Thin Glass Substrates with Through-Glass Vias: Fabrication and Application to Millimeter Wave Antennas

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***Abstract*— Glass interposers with fine-pitch through-glass via (TGV) technology is a promising approach to system in a package (SIP) integration. Millimeter wave applications, in particular, benefit from the superior RF properties, dimensional stability, and surface properties of glass. The ability to produce glass in very thin sheets (<100 um) aids in integration and eliminates the need for back-grinding, which can be expensive and a source for defects. The biggest challenge impeding the widespread use of glass as a microelectronics packaging substrate is the existence of gaps in the supply chain, caused primarily by the difficulty in handling large, thin glass substrates using existing automation and processing equipment. This paper presents a novel temporary bonding technology that allows the substrates to be processed in a fab environment without the need to modify existing equipment. The paper also discusses the use of laminated TGV and low loss stripline structures in millimeter wave phased arrays for applications where true time delays are required.**

Keywords—glass; through glass via; steering antenna; true time delay

I. INTRODUCTION

Fabricating reproducible low-loss tune-free RF modules for millimeter wave (mmW) communications is a challenge for commonly used packaging substrates such as ceramics, organic laminates, and silicon, creating an unmet need in the advanced mmW packaging industry. Silicon as a package substrate becomes lossy at higher frequencies, leading to detrimental power loss. [1] The most commonly used alternative substrate is organic-based laminate. Organic laminates do not have a high degree of dimensional stability, they absorb moisture, and have material variability that make them largely unsuitable for 5G communications and other challenging mmW applications. These issues only get worse at higher frequencies. [2,3]. Low temperature co-fired ceramic (LTCC) substrates have challenges due to roughness, ability to scale in size, and dimensional accuracy. LTCC layers are typically thick and shrink as they are fired making them difficult to use for mm-wave due to the variability.

Glass is a promising alternative substrate material for mmW applications due to its desirable electrical and physical properties and ability to be made in panel format with required thickness (~100 um) and in panel formats to reduce manufacturing costs. While overall loss depends on the specific glass composition, glass generally has high resistivity and a low loss tangent at frequencies up to 100 GHz relative to more commonly used materials. High purity fused silica, for example, has a loss tangent orders of magnitude lower than incumbent materials. Past work has shown the value of glass as a low loss material relative to Si, particularly > 1 GHz (see Fig. 1) [4]. Glass is also impervious to moisture and the thermal coefficient of expansion can be tailored to the application. The electrical properties of glass are insensitive to wide variations in temperature and humidity. This is also very important for mmW applications, where small variations in electrical properties and dimensions can have a large impact on module performance. In addition, glass can be made in thin sheets (<100 um) which eliminates the need for back-grinding during manufacturing. Thin substrates keep the overall package height low and allow for small diameter vias, enabling higher density circuitry. These same properties make it a good substrate for mmW integrated photonics as well.

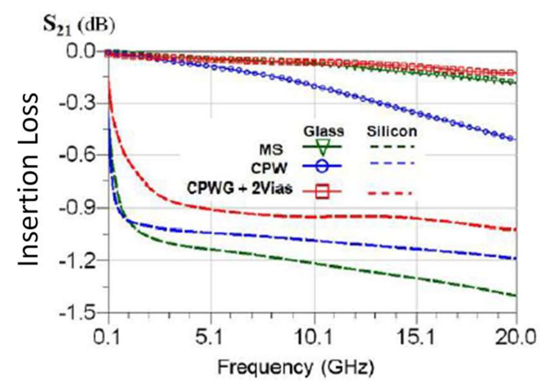
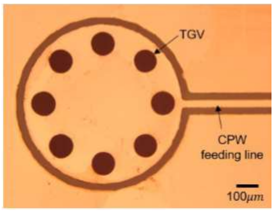
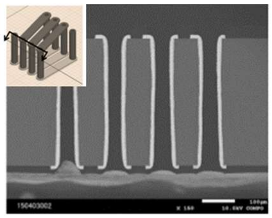


Fig. 1. Example of glass low loss performance relative to Si.

Over the past several years, numerous researchers working in RF and mmWave technology have produced a number of technology demonstrators showing the value of glass [1, 5, 6]. Figure 2 gives a sampling of some of these demonstrators, such as antennas [5] used in mmWave, integrated passive devices [1], MEMs switches [6] and interposers [7].

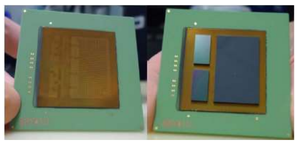


2a: Antenna [5]



2b: Integrated passive devices [1]

2c: MEMs [6]



2d: Interposer [7]

Fig. 2. Examples of devices fabricated in glass to take advantage of low loss.

II. THIN GLASS HANDLING

One challenge for the wide adoption of glass solutions has been the handling thin glass (e.g. < 0.2 mm thick), particularly in an automated fab environment. Mosaic Microsystems has developed a new approach that provides a handling solution utilizing a Si carrier and proprietary temporary bonding technology. This bonding layer is very thin (<1 um), can be used at high temperatures (> 400 ˚C) without out-gassing, and the bond remains temporary, allowing for downstream mechanical de-bond and assembly. Using a Si carrier provides a standard interface to process equipment and sensors, which significantly reduces barriers to process glass substrates in well-established process flows. Essentially process equipment see a standard Si wafer as an interface, with the 100 um thick glass on top. Finally, the mechanical de-bond approach lends itself well to downstream integration with other layers, integrated structures (inductors, capacitors, resistors) and devices.

Mosaic's temporary bond is stable (remains temporary and without outgassing) to over 400 °C, and leaves no residue after de-bond. These attributes allow the thin glass/silicon pair to be processed in existing fabs, leveraging existing processes, with only a mechanical de-bond to yield finished substrates. There are numerous benefits to this approach:

- Utilizing a Si carrier provides a familiar (Si wafer) interface to fabrication equipment, dramatically reducing barriers to entry
- Leveraging the large installed base of semiconductor processing equipment will enable the broad use of glass substrates as a packaging material
- Utilizing thin glass on a carrier avoids the need for back-grinding and polishing operations, which are both expensive and can increase reliability concerns
- The proprietary bond technology avoids outgas and can work at higher temperatures than standard temporary bond approaches
- Mechanical de-bond provides unique downstream wafer to wafer bond/multi-layer lamination strategies.

The key aspects of Mosaic's temporary bond process are summarized in Fig. 3. A thin inorganic surface treatment is applied to the silicon or glass carrier (for reasons above, a Si carrier is the primary approach but glass can be used as well). The thin glass substrate, which may contain through-glass vias (TGVs), is then bonded to the carrier. The bonded stack is then processed through downstream steps such as via fill, CMP, RDL/passive deposition and lithography and bumping.

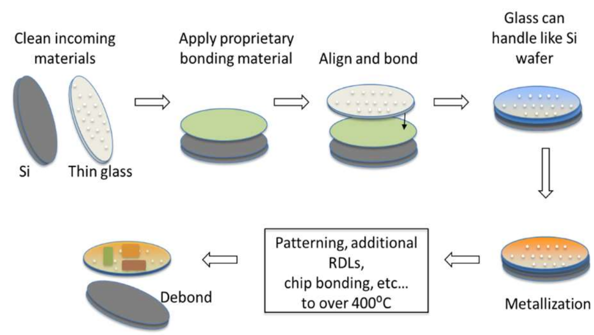


Fig. 3. Overview of the Mosaic thin glass handling solution..

As mentioned above, in addition to providing an easy handling solution, the innovation also addresses another key aspect: integration. The adhesive strength is optimized to be sufficient to enable downstream processing, but then be able to be de-bonded mechanically with low force. Depending on customer flow, this could take the form of transferring directly to dicing tape for die size dicing/singulation, transferring to another carrier for backside metallization, or bonding to another wafer for further wafer-level packaging. Since the bond strength can be adjusted, this approach can also be used to create multi-wafer laminations with ability to integrate passive devices, antenna and/or switches as appropriate, making it attractive for integrating glass in many potential products.

III. TRUE TIME DELAY APPLICAITON

The advances described above have application in important microelectronic applications. One particularly attractive application from both an electronic warfare and RF communication (5G and satellite) perspective is a scanning/steering antenna using true time delay (TTD). Here a fully microelectronic approach using laminates of thin glass substrates is proposed. The advantages of this approach are inherent lower cost, higher reproducibility, increased thermal stability and overall robustness. This approach also utilizes mature materials and processes but combines them in a unique way to enable multi-layer electronic modules suitable for TTD modules and other mmW components.

A key element of TTD modules is the ability to have high isolation (>33dB) between delay lines to avoid coupling between selected and unused delay lines that could cause undesired amplitude or phase variations. Very fine pitch grounded vias around a transmission line may be used to provide increased RF isolation (see Fig. 4). A typical rule of thumb for this "picket fence" is for the via pitch to be less than 1/20th of a guided electrical wavelength at the highest frequency of operation. The substrates must be thin (≤100 um) to allow for the proper impedance and via density, as well as mitigate any high frequency substrate moding in the Z axis. Incorporating striplines and TGV in thin low loss substrates provides an attractive approach to meet these objectives.

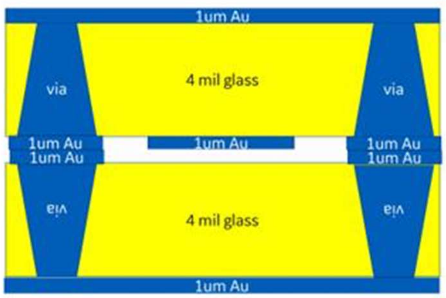


Fig. 4. Overview of the Mosaic thin glass handling solution..

Some of the requirements of a mmW TTD module and phased array Tx/Rx modules are:

- Low loss stripline, (100um thick glass with 1um Au, ~40um 50-Ohm Line, 0.13dB/mm at 50GHz
- Low cost die area (glass can be made and processed in low-cost wafer and panel format)
- High isolation (>35dB) between adjacent transmission lines (fine vias with a 135um pitch)
- Impervious to moisture and thermally stable mechanical geometry over temperature enabling constant impedance and time delay
- Highly stable and reproducible phase delay thru a multi-layer substrate (<5 deg at 50Ghz)
- Integrated resistors on the signal stripline layer for power combiners/dividers & coupler terminations (100-Ohm per square) (50 and 100Ohm values with a +-10% tolerance)
- Ability to solder attach Copper Pillar or Ball Grid Array silicon or gallium arsenide chips on the top
- Compatible metallurgy and solder mask on top and bottom layers for soldering
- Reliability under temperature cycling and solder reflow processes
- Higher temperature processing allowed compared to organic multilayer chip carriers
- Ability to solder to another chip carrier on the bottom
- Fine feature sizes (5um lines/space resolution)
- Thermal dissipation (Fine via pitch and metal vias allow for removal of heat.)

The temporary bond approach described above is well suited to address the challenges for fabricating TTD and similar devices. Since glass is bonded to the Si carrier, via fill, CMP and fine line (5 um) features is readily achievable using well-established processes. The ability to integrate passives and other structures into the glass layers as well as leveraging the mechanical de-bond approach to enable efficient processing of multi-layer stacks. Putting this all together into a process that leverages the distinct advantages of glass along with significantly improved manufacturability makes this approach attractive to enable important initiatives such as TTD phased array modules.

IV. Conclusion

Leveraging the properties of glass for high frequency applications has been of interest for a number of years, particularly for its low loss characteristics. The ability to produce glass in thin and large sheet formats provide additional benefits. Furthermore, a great deal of progress has been made in recent years in the ability to fabricate TGV and execute downstream processing. Some challenges have remained to achieve routine and high volume manufacturability for glass based substrates. Mosaic Microsystems provides a temporary bond solution that addresses the key challenges to enable manufacturability of TGV based modules, and provides additional benefits for downstream integration. These developments can be leveraged to enable efficient manufacture of glass-based components, modules as well as next generation multi-layer structures such as TTD modules.

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