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Laser Drilling of High-Density Through Glass Vias (TGVs) for 2.5D and 3D Packaging

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Abstract: Thin glass (< 100 microns) is a promising material from which advanced interposers for high density electrical interconnects for 2.5D chip packaging can be produced. But thin glass is extremely brittle, so mechanical micromachining to create through glass vias (TGVs) is particularly challenging. In this article we show how laser processing using deep UV excimer lasers at a wavelength of 193 nm provides a viable solution capable of drilling dense patterns of TGVs with high hole counts. Based on mask illumination, this method supports parallel drilling of up over 1,000 through vias in 30 to 100 μm thin glass sheets. (We also briefly discuss that ultrafast lasers are an excellent alternative for laser drilling of TGVs at lower pattern densities.) We present data showing that this process can deliver the requisite hole quality and can readily achieve future-proof TGV diameters as small 10 μm together with a corresponding reduction in pitch size.

Keywords: TGVs, laser drilling, advanced packaging, glass interposers, excimers

1. Why Glass Interposers?

The demand for ever higher functionality in small consumer electronics is pushing the microelectronics industry to use new packaging strategies – 2.5D and 3D. Moreover, these advanced packages enable high-value logic chips at the current node to be combined with memory and lower density logic in a more economical manner than monolithic devices. In turn, this is driving the development of thin (~ 100 μm) interposers that are needed as critical elements for both 2.5D and 3D chip packages. An interposer is a rigid insulator layer that acts as an interface between the high density I/O of the various logic and memory dies and the lower density substrate (see figure 1). Plus, in some 3D packages, this layer can be thicker to serve as both interposer and a structural package element. High density conductive microvias must be formed in the interposer to connect traces and pads on the top and bottom surfaces.

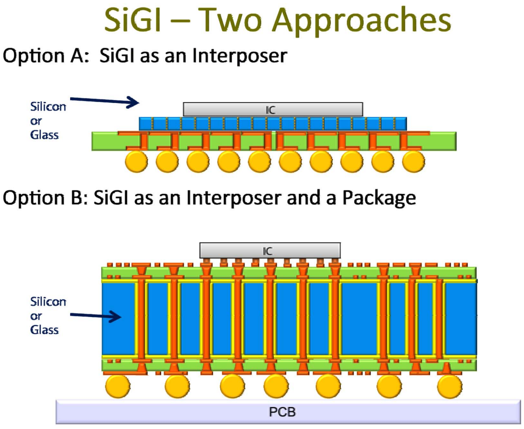

Fig. 1. Glass (or silicon) can be used as just an interposer or as both an interposer and part of the package. Image courtesy of Dr. Venky Sundaram, Georgia Tech, PRC.

Several materials have already been considered for interposers including glass, silicon, and organic laminates. Glass has several very attractive properties for use as interposers, including:

- Good dimensional stability
- Coefficient of thermal expansion matching to silicon
- Low insertion loss
- High electrical resistivity (10^{12}-10^{16} Ω-cm)
- High thermal stability (>500°C)
- Optically transparent for integrated photonic chips

Furthermore, thin (100 μm) glass can be produced economically in large area (up to several meters) panels with very uniform thickness[1)], whereas silicon must be thinned (by time-consuming grinding) and laminates must be assembled in a multi-stage process. In addition, organics cannot match the dimensional stability of glass and suffer from low

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thermal conductivity, poor dimensional stability and lithography limitations.[2)] Additionally, silicon's other obvious drawbacks are higher cost and higher electrical losses compared to glass.

2. The Challenges of Drilling High Density TGVs

It is recognized that a key hurdle to the widespread adoption of glass interposers is the challenge of drilling high density vias with the requisite cost and yields in a material that is too brittle and fragile at these thicknesses and sizes to support high-throughput mechanical handling and processing. There are five technologies that have been considered for drilling these "through glass vias" (TGVs) in interposers[3, 4)]:

- chemical wet etching
- dry etching
- sand blasting
- ultra sound drilling
- laser ablation

The laser is already a preferred mature tool for micromachining in numerous aspects of microelectronics manufacturing and packaging because it offers substantial advantages over alternative technologies. In particular, its non-contact nature and scalable output power enables the production of small, high precision features on a wide variety of materials.[5, 6, 7)]

2.1. Why Excimer Lasers?

Laser drilling requires that the target material efficiently absorbs the laser power, but glass is transparent at visible wavelengths. This dictates the use of infrared or deep ultraviolet laser light. Infrared lasers, such as the carbon dioxide (CO_2) laser, remove material by intense local heating leading to melting and vaporization of the target material. Plus, their long wavelength (10.6 μm) limits their spatial resolution because of diffraction; the smallest feature that can be machined with a laser scales with its wavelength. These two factors mean that infrared lasers are not the optimum choice for producing microvias in glass.

In contrast, deep-ultraviolet lasers can be focused to extremely small dimensions (hence its use in microlithography). And, they are well-suited to drilling small holes in glass because deep UV has a low penetration depth in the material, meaning there is little peripheral damage. Plus, shorter wavelength, deep-ultraviolet light can be focused to a given spot size with a greater depth of focus than longer wavelengths. Most important of all, these high energy UV photons vaporize target material in a relatively cold process called photoablation which directly breaks the atomic bonds in the material. So holes can be drilled with excellent quality, including sidewalls perfect for metallization, and without producing microcracking and re-cast (melted) debris.

Coherent offers the broadest choice of ultraviolet laser types (excimer, DPSS, and ultrafast) of any laser manufacturer. The optimum choice of ultraviolet laser depends on the specifics of the TGV hole pattern to be drilled. Glass interposers will most commonly require a dense two-dimensional pattern of through vias created at a high throughput rate. This requirement is best met by the excimer laser.

The excimer laser is by far the most powerful laser offering deep ultraviolet output; in laser material processing, power translates directly into throughput. The excimer is an industry-proven, 24/7 workhorse, both at lower levels for microlithography of ICs, and at kilowatt power levels for low temperature annealing of polysilicon (LTPS), which is the de-facto standard for recrystallizing silicon in flat panel displays. Excimers are available with a range of different powers and wavelengths. For high density TGV drilling, the authors believe the optimum excimer is one with a high pulse energy (> 500 millijoules/pulse) at the short UV wavelength of 193 nm. (Longer wavelengths would not produce the clean drilling results as at 193 nm.) The excimer output beam has a large rectangular cross-section which is ideal for use with a mask to create many holes simultaneously in an extended field of projected laser light. A high pulse energy enables a larger field to be irradiated above the threshold intensity for glass ablation, increasing throughput. This combination makes the excimer laser ideally suited for massive parallel drilling of many holes which is very advantageous in applications needing a high density of small high quality holes. For lower density hole patterns, the picosecond laser is often an excellent option – see side-bar.

2.2. Successful TGV Drilling

In the studies described here, we test drilled numerous different glass samples comprising several different thin borosilicate glass wafers and several different alkali-free flat glass wafers, with thicknesses of 100, 50 and 30 μm. We used a 193 nm excimer (Coherent LPXpro 305) with a pulse energy of 600 millijoules. As shown schematically in figure 2, we used a mask projection system capable of generating laser energy densities of more than 10 J/cm^2 at the sample surface and field sizes of up to 1 mm^2. The mask was fabricated to create a square symmetric array of TGV holes with a nominal hole diameter of 25 microns and a pitch of

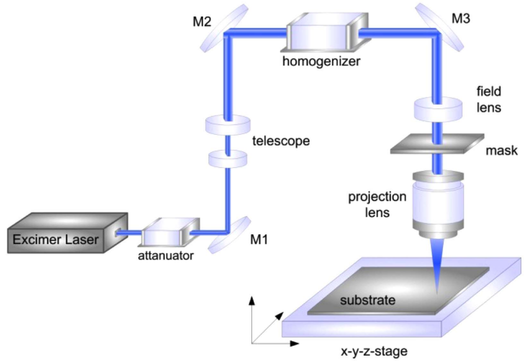

Fig. 2. Sketch of excimer laser mask projection setup for parallel drilling through vias in thin glass.

50 microns at the 1 mm^2 field size.

2.2.1. TGV quality independent of glass type

We found that although the minimum number of required pulses for through drilling varied between the different glass types, the hole shape, size, and quality were virtually the same in all cases. This can be seen in figures 3 and 4 that show microscope images for a 100 μm borosilicate sample and a 100 μm alkali-free glass sample, respectively. (700 pulses total pulses were used in both cases). These typical results show that in both glass types, clean holes are produced with no micro-cracking, and smooth sidewalls that are ideal for subsequent metallization.

2.2.2. Double-sided drilling

As can be seen figures 3 and 4, relatively large taper angles between entrance and exit holes are typically obtained in 193 nm excimer laser via drilling using 100 μm glass samples. (This natural depth of focus effect is reduced in the 50 and 30 μm thickness samples, as expected.) We found that the taper angle can be partially reduced in the 100 μm glass samples by employing higher fluences of above 10 J/cm^2. Careful optimization of the process parameter enables to balance the trade off between drilling speed, taper angle and micro-crack free quality holes. For glass thickness of above 100 μm we successfully demonstrated a double-sided drilling method that gives control on the entrance and exit hole diameter and the resulting taper angle. Figure 5 shows some typical results from this method using 350 pulses from the front followed by 350 pulses from the reverse side, at the same optimum 7 J/cm^2 fluence used for the samples in figures 3 and 4. The sample is from a 100 μm thick alkali-free wafer. Clearly the taper issue is greatly reduced and we believe it could be even further eliminated by careful process optimization.

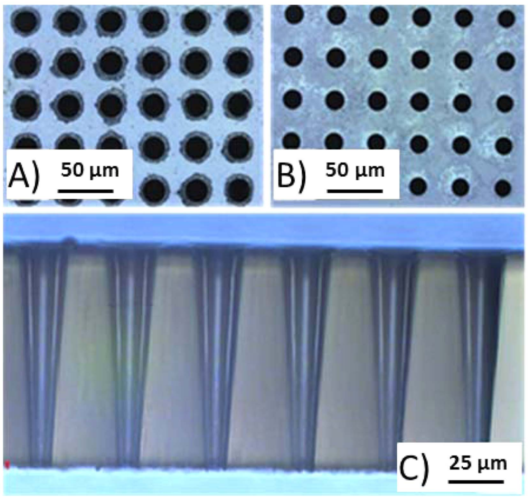

Fig. 3. 25 μm size vias drilled in 100 micron thin borosilicate glass. Entrance side (A), exit side (B) and side view (C). 700 pulses total.

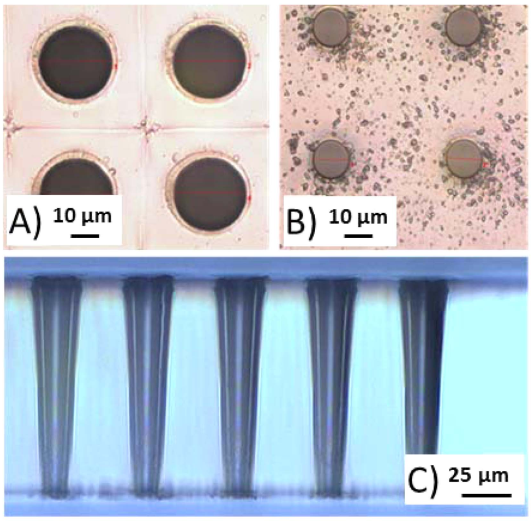

Fig. 4. 25 μm size vias obtained in alkali-free glass. Entrance side (A), exit side (B) and side view (C). 700 pulses total.

2.2.3. High drilling speeds

For all the glass types, we found that 700 total pulses were always sufficient to drill completely through the entire sample thickness, even at a thickness of 100 μm. After obtaining the above data on hole quality and shape using a

Fig. 5. Side view of through via holes in 100 μm glass obtained with an equal number of pulses from both sides.

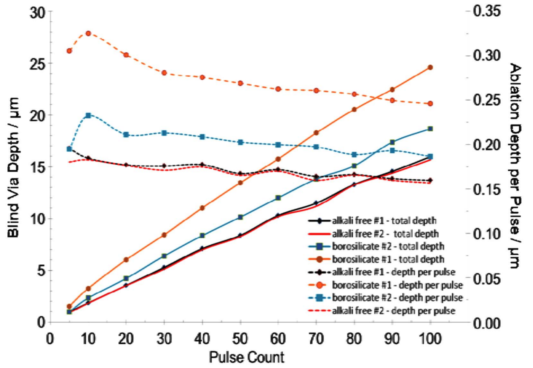

Fig. 6. Via depth and depth per pulse in four different glass types measured at 193 nm and 7 J/cm^2.

fixed 700 total pulses, we conducted a comprehensive series of tests on all the different glass samples, to determine how much material is actually removed by each pulse. From these measured ablation rates, we can calculate the minimum number of pulses required for through drilling based on glass type and sample thickness. This in turn allows us to calculate process speed for each sample.

Specifically, for each glass specimen, blind vias of up to 25 μm depth were mask projection drilled at a fluence of 7 J/cm^2. A laser scanning microscope (Keyence VK-X210) was used to determine the achieved depth from the mean value of a row of five blind vias drilled simultaneously with varying pulse counts. The resulting graphs for blind via depths and calculated ablation depth per pulse are shown in figure 6 for two types of borosilicate glass and two different types of alkali-free glass samples.

These typical data show the ablation rate decreases vary slightly as the hole gets deeper in all the samples, as is typical for laser micromachining of glass. They also clearly show that the ablation rates for borosilicate glasses are much higher than for alkali-free glasses and vary significantly between specific glass types, with an average for the fastest type of 0.28 μm per pulse. In contrast, the alkali-free glass samples all show almost identical ablation behavior ranging only from 0.18 to 0.15 μm per pulse.

What does this mean for TGV process speed? These test data were all obtained using slow pulse repetition frequencies between 1 and 25 Hz, to enable data analysis down to the single pulse level. In contrast, production would be expected to use higher frequency industrial excimer lasers, delivering a total drilling time for through vias in 50 μm micron interposers of less than 1 second per field at a laser pulsing rate of 300 Hz leading to 1000 holes / sec if a pitch of 50 μm is considered.

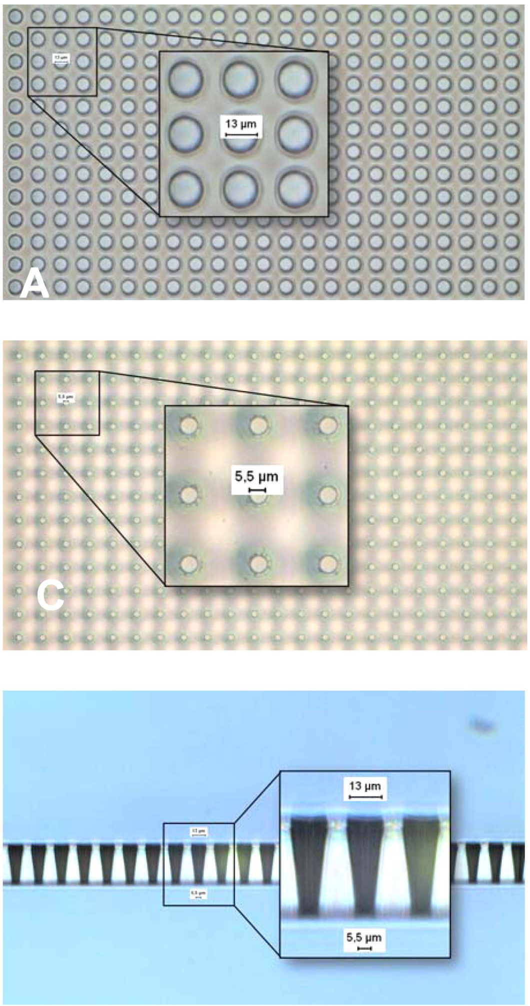

Fig. 7. 10 μm diameter vias drilled in 30 micron thin alkali-free glass. Entrance side (A), exit side (B) and side view (C). 230 pulses total.

2.2.4. Thinner interposers, smaller TGVs, and higher pitch.

Looking to the future, the drive to keep pace with Moore's Law and satisfy feature-hungry consumers means that we can expect some combination of thinner interposers, smaller diameters TGVs and higher pitch (hole density), or probably all three. To study the potential impact of such advances on the process outlined here, we drilled holes with a 10 μm on a 15 μm pitch in 30 μm alkali-free glass, using only 230 total pulses. Figure 7 shows the quality and shape of the holes produced. As can be seen, the holes display excellent uniformity and quality with no micro-cracking or other peripheral damage.

It is also useful to point out a major speed advantage of the photomask parallel drilling method, versus serial drilling using a tight focused beam from another type of ultraviolet laser such as a diode pumped solid state (DPSS). At a given parameter set for laser fluence, pulse frequency and field size, a fixed number of pulses is required to achieve a matrix of through holes using the mask imaging method. However, as the number of vias per area increases with the square of the pitch, the number of through vias which fit into the field will increase likewise. Hence, the parallel drilling rate (holes per second) actually increases with the square of the pitch size. In contrast, in the case of serial drilling, the number of vias per time is constant and virtually unaffected by via size and via density (pitch).

3. Side-bar

3.1. Serial TGV drilling with picosecond lasers

The excimer's short (ultraviolet) laser wavelengths enable clean microprocessing of glass. The large pulse energy and extended beam cross-section makes the excimer an ideal tool for drilling large numbers of densely packaged TGVs in a fixed pattern using a photomask. An alternative to using very short wavelengths is to use ultrashort pulsewidths, as generated by a picosecond laser such as the Coherent Rapid and Talisker series which are now well-proven in 24/7 applications such as processing the strengthened glass used in touchscreens. Here the narrow pencilled shaped beam makes these lasers an optimum method for serial processing of TGVs in a mask-less drilling method, which can be particularly cost-effective for larger pitch and/or random hole placements.

4. Summary

Consumer demand and the drive to keep pace with Moore's Law is pushing the development of 2.5 D and ultimately 3D architectures to get what is called "More than Moore". Thin glass (100 μm) glass has many advantages for use as interposers in 2.5 D designs. Drilling high density TGVs with high throughput and high yields is a critical fabrication step for these packages. We have shown here that the industry workhorse excimer laser provides an excellent solution to this challenge, including the ability to support future designs with smaller TGVs, higher pitch TGVs and thinner interposers.

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