of nucleus in some molecular systems are given [2]. A spectrum of emission and adsorption of nucleus 127I (203keV) in molecule of HI is calculated. As illustration in figure spectrum of emission of nucleus 127I (E=203keV)in HI is presented (fig. A is corresponding to the initial state of molecule: va=0, Ja=0; fig B ~ va=1, Ja=0).Estimates are made for vibration-nuclear transition probabilities for sets of molecules: diatomics, 3-atomic XY2, 4-atomic XY3, 5-atomic XY4(Td), 6-atomic XY3Y2 (D3h), 7-atomic XY6(Oh) ones.

1.L.Ivanov,V.Letokhov, JETP.93,396(1987);V.Letokhov,V.Minogin,JETP.69,1369(1975); A.Glushkov, L.Ivanov, Phys.Lett.A 170,33(1992);
2. A.Glushkov, S. Malinovskaya, Int. J.Quant. Chem. 99, 889 (2004);104, 513 (2005);104,496(2005).



P-21

Direct writing of polymethyl-methacrylate and polycarbonate with ultrashort pulses for rapid prototyping applications.

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As it has been commented by many authors, rapid prototyping of polymeric microdevices by means of laser direct writing represents clear advantages when compared with cleanroom technologies, as its flexibility (design can be easily modified), absence of intermediate materials (silicon, photoresists, etc.) or the easiness to manufacture non-planar geometries. Femtosecond lasers have overcome the main problems of other laser sources, as machinability of transparent materials or the appearance of heat affected zones. This way, manufacturing of polymers with fs-lasers represents an interesting strategy for microfabrication in an easy, fast and flexible way. However, some fundamental basis of the interaction of ultrashort pulses with polymers are still poorly understood. As an initial part of the present work, the ablation behaviour of two conventional thermoplastics, polymethyl-methacrylate (PMMA) and polycarbonate (PC) for femtosecond ultraviolet pulses has been investigated. As main conclusions, it can be stated that (i) these materials show more important incubation effect that others (metals, ceramics, glasses, etc.), what drives to a clear broadening of channels as a function of relative motion between the laser and the sample (feedrate) and (ii) a transition between a strong and gentle phase is observed as in many other kind of materials. A simple model that accounts these effects has been proposed and width and depth of microchannels parameterised as function of fluence and feedrate. This characterization has allow the fabrication of some polymeric prototypes in a controlled way (better than +/-2microns) and, after sealing by thermal bonding, transport of small amount of liquid achieved. In parallel, the writing of waveguides and diffraction gratings in PMMA and PC have been successfully carried out. Integration of both technology in order to fabricate opto-fluidic devices is currently developed at this moment. Some preliminary results will be shown.

P-22

PRODUCTION OF MICRO-PATTERNED AMORPHOUS Si/Ge BILAYERS AND THEIR CRYSTALLIZATION TROUGH LOW THERMAL BUDGET LASER ASSISTED TECHNIQUES

F.Gontad, E. López, S. Chiussi, J.Serra, P. González, B. León

Universidade de Vigo

Both amorphous and crystalline SiGe thin films are well established materials for Thin Film Transistor devices and solar cell applications. However, nowadays the increasing use of temperature sensible substrates in industrial nano-electronic and photovoltaic devices discards the applications of conventional processing technologies and promotes the search and development of new alternative techniques avoiding high substrate temperatures. It has been shown that the combination of Laser induced Chemical Vapour Deposition (LCVD) and Excimer Laser Crystallization (ELC) is such a satisfactory alternative strategy for obtaining high quality thin films of those alloys [1]. In this contribution, deposition of nano-patterned Si/Ge bi-layers and its subsequent crystallization is studied in order to provide single-chamber processing of high quality thin films through a low thermal budget bottom-up process. Uniform and homogeneous amorphous hydrogenated Silicon and Germanium films were produced on 3" Si(100) substrates by 193 Excimer Laser induced photolysis of disilane and germane, through LCVD in parallel configuration as well as micro-patterned Si/Ge bi-layers using nano-stencils as masks. Crystallization of the amorphous films was achieved using ELC and segregation effects of the elements studied for different number of laser pulses and laser fluences in an inert environment at room temperature. Both laser techniques, LCVD and ELC, were done using the same Excimer laser in the same processing chamber, providing a high integration of the techniques. Time of flight secondary ion mass spectrometry in Depth Profiling and scanning modes, X-ray photoelectron spectroscopy, scanning electron microscopy and atomic force microscopy were used in order to analyze composition, thickness, surface morphology and crystallinity of as-deposited and crystallized films.

[1] E. López, S. Chiussi, J. Serra, P. González, B. León, Thin Solid Films, 508 (2006) 48-52

P-23

Nonlinear optical properties of heavy metal oxide film glasses produced by pulsed laser deposition

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Heavy metal oxide glasses combine high linear (n) and nonlinear (n2) refractive indices with a broad transparency range, which makes them attractive candidates for the production of active optical waveguides in the near-mid infrared spectral region. Their optical properties strongly depend on the glass composition and the presence of ions such as Nb^+5 or Ti^+4 is desirable to enhance the nonlinear optical response. However, compositions having large heavy metal fractions devitrify or become opals. In this work we have produced transparent film glasses of the systems: Nb2O5-PbO-GeO2, Nb2O5-PbO-GeO2-Bi2O3 and Nb2O5–TiO2-TeO2 with large heavy metal fractions by pulsed laser deposition. The compositional analysis shows that while the oxygen content in the films determines their optical response, this can be effectively controlled by varying the deposition conditions. The linear optical properties of the film glasses have been determined by UV-visible absorption and spectroscopic ellipsometry. The refractive index (n) increases from 2.02 to 2.31, while the optical energy gap (Eg) decreases from 3.62 to 2.35 eV when increasing the heavy metal fraction except for glasses containing TeO2. The absorption coefficient is k

P-24

Optical Near-field Interaction Between Neighboring Micro/Nano-particles

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Parallel surface nanopatterning by the enhanced optical near-field under small transparent particles has been attracted great attention in recent years. The technique offers high productivity of nano-features on the sample surface based on the near-field ablation, etching, deposition and surface modification. Theoretical investigation of the field distribution was generally based on single particle models, e.g., Mie theory or Particle on Surface theory, of which the field interactions between the neighbouring particles have not been well explored. In this paper, the EM field distribution in the different particle array systems were simulated, including both mono-layered and multiple-layered particle aggregations. Some new effects, such as the edge effect of the particle array in which particles situated at the edge of particle array can produce higher field enhancement under them, has been identified. Experiments have been carried out to verify the theoretical findings. The influence of the surrounding medium on the optical near-field interactions is also discussed.

P-26

Microfluidic waveguides fabricated on glass chips using femtosecond laser pulses

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We describe the fabrication of microfluidic channel structures on the surface of borosilicate glass (n=1.516) slide by femtosecond laser direct writing for optical waveguiding application. Liquid with variable refractive index was filled in the microchannels, serving as the cores of the waveguides. The waveguide is formed by first scratching a microfluidic channel on glass surface using focused fs laser beam, which is indicated by the red arrow in Fig. 1a. The end-view of the microchannel (in the inset of Fig. 1) shows that the cross section has a width of approximately 7μm (measured at the top) and a depth of ~16μm. Then by mixing the two liquids (paraffin, n=1.474 and α-bromnaphtalene, n=1.658) with different volume proportions, we created waveguide cores of refractive indices ranging from 1.52 to 1.658. Filling the microchannel with a liquid of variable refractive index, thus far, generated our microfluidic optical waveguide. We observed the evolution of the transverse modes in the microfluidic waveguides using a CCD imaging system. By controlling the refractive index of the liquid in the microchannel, either multimode or single mode waveguiding can be achieved. Compared in Fig. 2a and b are a multi-mode pattern generated with a core of n=1.658 and a single mode pattern generated with a core of n=1.527, respectively. The single mode beam profile is further plotted in Fig. 2c, showing a symmetric distribution in the horizontal and the vertical directions. The microfluidic waveguides can potentially be used as an important component for biosensor application.

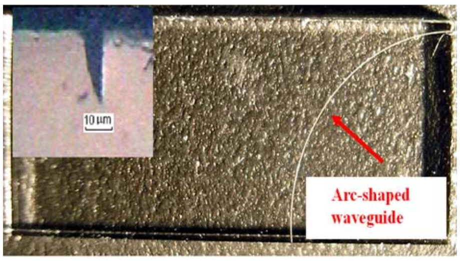

Fig. 1: **Top view of a 90° arc-shaped waveguide with radius of curvature of 5mm on a glass plate. Shown in the inset is the cross-section of the waveguide**

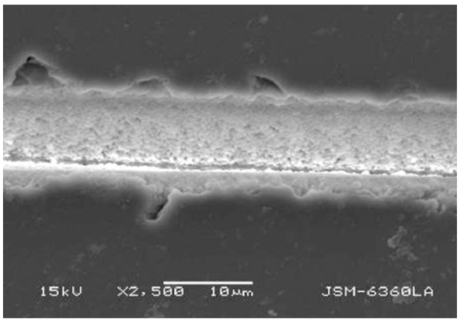

Fig. 2: SEM image showing the morphology of the internal wall of the microchannel.

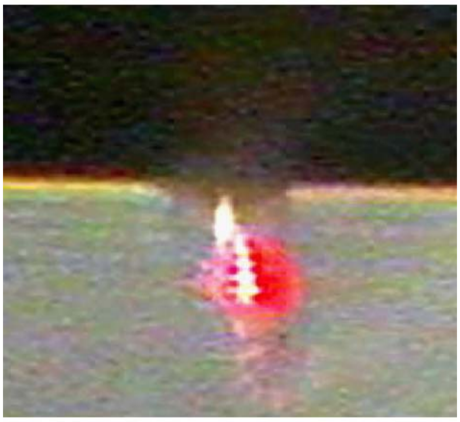

Fig. 3: Near field patterns of multi-mode beam

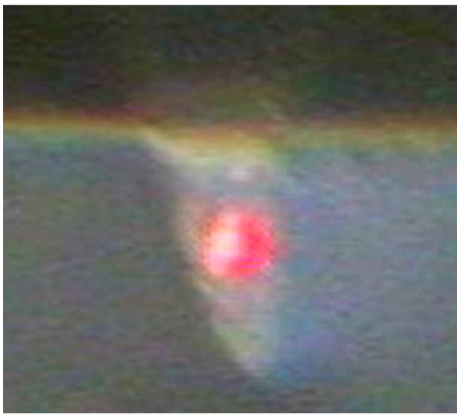

Fig. 4: Near field patterns of single mode beams

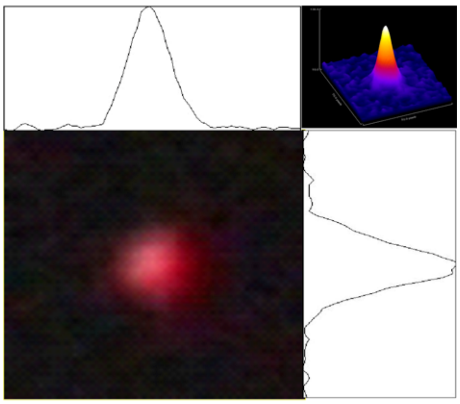

Fig. 5: Beam profile of the single mode beam

P-27

FS-time-resolved phase contrast microscopy in dielectrics

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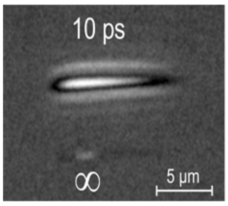
The highly nonlinear interaction of femtosecond (fs) laser pulses with transparent materials (glasses) allows the deposition of optical energy into the volume of dielectrics. This gives the possibility to induce micrometer-sized structural changes, which are associated with local refractive index changes. For positive refractive index changes, the writing of waveguides with fs-laser pulses has been demonstrated successfully in many different glasses. However, neither the dynamics nor the processes leading to the local refractive index changes are fully understood, which prevents an optimum control of the laser-induced modification process. We have performed time-resolved pump-probe microscopy with sub-micrometer and sub-picosecond resolution in order to investigate the temporal and spatial evolution of the modification processes in the volume of fused silica upon irradiation with single fs-laser (pump) pulses at 800 nm wavelength. Optical phase contrast (PC) and the transmission (T) images have been recorded at different delays between the pump and the 400 nm probe pulses, covering a time span from ~100 fs up to 10 ns. The focus is put here on a range of pump fluences slightly above the single-pulse threshold of permanent material modification, i.e., close to typical waveguide writing conditions. The observed PC images reveal transient changes of the local refractive index, whereas the T images can give direct insights into the dynamics of the laser-generated free-electron plasma. Our results indicate a significant thermal contribution to the refractive index changes along with strong absorption or scattering of the probe beam radiation in the focal region which both last for more than 10 ns. In the temporal delay range between 1 and 10 ns, laser-induced shockwaves are observed and their spatial propagation has been characterized. These results are discussed on the basis of recent models of the interaction of fs-laser pulses with dielectrics.



Phase contrast image single-pulse fs-excited fused silica at 400 nm probe wavelength for a pump-probe delay of 10 ps.
[pump: $E = 0.18\ \mu J$, $\tau = 90$ fs, $\lambda = 800$ nm, focusing depth 200 µm].

The image consists of 100 accumulated frames. "∞" denotes the permanent modification.

Darker regions correspond to a refractive index increase, whereas brighter regions correspond to a refractive index decrease.

P-28

Low-debris, efficient laser-produced tin plasma extreme ultraviolet source for the next generation lithography

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Present requirement for the next generation lithography is to develop high average power EUV light sources at 13.5 nm. Due to the high-power requirement of the EUV emission, conversion efficiency (CE) from a plasma-heating laser energy to an EUV emission energy becomes one of the most important parameters. The EUV CE should be optimized by controlling plasma parameters, such as the density and temperature of a plasma. The use of dual laser pulses could realize such a control. Generally speaking, a target with high concentration produces a high EUV emission energy. Strong self-absorption of the 13.5 nm emission, however, would become deleterious under high tin concentration, because of an optically thick plasma nature. In addition to this, a high concentration tin target produces a significant amount of debris, which causes a serious problem of damaging a set of focusing optics or condenser mirrors in a vacuum chamber. In contrast to these, a low concentration tin target would minimize the debris emission and reduce the self-absorption. Our approach is to use a liquid microjet target containing tin nano-particles with a tin concentration as low as possible to minimize the debris and to reduce the self-absorption. We used a low SnO_2 concentration (6%) regenerative liquid microjet target to minimize debris emission and self-absorption of the 13.5-nm EUV emission. As a result, we demonstrated a low-debris, efficient laser-produced plasma EUV source. A microjet target with 50 micron diameter containing tin nanoparticles was formed in a vacuum chamber. The EUV CE increased when the pulse separation time increased, and reached its maximum of 1.2% at 100 ns. The EUV CE under dual laser pulse irradiation became 3.4 times as large as that under single laser irradiation. This low Sn concentration made the low-debris emission possible and simultaneously realized the EUV CE larger than 1%.

P-29

Quality glass processing using LIBWE method

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LIBWE is a fast and precise way to etch and create well-defined structures on transparent substrates. This technique is applied to demonstrate the suitability of using it for high speed microprocessing of glass. A direct writing approach is used to etch structures directly onto quartz. A DPSS 3rd harmonic generation Nd:YAG laser with the wavelength of 355nm is used in this study. High speed etching of glass is successfully carried out at a high repetition rate of 10 kHz and high scanning speed of 100mm/s by a galvanometer. With high speed processing, the amount of processing time is much reduced. Microfluidic channels are created within a short time. 3D surface scan shows that they are of good cross-sectional uniformity. In addition, deposits are observed on the surface of the glass after the laser processing. XPS analysis further reveals that the nature of this deposit is attributed to carbon. An isotropic KOH treatment of the surface can remove this layer of deposits. Debris produced by LIBWE is also removed by laser cleaning, etc. Results from the various cleaning methods are examined and compared. Various ways to reduce the critical dimension of the etched features and to improve the surface roughness are explored.

P-30

3D Micro/Nano-structure Fabrication of Phase-change Film

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Laser-crystallized features were produced on initially amorphous phase-change films by femtosecond laser irradiation through microlens array. It was one high efficient patterning method since arbitrary features were created uniformly over large area at a short time. Sub-100 nm features can be made by using femtosecond laser. The patterned phase-change films included Ge2Sb2Te5, Sb2Te3, and GeTe films, with 30 nm thicknesses for each one. It was found that the amorphous and laser-crystallized phase states of different phase-change films have different reaction to alkaline solution. The different reactions of two phase states of different phase-change films to alkaline solution were discussed in detail in this paper. 3D micro/nano-structures, such as holes and bumps, in phase-change films were presented.

P-32

Micro-drilling of ceramic using pulsed Nd:YAG laser

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Laser micromachining can replace mechanical removal methods in many industrial applications, particularly in the processing of difficult-to-machine materials such as hardened metals, ceramics, and composites. It is being applied across many industries – semiconductor, electronics, medical, automotive, aerospace, instrumentation, and communications. Laser machining is a thermal process. The effectiveness of this process depends on thermal properties and, to a certain extent, the optical properties rather than the mechanical properties of the material to be machined. Therefore, materials that exhibit a high degree of brittleness, or hardness, and have favorable thermal properties, such as low thermal diffusivity and conductivity, are particularly well suited for laser machining. Percussion laser drilling technology is especially suitable for metal, ceramic, polyamide/polyamide, polycarbonate, Pyrex, quartz and composite substrates. Laser machining of ceramics is used extensively in the microelectronics industry for scribing and via hole drilling.

Rapid improvement of laser technology in recent years gave us facility to control of laser parameters such as wavelength, pulse duration, energy and frequency of laser. Different combinations of these parameters expand usage of the laser at micro scale. Methot of material machining by laser is preferred because of the being of clean, rapid and precise. In this work, we used two different pulsed Nd: YAG laser to determined pulse duration effect. The first one has minimum pulse duration of 0.5 ms, the other one has pulse duration of 7 ns. Experiments were done in vacuum environment for preventing oxidation. Diameters of hole were changed between 200 and 350 micron. The micro structures were analyzed using optic microscope.

P-34

Laser photoionization method detecting of single atoms and products of nuclear reactions

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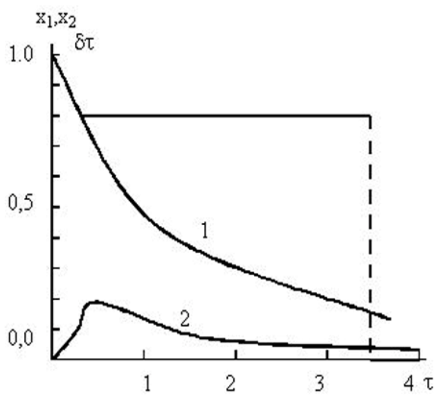
Odessa University

Laser photoionization detecting atoms in a beam and buffer gas attracts great interest for studying short-lived isotopes and nuclear isomers in experiments in real time of accelerator work which is used for their generation [1]. We propose new optimal schemes of laser photoionization method to problem of the nuclear reactions products detecting. It's studied the reaction of spontaneous 252Cf isotope fission on non-symmetric fragments, one of that is Cs nucleus. Usually the foil with implanted Cf ions is disposed before exit of the surface barrier detector that is sensitive to the nuclear decay fragments. Intensity of the fission reaction is of order of one event per second. Laser beam crossed the axe of collector of the nuclear fragments. The braking is realized in gas mixture 90% Ar+10% CH4) under pressure of 300 Torr. The heavy fragment of Cf nucleus fission created in ionized track 10(6) electrons which are collected on the collector. The collector is charged negatively 40mks later after nuclear decay and 10mks before laser action. The photo electrons, arised due to the selective two-stepped ionization are drafted to proportional counter for detecting. Usually a resonant excitation of Cs is realized by the dye laser pulse , the spectrum of which includes wavelengths of two transitions 62S1/2-72P3/2 (4555Å) and 62S1/2-72P1/2 (4593Å). This pulse also realizes non-resonant ionization of Cs excited atoms. We proposed new scheme,which is based on selective resonance excitation of Cs atoms by laser to states near ionization boundary and autoionization decay of excited states under action of electric field [2].In fig. we present the results of modelling for optimal form of laser pulse in scheme for detecting Cs isotopes: delta pulse + dotted line is optimal form of laser pulse; curves (1) x1 and (2) x2 are populations of ground (6s) and excited (np) states. 1.A.Glushkov, O.Khetselius et al,Rec.Adv.in Theory of Phys.Chem Syst.15, 285(2006);Nucl.Phys.A 734,21(2004).



P-35

The generation of ultra-short VUV and X-ray pulses in atomic, molecular and cluster systems in a strong laser field

Olga Khetselius, Alexander Glushkov, Alexander Fedchuk

Odessa University

Last experimental achievements in field of generating high harmonics of optical radiation during atomic ionization by powerful femtosecond laser pulses demonstrated a possibility of construction of the compact sources of VUV radiation (e.g.[1]). We are studying and modelling generation of the atto-second VUV and X-ray pulses under ionization of the cluster system in a intense laser field. In ref. [1,2] the results of our modelling the generation of the atto-second VUV and X-ray pulses under ionization of the cluster system molecular system 2D H2+ by femto-second optical pulse have been presented. Modeling is fulfilled within the relativistic scheme of the X- scattered waves method. Figure presentes the cluster Na10 response (our result), the molecular H2+ response for different internuclear distances 2.5, 3.5, 7.4, 16a.u. (data from [1,2]) with smoothed Coulomb potential and atomic (H) response [1] (spectral dependence) under ionization of the system by femto-second optical pulse. Our calculation show that the generation of the atto-second pulses (the splashes in fig.2) in cluster system is more effective and profitable (as minimum ~2 orders) than in similar molecular atomic one. Correspondingly, it has been shown earlier [1,2] that the generation of the atto-second pulses (the splashes in fig.) in molecular system is more profitable too (as minimum the 1-2 orders) than in similar atomic one. Corresponding spectral dependence of atomic (atom of H) response is also presented in fig. The effects considered give a hope of further progress in this direction, especially in work with cluster systems.

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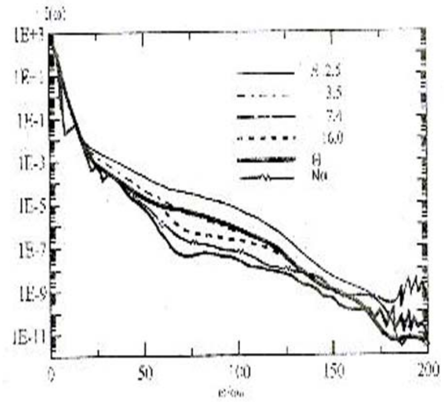

P-36

Femtosecond laser microdrilling of Alumina (Al2O3) ceramic

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Ceramic materials like alumina, aluminum nitride, zirconia and so on have attractive physical properties. Especially, alumina ceramic (Al2O3) substrates are widely used in electronic circuits due to their characteristic properties such as high dielectric strength (10 kVmm-1), good thermal stability and high thermal conductivity (28 Wm-1K-1). Nowadays, the smaller microelectronic circuits for mobile electronic components or devices are demanded requiring fabrication technologies for denser circuit patterns, smaller via holes and shorter separation. However, micromaching of alumina below 100~200μm size using conventional techniques like mechanical punching, drilling, or cutting faces severe problems such as tool wear and easy breaking of the workpiece. In this study, the microdrilling of alumna ceramic with good edge clarity and roundness using a femtosecond laser micromachining system (rep. rate 1kHz, wavelength 785nm, pulse duration 185 fs) is reported. The fabrication of microholes with sub-hundred micrometer in diameter often results in a poor quality hole due to the accumulation of sub-microparticles. To avoid the deterioration of hole quality with decreasing hole size, the condition of blowing air and laser beam interval for repeated ablation are controlled. Also, the results when Galvano scan mirror with telecentric lens is used for beam steering and when translation stages with a stationary objective lens is used for patterning are compared. Improvement of hole shape and drilling of small through holes are realized with process optimization.

Fig. 1: SEM picture of microholes fabricated in alumina using Galvano scan mirror system under conditions of laser energy= 126 μJ, scan speed=1 mm/s, number of scans=50, hole diameter= 440μm

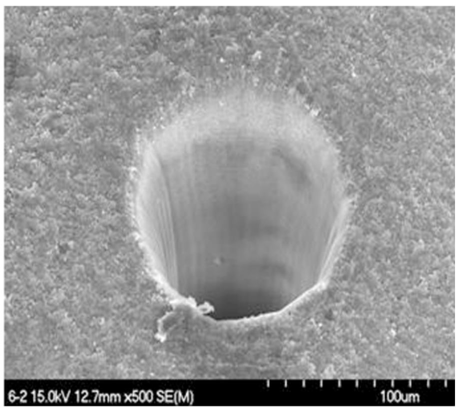

Fig. 2: SEM picture of microholes fabricated in alumina using Galvano scan mirror system under conditions of laser energy= 124 μJ, scan speed=1 mm/s, number of scans=60, hole diameter= 115μm

P-37

Influence of Laser Beam Irradiation Condition on Low Temperature Poly-Silicon Crystallization using a High-power Diode Pumped Solid State Laser

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Low temperature polycrystalline silicon (LTPS) technology using a high power laser have been widely applied to thin film transistors (TFTs) for liquid crystal, organic light emitting diode (OLED) display, driver circuit for system on glass (SOG) and static random access memory (SRAM). Recent, the semiconductor industry is continuing its quest to create even more powerful CPU and memory chips. This requires increasing of individual device speed through the continual reduction of the minimum size of device features and increasing of device density on the chip. The flat panel display industry also need to be brighter, with richer more vivid color, wider viewing angle, have faster video capability and be more durable at lower cost. We have developed innovative production tool of laser annealing for low temperature poly-silicon crystallization using high power diode pumped solid state (DPSS) laser. This paper introduces the main mechanisms of a laser crystallization using a DPSS laser and reports the results of a practical line beam laser crystallization method.

P-40

Nano-patterning by Diffraction Mask-Projection Laser Ablation

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Nanostructures attached to a substrate promise optical and electronic applications (LEDs or diodes). Moreover, applications for nanodots in various probing techniques (including Surface Enhanced Raman Spectroscopy) are also aspired. So far, however, the fabrication process of most nanostructures is still very complex and often too costly for industrial use. An alternative, versatile, fast, and relatively easy process is laser ablation of a thin film using diffraction-mask projection. In the latter technique, a pulsed excimer laser (wavelengths 248 nm or 193 nm) is sent through a phase mask. The phase mask modulates the phase of the incident beam and provokes distinct diffraction maxima. Using a Schwarzschild reflection objective, the resulting interference pattern is demagnified and projected onto a thin film. When the ablation threshold of the underlying substrate clearly exceeds that of the thin film, the film is ablated at positions where the intensity is in excess of the ablation threshold of the film while the substrate remains unchanged. Different shapes of nanostructures can be fabricated this way, depending on the pattern of the phase mask. The size of the resulting structures depends on various parameters like film thickness, material or demagnification. With this technique, GaN nanowires were produced with a striped mask [1] while Au and Ni nanodots were fabricated using a checkerboard mask [2]. This technique is in principle applicabel to every combination of thin film and substrate material, as long as the ablation threshold of the substrate is high enough in comparison to the film ablation threshold.

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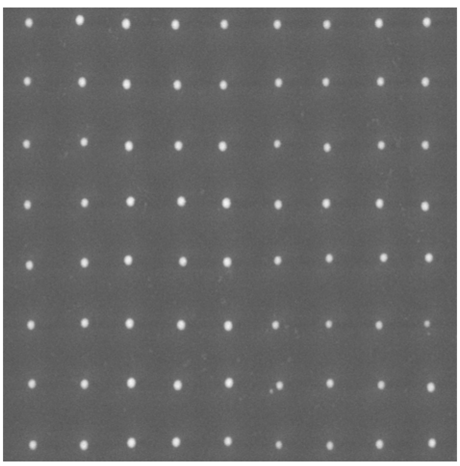

P-41

Microstructure studying of laser pulse irradiating metal targets in water

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The formation of surface-structures by pulsed laser irradiation of metal targets in atmospheric conditions has been interested in recent years because of the wide range of possible applications [1–4]. The characterization of the topographical evolution of the laser irradiated region as a function of the irradiation conditions is very important. The surface morphology of Ti foils irradiated by long single pulse Nd:YAG in atmospheric air was investigated by Gyorgy et.al. [5]. It was found that specific laser intensity can produce surface melting without large liquid displacement or vaporization. The effect of multi-pulse laser irradiation on solid surfaces was also widely studied in the last years due to its interest from both a physical and technological point of view [7-9]. Under the action of the laser pulses, a large variety of surface structures develops, such as periodic structures, ridges, volcanic-like craters, cones or columns [20-24]. Recently, the surface-morphology modification of Ti exposed to multi-pulse Nd:YAG laser irradiation in air at atmospheric pressure was also reported. They particularly showed the growth of crown-like structures on the surface of Ti targets [6]. In this paper microstructure of metal targets irradiated by nanosecond pulsed laser were studied. The targets were placed in water and irradiated by Nd:Yag (~6 nsec) pulsed laser. In this experiment, the targets were exposed to different harmonics of the Nd:Yag laser and the effects of wavelength on the surface was inspected. The effects of focusing spot, and laser intensity were also investigated in this experiment. The results show that the crater size, and kerf depends strongly on the laser characteristics.

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[3] I. Ursu, I.N. Mihai

P-42

Light diffraction on modulations of solid surface relief and low threshold IR multi-photon laser-molecular dissociation on surface. Laser microscopy

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It well known that the light diffraction on relief of surface can make a significant influence on dynamics of laser induced reactions, which are taken a place near relief with spatial modulated profile [1,2]. We present new optimal scheme for isotopic selective low threshold IR multi-photon dissociation of molecules near surface with periodic relief. There are considered possible improvements of so called “Stells” technology. It is carried out modelling optimal scheme for isotopic selective low threshold IR multi-photon dissociation of molecules near surface with periodic relief. The physical system is molecular gas (SF6, UF6), that is resonantly excited by the CO2 laser radiation near surface of the periodic Cu lattice. A definition of local electromagnetic fields and their increasing near surface, contribution of the surface relief parameters (form, depth etc) are quantitatively taken into account within non-linear theory of diffraction of limited 2D and 3D light beams on surface with arbitrary discrete Fourier spectrum of relief [1]. New multi-level model for optimization of excitation of molecular gas is considered and definition of optimal form for laser pulse to reach the maximal effectiveness of laser action in photodissociation process is carried out [2]. Numerical testing of optimized model for molecules of SF6, UF6 is carried out. The obtained results are used for proposition of a new laser isotope separation scheme with application to problem of the S and U isotopes separation. At last the modified Letokhov’s scheme of photoelectron (photoion) laser microscope is presented (look fig.: 1-needle; 2- adsorbed macromolecule on the needle surface; 3- fluorescenced screen; 4- source of voltage; 5- laser beams with frequences w1,w2).

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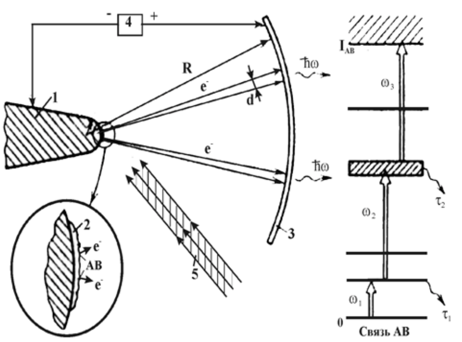

P-43

Estimation of Pulsed Laser Ablated Polyimide Sizes

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A thermal model for laser ablation of materials has been proposed. The model includes the deposition of ablated species in calculation of pulsed laser etch depth. The recession rate of the surface is calculated based on deposition of ablated materials to the surface due to collision with the enviromental molecules. The numerical solution of the heat equation with moving interface, it gives excellent fit to a wide nanosecond pulsed laser ablation experimental data for polyimide in air. In addition, the ablated polyimide sizes are estimated using this model.

P-44

Pulsed Laser-Induced Surface Modification of Silicon in Liquids

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In this work, nanosecond pulsed laser-induced surface modification of silicon has been investigated in water, ethanol and air. Surface irradiation of the samples was carried out using second-harmonic irradiation of Nd: YAG laser at applied fluence levels of 5-10 J/cm2. Under water and ethanol confinement, higher surface modification thresholds, lower ablation depth, and smaller micro spikes spacing were found in comparison to the dry experiments. The surface roughness and the evolution of its morphology were investigated using AFM and SEM. This study contributes to a better understanding of the physical processes involved in the laser ablation of silicon in liquids.

P-45

Femtosecond laser induced forward transfer (LIFT) process for skutterudite thin film patterning

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Laser induced forward transfer (LIFT) is a techniques which allows to deposit patterns, spots and lines with submicron resolution. The thin film which is deposited onto a substrate transparent to the laser wavelength used is transferred by using a single laser pulse onto the receiving substrate usually placed parallel to the source thin film. The use of LIFT for patterning of scutterudite material on SiO2/Si substrate using femtosecond pulsed laser is investigated in this paper; the importance of CoSb3 (skutterudite) comes from their thermoelectric properties. A femtosecond pulsed laser (Clark-MXR laser, wavelength: 750nm, pulse width: 150fs), and an MAX341 3-Axis NanoMax, Closed-loop piezo & Stepper Motors are used for this scope. Thin film of skutterudite deposited by Pulsed Laser Deposition on fused silica substrate is irradiated with a single laser pulse and transferred on a SiO2/Si acceptor substrate. Chemical composition and shape aspect of deposited spots were investigated by electron probe microanalysis (EPMA), Atomic Force Microscopy and Scanning Electron Microscopy

P-46

Formation of Graded Band Gap in CdZnTe by Nd:YAG Laser Radiation

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Riga Technical University

Band-gap structures on the basis of CdZnTe are perspective materials for creation of various semiconductor devices, in particular for highly effective converters of a sunlight, selective and broadband photo detectors, spectrally scanning lasers with a low threshold current [1]. The aim of this work is investigated an influence of laser radiation on redistribution of Zn atoms in CdZnTe by photoluminescence (PL) spectra to get further insight into processes that take place in CdZnTe crystals. The high gradient of temperature, arising at action of pulse laser radiation nanosecond range, causes redistribution of point defects (vacancies and interstitial atoms) toward of a temperature gradient. According to the effect, the interstitial atoms of Cd (Cdi) in Cd1-xZnxTe move along the temperature gradient while the Cd vacancies (VCd) and Zn atoms – in the opposite direction, into the bulk of the semiconductor where temperature is lower. Samples of Cd1-xZnxTe with x=0.06 were used in our experiments. PL spectra were measured at 5 K using an Ar+ laser for excitation. After laser irradiation of Cd1-xZnxTe crystal with intensity 0.2 MW/cm2 all the lines of PL spectra start to shift to lower energy of spectra (red shift). In turn, spectral shift of the A°X line at maximal laser intensity I=2MW/cm2 was 41meV. According to [2] such spectral red shift of A°X line leads to the decrease of Zn atom average concentration at the irradiated surface of CdZnTe till 2%. Actually this red shift must be higher, since concentration of impurity atoms exponentially decreases in the direction from the irradiated surface toward the volume of a semiconductor [3]. We have shown the possibility to form the graded band-gap in Cd1-xZnxTe crystal by the second harmonica of Nd: YAG laser radiation. The possibility to form the graded band-gap in Cd1-xZnxTe crystal by the second harmonic of Nd: YAG laser radiation have shown. The thermogradient effect has the main role in the redistribution of Zn atoms at the irradiated surface of Cd1-xZnxTe using Nd:YAG laser second harmonic with intensity from 0.2 MW/cm2 till 2 MW/cm2.

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P-47

Laser-Shaping of Hexagonal Ordered Triangular Gold Nanoparticles with Nanosecond Pulsed Laser Light

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In order to overcome the classical limits of silicon technology the use of molecular circuits is a challenging new possibility. The idea behind this is to use molecular wires as active elements and interconnections of devices that perform the basic electronic functions of rectification, amplification and information storage, thus reducing circuit dimensions to the molecular scale. To realize molecular circuits highly ordered arrays of nanoparticles which act as anchor points for the uni- and bi-directional molecular wires are necessary. A possible approach to obtain such regular nanoparticle arrays is nanosphere lithography (NSL) [1]. Depending on the species and length of the molecular wires, the distance between the metal nanoparticles as well as their size and shape have to be chosen independently. For these purpose we apply nanosphere lithography in combination with tailoring the dimensions of the nanoparticles with laser light. The latter method has been theoretically modeled and successful applied to noble metal nanoparticles [2]. In this contribution we present recent results on selective and precise tailoring of triangular gold nanoparticles using ns-pulsed laser light. The morphological changes have been investigated as a function of laser fluence and wavelength. In brief, monolayers of triangular gold nanoparticles in a periodic array were prepared by nanosphere lithography. For this purpose, gold were evaporated through the nanosphere mask. Subsequently, the mask was removed by sonicating the sample in a solvent, leaving behind periodic arrays of triangular gold nanoparticles. The particles have been tailored using ns-pulsed laser light choosing different fluences and wavelengths. The morphological and the accompanying optical changes were investigated by scanning electron microscopy and extinction spectroscopy. The most important among the numerous results is a change of the distance between the nanoparticles due to a shape change from triangular to oblate. Consequently, we can tune the gap size between the particles from approximately 100 nm to 120 nm. Thus, we can adjust the gap size precisely to the length of the molecules that should be used as molecular wires. Due to the reshaping of the nanoparticles, we observe an accompanying change in the optical properties, i.e. the surface plasmon resonance changes from 732 nm after preparation to 532 nm after tailoring with laser light, depending on the applied fluence. The main advantage of laser irradiation in comparisons to, e.g., thermal annealing is that nanoparticles in a well-defined area of the sample can be addressed. Possible applications of such laser tailored nanoparticles, e.g. as anchor points for functional molecular wires, will be discussed.

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P-48

Fabrication of DOE using Laser Direct Write Lithography System

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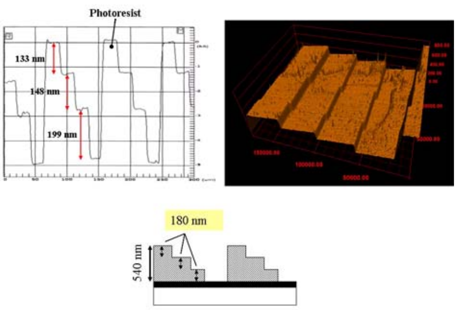
We fabricated the diffractive optical element (DOE) by the use of the laser direct write lithography system. Although it is difficult to draw to a large-sized substrate with electron-beam lithography system, since the laser direct lithography system makes it possible, production of the large DOE is expected. Furthermore, 2 and 4 levels phase-type DOEs were produced by dry etching processing to the substrate, and comparison of the diffraction efficiency of the amplitude- and the phase-type DOE was discussed.



P-49

Direct Laser Marking on CD ROM for Identification

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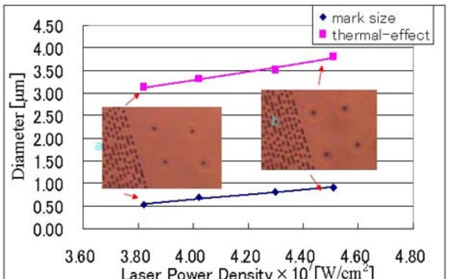
In order to attempt the direct laser marking on CD ROM medium for identification, laser machining was carried out against a thin metallic film in the transparent medium using a microscope with objective lens of NA=0.8 and a turn stage. Heat sources for the processing were a semiconductor laser excitation YVO4 disk laser (532 nm wavelength of second harmonic, max 5 W). The medium under consideration on laser marking is an aluminum thin film reflector layer, which was sandwiched between a polycarbonate (PC) of 1.2 mm and a protection film of 5 m thickness. The aluminum thin film (Al) is 100 nm in thickness. The obtained laser-marking sizes were less than 1 mm and were evaluated using SEM and AFM. The observation samples inside a transparency resin were obtained by tearing off a protection film, and the surfaces of the bared PC and protection film were examined. The surface conditions of laser-marking area were observed.



The relation between the power density and the mark size

P-51

Process of glass-ceramics reverse crystallization under Nd:YAG laser action

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St.Petersburg State University of Information Technologies, Mechanics and Optics

Class of glass-ceramics (GC) materials is characterized by low transparent in a visible range and a polycrystalline structure. It's possible to change properties of these materials due phase-structure modification. Laser IR irradiation could lead to amorphization of GC materials like it's shown in «Nonlinear optical blooming of glass-ceramics under Nd:YAG laser action» by V.P. Veiko, B.Yu. Novikov (this conference). In addition to this it may be reverse crystalline zones on highly transparent amorphous area under second laser irradiation at even plase. CO2-laser (10.6 mkm) is used for such kind of transformations traditionally. In this work reverse crystallization of GC under Nd:YAG laser (1.06 mkm) action has been investigated on the example of ST-50-1 – the most popular GC material for laser phase-structure modification. Near-IR radiation highly transparent (and so lowly absorb) in amorphous phase of GC. Because of this some problems under second Nd:YAG laser radiation treatment is existed. Mechanism and conditions of reverse crystallization, definition of results and measured characteristics of process will be planed to demonstrate at our poster.

P-52

Thin metal sheet bending and residual stresses relaxation by ns-pulse lasers in MEMS manufacturing

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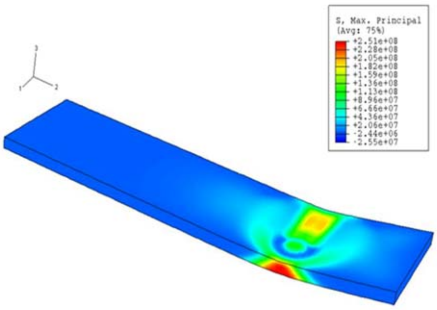
The use of continuous and long-pulse lasers has been previously considered for the bending of thin metal sheets for MEMS micro components. However, due to the specifically developed long-relaxation-time thermal fields responsible for the bending phenomenon, the final sheet deformation state is attained only after a certain reaction time, what, on one side, makes its internal residual stress fields more dependent on ambient conditions and, additionally, may difficult its subsequent assembly process for MEMS manufacturing from the point of view of subsequent residual stresses due to adjustment. Partial solutions to these problems (especially to the second) have been proposed through the use of ultra short laser pulses. However, although the problem of adjustment residual stresses can be readily solved in this way, the problem subsists for the bending up to realistic angles (in the order or greater than 1 mrad) of metal sheets with thicknesses in the range of 10-100 mm due to the average power required for a practical process suitability (normally far exceeding the average power level provided by fs lasers). In this context, the use of ns laser pulses has provided, according to the authors experience, a really suitable parameter matching for the laser bending of an important range of sheet components used in MEMS that, preserving the short interaction time scale required for the predominantly mechanic (shock) induction of deformation residual stresses, allows for the successful processing of components in a medium range of miniaturization but particularly important according to its frequent use in such systems. In the present paper, an overview is presented on the specific features of laser interaction in the timescale and intensity range needed for thin sheet micro forming with ns-pulse lasers along with relevant modelling and experimental results and a primary delimitation of the parametric space of the considered class of lasers for the referred processes.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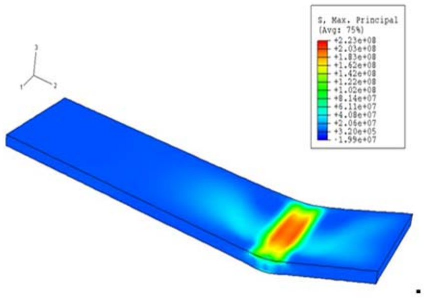
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+8.14e+07
+6.11e+07
+4.08e+07
+2.06e+07
+3.20e+05
-1.99e+07

P-53

Laser-assisted micromachining of Fe-alloys using a novel thermochemical etching technique with an optical fiber

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Laser-assisted micromachining technology has been widely applied for the fabrication of microstructures due to non-contact processing, high resolution, and little limitation in materials. In specialty, the laser-assisted etching is a micromachining technique in which a laser beam locally irradiates a workpiece immersed in an etchant to induce thermochemical reaction between the etchant and the workpiece. Laser-assisted etching is most advantageous in the sense that it is a single-step direct writing process requiring no pattern mask. Also, in comparison with laser ablation micromachining, it enables fabrication of microstructures with little heat affected zone and debris as well as high dimensional accuracy and shape clarity. The conventional lens-based laser etching system, however, requires many optic components such as a beam expander, a linear polarizer, a waveplate and an objective lens in order to protect optics on the beam path, and laser system and to tightly focus on the surface of a workpiece. Accordingly, a complicated laser beam alignment and exposure to the reflected or scattered beam are unavoidable during the etching process. In this study, a novel laser-assisted etching system utilizing an optical fiber as a machining tool as well as an optical waveguide is introduced to manufacture metallic grooves and holes. Complex optic elements are completely replaced by an optical fiber to reduce beam propagation loss and to simplify the machining system. In the proposed laser-assisted etching system, a pulsed Nd:YAG laser or a DPSS CW (Nd:YVO4) laser is used as the light source to induce thermochemical reaction for groove and hole fabrication. A stainless steel and an Invar® foil which are representative Fe-alloys are used as the workpiece for process study. The characteristics of high-aspect-ratio microgrooves and holes concerning process variables are closely examined. Also, the fabrication and applicability of Invar® shadow mask for OLED are demonstrated.

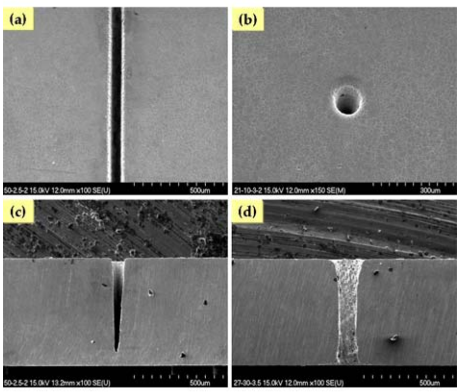

Fig. 1: (a) , (b) Top view and (c), (d) cross section of microgroove and microhole fabricated utilizing the proposed laser-assisted etching system

P-54

Aligned Growth of ZnO Nanowire by Catalyst-Free Nano-Particle Assisted Laser Deposition

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We have previously succeeded in growing ZnO nanorods and nanowires by a newly developed nano-particle assisted laser deposition (NPAD). In this report, the well-oriented, uniquely shaped ZnO nanonails have been vertically aligned to sapphire substrates by catalyst-free NPAD. The growth mechanism will be discussed, based on the observation of the growth behavior that has been investigated by variation of the laser ablation time.

P-55

Formation of Graded Band-gap in CdZnTe by YAG:Nd Laser Radiation

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CdZnTe is perspective material for creation of various semiconductor devices, in particular for highly effective converters of a sunlight, selective and broadband photo detectors, spectrally scanning lasers with a low threshold current [1,]. Pulse laser radiation is one of perspective methods of the directed updating electric and recombination properties of ternary alloy. The given method of processing has localness and short duration of influence on the semiconductor. A number of papers are devoted to influence of a pulse laser irradiation on the semiconductor [2, 3]. The purpose of this work is experimental investigation of the possibility grated band-gap creation in ternary alloy Cd1-xZnxTe. A mechanism for formation of graded band-gap in Cd1-xZnxTe sample using the second harmonic of a Q-switched YAG:Nd laser radiation (LR) is proposed which involves Thermogradient Effect (TGE). Results of investigation of the photoluminescence (PL) spectra at 5 K show that the concentration of atom Zn is increased owing to aggregation of the VCd with Zn after laser irradiation in the bulk of the sample. 1. The possibility to form the graded band-gap in Cd1-xZnxTe crystal by the second harmonic of YAG:Nd laser radiation have shown. 2. The Thermogradient effect has the main role in the redistribution of Zn atoms at the irradiated surface of Cd1-xZnxTe using YAG:Nd laser second harmonic with intensity from 0.2 MW/cm2 till 2 MW/cm2.

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P-56

Interferometric femtosecond patterning of metals

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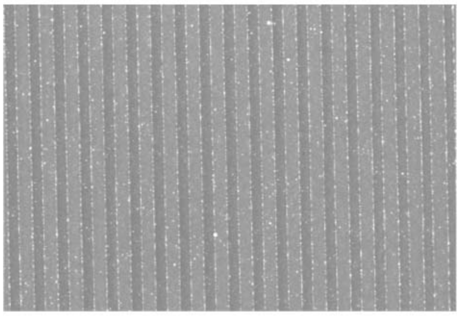
The gratings were ablated to chrome masks using either two- or four-beam interference pattern. Structures with period around one micrometer were ablated through 100 nm of chrome using just one femtosecond pulse of 1 mJ energy and 800 nm wavelength. Area of approx. 100*100 micrometers of good quality grating were obtained using single pulse. In figure are shown grating recorded to the chrome mask using two-beam interference. Similar structures were also made in stainless steel sample using higher number of pulses. The effect of pulse number and energy to the surface quality were also investigated. Results show that interferometric femtosecond patterning can provide effective way to manufacture gratings to the chrome masks and stainless steel moulds.



P-57

Nano-particle generation from Femtosecond laser ablation of materials

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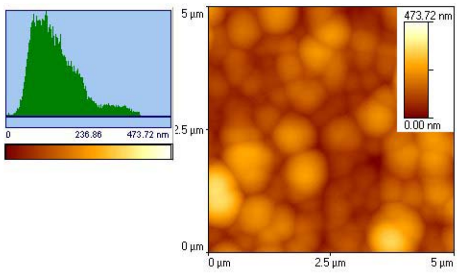
Ultrashort laser pulse ablation leads to the generation of intense plasmas expanding from a substrate surface. This highly ionised material, initially at almost solid state density, expands well after the pulse has been absorbed. and is collisionally cooled by the ambient gas. The resulting debris returning to the surface consists mainly of spherical nano-particles whose size distribution depends strongly on the ambient gas composition and pressure. We present results on the study of nano-particle size distribution and their physical properties (eg crystalline structure) with Ti6Al4V, Si, Alumina and fused silica ablated at 775nm with 180fs pulselength. For example, in Silicon, the particle size distribution is broad and peaks around 100nm in air while under liquid, the size distribution reduces dramatically with most particles < 50nm in size.



P-58

Modification of phase change memory materials during interaction with excimer laser pulses

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Bulk phase change materials of composition GeSb2Te4 and GeSb2Te4 · 10 mol.% SnSe2 have been subjected to excimer laser ablation. A KrF* excimer laser, having the wavelength λ= 248 nm, with pulse duration τFWHM ≈ 7 ns and 1 Hz repetition rate has been used in the experiments. A small amount of material from the irradiated area of every sample has been carefully extracted from the circular crater formed on the surface of the plate subjected to radiation. X-ray diffraction measurements on virgin samples and on the material from the irradiated zones, allowed us to get the fine structural modification determined by the interaction of the excimer laser pulses with the basical phase change memory materials. The main effect consists in the vanishing of the crystalline inclusions and transition towards a more homogeneous amorphous phase.

P-59

Enhancement of sensing properties of thin poly(methyl methacrylate) films by VUV surface modification

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Surface modification of polymeric films by light is an efficient method to tailor their properties and functionality for a variety of applications [1, 2]. VUV irradiation of Polymethylmethacrylate_(PMMA) thin films deposited on SiO2 layer, demonstrates a considerable increase of surface and bulk swelling in comparison to the non irradiated film areas. AFM images of surface morphology of the irradiated areas reveal that roughness is greatly enhanced to structures depending on the irradiation conditions. The appearance of micro- structures and domains of various shapes imply a considerable increase of the polymeric surface area and volume. Besides morphological changes, VUV, UV visible and IR absorption spectroscopy of the irradiated and non irradiated areas suggest chemical modification of the irradiated film areas. Swelling and chemical modification enhances the detection efficiency of the liquid/gas analytes (water, ethanol, etc) by many orders of magnitude. This method can be used to fabricate a polymer based sensor array to engineer its detection efficiency.

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[2] "Characterization of Polymer Layers for Silicon Micromachined Bilayer Chemical Sensors Using White Light Interferometry" Sens. Act. B vol. 111-112, pp. 549-554, 2005. D. Goustouridis, K. Manoli, S. Chatzandroulis, M. Sanopoulou, I. Raptis.

P-60

MICRO/NANO SELF-ASSEMBLED STRUCTURES FROM BLOCK COPOLYMER/SAMARIUM-IRON NANOPARTICLES HYBRID MATERIALS INDUCED BY VUV LIGHT

(1)S. Pispas, (1)E. Sarantopoulou, (1)K. Gatsouli, (1)Z. Kollia, (2) S. Kobe

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Thin films of block copolymer/samarium-iron metal nanoparticles hybrid organic-inorganic materials were prepared either by combination of wet chemistry [1], involving metal nanoparticle formation in block copolymer micellar templates and physical processing via casting or by spin coating and VUV laser illumination [2] at 157nm. A variety of self-assembled structures in the nanometer to micrometer scale were observed by imaging techniques, including TEM, SEM and AFM. Investigations show a closely related hierarchy of the structures formed in the different length scales. These self-assembled structures hold a large potential for nanotechnological applications.

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P-61

Laser assisted delamination of paint by inductive heating

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It has been shown recently, that paint removal from metallic surfaces can be accomplished by eddy-currents induced in the metal by high frequency magnetic fields due to the decomposition of the primer located usually between metal and paint. Due to destruction of the primer the cohesion between paint and metal gets lost and the paint can be removed in the shape of a solid plates. Nevertheless for practical use the paint must be cut into smaller pieces. For the latter purpose up to now high pressure water jets have been used. The latter tool is unfavourable due to the large amount of water dispersed on the work piece. Therefore a new concept has been developed where induction heating is combined with laser cutting or an appropriate choice of parameters as high frequency power, laser power, cutting gas pressure and processing speed successful operation could be proved, thus largely improving the performance of inductive delamination process. Important progress has also be obtained towards an automatic control of the process based on a temperature measurement.

P-62

Correction of ditch-shaped defects during KrF excimer laser ablation using a mask projection

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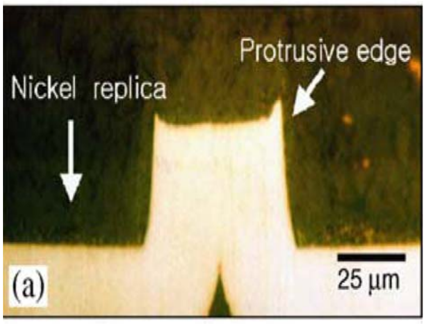
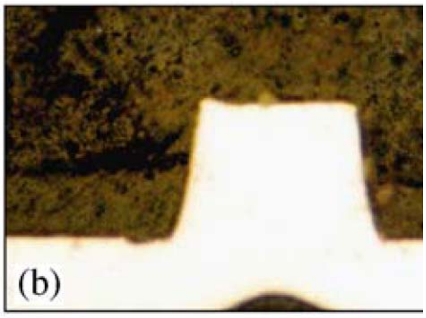
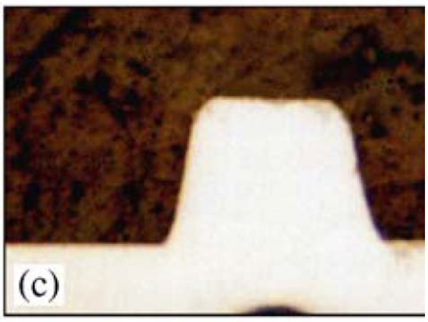
Using masks for laser ablation has proven useful in the fabrication of prototypes for the manufacturing of micro-fluidic devices. In this work, an excimer laser was used to engrave microscopic channels on the surface of polyethylene terephthalate (PET), which showed a high absorption ratio for an excimer laser beam with a wavelength of 248 nm. When 50 mm wide rectangular microscopic channels were made using a 500X500 mm square mask and a magnification ratio of 1/10, ditch-shaped defects were found at both corners. The calculation of the laser beam intensity showed that a coherent image in the PET specimen caused the defects. An analysis based on the Fourier diffraction theory enabled the prediction of a coherent shape at the image plane, as well as a diffracted beam between the mask and the image plane. The analysis also showed that the diameter of the aperture was a predominant factor toward the elimination of ditch-shaped defects in the rectangular microscopic channels on the PET produced by an excimer laser ablation. * figure explaination: Cross-sectional view of a nickel replica after electroforming on an ablated PET, with aperture diameters of (a) 5 mm, (b) 3mm and (c) 2 mm.







P-63

Temperature Dependent Heat Generation by Optically Active Rare Earth Ions for Full Body Cutting of LCD module

Kohei SOGA and Hiroshi MIURA*

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Recent development of liquid crystal display (LCD) modules requires a simple and inexpensive glass cutting process for the modules in each panel size from a mother glass sheet sub-assembly, where thin film transistor (TFT) and color filter glass sheets are glued with a spacing for injecting liquid crystal. The cutting process of the sub-assembly is very complex and the equipment for the process is expensive, since the TFT and the color filter glass sheets must be scribed by a diamond chip and are easily broken by pressing columnar rubber. We are developing a full body cutting (FBC) technology, where the mother glass sheets sub-assembly are cut all together with heat stress generated a laser light absorption. In the symposium, we will report three papers on the FBC in by InGaAs laser diode beam to be absorbed by Yb3+ ions doped in mother glass. The absorbed photon energy is converted to heat to generate heat stress for the FBC. In this method, the energy of excited electrons must be relaxed into lattice vibrations (phonon) to generate heat effectively by a process called multi phonon relaxation (MPR). The purpose of this paper is to find the experimental conditions for maximum conversion ratio from the optical absorption into the heat formation. The MPR process can be described by the following equation where the parameters are relating to electron-phonon coupling, energy separation between the energy level of interest and the next lower one and the dominant phonon energy of the host material. The parameters are experimentally decided by measuring the temperature dependence of fluorescence lifetimes of Yb3+ doped in glass. The temperature dependent heat generation efficiency was estimated by using the parameters.

$$W_{\mathrm{MPR}} = B\exp(-\alpha\Delta E)\left\{1-\exp\left(\frac{\hbar\omega}{kT}\right)\right\}^{-\frac{\Delta E}{\hbar\omega}}$$

P-65

Laser micro-welding of dissimilar materials using femtosecond laser pulses

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We recently proposed and demonstrated a new laser micro-welding technique based on the nonlinear absorption of focused ultrashort laser pulses. Because ultrashort laser pulses have very short duration of time ranging from picosecond to femtosecond, they can have a very high peak power. When such an intense ultrashort laser pulse is focused at the interface of two substrates, the intensity in the focal volume can be high enough to cause absorption through nonlinear processes (multiphoton absorption and tunneling ionization) and avalanche ionization. Through the nonlinear absorption process, the interface of the materials melts only around the focal spot, and consequently the materials can be locally joined by resolidification. Thus, this technique can join transparent materials without introducing a light-absorbing intermediate layer. An additional advantage of this technique is that the extremely short pulse avoids the unwanted side effects, such as thermal stress and cracking. Therefore, this technique has potential for welding dissimilar materials that have different coefficients of thermal expansion. In this paper, we present a systematic study on the micro-welding of dissimilar materials. We demonstrate a welding experiment of polymer materials that are transparent at the wavelength of the laser radiation. We also demonstrate a welding experiment of transparent and absorbing material. We used pairs of dissimilar materials, such as polymer and metal, and borosilicate glass and metal. In the experiments, an amplified femtosecond laser system generating 1-kHz 800-nm 85-fs pulses was used. The laser pulses were focused at the interface of two materials to be joined. The sample was mounted on a two-dimensional translation stage. By translating the stage perpendicular to the optical axis in the two-dimensional plane, we produced an array of small welding region with rectangular shape. After welding, we performed a simple tensile test in order to measure the joint str

P-66

Dynamics of the shock wave accompanied by nanoparticle formation in the PLA processes

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Pulsed laser ablation (PLA) has been used as an effective technique to produce nanoparticles with a precisely-specified size. Production of nanoparticles with the desired size is made possible because the conditions for evaporated mass and ambient gas pressure can be independently controlled in this technique. The interaction between the plume and the ambient gas play an important role in nanoparticle formation. Spectroscopic experiments have been conducted by other groups with the aim of investigation into the plume dynamics during the PLA process. However, shock waves were generated in the early stage of the PLA and were resulted to extensive reflection and diffraction of them, which makes the clarification of the nanoparticle formation process increasingly difficult. Hitherto, no attempt to introduce shock wave generation and reflection into the plume dynamics has been reported in relation to nanoparticle formation. In the present paper, the authors demonstrate the dynamics of the shock wave relevant to nanoparticle formation by solving the one-dimensional fluid equation in a flow field generated immediately after PLA in the closed space between the target and a plate. The classical nucleation theory has certain effects on the qualitative prediction of nanoparticle formation, although it cannot quantitatively describe the formation mechanism since it disregards dimerization of the plume-species' atoms. The existing theory was therefore used in the present calculations since it provides an efficient method of predicting nanoparticle formation. The light emission from the plume during the laser ablation process in the closed space was also observed. The linear plot of the emission strength represented from the results was compared with the calculation results and some agreements between these results were observed. Thus, it can be expected that more suitable solutions will be obtained by improving the nucleation model using these kind of experimental results.

P-67

Fabrication of microstructures on cemented tungsten carbide by a femtosecond laser

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Nagaoka University of Technology

Recently, high-precision dies and molds for smaller products are highly required in many manufacturing fields. Hard die materials, such like cemented carbide, are difficult to machine by cutting tools and the EDM is mainly used. The dies made by these methods need to be polished after machining. The polishing process takes many laborers and long processing time. Demands on shorter production time of the dies are ever increasing. The direct processing of the high-hardness die materials by laser machining is considered to have a great potential. In this study, a femtosecond laser has been used to machine microstructures on a plate of cemented tungsten carbide and compared to the results obtained by a nanosecond laser. The laser used delivered 100 fs pulses at 785 nm with 1 kHz repetition rate. Effects of focal position of the femtosecond laser beam are examined: removal rate is larger when it placed before the surface of the specimen. Air-breakdown is observed in this case. We consider that heating by the breakdown plasma on the surface might increase the removal rate. Surface roughness of Ra=0.4µm or less is obtained by 150 µJ pulses at the scanning speed of 0.4mm/s. Only small amount of deposited debris is observed in a groove machining, while significant amount of debris and re-solidified metal are observed in machining a small square dent. It is possible, however, to eliminate the re-solidified metal deposition by optimizing the machining conditions but a thin layer of debris, less than 10 µm thick, still remains. The thickness of heat affected zone is estimated to be less than 0.5µm, with no crack or void on the surface. The layer of deposited debris is easily removed by second laser irradiation with significantly lower pulse energy. The machined surface has a characteristic periodic structure with a shorter period than the laser wavelength. Nanosecond lasers show larger machining rates with larger heat effects compared to the femtosecond laser.

P-68

Surface morphology-dependent formation of ripples on Si, SiC, and HOPG substrates

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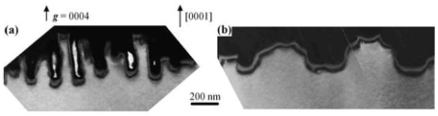
Laser-induced periodic structures, referred to as "ripples", have attracted much attention both from fundamental and application-oriented aspects. In particular, the formation process of fine ripples, whose period is several times smaller than the wavelength of the irradiated laser beam, have extensively been studied in recent years. In this paper, we will discuss the effect of initial surface roughness on the formation of fine and coarse ripples. We will also discuss the cross-sectional profiles of ripples on highly oriented pyrolytic graphite (HOPG). The light source used in our experiment was a Ti:Sapphire regenerative-amplifier based on a chirped pulse amplification system operating at 800 nm (Spectra-Physics, Spitfire). HOPG (HT-MDT corp.), silicon (Mitsubishi Materials corp.) and single crystal 4H-SiC (Sterling semiconductor corp.) wafers were used in this experiment. To study the effect of surface roughness and thickness, we prepared different surface morphologies by rubbing the surface of 4H-SiC wafer with a diamond wrapping film (Imperial, grain size: 1 micron). The surface roughness of the sample surface was inspected by an atomic force microscope (AFM). The drastic reduction of the threshold fluence was observed for the fine ripple formation on the roughened surface of 4H-SiC compared with the relatively smooth as-grown surface. This reduction of the threshold fluence was found only for the fine ripple and not for the coarse ripple. Based upon this result, we will discuss the reason why the laser pulse duration shorter than the lattice deformation time is needed to generate the fine ripple structure. The ripple structures formed on HOPG surface revealed that the cross-section of ripple structure on HOPG shows the concave shape, while those on Si and SiC show the convex shape. The detailed discussion of the results will be presented in this conference.



P-71

Laser Surface Nanotexturing and Applications

Wei Guo(1,2), Lin Li(1), Zhu Liu(2), Zengbo Wang(1) , Philip Crouse(1), David Whitehead(1)

(1)Laser Processing Research Centre, School of Mechanical, Aerospace and Civil Engineering, University of Manchester, Sackville Street, Manchester, M60 1QD, UK
(2)Corrosion and Protection Centre, School of Materials Science, University of Manchester, The Mill, Manchester M60 1QD, UK

Laser surface nanotexturing is very desirable in microelectronics and other applications. Compared with electron beam and focused ion beam lithography techniques, laser texturing has an advantage of simple setup, fast speed and massive processing. In this paper, a near-field technique was developed to overcome the diffraction limit for direct laser surface nanopatterning. For the first time, it was demonstrated that different nano-features can be written on the substrates in a large surface area. By using an angular incident laser beam with a self-assembled particle-lens array, millions of nanostructures can be accomplished by a few laser pulse exposure.

P-72

Amorphous structure of ripple on SiC studied by micro Raman spectroscopy

Makoto Yamaguchi [1] Shigeru Ueno [1], Ryota Kumai [2], Keita Kinoshita [2], Takuro Tomita [2], Shigeki Matsuo [2], Shuichi Hashimoto [2]

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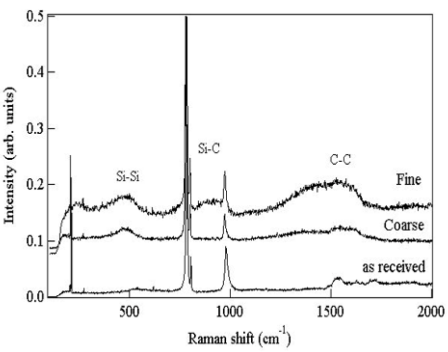
Periodic structures, so-called “ripples”, are produced on a solid surface by the irradiation of femtosecond laser pulses with an energy around the ablation threshold. This structure has been studied in a wide variety of fundamental and applied research. Although extensive study has been performed with respect to the formation of femtosecond laser-induced ripple, less work has been done to reveal the crystalline properties of the ripples.[1] In this conference, we will report the crystallographic characterization of ripple structures on a single-crystalline (c-) silicon carbide (4H-SiC) by micro-Raman spectroscopy. The samples are irradiated with near-infrared femtosecond laser pulses by a Ti: Sapphire regenerative amplifier system based on a chirped pulse amplification (Spectra-Physics, Spitfire). Pulse energy, and pulse repetition of the laser used is 0.5-40uJ/pulse, and 50Hz, respectively. The laser beam is focused onto the sample by a Plano-convex lens (f=100) Renishaw inVia Raman system in the backscattering configuration is used. Figure shows the Raman spectra recorded at a fine ripple, coarse ripple, and untreated surface. Sharp peaks (200 cm^-1, 780 cm^-1 and 970 cm^-1) are attributed to the acoustic/optical phonons in c-4H-SiC. At fine and coarse ripples, three broad band peaks are observed. The bands around 480cm^-1, 880cm^-1 and 1500cm^-1 are assigned to amorphous (a-) Si, a-SiC and a-C respectively. Intensity of a-SiC band at a fine ripple is larger than that at a coarse ripple. These results indicate that structural change from c-SiC to a-SiC can be caused at the initial stage of ripple formation, followed by transformation from a-SiC to a-Si and a-C. The formation process of ripple structure should be discussed in terms of phase transformation and/or atomic migration triggered by the interaction between light and material, in addition to the change of surface morphology such as periodicities.

[1] Appl.Phys.A,79,1429 (2004), F. Costache et al.



P-73

Tribological property of DLC films with femtosecond-laser induced nanostructure

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(2) Kyoto University,
(3) Eyetec Co., Ltd.

Applications of diamond-like carbon (DLC) films to tribological technology are of growing interest due to their excellent surface smoothness and low frictional coefficient. In our recent studies [1-4], we have shown that DLC and TiN film surfaces are structured on a nanometer level by irradiating femtosecond (fs) laser pulses. Furthermore, with the Raman spectroscopy of the nano-structured film surface, we have found that the thin DLC film is modified into a glassy carbon (GC) layer [2]. Here we report tribological properties of the DLC film (hardness, HV 3000) of which surface has been nanostructured with fs-laser pulses. A broad area of more than 15 mm x 15 mm on the DLC surface was nanostructured using a precise target-scan system developed for the fs-laser processing. Friction coefficient of the surface-treated specimens was measured in air with a ball-on disc friction test machine using balls made of hardened bearing steel (~ HV 600) and of WC-Co metal (~ HV 1600). We have found that the frictional properties of DLC film are greatly improved when molybdenum disulfide layer is coated on the nanostructured surface. For example, the friction coefficient of DLC surface was observed to decrease down to 0.07 from 0.18 for the steel ball and to 0.02 – 0.04 from 0.08 for the WC-Co ball. On the other hand, a net-like patterning of nanostructured zone has been shown to increase the friction coefficient of the surface. The results demonstrate that the tribological property of DLC surface can be controlled with the fs-laser induced nanostructuring.

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[1] N. Yasumaru, K. Miyazaki, J. Kiuchi: Appl. Phys. A, 76 (2003) 983.
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[3] K. Miyazaki, N. Maekawa, W. Kobayashi, M. Kaku, N. Yasumaru, J. Kiuchi: Appl. Phys. A, 80 (2005) 17.
[4] N. Yasumaru, K. Miyazaki, J. Kiuchi: Appl. Phys. A, 81 (2005) 933.

P-74

Femtosecond laser fabrication of metamaterials for high frequency devices

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Dry etching by femtosecond lasers is used for configuration of micro structures. Films of few hundreds nm of gold deposited on glass or silicon are precisely processed by tightly focusing a femtosecond laser with 150fs pulse duration, 775nm wavelength, and energy of hundreds of nJ. The laser fluence is hold just above the ablation threshold. Thus, the evaporated film leaves behind structures with thin lateral size of about 1µm, without affecting the substrate. Using this technique the fabrication of micro devices is demonstrated. The periodic structures are designed to behave as a left handed metamaterial at a given frequency in the GHz-THz range. The fabricated metamaterials have applications for antenna, couplers, etc. in the high frequency range.

P-75

Ultra-short pulse laser processing of Galium Nitride semiconductor epitaxial layers: theoretical modeling.

Irina N. Zavestovskaya Oleg.N. Krokhin Peter G. Eliseev

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The processes of the terawatt/cm2-laser irradiation and ablation of the transparent materials such as nitride semiconductor, sapphire and others are considered theoretically. The power consumption under the ablation process is described in terms of the nonlinear mechanism of the tunneling absorption. Laser ablation of the TW/cm2 range laser irradiation is suitable technique for processing and machining of transparent materials. A comparison of the ablation threshold has been performed for different transparent materials under very similar irradiation conditions. GaN epitaxial layers on the sapphire substrates, sapphire and silica-based glasses are tested. It was determined the laser-induced damage threshold and result shows the correlation of the LIDT with energy bandgap and other material characteristics. The threshold appears to grow as about third power of the energy bandgap. The power consumption under the ablation process of transparent materials is described in terms of the induced absorption with an effective absorption coefficient of 2.5×104 cm-1. The linear absorption in GaN at 400 nm is less than 100 cm-1. It means that there is an effective nonlinear mechanism of the power irradiation absorption in the transparent frequency region at TW/cm2-range of power density. It is well known from the general theory of the nonlinear ionization of the atoms and solid materials that the character of the nonlinear ionization under a field action is determined as the intensity I as the irradiation frequency w. The important parameter of this theory is adiabaticity parameter g. It was shown that if g << 1 (high value of the laser power and the case of low frequencies) there is realised the tunneling mechanism of absorption in the electric field. For GaN Eg » 3.43 eV and for I = 40 TW/cm2 g ~ ½ and w = 1015 s-1. It means that for the ablation processes in GaN at terrawatt laser power it is realized the tunneling mechanism of absorption. Using the dependencies of w we was determined the LIDT dependence on Eg3 which is in good agreement with experimental results. For other transparent materials parameter g are much smaller than for GaN since the bandgap of GaN is the smallest one. In all the experimental results there realized the tunneling mechanism of ionization. The corresponding increasing of the absorption coefficient was determined. For GaN we had estimated a about 104 cm-1 that is in good agreement with the experimental results.

P-76

The Second-order Doppler Error of Laser Dual-frequency Interferometer

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Only first-order Doppler frequency shift is considered in present laser dual-frequency interferometers, however second-order Doppler frequency shift should be considered when measurement corner-cube (MCC) moves at high velocity or variable velocity because it can cause considerable error. The influence of second-order Doppler frequency shift on error of interferometer was studied in this paper, and the model of second-order Doppler error was put forward. Moreover, the model was simulated at high velocity and variable velocity motionrespectively. The simulated results show that the second-order Doppler error is in proportion to the velocity of MCC when it moves at uniform motion and the measured displacement is certain. When the MCC moves at variable motion, the second-order Doppler error doesn't only concern velocity but also acceleration. When muzzle velocity is zero the second-order Doppler error caused by acceleration of 0.6g can be up to 2.5nm in 0.4 seconds, which is not negligible in nanometer measurement. Moreover, when muzzle velocity is nonzero, the accelerated motion may result in more error and decelerated motion may result in less error.

P-77

Quality and Yield Enhancement of IR-Laser Ablation by Harmonics Seeding

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Laser ablation of semiconductors with nano- and picosecond IR sources exhibiting a quantum energy below the band gap is characterized by low ablation rates accompanied by a poor surface quality due to weak absorption. This can be overcome by the use of frequency converted lasers, at the expense, however, of a considerable energy loss by the conversion process. We present a method which combines high energy efficiency and good surface quality by simultaneous irradiation of the sample with a superposition of the fundamental beam (λ=1064 nm) and a small amount of its second (SH) or third harmonic (TH), generated in a thin nonlinear crystal. Conserving the total energy fluence, the high absorption at the harmonic wavelength leads to an electron population in the conduction band which is sufficient to start the ablation process by absorption of the IR radiation. In this fashion, the ablation yield can be increased significantly. In addition, the ablation quality was demonstrated to improve in terms of surface smoothness. While the effect is insignificant for femtosecond laser pulses, it becomes quite efficient for longer pulse durations, where inexpensive and robust laser sources are easily available.

List of Authors

Tuesday, April 24	Wednesday, April 25		Thursday, April 26		Friday, April 27	
Großer Festsaal	Großer Festsaal	Elise Richter Saal	Großer Festsaal	Elise Richter Saal	Großer Festsaal	Elise Richter Saal
Arrival Time	S1-1 9:00 **Nakata** (Inv.)	S3-1 9:00 **John** (Inv.)	S1-3 9:00 **M. Schmidt** (Inv.)	4-2 9:00 **Kim** (Inv.)	S1-5 9:00 **Obara** (Inv.)	8-1 9:00 **Bellec** (Inv.)
	9:30 Reif	09:30 Bekesi	9:30 Miyazaki	09:30 Fukuda	9:30 Audouard	9:30 Lippert
	9:50 Zhao	9:50 Ganser	9:50 Mizoshiri	9:50 Molpeceres	9:50 **Hoeche** (Inv.)	9:50 Glushkov
	10:10 Sun	10:10 Maerten	10:10 Ko	10:10 Zoppel		10:10 Ueta
	Coffee Break 10:30-11:00					
11:00-15:00 **Registration Time**	S1-2 11:00 **Boneberg** (Inv.)	S3-2 11:00 Katayama	S1-4 11:00 **Papazoglou** (Inv.)	4-3 11:00 Arnold	7-1 11:00 **Wintner** (Inv.)	S3-3 11:00 **Nolte** (Inv.)
	11:30 Stoian	11:20 Brockmann	11:30 Baumert	11:20 Gaspard	11:30 Ooie	11:30 Mai
	11:50 Izawa	11:40 Weiler	11:50 Solis	11:40 Zhou	11:50 Baersch	11:50 Hoult
	12:10 Horn	12:00 Hoenninger	12:10 Mauclair	12:00 Pique	12:10 Yousif	
	12:30-14:30 **Time Bandwidth Products AG** **Poster Lunch Session**		12:30-14:30 **Hi-Q-Laser** **Poster Lunch Session**		12:30-14:30 **Poster Lunch Session**	
	S2-1 14:30 **Rode** (Inv.)	6-1 14:30 Howard	S2-3 14:30 **Cheng** (Inv.)	5-1 14:30 Meunier	7-2 14:30 **Stoiber** (Inv.)	9-1 14:30 Arai
15:00-15:30 **Opening Remarks**	15:00 M. Hong	14:50 Zhigang	15:00 Anderson	14:50 Hahn	15:00 Chollet	15:00 Okamoto
	15:20 Misawa	15:10 Wu	15:20 Nishiyama	15:10 Makimura	15:20 Farsari	15:20 Kraus
15:30-16:30 **Plenary Talk** **Bäuerle** (Inv.)	15:40 Neumeister	15:30 Komatsu	15:40 Nakamura	15:30 Kobe	15:40 Strassl	15:40 Demir
	16:00 Passinger	15:50 Boehme	16:00 Noh	15:50 Guo	16:00 Miyashita	16:00 Ashkenasi
Coffee Break 16:30-17:00	Coffee Break 16:30-17:00					
4-1 17:00 **Forsman** (Inv.)	S2-2 17:00 **König** (Inv.)	11-1 17:00 Delmdahl	S2-4 17:00 **Perrie** (Inv.)	9-2 17:00 Dickmann	7-3 17:00 Stampfl	10-1 17:00 **Newaz** (Inv.)
17:30 Veiko	17:30 Gonzalo	17:20 Baek	17:30 **V. Schmidt** (Inv.)	17:20 Michalowski	17:20 Serra	17:20 Sari
17:50 Ito	17:50 Miyamoto	17:40 Cefalas	18:00 Ohmura	17:40 Naeem	17:40 Hanada	17:40 Moalem
18:10 Haglund	18:10 Zh. Wang	18:00 Sarantopoulou	18:20 Tomita	18:00 Fortunato	18:00 Guillermot	18:00 Richter
18:30-20:00 **3D-Micromac Welcome Reception**					18:30-19:00 **Closing Remarks**	
	19:00 LPM Committee Meeting		19:00 **Femtolasers** **Company Reception**		19:00 **LPM Conference Dinner**	