

Laser-Induced Backward Transfer and Laser-Induced Periodic Surface Structures: New Horizons for Visual Arts and Design

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This work explores the application of laser-induced backwards transfer (LIBT) and laser-induced periodic surface structures formation (LIPSS) methods for glass marking in the creation of artistic pieces. Pre-cut glass slabs were coated with optically gradient films of varying gray tones, subsequently augmented at the second exposure by the localized formation of periodic nanostructures exhibiting rainbow-like holographic effects. The patterns were fabricated across an array of glass slabs stacked together, further enhancing the perception of depth. The results demonstrate promising potential for recording rainbow holographic elements, including 3D illusion effects, angular dependent color shifting, and holographic depth enhancement. The developed method opens new possibilities for glass coloration both for the wide range of decorative and functional purposes.

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1. Introduction

Art and technology are becoming increasingly interconnected, opening new avenues for creative expression and innovation. Among various artistic media, glass stands up for its unique physical properties such as transparency, reflectivity, and its ability to transmit and refract light with a certain degree of spectral selectivity. These features allow both artists and civil engineers to create dynamic visual effects and transform surrounding spaces through light interaction [1-3].

The composition of the glass together with its surface design significantly influences the visual outcome, its interaction with light, and the functional characteristics of the final artistic installation. As a result, artists are increasingly interested in advanced image application techniques onto glass surfaces [4]. Reverse glass painting is one of the most peculiar classical techniques, in which artists used the glass plates as canvas. The resulting image was viewed from the opposite side through glass, so the color strokes had to be applied “from the inside out”: first the frontal details, and then the background [5-7]. In our work, we aim to revitalise this technique, giving it a new life using modern technologies.

One of the most promising methods (and a conceptual successor of reverse glass painting) is the technique of laser-induced backward transfer (LIBT), which was earlier shown to be useful for contrast marking of glass products [8-10]. In LIBT the glass surface coloration is produced by the laser evaporation of a small amount of donor metal target placed closely to the acceptor glass, so the ablated metal particles get deposited to the glass in layers of controllable thickness (Fig.1a). LIBT is known for its simplicity and high degree of control, which makes

possible the production of both monochrome and multicolor patterns on the glass surface [10-11].

In turn, laser-induced periodic surface structures (LIPSS) are the well-known phenomena of ordered ripples formation on the laser-treated material surface (e.g., thin metal film deposited to a dielectric substrate [12]). LIPSS periods can usually vary in the range of laser wavelength and less (Fig.1b), making them applicable as diffractive optical gratings, rainbow-type holograms, and optical protection marks [13]. Recently, Muira et al. have shown an experimental combination of LIBT and LIPSS approaches for glass nanostructuring [14], although the complex interplay of the physical processes in combination of these methods in currently understudied, which obstructs the patterning scalability. Earlier, we have demonstrated the simpler two-step approach, based on the finding that LIBT-deposited films are also a suitable medium for LIPSS generation [15]. Thus, the metal layer locally deposited by laser exposure can open up new functionality in the form of a color-shifting effect when illuminated with white light [13].

In recent years, both methods have attracted the attention of researchers, artists, and engineers alike, reflecting a growing intersection between scientific innovation and art creation [16]. If LIBT technology was originally used in printed electronics and nanotechnology [8-9], and LIPSS technology was used for surface modification of functional substrates [17], then their adaptation in artistic practices significantly expands creative possibilities and allows creating new visual effects that were previously unavailable by traditional approaches.

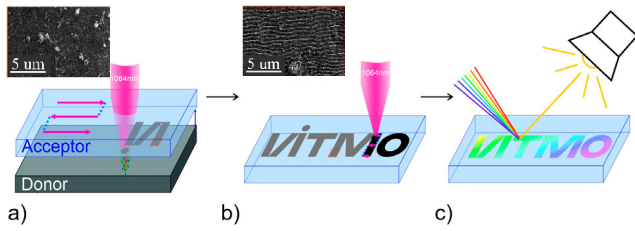


Fig. 1 (a) Film of glass using the laser-induced backward transfer (LIBT) method using a metal plate as a donor material. (b) The formation of laser induced periodic surface structures (LIPSS) on the transferred film during repeated laser exposure. (c) The color response when the formed grid is illuminated with white light. The insets show SEM images of the corresponding films [15].

The purpose of this study is to explore the use of LIBT and LIPSS methods to create novel visual effects in glass-based artworks. This paper shows experimental techniques for creating unique visual effects and structural patterns using LIBT and LIPSS methods on glass surfaces.

2. Methods and materials

The study used a MiniMarker-2 laser installation (Laser Center LLC, Russia) based on a MOPA fiber nanosecond laser source (VPG Laserone, Russia) with maximum average power (P) of 20 W, wavelength (λ) of 1064 nm, pulse repetition rate f from 20 to 99 kHz, scanning speed V from 0.1 to 8000 mm/s, and pulse duration τ from 4 to 200 ns for performing both the LIBT and LIPSS techniques. The polarization of the radiation was controlled by means of a previously developed module [18], consisting of a Glan-Taylor prism and a half-wave plate embedded in the optical path of the laser system between the collimator and the system of galvanometric scanners. To focus the radiation on the samples, a flat-field lens with a focal length of 216 mm was used, the field size was 100x100 mm, and laser spot diameter about 55 μm . The average power of the laser radiation after the lens was controlled using the Gentec Electro-Optics SOLO2 power meter.

Grade 2 pure titanium plates (10 mm x 10 mm x 2 mm) were used as a donor for LIBT. Titanium samples were used as obtained. Levenhuk Discovery 50 borosilicate glass (Levenhuk, China) with a thickness of 1 mm served as the acceptor of the material. Original 75 mm x 25 mm x 1 mm glass slabs were cut into even 25 mm x 25 mm x 1 mm pieces by laser scribing technique using the auxiliary CO₂ laser setup "C-Marker" (Laser Center LLC, Russia).

Parameters for LIBT-based creation of grayscale films were found experimentally (see in the Results and Discussion section below), while regimes for LIPSS formation were known beforehand from our previous research [15]. LIBT was performed without any additional spacer between donor and acceptor samples, so the air gap was about 10 μm consisting of initial surface roughness values of glass and metal. Parameters for LIPSS formation were set as follows: $P = 85 \text{ mW}$, $V = 1 \text{ mm/s}$, $f = 40 \text{ kHz}$, τ

$= 4 \text{ ns}$, line spacing L_y were calculated using the following relationship (1) and equals 60%.

$$L_y = \left(1 - \frac{1}{N \cdot d}\right) \cdot 100\%, \quad (1)$$

where $N = 50 \text{ lines/mm}$ - spatial resolution, $d = 50 \mu\text{m}$ - beam diameter, L_y - overlap coefficient in the Y-direction.

An illustration of the method is shown in Fig. 1. Optical images of the paintings created were obtained using a Carl Zeiss Axio Imager A1m optical microscope. MSFU-K microscope-spectrophotometer (Lomo, Russia) was used to study the spectral properties of the samples. The Bambu Lab P1S 3D printer (Bambu Lab, Shenzhen, China) was used in the assembly of the final art piece.

3. Results and Discussion

Combining LIBT and LIPSS methods, we created a series of images distributed across an array of glass plates. The collage we produced was used as the image to be recreated on the glass surface, as shown in the Fig. 2.

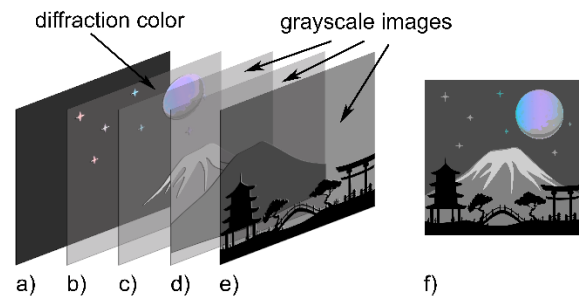


Fig 2 a)-e) Diagram of the arrangement of images on glass plates created by LIBT and LIPSS methods f) The final image when combining layers, a)-e), front view. During LIBT processing, the following parameters remained constant: $f = 60 \text{ kHz}$, L_y about 70 %, and $\tau = 100 \text{ ns}$. Specific settings used to produce images (a), (d), and (e) were as follows: a) $P = 5.62 \text{ W}$, $V = 385 \text{ mm/s}$; d) $P = 5.62 \text{ W}$, $V = 200 \text{ mm/s}$; e) $P = 6.6 \text{ W}$, $V = 30 \text{ mm/s}$.

In order to create solid shapes, the LIBT method was used to obtain grayscale films. The color contrast was controlled through the adjustment of laser parameters, specifically the power and scanning speed of the laser beam during film deposition. A reference palette was developed based on a matrix of LIBT parameters (Fig. 3a), which served to guide the selection of contrast levels and grayscale tones for the final image. The patterned matrix surface consists of multiple $4 \text{ mm} \times 4 \text{ mm}$ deposition zones. Each region was re-exposed during LIPSS parameter optimization, resulting in a subarray of $0.5 \text{ mm} \times 0.5 \text{ mm}$ regions. The resulting processed sub-surface exhibited controlled variation in the optical and morphological characteristics of the film, depending on the laser parameters (Fig. 3b and 3c).

Fig. 4 shows the transmission spectra of laser-transferred films produced at a fixed power of 4.71 W, with scanning speeds ranging from 10 to 360 mm/s. The results demonstrate a systematic increase in transmittance with scanning speed, indicating a decrease in film thickness and optical density. At the lowest scanning speed (10 mm/s), transmittance drops below 1%, corresponding to a dense and optically opaque film. In contrast, at the highest speed (360 mm/s), transmittance reaches approximately 85%, producing a nearly transparent film. Transmittance spectra remain neutral in the whole visible bandwidth (400–800 nm), which makes it possible to observe a visual difference in contrast.

Diffraction colors seen on Fig.2b were created by applying additional LIPSS structuring to the transferred film. For this, direct laser recording was repeated in LIPSS formation regimes. Image on Fig.2c was created by bleaching the already formed film at second exposure, which made it possible to highlight it against the background of other patterns. Figure 5 demonstrates the films formed on glass, revealing controlled optical contrast through laser parameter variation. In Figure 5a, the foreground appears distinctly darker due to a higher optical density film, blocking most transmitted light. Figure 5b depicts a snow-capped mountain image, where the white snow contrasts sharply against the dark background; micrographs in both reflected and transmitted light modes (insets) confirm the low optical density of this film. Figure 5c shows a moon and stars with iridescent colors, arising from periodic nanostructures visible in the 5- μm scale micrograph inset; these structures induce angle-dependent color-shifting effects. The systematic transition from opaque (a) to translucent (b) and structurally colored (c) regions confirms precise contrast tuning via laser processing parameters (see Table 1 for detailed parameter correlations). The periodicity of the relief is 0.67 ± 0.12 , which is consistent with the previously obtained results within the margin of error [15].

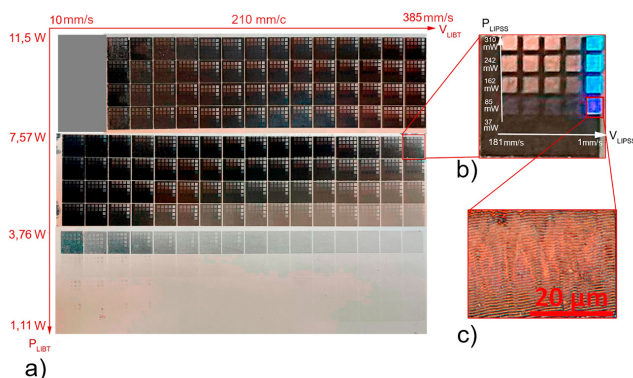


Fig. 3 (a) The matrix of LIBT parameters for obtaining different shades on glass using titanium as a donor material. (b) Selected regimes for LIPSS formation on the semi-transparent film. (c) Optical image of LIPSS obtained.

Table 1 Laser exposure parameters for the formation of images (b) and (c) from Fig. 2.

Parameters	“Sky” layer (Fig 2b)	“Snow” layer (Fig 2c)
P W	4.41	0.085
V mm/s	181	1
f kHz	60	40
τ ns	100	4

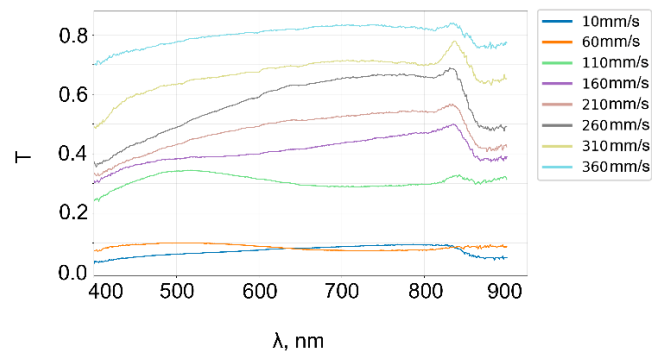


Fig. 4 Transmittance of laser-transferred films as a function of scanning speed at fixed power (4.71 W).

We have previously shown [13] the installation scheme, where to study the diffraction effect, the sample was illuminated with white light and rotated in azimuth (θ) to a fixed polar illumination angle ϕ as shown at (Fig. 6). So, due to the change in the viewing azimuthal angle, the color of the observed structured image also changed, as shown in Fig. 7. After recording all the images, the glasses were assembled into a 3D printed box (Fig. 8), in which, due to the thickness of the glass, the effect of depth and parallax was visually created, where objects closer to the observer moved more strongly relative to the background when the viewing angle changed. Thus, by combining LIPSS and LIBT methods, it turned out to create a product with a set of unique visual properties, which can be used in the fields of art installations and become a new way of self-expression for artists.

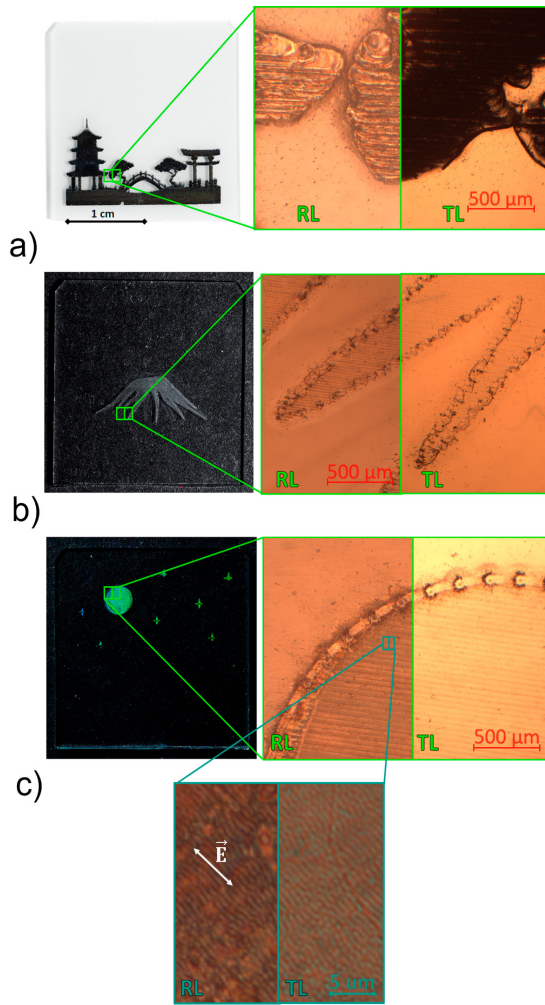


Fig. 5 a)-c) Photograph of the formed image on glass with inset micrographs in reflected and transmitted light.

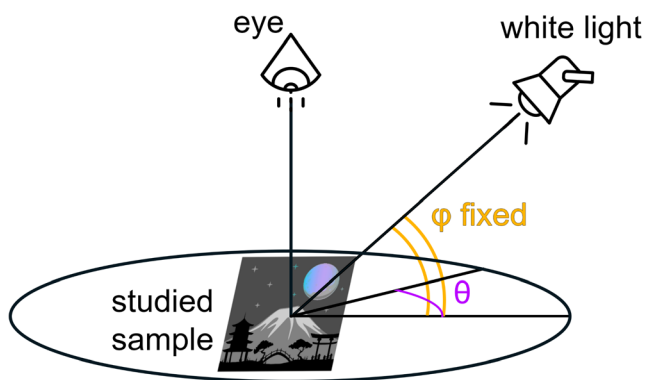


Fig. 6 Installation diagram for capturing diffraction color changes.

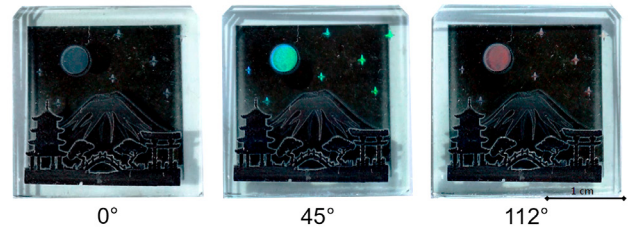


Fig.7 The photo of the product is a front view, the angle of illumination relative to the object is signed from below. At an angle of $\theta=0^\circ$, no color response is observed, while at angles of $\theta=45^\circ$ and $\theta=112^\circ$, the blue and red colors of the structured areas are visible.

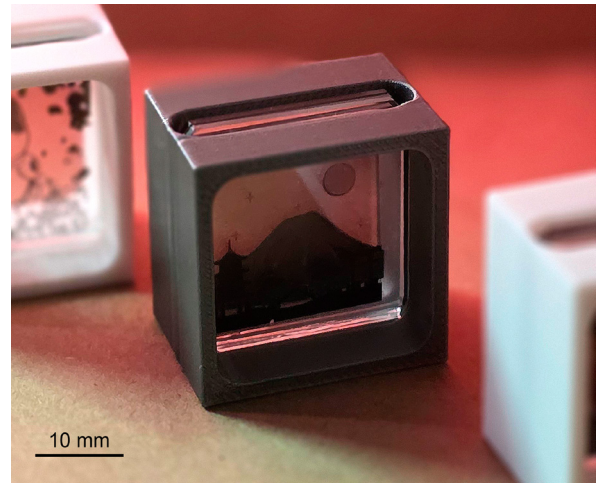


Fig. 8 Final appearance of the assembled optical artwork. The spatial configuration of layered glass plates creates a parallax and depth effect, integrated into a compact display form.

4. Conclusions

This paper demonstrates a novel approach to artistic glass processing using modern laser technologies - laser induced backward transfer (LIBT) and the formation of laser-induced periodic surface structures (LIPSS). Combining the LIBT and LIPSS methods made it possible to create visual effects on glass: from 3D illusions produced by glass layering to rainbow-like holograms features.

It has been experimentally demonstrated that adjusting the parameters of laser processing allows to effectively control the image contrast, grayscale tones, and optical transmittance, which can be tuned from 1% to 85%. In addition, due to the spatial separation of individual layers, it was possible not only to achieve the appearance of diffraction colors, but also enhance the depth perception.

The results obtained open up prospects for the creation of unique art objects, interior and facade solutions, providing new means of self-expression for artists and civil engineers.

The integration of laser technologies into art is shown to significantly expand the possibilities of artists and designers, allowing them to implement visual effects previously unavailable by traditional methods.

Acknowledgments and Appendixes

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