Glass Enabled Systems Integration

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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, laminates and silicon has been the materials of interest for interposer materials given their prevalence in IC production; however, they present many limitations in material and technical capabilities. In contrast, glass is becoming viewed as an economically and technically viable option for RF-based IC packaging. In this publication we present a novel photo-definable glass ceramic material for the wafer level packaging of RF electronics. Furthermore, we present on our efforts to leverage this materials unique processing capabilities to create High-Q passive devices, such as inductors through an undercutting manufacturing process.

Index Terms - Glass, packaging, dielectric material, through-glass-vias.

I. INTRODUCTION

Interposer technologies are gathering more importance in IC packaging as the IC 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. Recently, glassy materials have become more commonly viewed as a good material for microwave (MW) and radio frequency (RF) electronic packages. Glassy materials offer a number of advantages over traditional interposer materials, such as laminates and ceramics, including: (1) better material properties, (2) decreased surface roughness to mitigate current crowding, (3) the ability to create smaller I/Os with greater densities, and (4) the opportunity to process devices in large panel formats.

Several glass manufacturing techniques are available on the market today for the formation of through glass vias (TGVs) for I/Os and interconnects, including laser ablation, electrostatic discharge, ultrasonic milling, and wet chemical etching. While each of these approaches have unique advantages, wet chemical etching offers a number of benefits. These include: (1) process simplicity, (2) low processing tool capital cost, (3) batch manufacturing for lower production costs, and (4) the decreased formation of micro-fractures between structures, commonly seen in processes that input high levels of thermal and mechanical stress to the glass.

3D Glass Solutions, Inc. has developed a novel glass ceramic material, called APEX® Glass ceramic that enables the production of highly anisotropic 3D structures in glass using photolithographic patterning, baking, and wet chemical etching. With this material, features of any pattern may be etched into the glass. Features such as TGVs, trenches, and cavities may simultaneously be microfabricated using a precise, rapid, and cost effective batch manufacturing process.

APEX® Glass ceramic is processed using a simple three-step process (Fig. 1). First, a chrome- on-quartz mask is placed directly onto the glass wafer, without photoresist, and exposed to 310nm of light (Fig. 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 (Fig. 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.

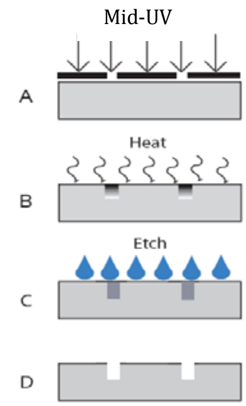
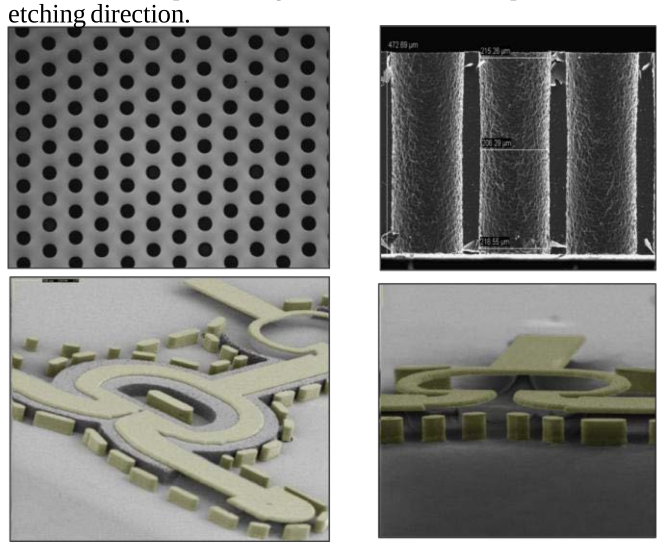


Fig. 1. Processing steps of APEX™ Glass Ceramic.

In the final processing step (Fig. 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 (Fig. 2). The desired structure depth can be controlled by etch concentration, processing duration, bath temperature, and etching direction.



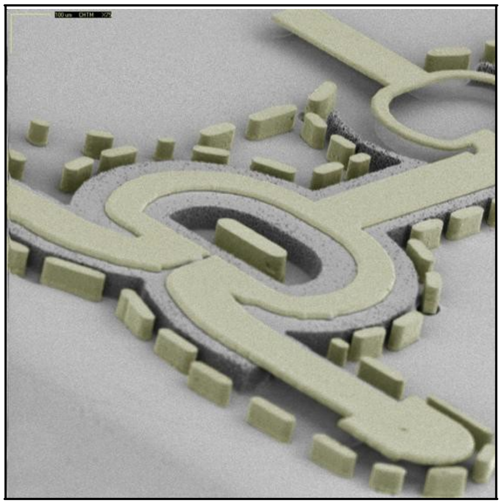


Fig. 2. (Left) an array of 60 micron diameter TGVs; (Mid) a cross-section of 200 micron diameter TGVs, and (Right) a cross-section of 41 micron diameter, 440 micron deep blind vias.

A. *Glass for RF Electronics*

RF electronic substrates come in a variety of material sets, including glass reinforced epoxy laminates (such as FR-4), silicon liquid crystal polymer, and ceramics. For a number of reasons, including surface roughness, material constants (such as dielectric constant, loss tangent, Young's modulus, etc.), processability, and cost the RF community is continuously looking for new materials as new applications continue to push current material property limits.

APEX™ Glass is a dielectric material very similar to other types of glass, such as BK7 (Schott) and is able to be processed using standard IC processing techniques. Table 1 below shows some relevant material properties specific to RF electronics.

TABLE 1
Summary of RF Relevant Material Properties

Young's Modulus	81 GPa
Electrical Resistivity	10^{12} Ω
Coefficient of Thermal Expansion	10 ppm/K
Loss Tangent (3.3 GHz)	0.0086
Loss Tangent (10.2 GHz)	0.0106
Dielectric Constant (3.3 GHz)	6.58
Dielectric Constant (10.2 GHz)	6.575

II. WET 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. Fig. 3 below compares laser ablated glass to the wet etching of APEX™ glass.

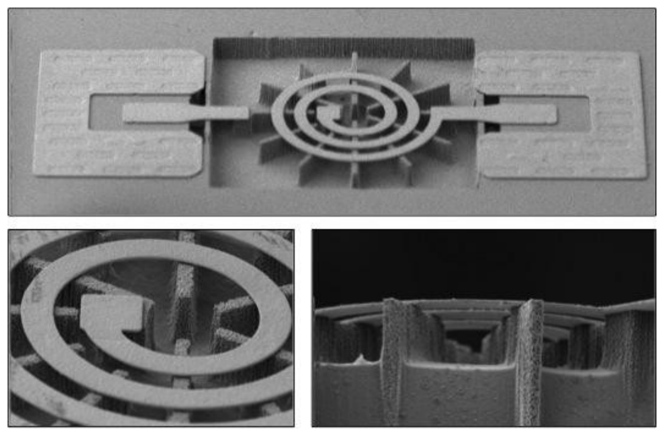


Fig. 3. (Top) Laser ablation of 25 micron diameter TGVs in borosilicate glass. (Bottom) 14 micron diameter TGVs wet etched into APEX™ Glass. Notice the glass sputtering and irregular shape of the ablated TGVs compared to the lack of debris sputtering and the high fidelity of the wet etched APEX™ Glass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

III. MANUFACTURING APPROACH

A. *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.

B. 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.

C. 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.

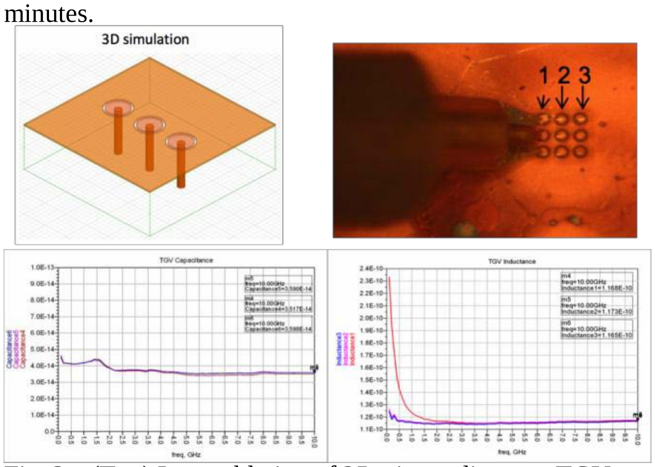


Fig. 3. (Top) Laser ablation of 25 micron diameter TGVs

IV. 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 (Fig. 4A). Total etch time of the 100mm wafer was 4 minutes. Fig. 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 (Fig. 4B). Fig. 4C shows a cross section of the anisotropic etch profile.

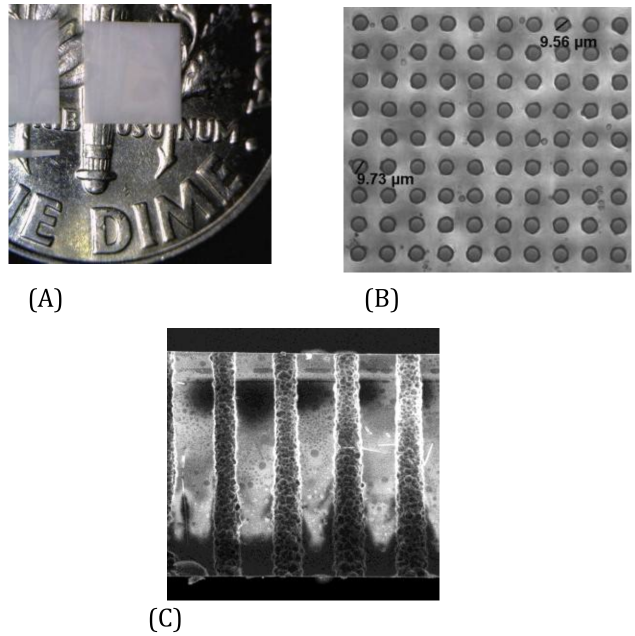


Fig. 4. (A) An array of 40,000 10 micron diameter TGVs on a dime, (B) a close up of 10 micron diameter, 20 micron pitch, TGVs, and (C) a SEM image of the 10 micron diameter TGV cross section.

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 microfracture-free product, leading to a more reliable product. 3D Glass Solutions has demonstrated the optimized production of 8 million 10 micron holes in a single wafer.