Cost Effective 3D Glass Microfabrication for Advanced Packaging Applications

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ABSTRACT

Historically, while glasses have many desirable attributes for IC packaging, such as mechanical strength, high electrical resistivity, and high thermal stability they have been very difficult to fabricate 3D structures in. To address these concerns 3D Glass Solutions has developed APEX™ Glass. With APEX™ Glass, complex features such as anisotropic through glass vias (TGVs), trenches, and wells, among other features, may easily be processed using a simple three step manufacturing process.

3D Glass Solutions produces a wide variety of custom manufactured components for the IC industry. Of particular interest to many of our IC customers are interposer substrates. 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. APEX™ Glass is an ideal substrate for many interposer applications, providing significant cost and technical advantages over silicon and laser-ablated glass substrates. In this white paper we present 3D Glass Solutions' efforts in producing custom built, high volume manufactured, interposer technologies for IC packaging customers.

INTRODUCTION

Historically, glass has not been viewed as a cost effective material for the IC packaging community; while glasses have many desirable attributes such as mechanical strength, high electrical resistivity, and high thermal stability they have historically been very difficult to fabricate 3D structures in. To address these concerns 3D Glass Solutions has developed APEX™ Glass. With APEX™ Glass, complex features such as anisotropic through glass vias (TGVs), trenches, and wells among other features may easily be processed using a simple three step manufacturing process.

3D Glass Solutions produces a wide variety of custom manufactured components for the IC industry. Of particular interest to many of our IC consumers are interposer substrates. 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 cost hurdles. In contrast, glass interposer technology presents a low cost alternative, yet attempts at producing advances through glass vias (TGVs) arrays using

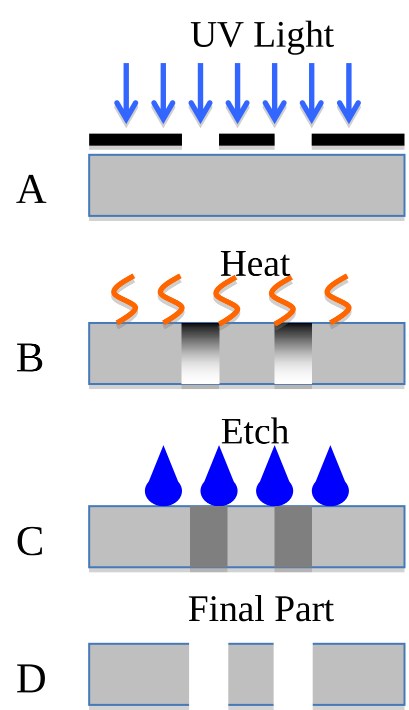


Figure 1: Processing steps of APEX™ Glass Ceramic

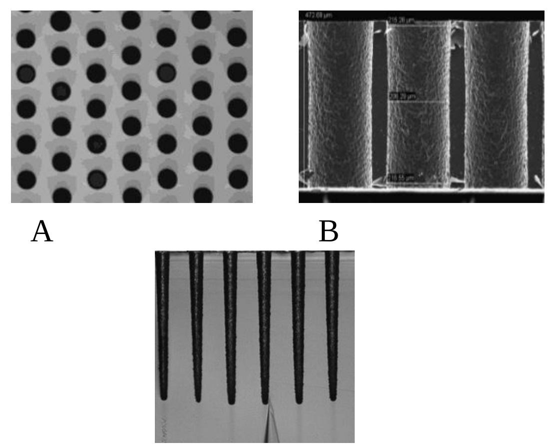
traditional methods, such as laser ablation, have inherent process flaws, such as reduced interposer mechanical strength and debris sputtering among others.

In this white paper we present 3D Glass Solutions' efforts in using out proprietary APEX™ Glass to create high volume manufactured interposer packages. We present on (1) why APEX™ Glass versus silicon and glass laser ablation technologies, (2) our efforts to produce large arrays of TGVs, (3) TGV metallization efforts, and (4) backend manufacturing integration efforts.

BACKGROUND

APEX™ Glass 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 using a 310nm light source (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 (e.g. 10%) solution, etching the ceramic state 60 times more preferentially than the glass state. In this manner a wide variety of anisotropic features, such as posts, wells, TGVs, microfluidic channels, blind vias, or other desired features are gently etched **(Figure 2)**. The desired structure depth can be controlled by etch concentration, process duration, bath temperature, and etching direction.



A B C

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

Material Comparisons

APEX™ vs. Silicon

Historically, silicon has been the material of choice for interposers given its prevalence in IC production, but it presents many technical and cost hurdles. First, anisotropic etching of silicon requires multi-million dollar tools capable of processing only one wafer at a time. Second all processed through silicon vias require oxidation to prevent electrical shorts due to voltage breakdown. In contrast, APEX™ Glass material is batch processed 25 wafers at a time using standard wet etch technologies. Furthermore, APEX™ Glass is already a dielectric material (10^{12} Ω/cm^2 resistance) and does not require any further processing for electrical isolation.

APEX™ vs. Glass Laser Ablation

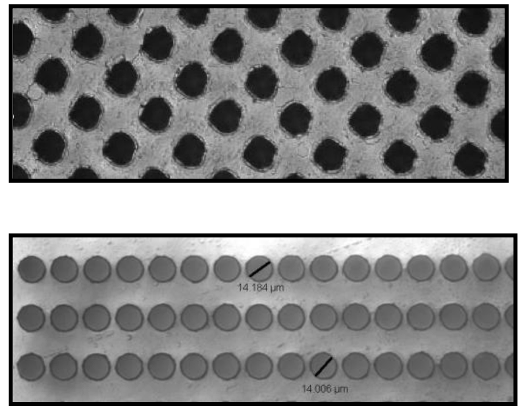


Figure 3: (Top) Laser ablation of 25 micron diameter TGVs in borosilicate glass. (Bottom) 14 micron diameter TGVs wet etched into APEX™ Glass.

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 the 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 angle of laser ablated TGVs typically range from 80-85°; and (5) they inject a large amount of heat shock into the glass substrate creating micro-fractures that lead to decreased mechanical strength of the interposer packages and thus decreasing product reliability. **Figure 3** compares laser ablated glass (top) to the wet etching of APEX™ Glass (bottom).

APEX™ Glass MANUFACTURING APPROACH

Exposing

Research into the exposure of APEX™ Glass for the formation of TGVs has been optimized to created the most anisotropic exposure pattern, with reduced light scatter, and to have the shortest processing times. Exposures are accomplished using a 500W OAI flood exposure tool with 300-320nm narrow pass mirrors. Exposure energy densities ranging from 2-32 Joules/cm^2 may be used, but we have identified that 6-12 Joules/cm^2 produces the most anisotropic etch. Exposures are performed using contact lithography of a quartz/chrome mask directly in contact with an APEX™ Glass wafer (no vacuum).

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 observes over the course of our previous manufacturing work that the bake schedule of 1) 500C for 75 min 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

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. Etch performance of the glass is largely independent of acid concentration and has a broad sweet spot existing between 3 and

10% (v/v) HF in DI water. At 3D Glass Solutions we use an acid concentration of 4% in DI water for all production. All interposer parts are double-side etched by placing the processed wafer onto a standard wafer boat. Etching is performed using a custom built JST etching station. The JST wet etch station uses a cascade overflow system with an in-tank sonication transducer. Etch rates correlate directly with HF concentration and range between 6-60 μm/min.

RESULTS

Working with our customers, we have produced large TGV arrays of 10-100μm diameter vias in thin substrates (125-500μm) with targeted TGV aspect ratios (interposer thickness-TGV diameter) ranging between 5-15. Using the above-described manufacturing approach, we are able to create TGV arrays as small as 14 microns in diameter in 125 micron thick APEX™ Glass at 17 micron center-to-center pitches. As can be seen in **Figure 3 (bottom)**, the production of these ultra-small TGVs yielded high geometric fidelity. Further SEM analysis of the manufactured TGVs revealed no formation of micro-fractures or debris sputtering. Using this approach, we are able to routinely obtain a via aspect ratio of 10:1. **Figure 4 (left)** above shows 50μm diameter TGVs in 500μm thick glass. **Figure 4 (right)** demonstrated the anisotropic etch of the described approach.

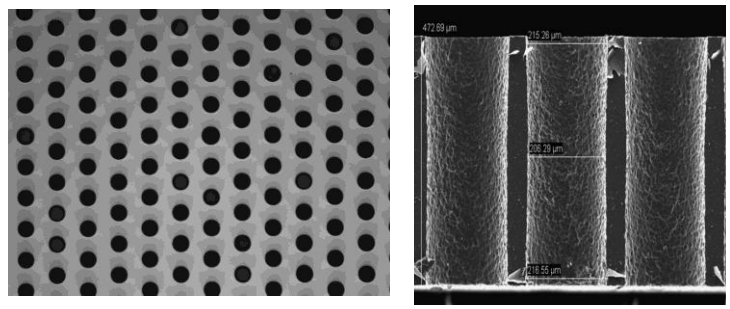


Figure 4: (**Left) 50 micron diameter TGVs in 500 micron thick glass. (Right) Cross-section of 100 micron diameter TGVs in 500 micron thick glass.**

<u>Copper Filling of TGVs</u>

At our production facility we routinely produce TGV arrays consisting of 40 to 100 micron diameter TGVs, with TGV diameter to interposer thicknesses ratios ranging between 4:1 and 10:1. Copper filling of these TGVs is conducted internally using an internally designed and built electroplating system. Direct Current (DC) electroplating is employed using a seed layer at the bottom of the TGVs and plated out under low currents to prevent mass-transport limited environments. In this manner, the TGVs are completely copper filled from boom to top. After copper filling, the substrates are planarized using standard glass lapping and polishing steps to remove any over-plating and to bring the wafer into thickness specification.

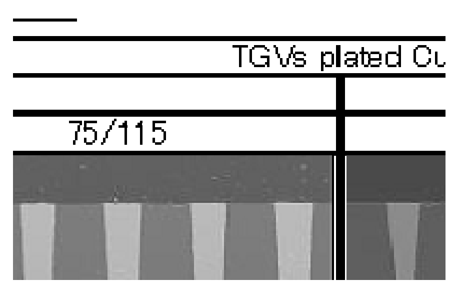


Figure 5: Cross section of copper plated through glass vias produced using galvanic methods. Notice the void free electroplating of copper.

Figure 5 shows a cross-sectional SEM of the copper-filled TGVs. It can be seen that filling of the TGVs with the described approach yields defect- and void- free filled TGVs. Furthermore, analysis shows no pistoning of the copper plating after 1000 thermocycles (-40C to 250C).

Surface Metallization

We have incorporated several types of surface metallizations onto our interposer packages for our customers. We have deposited a wide variety of metals including Ti, Cr, Au, Ag, Pt, Ni, NiCr, and TiW among others, with deposition techniques including electroplating techniques, electroless plating techniques, evaporation, and sputtering **(Figure 6)**. Furthermore, we have successfully demonstrated passivation of surface metallization using CVD SiN, sputtered SiO_2, and photodefinable polyimide.

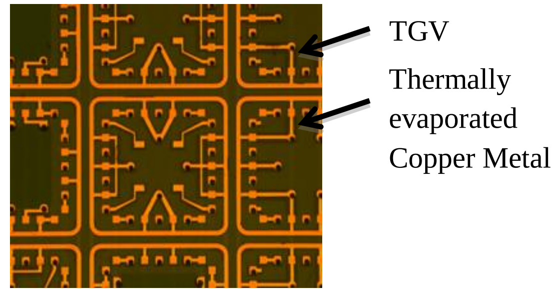


Figure 6: APEX™ Glass ceramic is amenable to downstream IC processes such as surface metallization and dielectric depositions.

CONCLUSIONS

3D Glass Solutions is a customer driven business and has produced a variety of interposer components for our customers. We provide custom production of TGVs in APEX™ Glass and metal filling with electroplated copper. Furthermore, 3D Glass Solutions incorporates several techniques for surface metallization and passivation. All of these technologies are in manufacturing today and are available for your production needs. Contact us today through our website: http://www.3dglasssolutions.com/ or call us directly at 1-866-559-8982.