Glass Packaging for RF MEMS

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Abstract

In recent years, advancements in High Performance Computing and Photonics are driving towards high density semiconductor packaging requirements that are creating a need for the adoption of novel material sets. Glass has many attractive properties that help address product level challenges such as low height, and smaller, packages. Glass also offers high resistivity, low dielectric constant, adjustable coefficient of thermal expansion (CTE), and low electrical loss. These properties can also be leveraged for RF and Mobile applications where battery life is paramount. To further utilize glass' material properties for interposers and compact substrates, it is necessary to form precision or Through Glass Vias (TGVs). Mobile cellular networks are rapidly evolving towards fifth generation (5G), which is set to exploit a wider spectrum of frequencies that range into millimeter wave (mmWave). RF MEMS technology is a promising approach to addressing RF Switches, which are key building blocks into Radio Frequency Front Ends (RFFE). In this paper, we show the usage of glass based packaging solutions and TGVs to offer low form factor, broadband RF MEMS switches.

Key words

Glass interposer, through glass via (TGV), RF MEMS, glass substrates, RFFE.

I. Introduction

Recent advancements in semiconductor packaging have allowed for the adoption of new materials sets. Considerable effort is being given to extending interposer technology into 3D-IC stacking. Fan-Out Wafer Level Packaging (FO-WLP) has become a popular consideration, especially to lower cost. [1] In RF, the rapid proliferation of mobile devices and the Internet of Things (IoT) has posed an increasingly difficult set of requirements. Introduction of a greater number of frequency bands, standards that incorporate multiple-input-multiple-output (MIMO) configurations and antenna-sharing all must be supported in limited available space for handheld devices. Smaller and thinner packages are needed, along with lower electrical losses, to conserve power and maintain battery life as this new functionality is introduced. Glass is proving to be an excellent packaging material as designers address these challenges. [2]

The beneficial material properties of glass such as high resistivity, low electrical loss, low dielectric constant, and adjustable coefficient of thermal expansion (CTE) have been exploited by researchers who have demonstrated high-Q inductors and passives that offer excellent RF performance [3]- [6].

Precision hole or via formation in glass and metallization of vias for usage in electrical interconnects, or in the construction of Integrated Passive components, is an area that continues to mature towards volume manufacture. Work in recent years has also demonstrated the reliability of these structures in glass [7]- [9].

Over the past several years, Corning Incorporated, has made significant advances in the producing high-quality vias in glass substrates of various formats such as wafer or panel level. Glass substrates with holes have been shown to have strength that is equivalent to bare glass, and filled vias have been shown to have excellent mechanical and electrical reliability after thermal cycling [9]- [10].

For broad level acceptance, any packaging solution must also be cost-effective. Glass forming processes such as Corning's fusion forming process, can form high quality substrates in large formats (>> 1 m in size). Ultra-slim flexible glass with thicknesses down to ~100 μm can also be produced, which offers another opportunity to reduce manufacturing costs.

Within RF, filtering and switching components are among the first applications to exploit the usage of glass for higher performance packaging. Some of the recent advances are described along with new applications for glass-based solutions.

With the explosion of mobile data demand, fifth generation (5G) mobile networks are set to use a new set of frequency spectrum that ranges into the millimeter wave (mmWave) bands to support increased capacity and higher data rates. Managing this large increase in frequency bands in an efficient and cost-effective manner will be a major challenge for the successful deployment of next-generation networks. Co-existence of the air interfaces, as well as the increase in frequency bands, requires filtering over both narrow and broad bands. Usage of broad band filters (i.e. diplexers and multiplexers) is anticipated to increase dramatically with the adoption of 5G and MIMO configurations. Glass offers the ability to achieve higher performance, passive-based RF filters that are used to separate classes of spectrum. Results for lumped element filters implemented on glass are shown to be higher in performance and offer lower loss as contrasted to silicon and ceramic-based solutions. It is particularly important that lower losses be maintained over a wide range in frequency (up to 6 or 7GHz) to account for the new spectrum now being adopted for 5G. While Moore's law has continued to allow major advances in signal processing and integration on the digital side, the RF/analog front-end needs to keep pace to provide truly reconfigurable and reusable solutions in the future.

One of the more promising technologies to enable low-cost, high performance, RF tuning and configurability has been the micro-electro-mechanical switch (MEMS). These compact mechanical devices improve upon or eliminate most of the undesirable side-effects of solid-state devices (such as non-linearity, high RF losses above 3GHz, and excessive power consumption). In the past, MEMS devices have struggled to achieve minimum reliability requirements and have been cost prohibitive due to process complexity and packaging limitations.

Recent advancements have been made by General Electric spinout Menlo Microsystems in integrating a metal-on-glass RF MEMS process with state-of-the-art through-glass-via (TGV) packaging to create an RF development platform that will address the performance, reliability, and cost requirements for next-generation RF front-end solutions. Other potential TGV advantages over competitive technologies in the RFFE are also shown.

II. Glass Based MEMS Device

Usage of MEMS for RF switching devices has been recently described by Moran et al. (see Fig. 1) [11]. RF Front End modules for 5G will require broadband performance and best in class linearity. Ohmic RF MEMS combine metal switch architectures on fully insulating glass to enable the necessary broadband performance with linearity better than 90dBm. This electrostatically actuated cantilever based MEMS device represents an important advancement in MEMS switching technology. Key innovations include the cantilever metallurgy resulting in metallurgical structures that give increased strength, creep resistance and stable contact resistance that enables long life performance. Menlo's alloy compositions were engineered to maintain both grain stability and minimal strain rate for typical MEMS loads at operating temperatures up to 500°C. This specialized cantilever design leads to longer life performance. Figure 2 demonstrates typical lifetime performance showing a stable 0.3Ω resistance for >12 billion cold switched cycles.

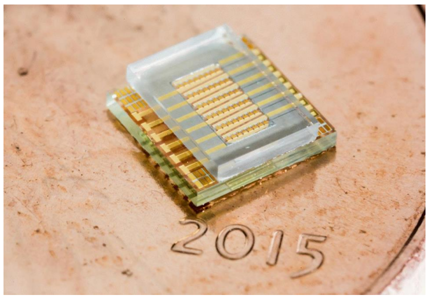

Fig. 1: Menlo Microsystems' 6-Channel, 25W per channel, SPST RF MEMS switch. This combination of glass and metal enables highly broadband RF switches.

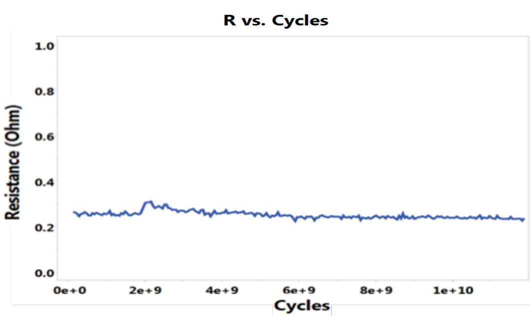

Fig. 2: Typical Resistance of 6-Channel 48-cantilever MEMS switch from Menlo Microsystems

Glass based RF switch devices exhibit significantly lower insertion loss which is a key attribute that is valuable for battery operated systems. Figure 3 shows a direct comparison of the same SPST RF MEMS switch designs fabricated on separate substrate materials; silicon and glass. The reduction in insertion loss for the same design on the glass substrate at 6GHz is 0.35 dB and can be as much as 0.9 dB at 28GHz.

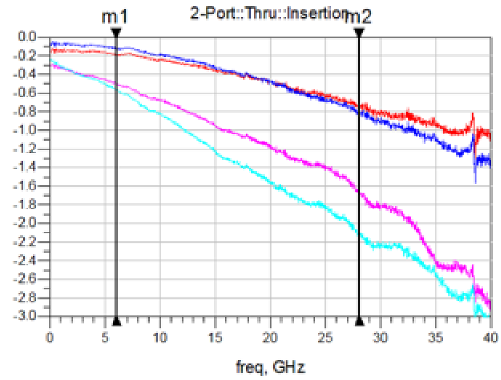

Fig. 3: Insertion loss of two Menlo Microsystems RF MEMS SPST switch designs on both glass (top two traces) and high resistivity silicon (bottom two traces). The glass based performance is 0.8 dB vs. 1.7 dB for Si at 28GHz in frequency.

RF switch functionality is used broadly in the design of RF Front End (RFFE) modules for the design of antenna tuning elements. Tuners are used to create a more optimal match, thereby providing greater spectral efficiency. Tuners can compensate for environmental factors, improve performance, and decrease design cycle time. Antenna tuners are sometimes placed anywhere from 1 to 8 times in a mobile handset, therefore it is a key to have a tuning solution that has a low Ron x Coff or Figure of Merit (FOM).

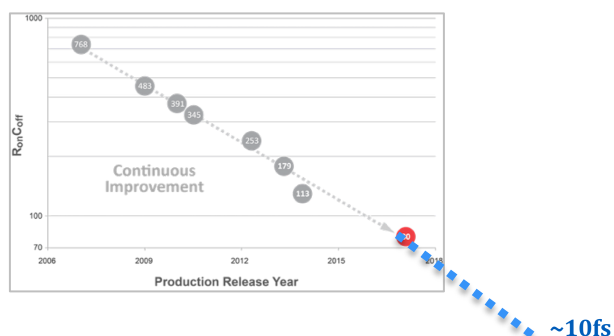

Fig. 4: Figure of Merit (Ron x Coff) comparison for RF MEMS-based switch to SOI-based products. Source: Menlo Microsystems & pSemi

Advantages for MEMS-based RF switches are shown in Figure 4, where we can observe FOM (Figure of Merit) that is ~ 1/8th of the current generation SOI based approaches.

Additional advantages of the architecture are seen when we look at the high frequency operation of the device as shown in Figure 5.

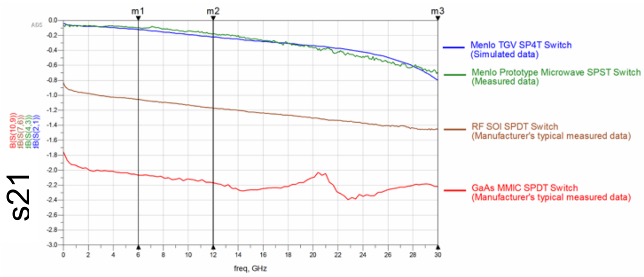

Fig. 5: Broadband performance of RF MEMS-based switch has been demonstrated to outperform other technologies. Source: Menlo Microsystems.

Here we can see lowest in class insertion loss as compared to RF switches based on either SOI or GaAs. Glass-based packaging is providing lower parasitics in the form of lower bulk resistance, which leads to the lower insertion loss. In addition, the low dielectric constant of glass improves high frequency performance as well. In addition to the ability to operate from DC to high frequency (> 30 GHz), these devices are operable from 10W to >1kW opening the technology to markets beyond mobile handsets. The architecture is simple and scalable with low insertion loss and high linearity, making it attractive for a broad range of applications.

Incorporation of TGV in future MEMS designs will provide even greater benefits to performance, size and interconnect integration while maintaining the necessary hermetic wafer package requirement. Glass will help lower dielectric and RF losses because the interconnect distances will be lower, thereby increasing compactness at the product level. TGV and metal MEMS devices will create a differentiated switching platform that combines the low loss and minimal power dissipation of mechanical relays with the speed and electrical integration of solid state relays.

III. RF Front End

Mobile RF front ends have evolved to include multiple frequency bands, carrier aggregation, MIMO, and are heading towards even higher frequencies and wider bands to enable higher data rates. In the RF front-end (placed between antenna and transceiver), there are many passive elements required to provide enough filtering and isolation for the multi-band multi air interface standards to co-exist. The current RF front-end (RFFE) challenge is to increase the functionality with a smaller/thinner package size, lower power consumption, and lower losses inside the device. A glass-based substrate could be an excellent choice for these challenges.

Through Glass Vias have been used to make integrated passive devices (IPDs). [2] Metallization of the TGV and surfaces can be leveraged to make three dimensional inductors as shown in Fig. 6. That combined with surface metallization and dielectric to form MIM (metal-insulator-metal) capacitors, provides a way to leverage the insulating properties of glass to make high Q inductors and therefore a better class of broadband filters and diplexers.

Passives based on TGV utilize plated copper and have a number of advantages compared with IPDs made from LTCC. LTCC-based designs often use an Ag paste which has lower metal conductivity and therefore have limitations on Q values. Furthermore, the smoother surfaces on glass lead to lower electrical resistance of plated copper, and improved parasitic capacitance given by glass insulating properties, results in increased Q-factor. Finally, precision TGV technology utilized in 3D IPD lends itself to thinner devices and ability to provide smaller footprint. This is summarized in Fig. 6 and 7.

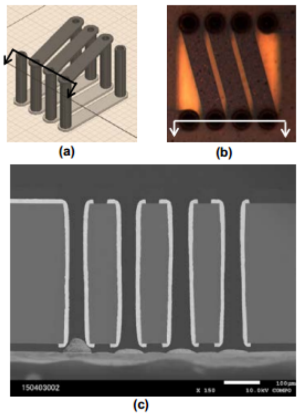

Fig. 6: 3D TGV inductor structure (a) 3D rendering, (b) top-down photograph (c) cross-sectional SEM of TGV with conformal Cu plating on the TGV sidewalls, and the top and bottom sides of the glass to form a 3D TGV inductor.

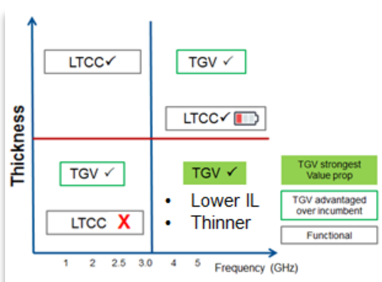

Fig. 7: The properties of glass make it well-suited for RF devices with excellent high frequency performance.

IV. Conclusion

Glass continues to be an important material for next generation packaging advances. Prospects towards low cost can be made through the usage of panels which can be scaled to very large sizes and created to be as thin as 100 µm. TGV formation has matured in wafer and panel format with multiple examples in the supply chain of metallized glass panels. The insulating properties of glass make it ideal for use in RF applications for low loss performance at high frequencies tracking the evolution of networks into 5G. We anticipate that applications such as High-Performance Computing and Photonics will make use of the material properties as well.

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