Technical Communication

Scanned Mask Imaging Solid State Laser Tool for Cost Effective Flip Chip – Chip Scale Package Manufacture

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The IC packaging industry is now being driven by mobile devices, a market where cost and size are key. Going to finer line widths and spacings allows a reduction in the number of layers making up a multilayer chip package, giving a reduction in the cost and height profile of the device, as well as improved signal latency. Embedding conductors within a dielectric film makes it possible to plate to the required thickness without lateral growth of the traces. Using an ablative laser process to do this avoids the financial and environmental costs of lithographic processes. A method for the 3D structuring of dielectric films with pads, traces and vias with a resolution down to 2µm is described. The set up uses a frequency tripled solid state laser to raster scan a binary mask, which is subsequently imaged onto a substrate with a maximum image field of 20x20mm. This offers performance and cost advantages over alternative methods.

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1. Introduction

The semiconductor industry continues to meet the targets set by International Technology Roadmap for Semiconductors (ITRS) [1]. The targets follow Moore's law, which predicts that the number of transistors on a chip will double every 2 years. With feature sizes down to 22 nm on commercially available Integrated Circuits (ICs), the feature density on these semiconductor devices is rapidly increasing. For a given circuit design, the pitch of the input and output (I/O) connection pads must therefore decrease resulting in a higher I/O density. On top of this, Shannon's law of circuit complexity [2] predicts that circuit architecture complexity increases at a faster rate than the transistor number predicted by Moore's law. In combination with Rent's Rule [3], which describes a power law relationship between the number of I/Os on a circuit and the circuit complexity, these devices require increasingly higher density interconnects [4]. There is a need for increasingly more complex interconnections with more input/outputs at finer pitches with improved signal integrity and reduced signal latency, all at reduced costs. This has driven research into alternative manufacturing technologies that might bridge the interconnection gap between sub-micron scale ICs and millimetre scale Printed Circuit Boards (PCBs).

For economic reasons, the IC packaging industry has preferred to incrementally advance photolithographic PCB manufacturing technologies to date, and these are now reaching their limits for cost effective IC package manufacture [5]. The vias which link the layers in the multilayer packages are laser drilled prior to the multistep, lithographic processes used to form conductive pathways on the surface of substrates. As well as being a multistep process, this has the additional disadvantage of requiring accurate registration of the features in the two process steps, typically resulting in capture pads which are twice as large as the vias they capture. By micromachining the vias in the same process step as the capture pads, the registration of the two features can be as accurate as ±1µm. Having nearly landless microvias gives significantly more routing space per layer, reducing the number of layers required which reduces both cost and signal latency.

Ablating features into a dielectric and subsequently plating within these features to embed the conductor improves adhesion of small traces and reduces the chance of copper bridging in the plating process, improving yield. The dielectric also confines the plating to the feature, meaning the trace can be plated to the required conductor thickness without any lateral growth of the conductor.

Given the multitude of advantages presented by ablative laser processes in patterning dielectrics for advanced packaging applications, this paper briefly discusses some of the existing technologies for fine scale ablation of dielectrics. M-Solv's patented Scanned Mask Imaging (SMI) technology [6] is then introduced as a novel alternative, which combines the benefits of multiple competing technologies.

2. Current ablative laser technologies

Two ablative laser processes are the most obvious contenders to be used to structure dielectrics for advanced package applications: excimer laser mask projection tools and frequency tripled solid state laser direct write tools [7]. Both systems use light in the ultraviolet region which improves imaging resolution in the former, and the minimum focal spot size in the latter. The high energy photons from both lasers are strongly absorbed in the electron absorption bands of many polymers, resulting in absorption lengths typically shorter than a few microns. This reduces the fluence required for ablation, and limits the size of the heat affected zone.

2.1 Excimer laser processing

Excimer lasers offer the highest average power in the ultraviolet region. Since throughput of a micromachining tool scales approximately with average power reaching the substrate, excimer laser systems can offer high throughput. In an industrial environment, KrF and XeCl lasers emitting radiation at 248nm and 308nm respectively offer the best value in terms of cost per watt. However, the cost of ownership of excimer laser systems remains high compared to solid state lasers due to the short lifetime of electrical components and optics, and the infrastructure needed to handle the gases used.

Excimer lasers produce a highly multimode beam ideal for imaging. In micromachining applications, average powers of a few hundred watts are achievable with repetition rates of a few hundred hertz, giving pulse energies up to around one joule. A typical system is comprised of beam shaping and homogenizing optics used to illuminate a mask which is subsequently imaged onto the substrate by a projection lens. This approach can achieve feature resolutions down to a few microns, with good depth uniformity and depth control. The etch rate of the many polymer films at 1 J cm^{-2} is of the order of 1μm per shot. Lowering the fluence enables better depth control, but typically results in more tapered side walls in the ablation. Excimer systems have a process time independent of the pattern complexity, which makes them ideal for the high density routing layers required in the next generation of advanced chip packages.

2.2 Frequency tripled solid state laser processing

Frequency tripled solid state lasers offer a lower cost solution. Comparatively, they have much lower maintenance costs and a lower purchase cost per watt of laser power. They can have comparatively good beam quality, with M^2 values close to 1, making them ideal for focusing to a small spot. Such systems are typically comprised of a pulsed or quasi-CW laser, beam expander, galvanometer scan head to deflect the beam across the substrate and an f-theta scan lens such that the beam remains in focus across the field of the scanner.

In this approach the pattern is defined by a CAD/CAM file offering more flexibility than mask projection systems, and fast on the fly changes to circuit design. Also, it does not suffer from printed in defects: errors defined by a defect in the mask which are repeated in every device. In an ablative process, the feature resolution is defined largely by the size of the focal spot, the laser-material interaction and the beam speed across the substrate. The best feature resolution achievable is therefore dependent on a number of factors but is of the order of 10μm line width and space [8].

Flexibility in circuit design makes these systems ideal for low volume prototyping [9], however they are limited by process times dependent on pattern complexity, design rules to keep beam velocity constant across the substrate and some limitations in the features they can process. Complicated control systems can be used to overcome some of these issues, however it remains challenging and time inefficient to ablate large features to a uniform depth by overlapping scribes made by a focal spot size much smaller than the feature size. These systems are therefore not usually suited to high volume production in advanced packaging applications where high densities and complex pattern designs with large ground plane regions are a requisite.

3. Scanned mask imaging solid state laser optics

The SMI process uses a frequency tripled, Q-switched, multimode, solid state laser. Commercial models can have average powers of up to 180W in a single cavity, with typical pulse lengths of tens to hundreds of nanoseconds. Manufacturers optimize the cavity for use at a particular repetition rate, often around 10kHz. This leads to pulse energies in the millijoule regime, so clearly to obtain the same fluence as an excimer laser process, a much smaller spot is required. M-Solv's solution is to raster scan a smaller beam with a flat top profile across a binary mask, which is subsequently imaged onto the substrate. This gives imaging resolution and throughput similar to that of an excimer system, with the much lower cost of ownership of a solid state laser tool.

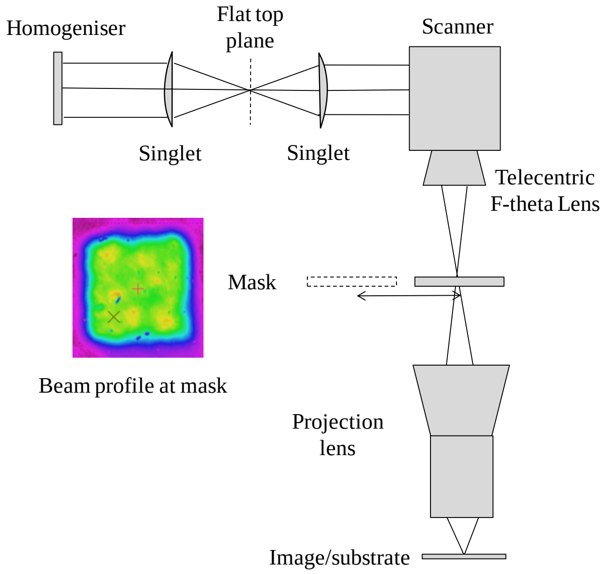

Fig. 1 System schematic of M-Solv's scanned mask imaging technology.

A schematic of the optical system used for SMI can be seen in Fig. 1. The laser beam is expanded using a Keplerian telescope prior to the homogenizer. The beam is then passed through the homogenizing element, which forms a square, flat top plane at the beam waist of a plano-convex singlet. The homogenous plane formed is then imaged onto the mask using an infinity imaging system consisting of a second singlet and an f-theta scan lens, which is mounted to the scanner. The divergence of the beam after the beam waist at the mask is defined by the homogenizer, the first singlet and the lenses in the infinity imaging system.

Care must be taken to design the system such that the aperture of the scanner and the entrance pupil of the f-theta lens are not overfilled, but that the divergence at the mask is high enough to obtain the desired numerical aperture on the object side of the projection lens to maximize the lens resolution.

The spot size at the mask should be such that the fluence is below the damage threshold of the binary mask. The results presented in the following section were obtained using a chrome on quartz mask, and the damage threshold was assumed to be similar to the excimer laser damage threshold: 100 mJ cm^{-2} [10]. The magnification of the projection lens should be selected to give the desired fluence at the substrate. A demagnification of 3.5 was chosen for the current lens, offering a good compromise between high resolution and fluence at the substrate, whilst limiting the mask size. The mask is then imaged onto the substrate by the projection lens.

By using a telecentric f-theta lens, light is incident approximately normal to the mask, limiting the size of the first lens element required in the projection lens. An advantage of using a galvanometer scan head to deflect the beam across the mask is that there is complete flexibility in how the mask is raster scanned. This allows some control over the time between consecutive shots on a given part of the substrate, which can affect the thermal loading of the substrate and the size of heat affected zones.

Illuminating the mask with a flat top, homogenous beam offers several advantages over the approximately Gaussian multimode beam profile from the laser. It lowers the peak fluence of the beam, reducing the risk of damaging the mask, as well as reducing the percentage of the beam with a fluence below the ablation threshold of the substrate. It also reduces the coherence length of the beam which is beneficial for imaging as it avoids the appearance of diffraction fringes at the edge of ablated features in the substrate [11]. The beam profile at the mask can be seen in fig. 1.

By mounting the mask on a stage, it is possible to precisely overlay two images at the substrate to create 3D structures in the material. This enables the drilling of microvias in the same process step as the patterning of the routing layer, facilitating landless pads. The accuracy of the registration of the two images is dependent on the mask alignment to the mask stage, the accuracy of the stage itself and the magnification of the imaging system, with registrations better than ±5µm at the substrate easily achievable.

4. Scanned mask imaging results

In these preliminary studies, the laser ablation of Kapton® (a polyimide film by DuPont™), and Ultimax™ (a dry film by Taiyo Ink) on a copper clad laminate, were investigated. The Ultimax™ material is designed specifically as a build up material for flip chip applications. The spot size at the mask was measured using a CCD beam profiler. The power was then measured using a thermopile power meter at a range of frequencies and the frequency tuned to obtain a fluence of 79±3 mJ cm^{-2} at the mask. With a lens demagnification of 3.5, this gives a fluence of 0.97±0.04 J cm^{-2} at the substrate. Increasing numbers of shots were fired at different sites on each substrate to determine the etch rate at the specified fluence.

The depth of the ablated crater was measured using a white light interferometer. The error in the depth measurements of the Ultimax™ substrate are significantly greater due to an approximately 2µm peak to trough periodic variation in the height of the film propagated from the glass fibre weave in the laminate. The results are shown in fig. 2, and the etch rates determined to be 0.50±0.01 µm/shot and 0.78±0.04 µm/shot for Kapton® and Ultimax™ respectively.

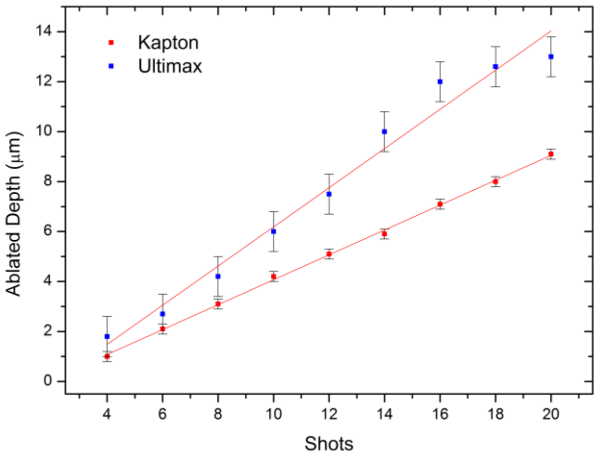

Fig. 2 Graph showing the etch rate of Kapton® and Ultimax™ with a fluence of 0.97±0.04 J cm^{-2} in the SMI system.

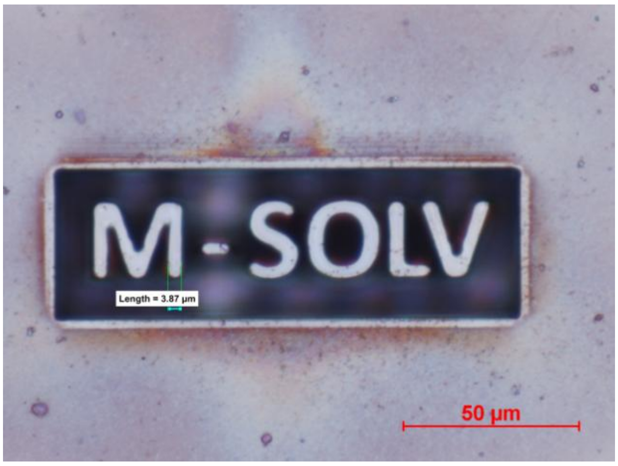

Fig. 3 Optical microscope image of the word "M-Solv" ablated into Kapton® using the SMI process. The minimum line width is 4±1µm.

Fig. 3 shows an optical microscope (OM) image of the word "M-Solv" ablated into Kapton® where the widths of the lines making up the characters are 4±1µm. The mask was raster scanned with a mark speed and pitch such that each area received 25 shots, which gave an ablated depth of 10±2 µm.

Fig. 4 shows an OM image and SEM micrograph of a resolution chart ablated into Kapton® using the 25 shots per area mask scan, demonstrating the resolution of the SMI system. The chart includes a 1 µm feature at the substrate which is not fully resolved by the projection lens. The first set of 3 lines visible in the figure is 2 µm lines separated by 2 µm at the edge of the lenses resolution limit. This resolution is similar to that obtained with commercially available ablative excimer laser systems. These lines are followed by sets of 3 lines with line widths and spacings of 3 µm, 4 µm, 5 µm, 10 µm and 15 µm.

The 3D structures in fig. 5 were micromachined to two different depths by overlaying the image of two areas on the mask. The image shows an 80 µm via machined down to the copper clad laminate, and a capture pad and 16 µm traces machined only part way through the Ultimax™ dielectric film. The features in the image are well registered with each other, highlighting the possibility of shrinking the capture pad to create more routing space in a layer.

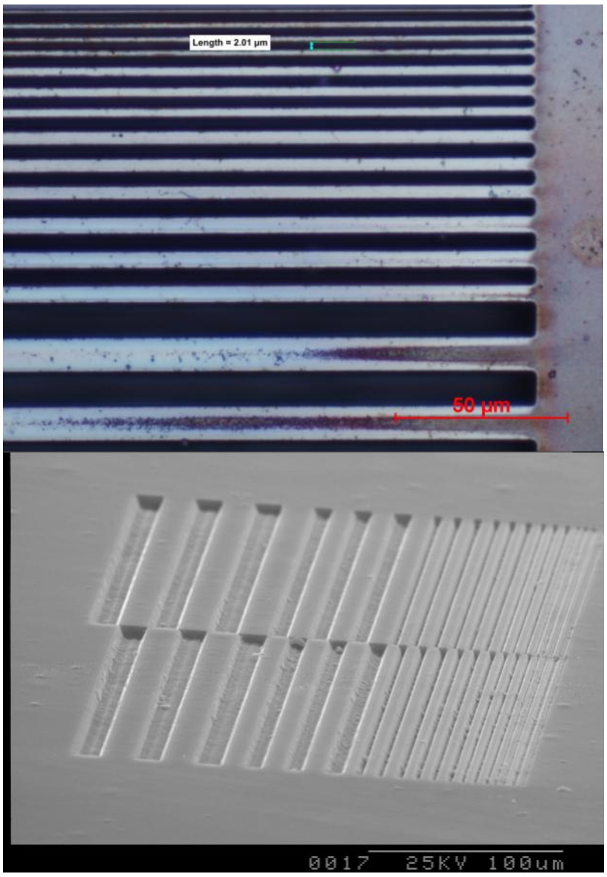

Fig. 4 OM photograph and SEM micrograph of resolution chart ablated into Kapton® using the SMI optical system with minimum line widths and spacings of 2 µm.

5. Summary

Embedding conductors within a dielectric confines the conductor when plating, enabling finer feature resolutions. Ablative laser processes can be used to structure dielectrics, reducing the number of manufacturing steps compared to photolithographic processes. They also allow vias to be machined in the same process step as the routing layer, significantly reducing the minimum size of the capture pads increasing the space available for signal routing. This, in combination with smaller signal pathways, reduces the number of routing layers required in an advanced chip package, which reduces the cost and height profile of the package whilst improving the signal latency and integrity.

Frequency tripled, direct write, ablative solid state laser systems have process times dependent on pattern complexity and therefore are not ideally suited to high volume manufacture of dense patterns comprised of complex and varied features. Excimer laser systems can achieve a high throughput at the required feature resolutions, however have a higher cost of ownership than solid state laser systems.

The SMI optical system was introduced as an alternative to the above technologies offering a high throughput, high resolution, solid state laser mask imaging system. The results of the imaging system were presented and feature sizes down to 2 µm line width and spacing were demonstrated in commercially available thin films currently used in the electronics industry. Excellent registration of vias to pads was achieved, facilitating near landless pads and creating additional routing space. This SMI technology represents a highly cost effective solution to the demanding requirements of the advanced packaging industry with estimated cost of ownership less than half that of an excimer laser based system.

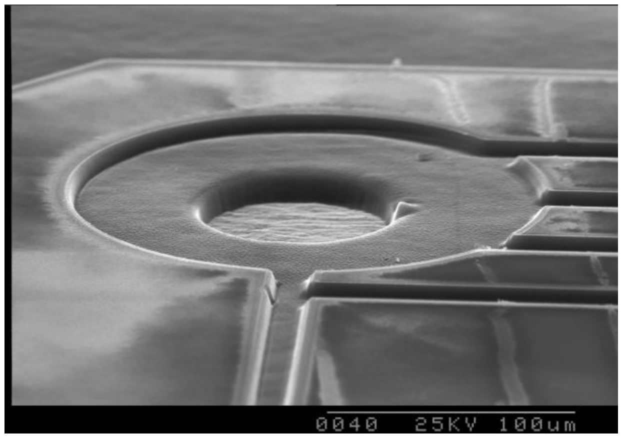

Fig. 5 SEM micrograph of an 80 µm via machined through the 20 µm Ultimax™ film to the copper clad laminate beneath. The image also shows the capture pad, 16µm signal traces and a large uniform ground plane machined 8 µm deep in the film and well registered to the via.

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