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Cost effective 3D Glass Microfabrication for Advanced Electronic Packages

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Abstract

Interposer technologies are gathering more importance in IC packaging as the industry continues miniaturization trends in microfabrication nodes and IC packaging to meet design and utility needs in consumer electronics. Furthermore, IC packaging is widely seen as a method to prolong Moore's law. Historically, silicon has been the material of interest for interposer materials given its prevalence in IC production, but it presents many technical and costs hurdles. In contrast, glass interposer technology presents a low cost alternative, yet attempts at producing advanced through glass vias (TGVs) arrays using traditional methods, such as laser ablation, have inherent process flaws, such as reduced interposer mechanical strength and debris sputtering among others.

In this extended abstract we present 3D Glass Solutions' efforts in using our proprietary APEX™ Glass ceramic to create various interposer technologies. This extended abstract will present on the production of large arrays of 10 micron diameter TGVs, with 20 micron center-to-center pitch, in 100 micron thick APEX™ Glass ceramic and the comparisons of wet etching of APEX™ Glass vs. laser ablation.

Keywords: Glass, Through Glass Vias, Interposer, 3D Glass

Introduction

Interposer technologies are gathering more importance in IC packaging as the industry continues miniaturization trends in microfabrication nodes and IC packaging to meet design and utility needs in consumer electronics. Furthermore, IC packaging is widely seen as a method to prolong Moore's law. Historically, silicon has been the material of interest for interposer materials given its prevalence in IC production, but it presents many technical and costs hurdles. In contrast, glass interposer technology presents a low cost alternative, yet attempts at producing advanced through glass vias (TGVs) arrays using traditional methods, such as laser ablation, have inherent process flaws, such as reduced interposer mechanical strength and debris sputtering among others.

To address these issues, 3D Glass Solutions has developed a novel glass ceramic material, called APEX™ Glass ceramic. With this material, features such as through glass vias (TGVs), trenches, and embedded microstructures, such as microfluidic channels may simultaneously be micro-fabricated using a precise, rapid, and cost effective batch manufacturing process.

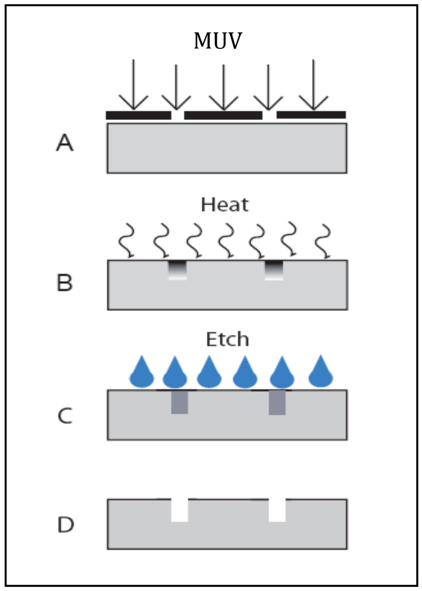


Figure 1: Processing steps of APEX™ Glass Ceramic.

APEX™ Glass ceramic is processed using a simple patented three- step process **(Figure 1).** First, a chrome- on-quartz mask is placed directly onto the glass wafer, without photoresist, and exposed to 310nm of light (Figure 1A). During this step, photo-activators in the glass become chemically reduced. In the second step of the production process, the wafer is baked in a two-step process (Figure 1B). First, the temperature is raised to a level that allows the photo- activators to migrate together forming nano-clusters. Next the temperature is ramped to a second temperature to facilitate the coalescence of ceramic-forming ions around the previously formed nano-clusters. During this step of the baking process, any previously exposed regions are converted into a ceramic state, where increased levels of exposure lead to more complete ceramic formation.

In the final processing step (Figure 1C), the wafer is etched in a dilute hydrofluoric acid (eg. 10%) solution, etching the ceramic state 60 times more preferentially than the glass state. In this manner a wide variety of features, such as posts, wells, TGVs, microfluidic channels, blind vias, or other desired features are gently wet etched **(Figure 2).** The desired structure depth can be controlled by etch concentration, processing duration, bath temperature, and etching direction.

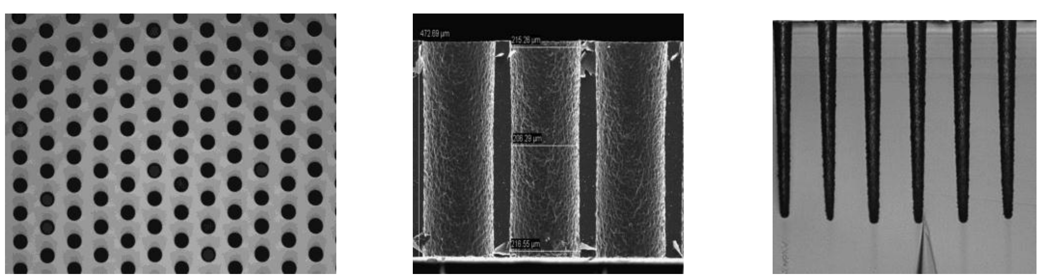
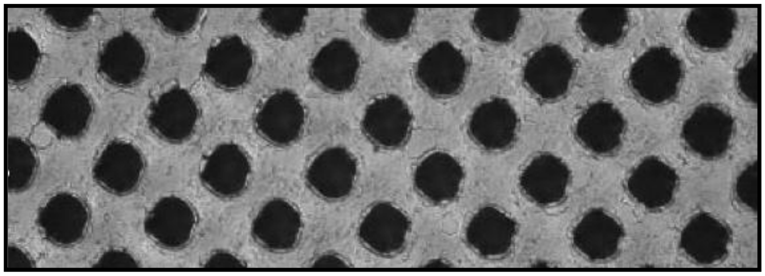


Figure 2: (Left) an array of 60 micron diameter TGVs; (Mid) a cross-section of 200 micron diameter TGVs, and (Right) a cross-section of 41 micron diameter, 440 micron deep blind vias.

We etch vs. laser ablation.

Several companies and academic organizations are focused on the production of TGVs using high power lasers. While this process has shown good success in the creation of TGVs there are several inherent concerns associated with laser ablated TGVs. These include: (1) Laser ablation tools are very costly, easily exceeding $2M; (2) By design ablation manufacturing approaches are serial, able to produce only small arrays of TGVs on a single wafer at a time; (3) the high temperature ablation process sputters a large amount of debris around the holes that may interfere with further processing steps; (4) the sidewall of laser ablated TGVs typically range from 80-85^{o}; and (5) they inject a large amount of heat shock into the glass substrate creating micro- fractures that lead to decreased material strength of interposer packages, decreasing product reliability. **Figure 3** below compares laser ablated glass to the wet etching of APEX™ glass.



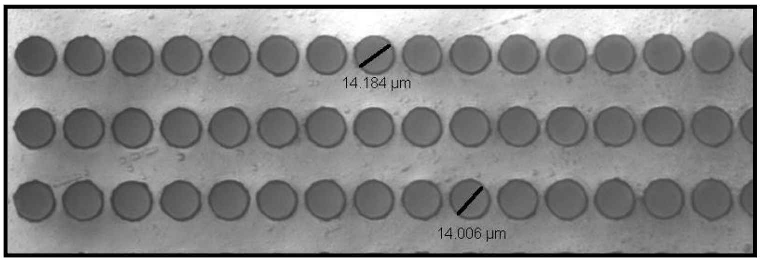


Figure 3: (Top) Laser ablation of 25 micron diameter TGVs in borosilicate glass. (Bottom) 14 micron diameter TGVs wet etched into APEX™ Glass. Notice the glass sputtering and irregular shape of the ablated TGVs compared to the lack of debris sputtering and the high fidelity of the wet etched APEX™ Glass TGVs.

Manufacturing Approach

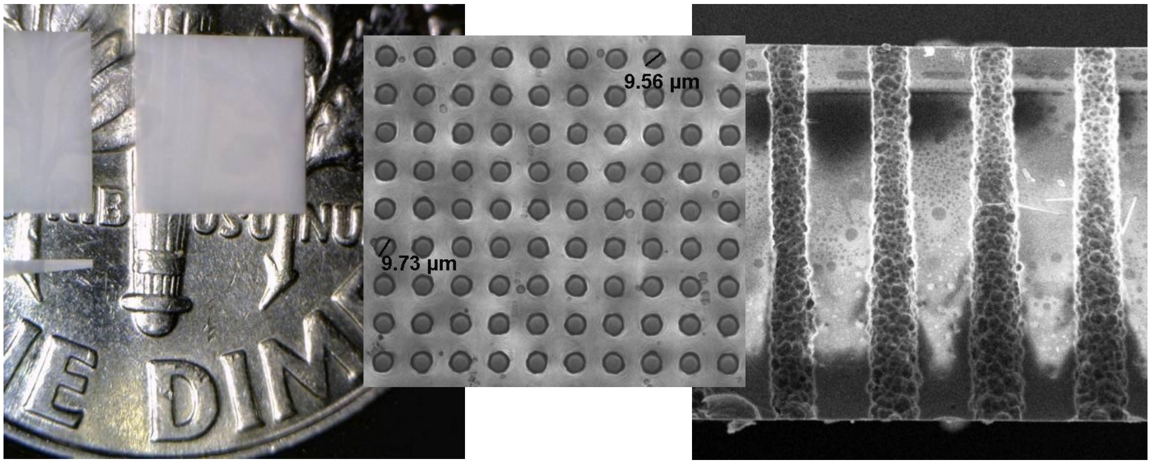
Exposing Research into the exposure of APEX™ Glass ceramic for the formation of micro-TGVs (<20 microns) was performed to identify a method which created the most anisotropic exposure pattern, reduced light scatter, and fastest processing time. Exposure occurred using a 500W OAI flood exposure tool with 300-320nm narrow pass mirrors. Exposure energy densities ranging from 2-32 Joules/cm2 were evaluated using 100mm diameter, 100 micron thick substrates. Exposure was performed using contact lithography of a quartz/chrome mask directly in contact with an APEX™ Glass ceramic wafer (no vacuum) placed onto a black matte base. Exposures of 2, 4, 8, 12, 16, 24, and 32 Joules/cm2 were evaluated. All samples were baked and etched under the same conditions. It was identified that for the production of 10 micron diameter TGVs at 20 micron center-to- center pitches that 4 Joules/cm2 produced the most anisotropic etch.

Baking As previously described, baking converts the exposed glass into the ceramic state. There are many variables during the baking step including temperature, time, and ramp rate. We have observed over the course of our previous manufacturing works that the bake schedule of [1] 500C for 75 minutes at a ramp rate of 6C per minute and [2] 575C for 75 minutes at a ramp rate of 3C per minute consistently yielded the highest conversion of nucleated glass into the ceramic state, translating into increased anisotropic etching.

Etching is perhaps the most important step of the three-step manufacturing process and considerable amount of effort went into identifying the most appropriate etch setup to obtain the greatest degree of anisotropy, manufacturability, and performance. A small Design of Experiments (DOE) was performed using acid concentration, etch time, and performance. It was identified that performance was largely independent of acid concentration with a broad sweet spot existing between 3 and 10% (v/v) HF in DI water, therefore, we chose an acid concentration of 4% in DI water for all experiments. All parts were double-side etched by placing the processed wafer onto a custom made jig. Etching was performed using a custom built JST etching station. The JST wet etch station uses a cascade overflow system with an in-tank sonication transducer. Total etch time to etch 8 million 10 micron diameter TGVs in a 100mm diameter wafer was 4.0 minutes.

Results

Using the above described protocol we produced a wafer containing 8 million 10 micron diameter TGVs. TGV arrays were arrayed in 40,000 TGV groupings. Total etch time of the 100mm wafer was 4 minutes. **Figure 4** below shows several images of the produced 10 micron diameter, 20 micron center-to-center pitch, TGV array. The average TGV size is 9.61 microns with a standard deviation of 0.15 microns.



(A) (B) (C)

Figure 4: (A) An array of 40,000 10 micron diameter TGVs on a dime, (B) a close up of 10 micron diameter, 20 micron pitch, TGVs, and (C) a SEM image of the 10 micron diameter TGV cross section.

Conclusions

APEX™ Glass is an ideal substrate for 2.5D and 3D IC packaging applications. Wafer processing is accomplished through standard batch IC processes enabling a low cost alternative to silicon interposers. Furthermore, wet etching of the 3D structures, such as TGVs, produces a micro fracture-free product, leading to a more reliable product. 3D Glass Solutions has demonstrated the optimized production of 8 million 10 micron