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.

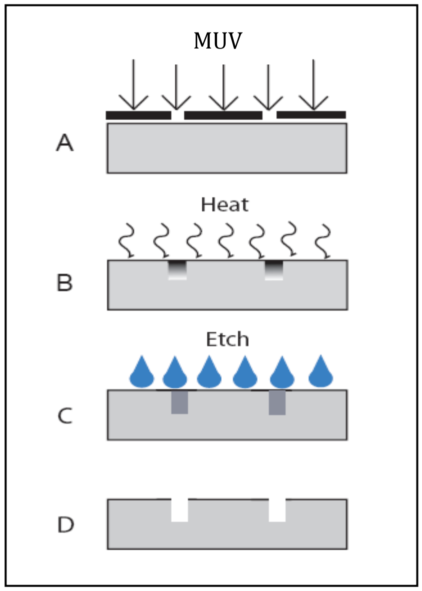


Figure 1: Processing steps of APEX™ Glass Ceramic.

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.

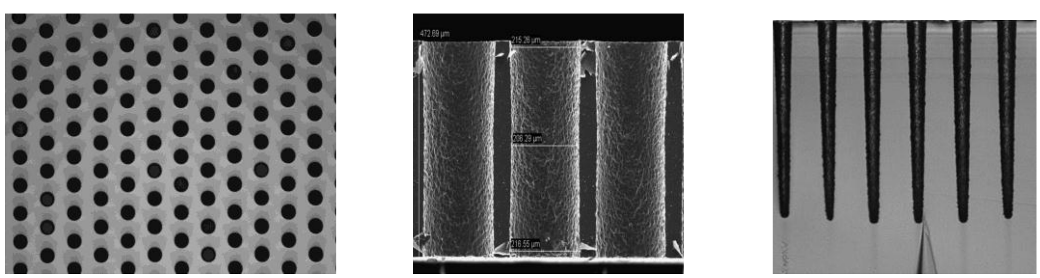


Figure 2: (Left) an array of 60 micron diameter TGVs; (Mid) a cross-section of 200 micron diameter TGVs, and (Right) a cross-section of 41 micron diameter, 440 micron deep blind vias.

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.

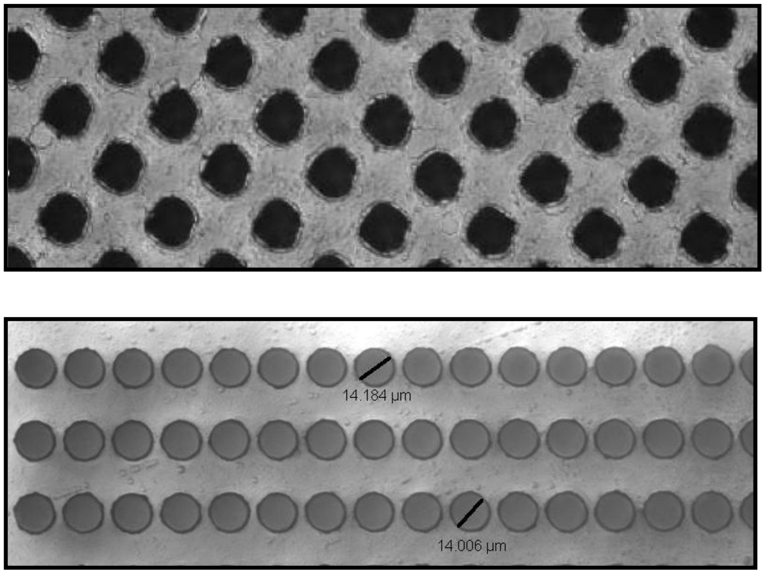


Figure 3: (Top) Laser ablation of 25 micron diameter TGVs in borosilicate glass. (Bottom) 14 micron diameter TGVs wet etched into APEX™ Glass. Notice the glass sputtering and irregular shape of the ablated TGVs compared to the lack of debris sputtering and the high fidelity of the wet etched APEX™ Glass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

Manufacturing Approach

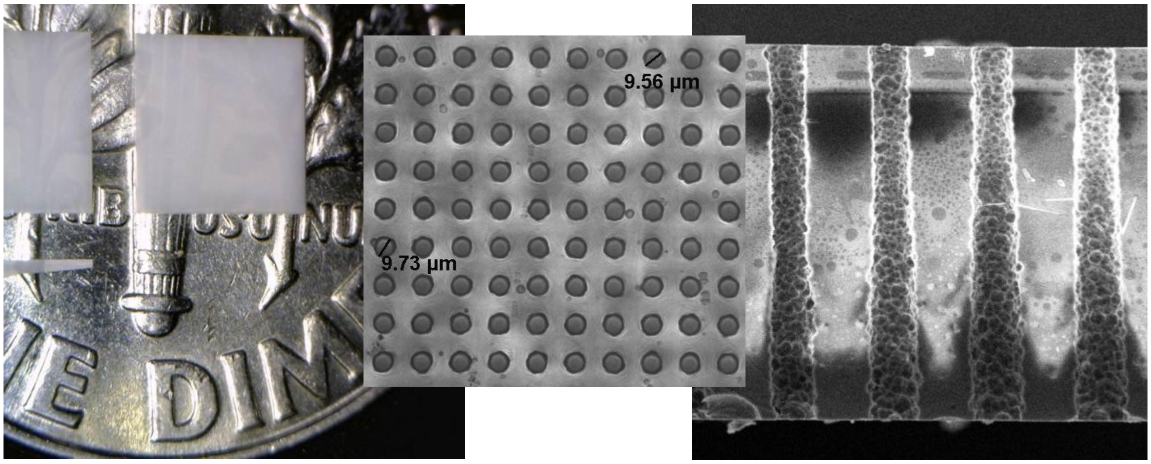
Exposing Research into the exposure of APEX™ Glass ceramic for the formation of micro-TGVs (<20 microns) was performed to identify a method which created the most anisotropic exposure pattern, reduced light scatter, and fastest processing time. Exposure occurred using a 500W OAI flood exposure tool with 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

Cost-Effective Precision 3D Glass Microfabrication for Electronic Packaging Applications

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3D GLASS SOLUTIONS

Who is 3DGS?

- We are a division of Life BioScience, Inc.
  - Life BioScience, Inc. produces a wide variety of custom glass structures for a diverse array of markets.
    - Microfluidic channels, molds, and micro-filters among others.
- 3DGS was created to serve the IC community by:
  1. Selling APEX™ Glass raw material
  2. Licensing market specific applications
  3. Providing consultation on APEX™ Glass microfabrication techniques
  4. Building custom prototype and small-medium volume part processing
- We are a 100% customer-driven company
- We are currently working with 45 industry leaders in design, BEOL fabrication, equipment manufactures, and material suppliers
- We have a variety of IP elements surrounding compositions, processing, and applications of Photo-Structurable Glass Ceramics in the IC packaging industry

3DGS: From Concept to Production

Design

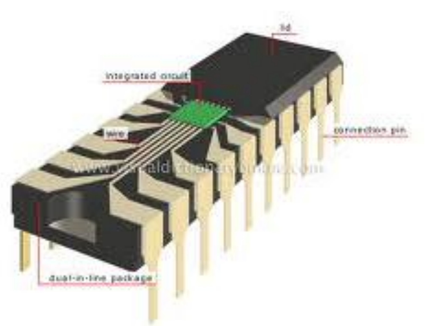
3D CAD, Material Consult, Iterate, and Optimize

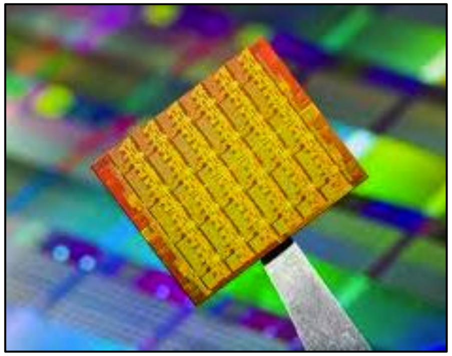
Prototype

Demonstrate Prototype Feasibility and Transition

Production

Optimize Cycle Time, Yield, Cost, and Quality



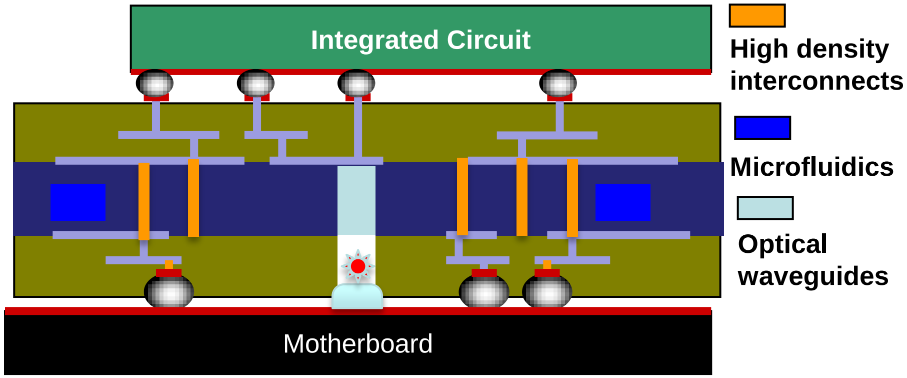


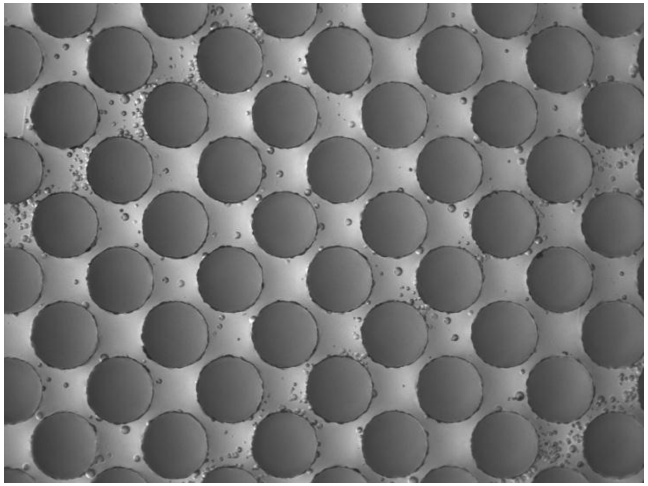
APEX™ Glass: A Simple Microfabrication Approach

2-6 minutes | 3 hours | 5-30 minutes

APEX™ Glass Wafer → Mask & Expose to UV Light → Bake to Form Ceramic → Etch Away Ceramic → Final Part

Advanced Microelectronics Packaging Solutions





100um Diameter TGVs

APEX™ Glass Ceramic:

- A single material for: (1) HD-TGVs, (2) Integrated optical elements, and (3) advanced cooling.
- Create precise micron-scaled structures in glass
  - With sub micron accuracy
  - Of any pattern
  - With multiple step etches
    - Cavities, wells, buried electrical lines, etc.
- Produce over 300,000 vias/cm^2
- Produce over 1MM TGVs in less than 30 minutes of processor time

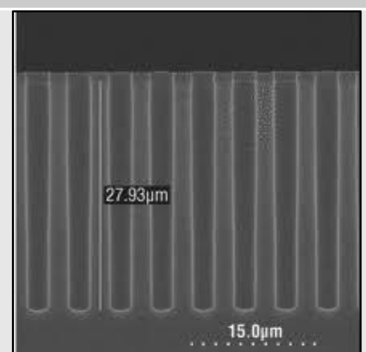
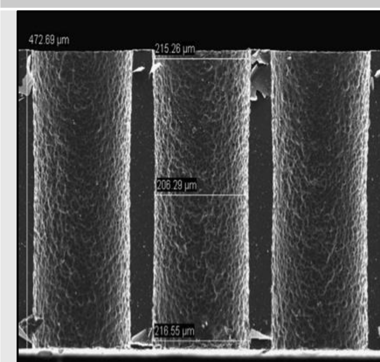
Interposer Material Comparisons

Characteristic	Ideal Properties	Glass Laser Ablation	Silicon	APEX™ Glass
Electrical	• High resistivity • Low loss			
Physical	• Smooth surface finish • Large area availability • Ultra thin			
Thermal	• High Conductivity • CTE matched to Si			
Mechanical	• Post Process High strength • Post Process High modulus			
Chemical	• Resistance to process chemistry			
Processability	• Ease of via formation and metallization • Feature size and fidelity			
Cost	• Low cost per I/O • Tooling cost			

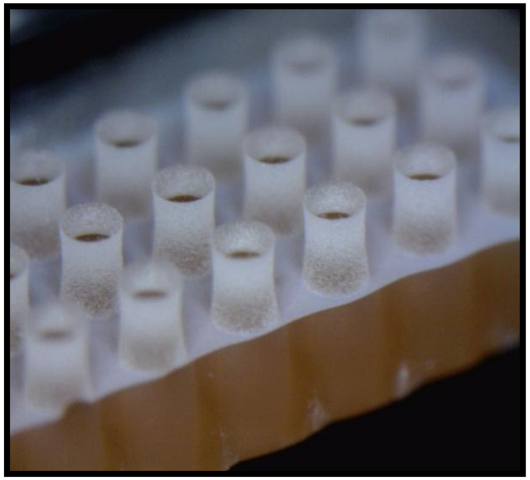
Adapted from Prof. Tummala, GT-PRC

Good Fair Poor

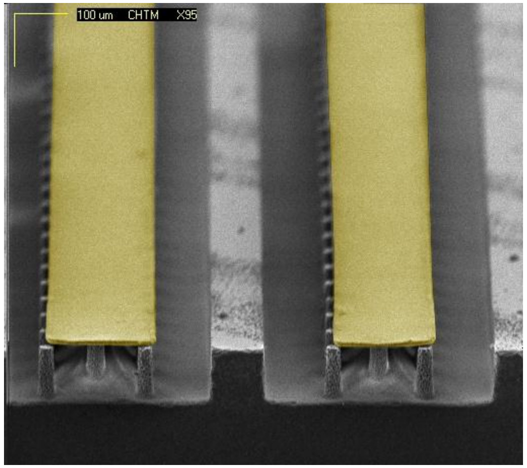
Interposer Material Comparisons

Characteristic	Glass Laser-Ablation	Silicon	APEX™ Glass
General Manufacturing Approach	Serial	Serial	**Batch**
Pattern Approach	CAD drawing	Photo mask with Hard mask	**Photo mask**
Etching Approach	Thermal Ablation	Reactive Ion Etching	**Wet Chemical Etching**
Critical Dimension (demonstrated)	30µm	<5µm	**5µm**
Need for Passivation	No	Yes	**No**
Substrate Form-factor	--Large Panel --Wafers	--Limited Panel --Wafer	**--Limited Panel** **--Wafer**
Defect Formation	Very high due to significant localized heat shock	Zero – Very Little	**Zero – Very Little**
Cross-section of various via technologies			

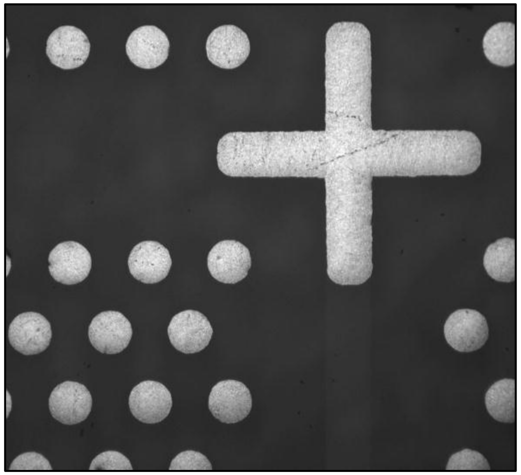
APEX™ Glass Ceramic Applications



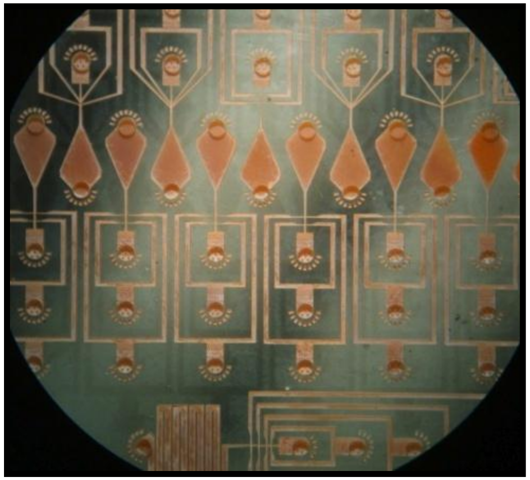
Optical waveguides



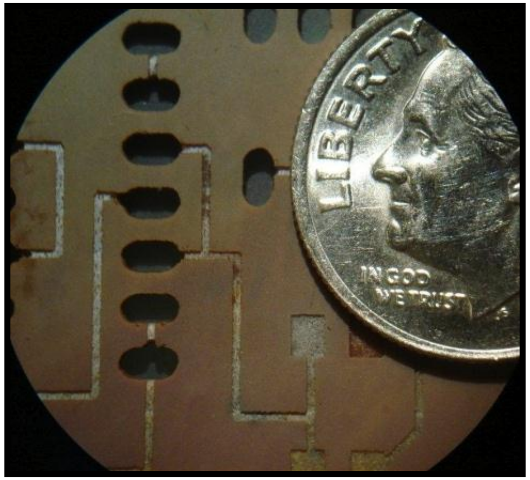
Custom RF Electronic Packages



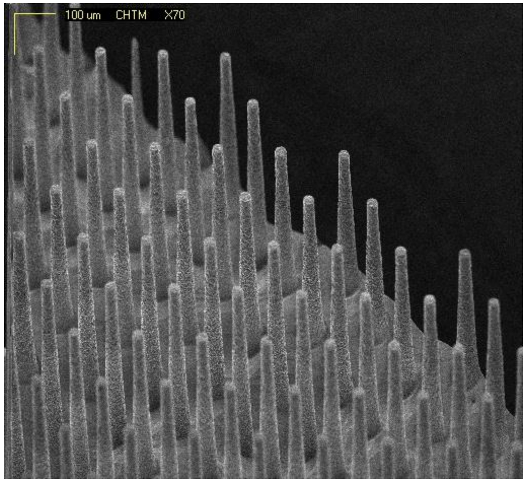
Hermetic Copper Filled Vias



Custom Micro-Fluidic Devices

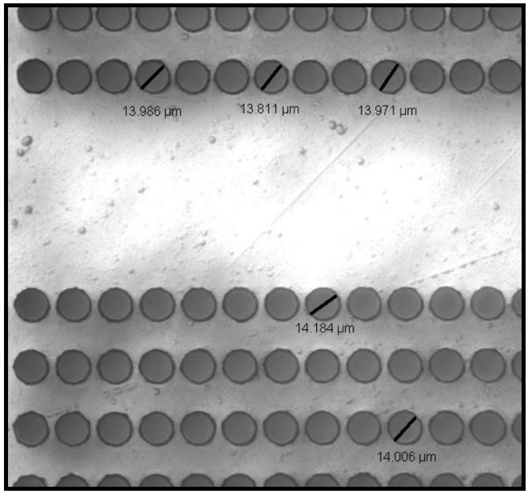


High Temp. Electronic Boards

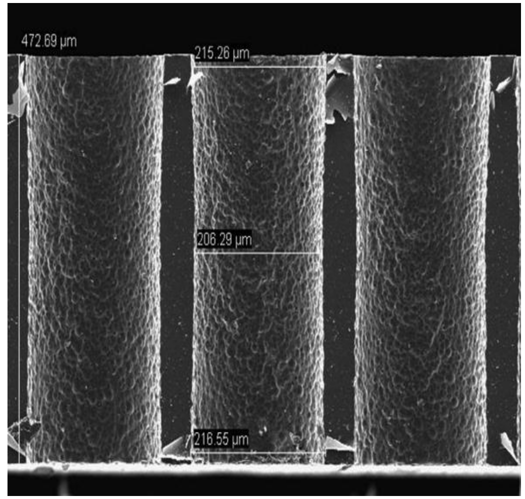


General 3D Microfabrication

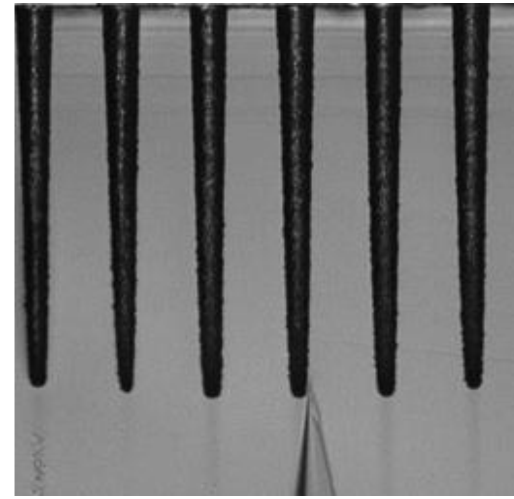
IC Applications in APEX™ Glass



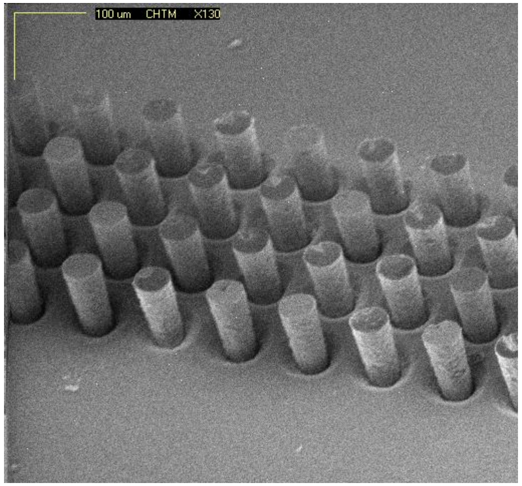
High Aspect Ratio TGVs



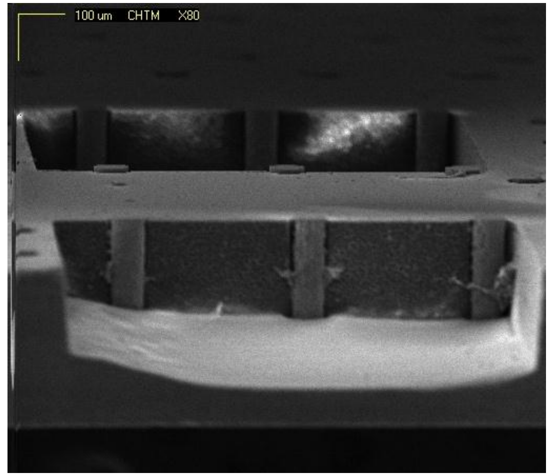
Anisotropic Etch Profiles



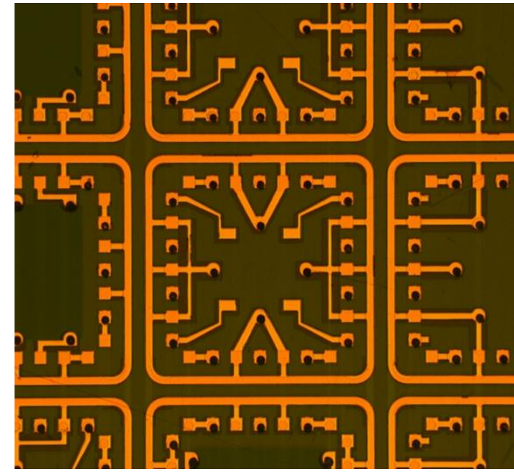
High Aspect Ratio Blind Vias



Bump Bonding Copper Filled TGVs



Multi-Step Processing

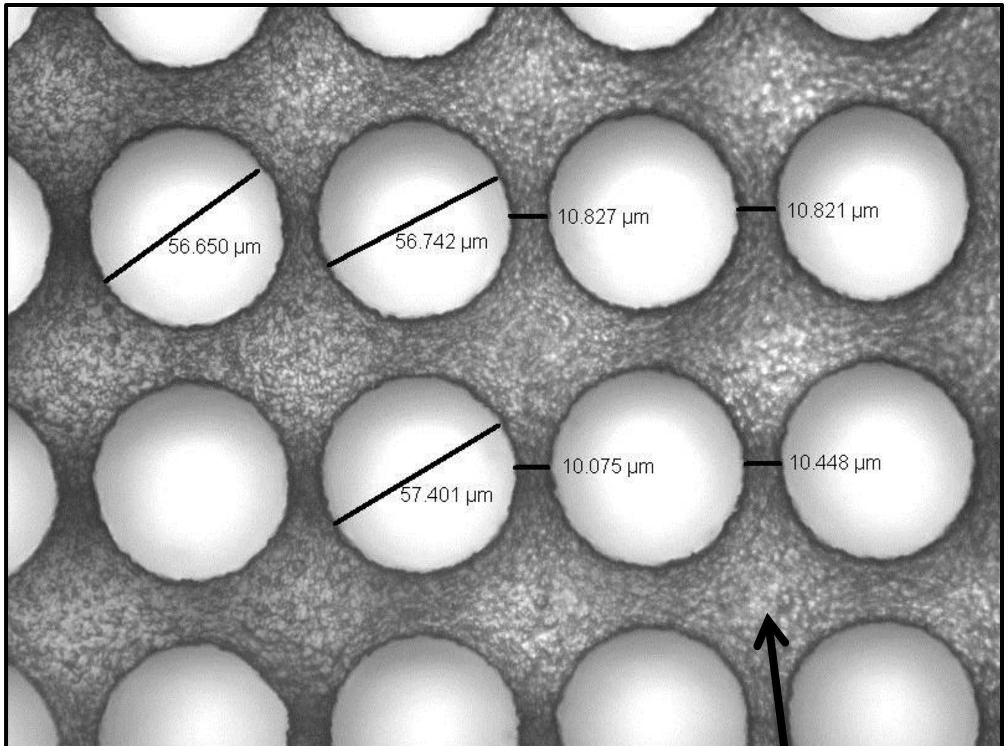


BEOL Compatible

APEX™ Glass Ceramic Technical Specifications

Metric	APEX™ Glass	Silicon	FR-4	LTCC
Thermal expansion	9-10 ppm/K	2.6ppm/K	15 ppm/K	5.9-10 ppm/K
Dielectric constant	5.7	11.7	4.7	5.9 – 7.9
Tg	450 C	N/A	110-200 C	N/A
Young's Modulus	81 GPa	185 GPa	17 GPa	12-27 GPa
Manufacturing method	Semiconductor based	Semiconductor based	CNC drilled	Screen printing
Minimum through hole size	<5um	<10um	100um	75-100um
Material thickness	<100um	<100um	40um	<100um
Transparent	>90% 370-2300nm	IR	No	No
Halogen Free?	Yes	Yes	No	Yes

High Density Interconnects in APEX™ Glass Ceramic



Material Thickness: 250µm
Center-to-Center Pitch: 65µm
TGV Aspect Ratio: 4.5:1
Vias per cm^2: 23,661

Diameter	Edge Gap
56.65µm	10.83µm
56.74µm	10.82µm
57.40µm	10.08µm
56.36µm	10.45µm

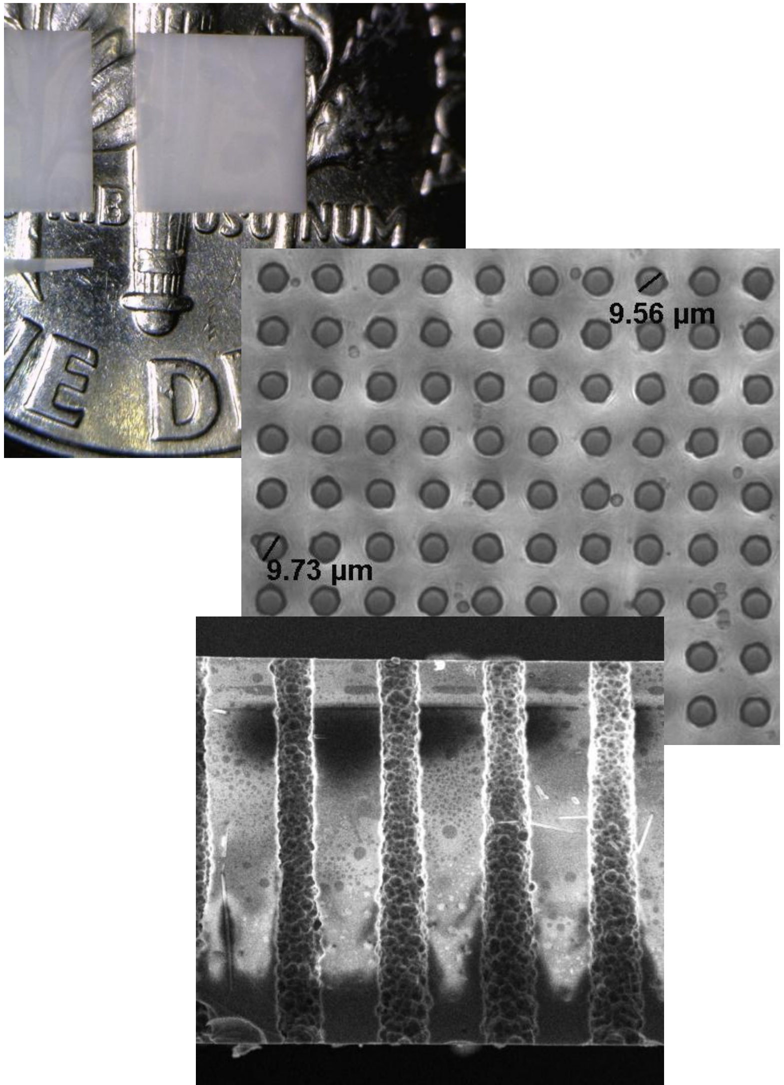
Increased Surface roughness
Due to mechanical lapping

Create Sub-10 micron TGVs

<u>Processing Parameters:</u>

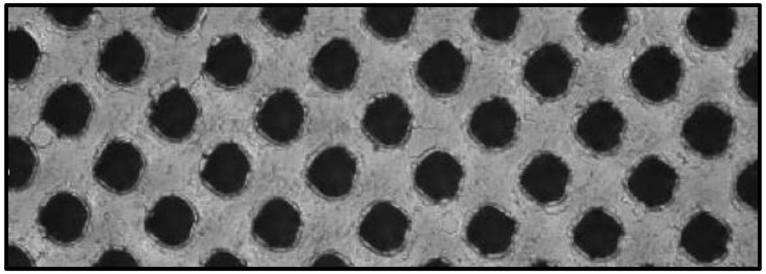
- 10µm patterns on 20µm pitch
- Array pattern: 40,000 TGVs per array
    - Wafer had 100 arrays
    - Total TGVs 4,000,000
- Exposure: 22 Joule/cm^2 at 310nm
- Etch time: 4 minutes
- Results: TGV diameter 9.61 microns +/- 0.15 microns

- Produce over 100M TGVs in an 8” wafer in under 30 minutes of processing time



APEX™ Glass vs. Laser Ablation

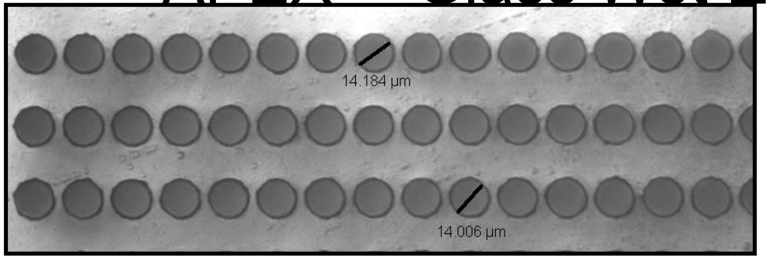
- Wet etching has several advantages over laser ablation and other processes, including:
  1. Significantly lower capital costs
  2. Faster processing times
  3. No debris sputtering
  4. Highly anisotropic profiles
  5. No localized heat shock from fs lasers
  6. Micro-fracture free products
- APEX™ Glass Interposers have been measured to maintain their native Young's modulus
  - Native glass' Young's Modulus: 81GPa
  - 75µm diameter TGV interposer array's Young's Modulus: 80GPa
- Enables manufactures to produce unrivaled glass products with extremely narrow pitches while still maintaining structural integrity



25um Dia.

Versus

APEX™ Glass Wet Etch



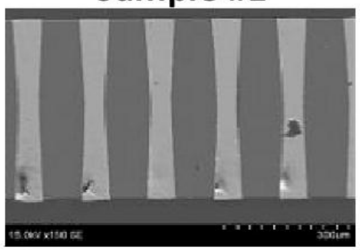
14um Dia.

Diameters	Edge-gap
13.96µm	4.13µm
13.81µm	4.24µm
13.97µm	4.11µm
14.18µm	3.94µm
14.00µm	3.99µm

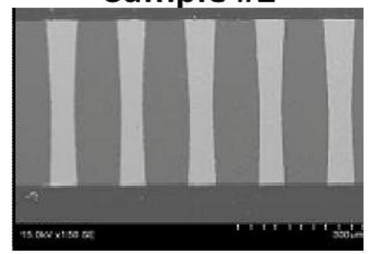
TGV Copper Plug Plating

- Plating is accomplished using a bottom-up approach
- A good metal filling approach for TGVs with >5:1 aspect ratios

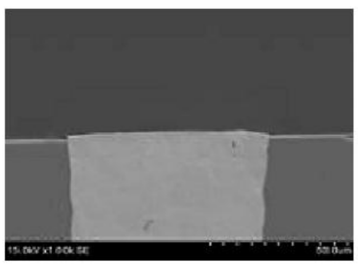
Sample #1

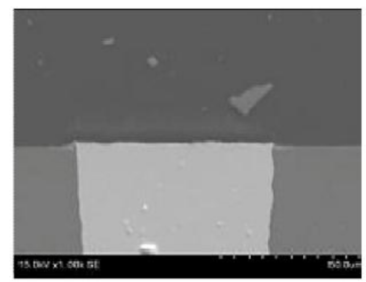


Sample #2

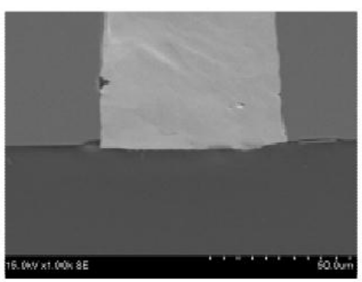


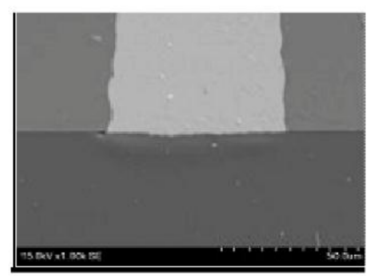
Wafer
Cross-Section





Top of Plated
TGV Close Up





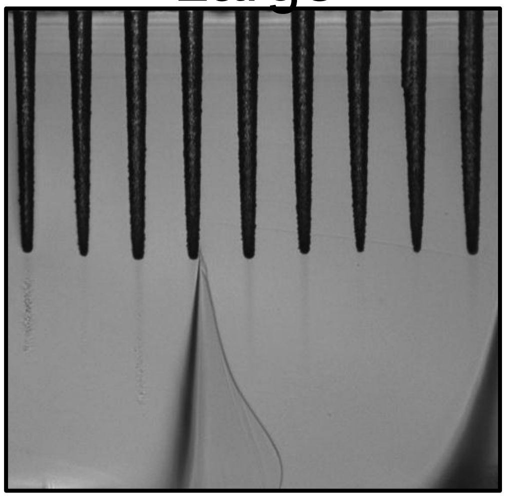
Bottom of Plated
TGV Close Up

75um Diameter, 115um Pitch, Wafer Thickness = 500um
Through Glass Via is 100% Plated with Copper

Images courtesy of SHINKO

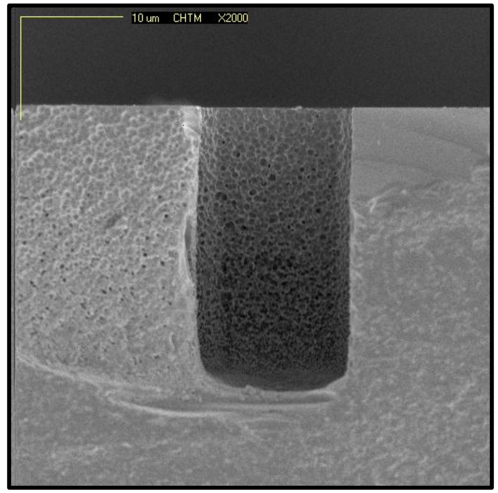
Blind Vias

Large



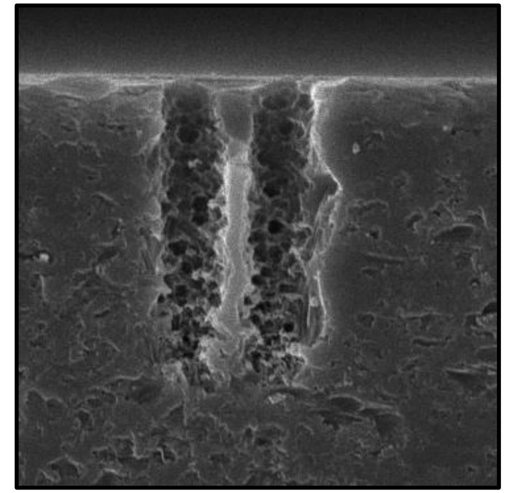
Specifications:
- Substrate Thickness: 1mm
- Blind Via Depth: 440μm
- Topside Diam.: 41μm
- Bottom Diam.: 19μm

Medium



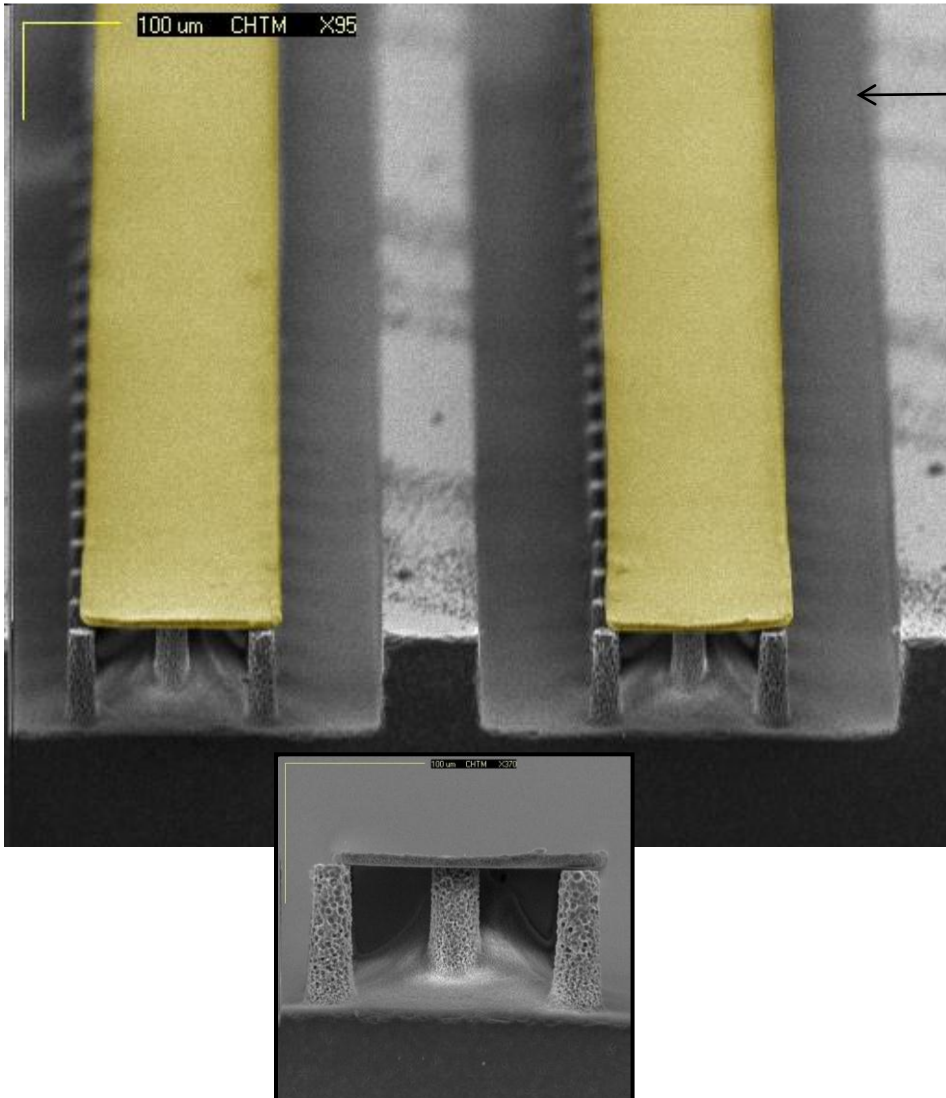
Specifications:
- Blind Via Depth: 23μm
- Topside Diam.: 10μm
- Bottom Diam.: 10μm

Small



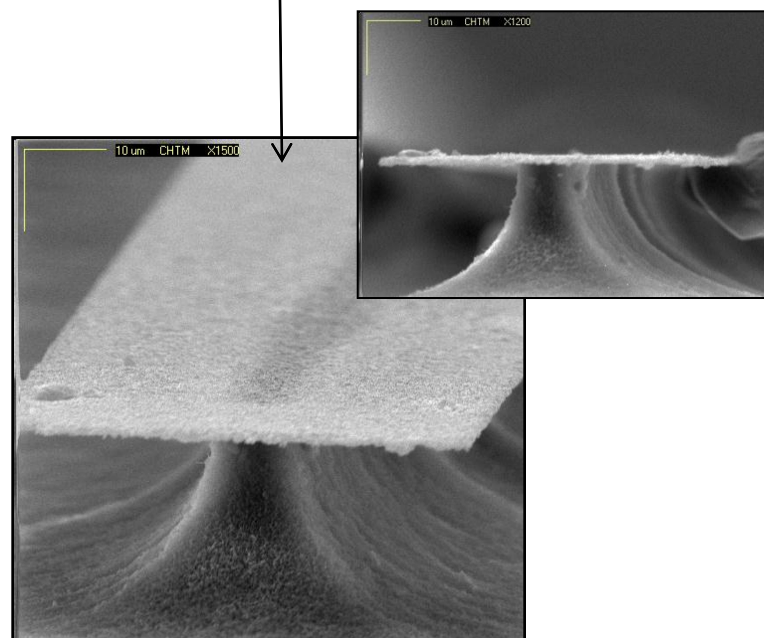
Specifications:
- Blind Via Depth: 35μm
- Topside Diam.: 5μm
- Bottom Diam.: 3μm
- Pitch: 7μm

Metal Rails for more Efficient RF Electronics



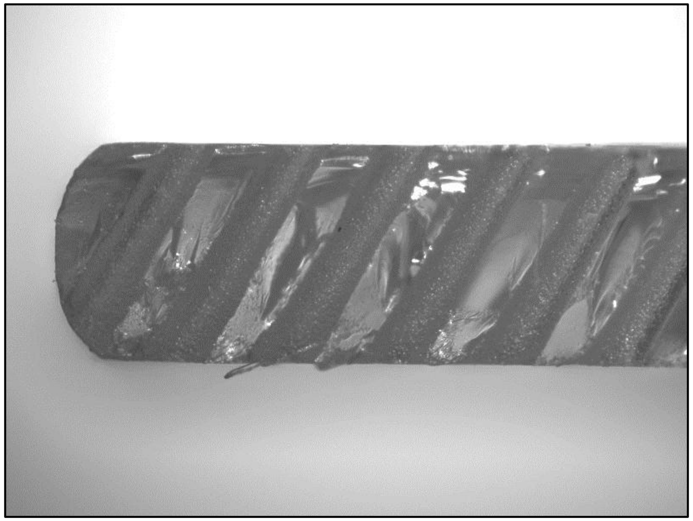
5µm thick copper metal line resting on an array of 20µm diameter, 90µm tall pillars.

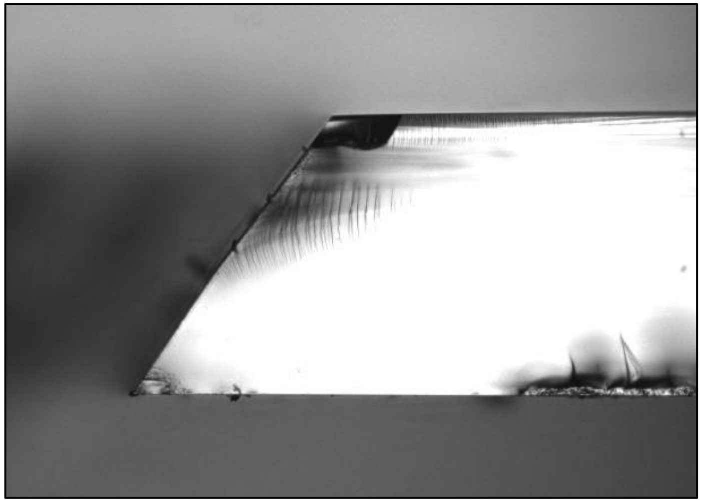
2µm thick copper metal line resting on 10µm wide glass rail



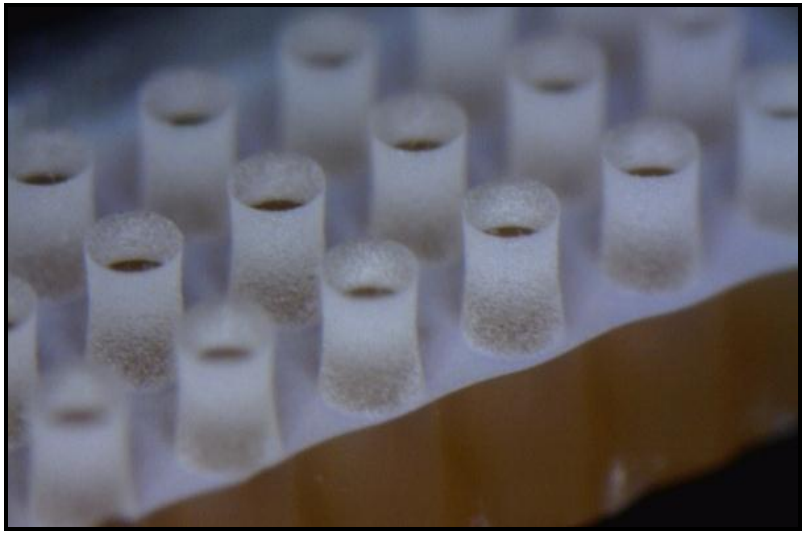
Angled Etches for Embedded Optical Components

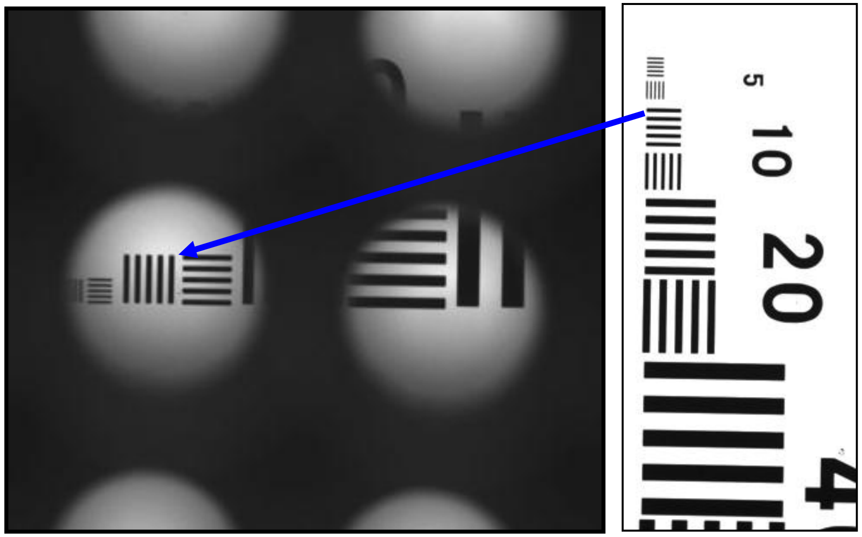
- Historically, making angled features in glass has been extremely difficult
  - 1-offs: extremely low yield
- 3DGS has demonstrated angles ranging from 0-45^o using our standard fabrication approach
- Enables:
  - Integration of optical elements with electronics package
  - Mirrors
  - Filters (long, short, narrow pass)
  - Gratings



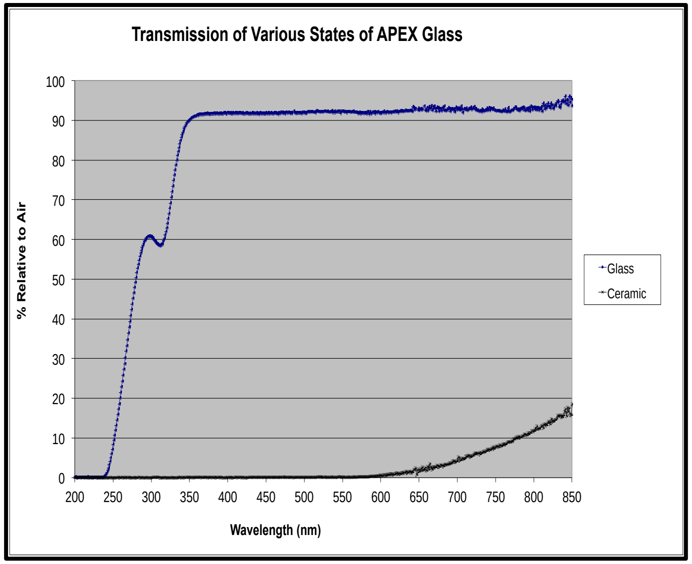


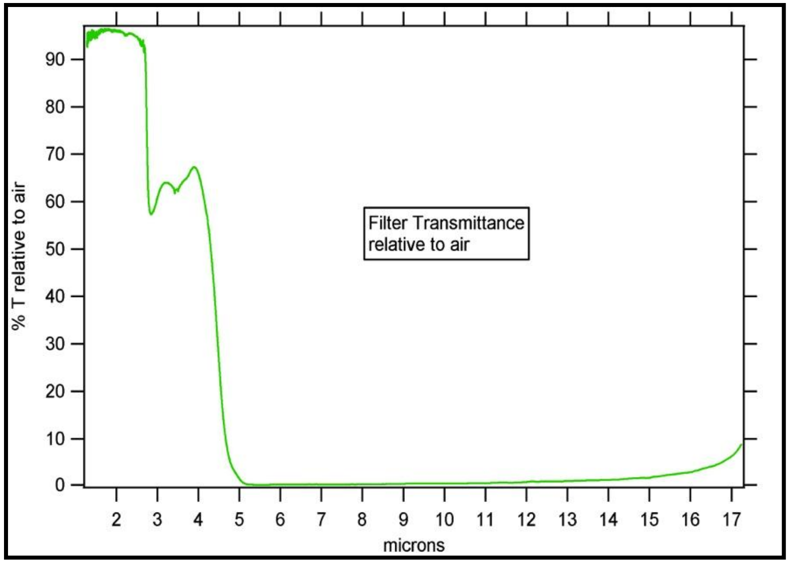
Create Spatially Resolved Optical Elements





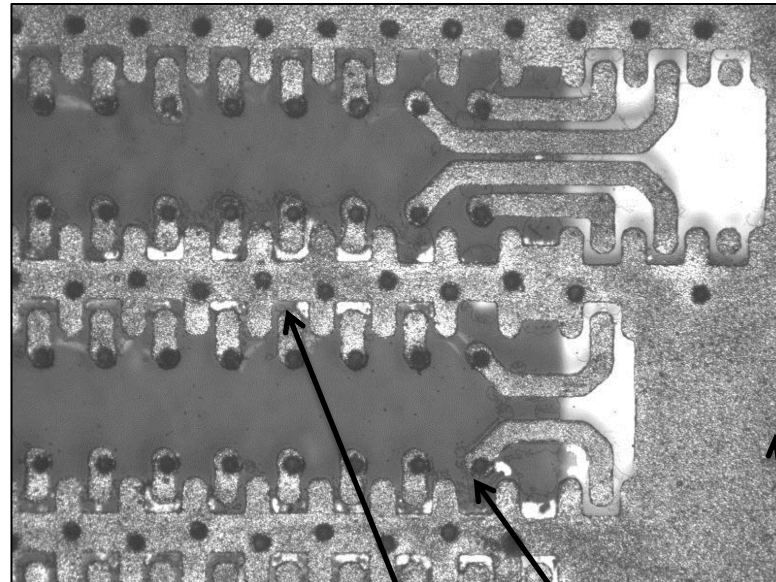
Sizes in microns

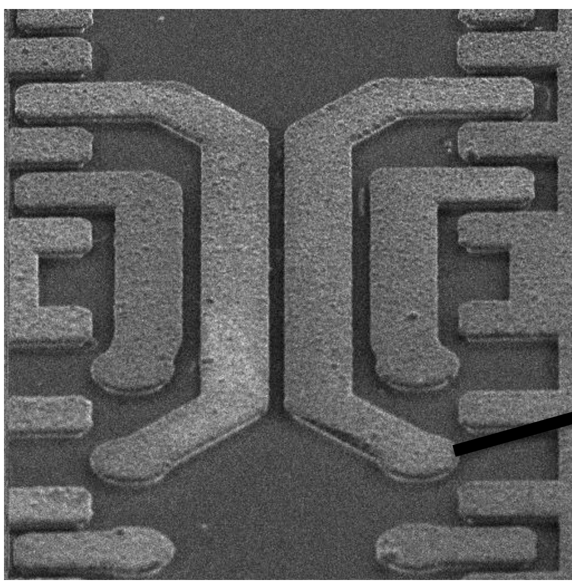


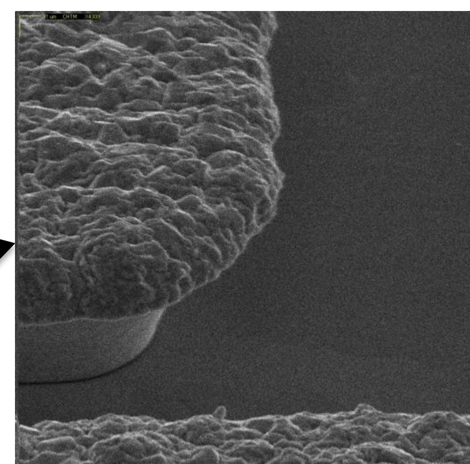


Metal Adhesion on APEX™ Glass

- Metal adhesion to glass has historically been very difficult to accomplish
- 3DGS has identified a process protocol that gives great metal adhesion
- Used this to demonstrate thick-film surface electroplating







40um TGV

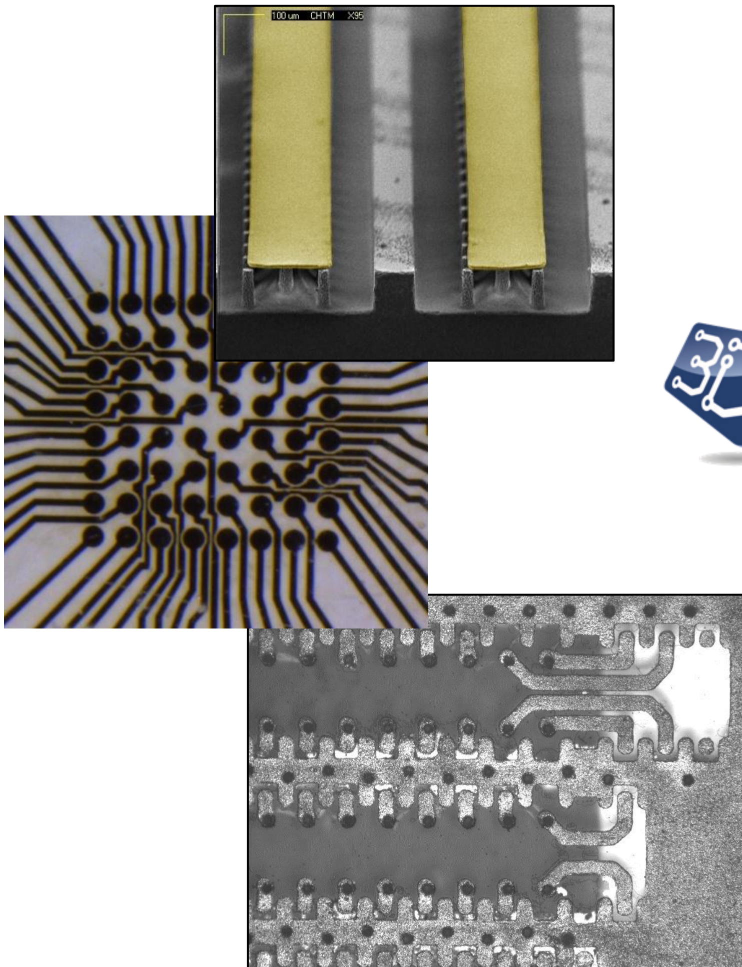
Backside Electroplated Copper

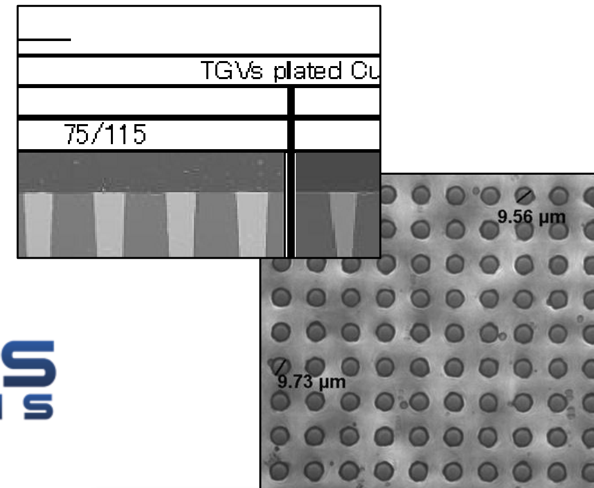
Topside Electroplated Copper

Conclusion:
Advanced Capability = Advanced Microdevices

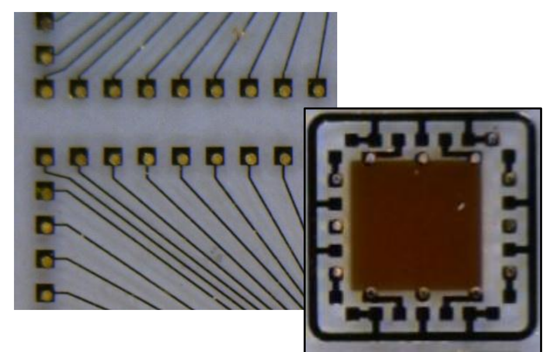
Advanced Designs

Capable Technology





Component Driven



Thank You

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