Cost effective Precision 3D Glass Microfabrication for Electronic Packaging

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The most singular focus of the electronics industry during the last 50 years has been to miniaturize ICs by miniaturization of transistors and on-chip interconnections. Two major problems are foreseen with this approach; (1) electrical leakage and (2) the lack of improved electrical performance beyond 16nm. As a result, the industry is transitioning from the current SOC-based approach to a through-silicon-via (TSV) based 3D IC-stacked approach. However, a major challenge remains; these 3D ICs need to be interconnected to other ICs with a much higher number of I/Os than are available with current ceramic or organic interposers. While silicon interposers currently in development can provide these high I/Os, they cannot do so at low enough cost.

In this extended abstract, 3D Glass Solutions, a division of Life BioScience, Inc., presents our efforts in glass interposer microfabrication. Glass interposers possess many advantages over silicon interposers including: cost, production time, and scale. 3D Glass Solution's APEX™ Glass ceramic is a photo-sensitive material used to create high density arrays of through glass vias (TGVs) using three simple processing steps: exposure, baking, and etching. To date, we have been successful in producing large arrays of 12 micron diameter TGVs, with 14 micron center-to-center pitch, in 125 micron thick APEX™ Glass ceramic. This extended abstract covers (1) on our efforts producing high aspect ratio TGVs in ultra thin (75-250 micron) APEX™ Glass ceramic wafers, (2) maximum TGV aspect ratios, and (3) TGV fidelity and limits of manufacturing.

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

Introduction

3D Glass Solutions has developed a novel glass ceramic material, called APEX™ Glass ceramic. APEX™ Glass ceramic is processed using standard photolithography techniques in a patent-pending three step process (**Figure 1**). With this material features such as TGVs and microfluidic channels are simultaneously microfabricated in a precise, fast, and cheap process. The first step involves the direct patterning of an APEX™ Glass ceramic wafer using a quartz/chrome mask (no photoresist required). In this contact lithography step, the mask is placed directly onto the wafer and then exposed to ultraviolet light (Figure 1A). During this step, photo-activators in the glass become chemically reduced. In the second step of the process, the wafer is

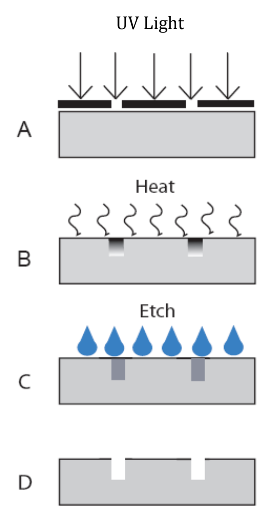

Figure 1: Processing steps of APEX™ Glass Ceramic

baked in a two-step process. First, the temperature is raised to a level that allows the photo-activators to migrate together forming nano-clusters. A second temperature ramp is employed to facilitate the coalescence of ceramic-forming ions around the previously formed nano-clusters. During this step of the baking process, the exposed regions are converted into a ceramic. In the final step (Figure 1C), the wafer is etched in a dilute hydrofluoric acid (5-10%) solution creating posts, wells, TGVs, microfluidic channels, or other desired features. The desired structure depth can be controlled by etch concentration, processing duration, and etching direction.

Approach

Exposing

Research into the exposure of APEX™ Glass ceramic for the formation of TGVs 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 of 2-32 Joules/cm^2 were evaluated using 100mm diameter, 0.5mm 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/cm$_2$ were evaluated. All samples were baked and etched under the same conditions. It was identified that 12 Joules/cm^2 produced the most anisotropic etch (see Figure 3 below).

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 has 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 largest max etch aspect ratio, 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 5% HF in DI water, therefore, we chose an acid concentration of 4% in DI water for all experiments. All parts were single side etched by placing the processed wafer onto a custom made jig with a Viton® gasket backing and compressing the wafer along the edges to provide a water tight seal, protecting the back side of the wafer. 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 (Figure 4).

Results

We explored the production of 10-100µm diameter vias in ultrathin substrates (75-250 µm) with targeted TGV aspect ratios (interposer thickness : TGV diameter) ranging from 5-15 being pursued. Using the above-described manufacturing approach, we were able to create TGV arrays as small as 13 microns in diameter in 125 micron thick APEX™ Glass ceramic at 14 micron center-to-center pitches. As can be seen in **Figure 2A**, the production of the 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 were able to obtain a maximum via aspect ratio of 13:1, creating 29 micron diameter vias in 370 micron thick APEX™ Glass ceramic (**Figure 2B**). Furthermore, **Figure 2C** demonstrates the anisotropic etch of the described approach.

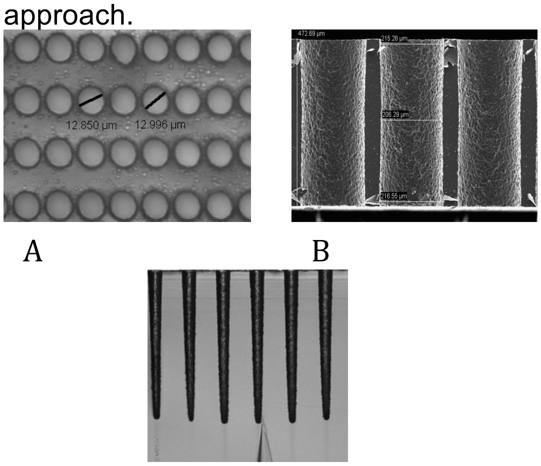

Figure 2: (A) Production of 13 micron diameter TGVs in 125 micron thick APEX™ Glass ceramic. (B) SEM of TGV profile. (C) Blind via production (41µm diameter, 480µm depth).

Downstream processing

Furthermore, 3D Glass Solutions explored the downstream processing of APEX glass with a variety of process techniques. We have demonstrated the plug plating of TGVs in APEX™ Glass ceramic with copper (Figure 3A). We have also demonstrated downstream glass processing to create secondary and teritary glass structures such as etched cavities for imbedded components (Figure 3B). Finally, we have demonstrated several types of surface metalizations with a wide variety of metals (including Ti, Cr, Au, Ag, Pt, NiCr, among others) and deposition techniques (including galvanic, electroless, thermal evaporation, and sputtering) (Figure 3C).

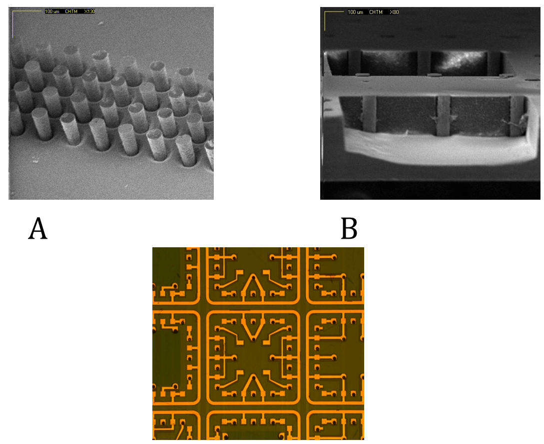

Figure 3: (A) An isometric view of an array of copper plated TGVs where the glass has been etched back to reveal the copper profile. (B) Multiprocessing of APEX™ Glass may include several etch steps for TGVs and cavities. (C) APEX™ Glass ceramic is amenable to downstream IC processes such as metallization and dielectric depositions.

Conclusions

3D Glass Solutions has demonstrated the production of 13 micron diameter anisotropic TGVs in APEX™ Glass with a maximum aspect ratio of 13:1. This process enables the production of over 400,000 TGVs/cm^2. LBSI has produced over 1,000,000 TGVs in as little as 30 minutes of processing time, demonstrating costs as low as 2X10^{-6} dollars per via.