Ultra-thin glasses for semiconductor packaging

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Abstract

Glasses are homogeneous, many glasses have excellent dielectric properties at GHz frequencies and some have thermal expansions (CTE) which are close to silicon. Ultrathin glasses (UTG) with thicknesses of 25 µm to 200 µm (0.001 to 0.0079 inch) offer numerous options for packaging, integration and co-processing in semiconductor manufacturing processes. We introduce SCHOTT UTG including paths to further improve their mechanical stability and strength. We use laser ablation in 50µm thick glass and show via fabrication with a potential of mass manufacturing with via diameters of 30µm, 38µm pitch and a position accuracy of +/- 1µm. The structures are metallized using sputtering and electroplating which leads to hermetic, tight conducting through glass-vias (TGV).

Key words

Interposers, Materials and Manufacturing Technology, photosensitive glass, photo-structurable glass, Silicon/Glass/Organic Interposers, 2.5D Packaging on Silicon/ Glass/Flexible Interposers

I. Introduction

The ever increasing data rate and data volume especially the increasing mobile data volume leads to a number of clear trends affecting electronic packaging. One trend is further miniaturization together with a usage of frequency bands in the higher GHz range up to 125 GHz. This means the dimensions of components reach the order of the GHz wavelength which needs high manufacturing precision for packaging. A promising platform utilizes dielectric materials with defined material parameters, smooth surfaces and defined metal-to-dielectric interfaces. This allows for accurate impedance matching through a whole integrated package. In the past one packaging option was the use of through-silicon-vias (TSV) [1], which is etching of vias in silicon, oxidation to form a dielectric layer followed by metallization. A recent alternative to TSV which are limited in performance is the use of glass interposers [1,2]. Especially ultrathin glass (UTG) offers large potential for further compact packaging and miniaturization. Pristine glass surfaces show very smooth surfaces with roughness values of less than 1 nm. The glasses can be chosen with a thermal expansion adapted to silicon or to other materials used in electronic applications. Stable metallization is possible on glasses, which allows conducting structures like microstrip lines with low losses and defined impedances as well as through-glass-vias (TGV) [3]. At frequencies above 30 GHz TGVs show superior signal processing properties over TSVs. Glass based interposers are therefore not only an economic alternative [4] for further integration in electronics. 2-3 dimensional integration [5] in complex multilayer packages with integrated active (CPU, memory, logic) and passive (capacitances, inductances, filter elements) components is possible using glass interposers [6,7] and structured ultrathin glass substrates. Glasses enable ultrafast signal processing capabilities in extremely compact devices [8].

Glass sheets from SCHOTT are available in a wide range of dimensions in thicknesses from 25 µm to 200 µm and more, in standard wafer geometries and as rectangular sheets with widths of up to 500mm (20 inch). SCHOTT offers different ultra-thin glass types with CTE varying between 3.2 ppm K^{-1} and 7.2 ppm K^{-1}.

In addition, SCHOTT offers a glass – glass ceramic material which allows 3D photo-structuring, Foturan® II [9,10]. Properties of this material in comparison to three glass sheet materials are shown in table 1.

The paper is organized as follows. In section II we describe the manufacturing process of UTG, section III deals with improvements of glass strength and in section IV results of glass via fabrication using laser ablation are shown. Section V is devoted to metallization and the formation of hermetic conducting TGVs.

II. Manufacturing Process Thin Glass

For the manufacturing of ultra-thin glass SCHOTT has developed its proprietary down-draw technology. This technology can be applied for a wide thickness range between typically 1mm and down to 25µm. The thickness can be adjusted very precisely. The process creates a fire polished pristine surface with an extraordinary flatness and a residual roughness of less than 1 nm. The total thickness variation (TTV) is in the range of 5µm -10µm, depending on absolute thickness and required product quality. The process is highly flexible also towards materials with different thermomechanical properties. The thin glass can be produced either as sheets or on roll. The latter is important for future high volume downstream processing. Figure 1 shows the schematic diagram of the down-draw process. Some relevant properties of different glass types are listed in Table 1. As a comparison we also give the properties of our 3D photo-structurable glass Foturan®II [9,10].

Table 1: Properties of different glass types

	unit	**AF 32®eco**	**D 263®eco**	**MEMPAX®**	**FOTURAN®II**
glass type		aluminum borosilicate	aluminum borosilicate	borosilicate	lithium aluminum silicate
refractive index, n_d		1.5100	1.5231	1.4714	1.5150
CTE (20-300 °C), α	ppm/K	3.20	7.20	3.25	8.53
transformation temperature, T_g	°C	717	557	532	455
thermal conductivity at 90°C, λ	W/(m K)	1.16	1.06	1.12	1.28
Dielectric constant at 5 GHz, ε		5.1	6.3	4.4	6.3
Dielectric loss tangent at 5 GHz, tanδ	10^{-4}	49	101	73	109
Chemical toughening possible		no	Yes	no	no

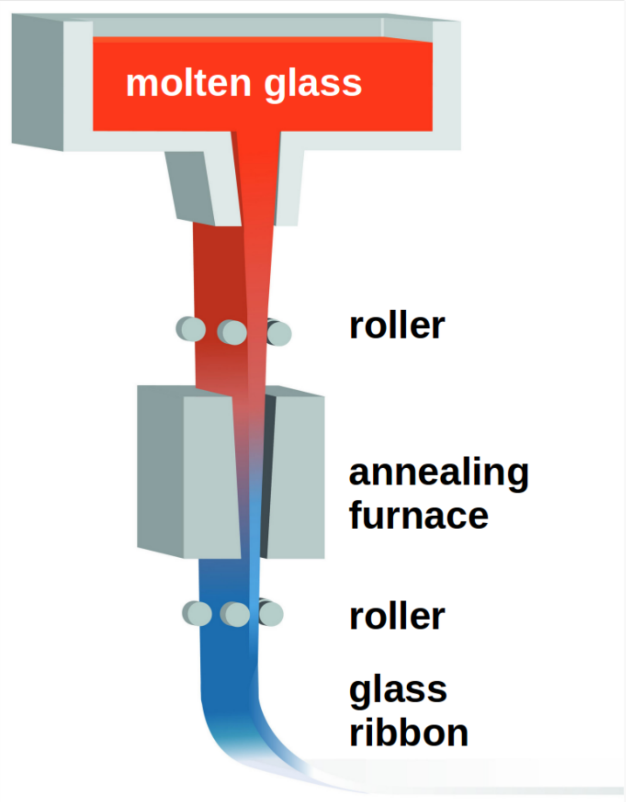

Figure 1: Principle of down-draw technology

III. Enhanced Glass Strength

Glass, even when it comes in ultra-thin formats, retains its intrinsic fragile nature. This fact is a major challenge when bringing such materials into mass production environments. Consequently, we consider glass strength as an important research goal on the way to increase the market penetration of ultra-thin glass to higher levels.

As for any fragile substance, such as ceramics or most oxide (poly) crystalline materials, the strength of glass is a function of its surface and edge integrity. The most prominent model for glass strength postulates the presence of tiny discontinuities in the microstructure within the glass, the so called "microcracks", which serve as fracture origins. These microcracks are statistically distributed within a glass and on the glass surface and differ in direction, length and size. Therefore, the strength of a glass product depends on its critical flaw with respect to the amount and direction of the tensile stress which is applied to the microstructure. Due to the missing interaction between microcracks and light as well as sonic waves, a detection of the critical flaw by nondestructive material testing seems to be impossible, like ultrasonic or laser based methods. Destructive strength testing techniques always imply the use of statistics. Hence glass strength always needs to be derived from a failure statistic. Unfortunately, most of the well-known testing methods for edge strength, like four-point-bending, do not work for ultra-thin glass due to its inherent flexibility. We developed a set of destructive test methods such as an adapted cylinder test. In this test the edge strength of a specimen can be assessed by successively bending it around cylinders with decreasing diameter and thus applying gradually more tensile stress on the outer side of the specimen until breakage. The data derived from these destructive testing methods are the basis for process improvements and ultimately practical improvements of strength in the ultra-thin glass product family. The perspectives from which one can approach the topics are threefold: (Nearly) flawless processing (e.g. separation), flaw reduction after processing and material composition. The combination of the three ways leads to a significant increase in edge strength and thus a wider applicability of ultra-thin glass

Figure 2 depicts the typical so called "Weibull –net", a common approach for displaying Fracture and Lifetime effects [11]. As separation processes are the main lever for introducing strength impairing flaws into the glass, continuous improvements of the current processing portfolio (Std. Cut) have been carried out. These equipment and process modifications resulted in an improvement of factor 2 in edge strength (Adv. Cut). Further improvements with flaw reduction techniques like etching and the utilization of the chemically toughenable glass D 263® T eco result in an improvement of a factor 4-5 ("ion-ex"). In labscale experiments, we succeeded in demonstrating an increase of edge strength by a factor of 10 by modifying the material composition and subsequently applying the same processes of edge treatment as in the case of D 263® T eco.

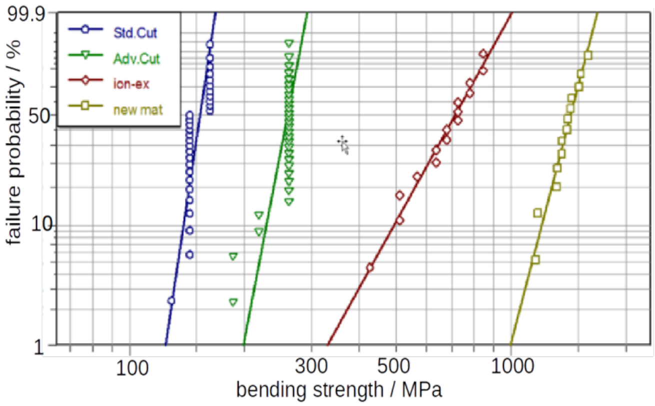

Figure 2: Edge strength after cutting and different post-treatment processes

It should be noted here, that ion exchange post-processing only works for glass that contains alkalines. The increase of strength is achieved by incorporating a compressive strength via substitution of the smaller Na+ ion by the larger K+ ion and thus reducing tensile stress on the glass surface. The resulting compressive stress can be controlled by parameters such as the depth of the diffusion (Depth of Layer – DOL).

IV. Via Formation

Different technologies can be applied to produce patterns on glass substrates. For larger structures, for example, the ultrasonic method is used, and also sandblasting is an option. However for small dimensions (<100µm) and ultra-thin glass the established technologies cannot be applied.

The high brittleness and the low thermal conductivity have to be considered for choosing suitable structuring technologies. The scalability and cost efficiency of high volume production is also a very important selection criterion. Emerging technologies like ultrashort laser processing can overcome these bottlenecks [12]. The high flexibility in terms of via diameter and any desired positioning onto the entire wafer in one run is a strong argument for laser based approaches [13]. The challenges of laser based processes are induced internal stresses. The thermal load, can be minimized with a spatial-temporally tailored laser-glass interaction set by well-defined process parameters, e.g. tailored beam shaping, beam focusing, and process strategy. Figure 3 demonstrate the capability of the selected processing set-up. High accurate positioning (<1µm) and very good circularity of the via, without residuals on the surface after cleaning indicate the good quality level. Especially, the stability of the 8µm bar (between two vias) over the complete process chain was unexpected, and indicate very low stress level.

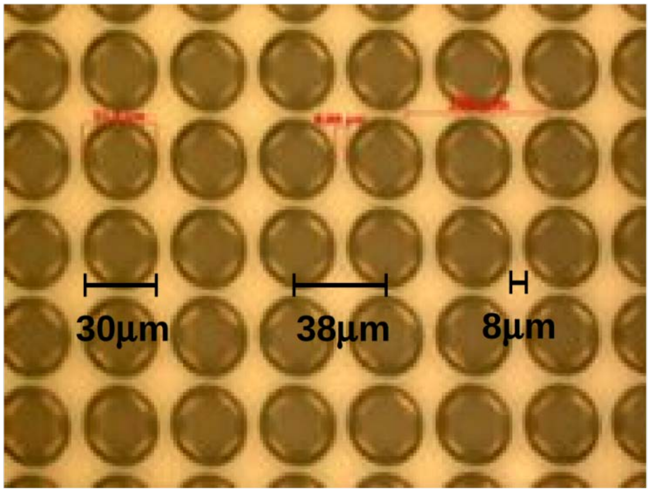

Figure 3: Laser drilled through vias in 30µm thick glass

It has to be noted that the stable processing of 50µm thick sheets is challenging and requires additional special measures, especially for handling. The thermally or mechanically induced stress threshold for breakage of 30-50µm thick glass is much lower compared to glasses of more than 100µm thickness. We solved these difficulties by different approaches, like frame mounting in case of double-side processing or carrier mounting for one-side processing (see Figure 4).

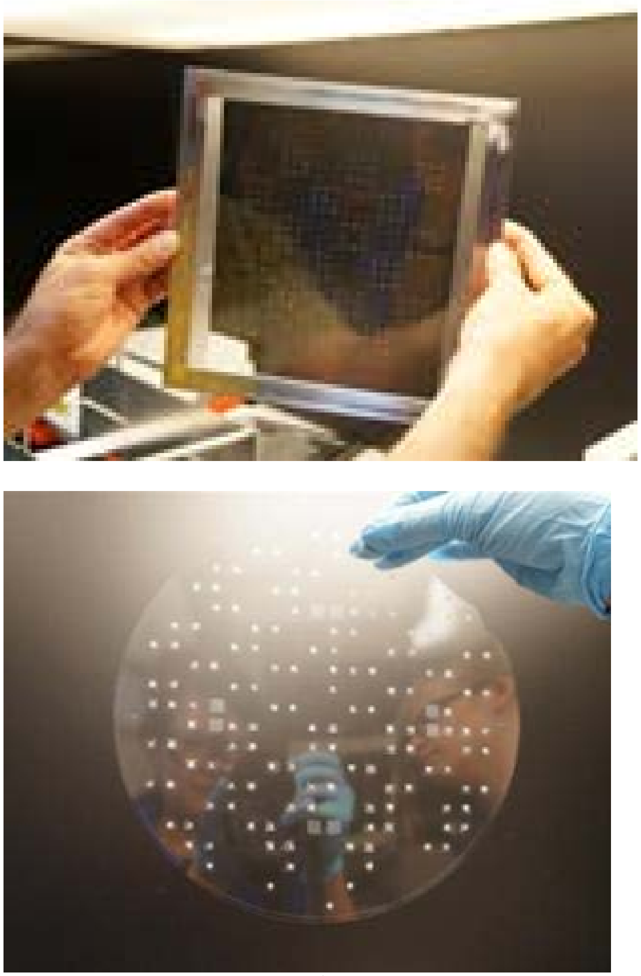

Figure 4: Frame mounting (top) and free standing (bottom) glass interposer

V. TGV Metallization and Characterization

An important part is the manufacturing of heat and electrical conducting metal vias in interposers [14,15]. In the following we describe metal via fabrication.

A. Design

The impact of the radius and pitch of TGVs on their electrical performance has been investigated in a previous ECTC publication [6] .

A test layout has been designed to measure the yield of the through substrate metallization with via chains. The design for the 200 mm wafers is shown in Figure 5.

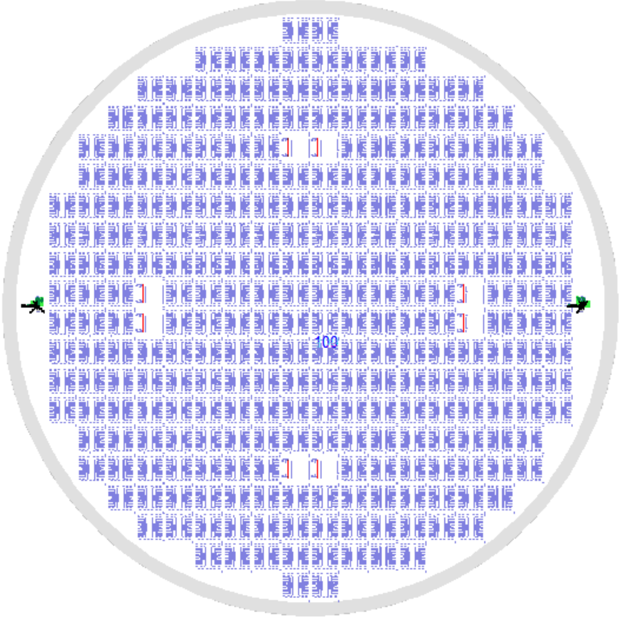

Figure 5: Design of the 200mm glass substrate

The chip size is defined as 10 by 10 mm. The usage of a 200 mm mask aligner allows to realize different chip layouts. There are three chip designs with different via pitch and numbers of vias in the chain. The smallest pitch of the 50 µm via is 100 µm with a total number of 420 vias in the chain. The chip with a via pitch of 150 µm has a via chain of 224 vias and the chip with the 300 µm pitch has a chain with 400 vias. The chip design with the 100 µm pitch is shown in Figure 6. The complete chain could be measured and also single lines which contain of a daisy chain of 20 vias.

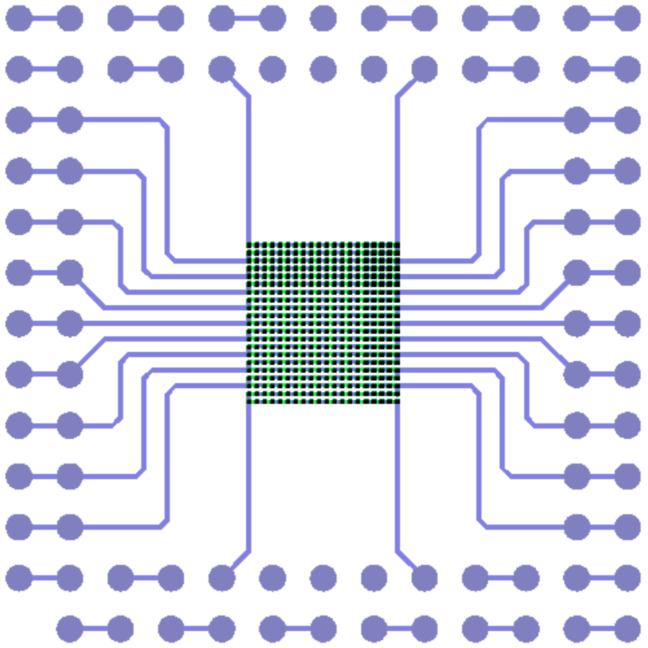

Figure 6: Chip design with a via pitch of 100µm

The RDL on the front side is used to reroute the TGV chain contacts on a 400 µm contact pitch. The glass chips can be assembled on a printed circuit board for second level reliability tests.

B. Metallization of the through substrate via

The standard through silicon vias (TSV) are generated as blind vias and filled up with copper. After the metallization the via is opened from back side by grinding. The through glass vias are generated as through hole. A new process for the metallization was developed for the TGVs and is shown in Figure 7. The glass wafer with vias is placed on a carrier wafer. The stacking of the wafers forms a blind via like shape of the TGV. The wafer is sputtered together with the carrier to apply the seed layer which belongs on 200 nm titanium adhesion layer and 400 nm copper layer.

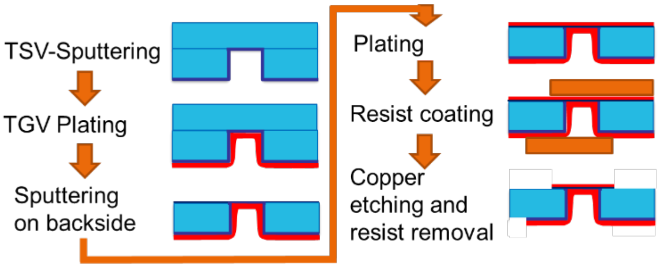

Figure 7: Process flow for TGV metallization

The copper thickness is increased by electroplating. Optimized electrolyte is used which allows a conformal copper deposition also in blind vias with high aspect ratio. Figure *8* shows the 200 mm wafer after copper plating. A copper thickness of 4 µm was plated. The via is not completely filled with copper regarding shorter plating time and better thermo-mechanical reliability. This copper layer is used for the via metallization and the routing on top of the glass surface.

Figure 8: 200 mm wafer after copper plating

Regarding this new developed process a hermetic closed via is generated which is shown in Figure 9. After the plating the metal layer is stable enough to cover the via on the bottom without the carrier wafer. The carrier wafer is removed and the back side can be metallized by sputtering of a seed layer and electroplating. The resist is applied on both sides and the RDL is generated by subtractive copper etching.

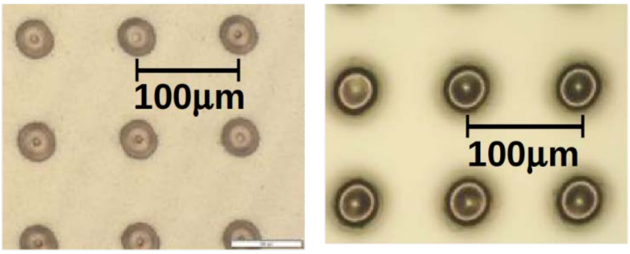

Figure 9: TGVs after the first metallization from front side view (left) and from backside view (right)

The conformal metallization of the via sidewall is verified by x-ray measurement. This allows a non-destructive control of the complete 200 mm wafer. The x-ray inspection leads to a gray scale picture where metal will be shown darker. In case of a homogenous metallization the picture contains of a constant gray value. Figure 10 shows the TGV array after electroplating. The sidewalls of the vias show a conformal metallization without any inhomogeneity. This proofs that the process works with excellent results.

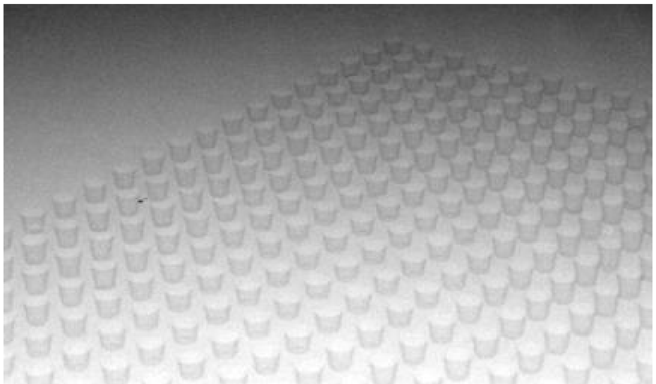

Figure 10: 50µm TGVs after electroplating

Figure *11* shows a cross-cut of the both-side metallized TGV array with a pitch of 100 µm. The TGV was closed by the first plating process at the bottom of the via. After this the metallization from the backside was done.

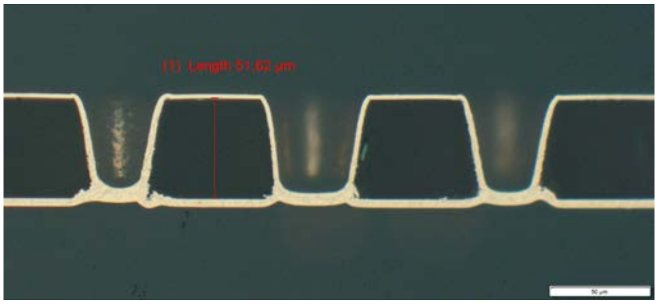

Figure 11: Metallized TGVs with a pitch of 100 µm in ultra-thin 50 µm glass

VI. Conclusion

We discussed several unique properties for the application of ultra-thin glass and glass ceramics. Wafer with 50µm thickness and 200mm diameter were successfully processed. TGVs can be formed on ultra-thin glass by laser-based drilling with high precision. A new process for the metallization leads to excellent results. Based on these we can conclude that glass interposer can be a real alternative to silicon. Especially for those applications that can benefit from the special properties of glass, like excellent long term stability, close to perfect homogeneity and surface roughness, high chemical resistance, low dielectric constant and low dielectric loss also in the GHz frequency range.

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