Substrate Integrated Waveguides in Glass Interposers for mmWave Applications

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Abstract—This paper presents the first demonstration of Substrate Integrated Waveguides in glass interposers operating in D-band (110 GHz to 170 GHz) for mmWave applications. The material stack-up consists of 100 μm thick AGC ENA1 glass core laminated with 15 μm thick Ajinomoto Build up Films (ABF GL102) on both sides. The stack-up has been metallized using a newly developed Semi Additive Process (SAP). SIWs have been fed using broadband microstrip taper transitions. Conductor Backed Coplanar Waveguide (CBCPW) to microstrip transitions were designed to probe the samples. Cascade Infinity Probes (170-S-GSG-75-BT) were used for the electrical measurements. The measured insertion loss of glass based SIWs varies from 0.5 dB/mm to 1 dB/mm in the entire D-band. For most of the frequencies it varies in the range of 0.5-0.8 dB/mm. The performance of glass interposer based SIWs has been compared with SIWs in LCP and silicon interposer.

Keywords—D-band, Glass-based packaging, interconnects, SIWs

I. INTRODUCTION

The development of 5G wireless networks has explored the use of millimeter wave region, particularly carrier frequencies like 28 GHz and 39 GHz. As these communication standards continue to evolve, the carrier frequencies above 100 GHz will be used to provide the wide physical bandwidth needed for the beyond 5G networks [1]. This presents unprecedented challenges and opportunities for the development of RF and microwave technology above 100 GHz.

To meet the stringent performance requirements of mmWave modules, interconnects with low loss, zero cross talk, high power handling capability and good broadband performance are required. Substrate Integrated Waveguide (SIW) technology [2] is promising for such applications as it preserves the advantages of bulky waveguides in a low-profile form factor that is easy to integrate with planar structures. It can be used as a building block to make interconnects and other passives such as filters, couplers, power dividers etc.

In the past, SIWs above 100 GHz have been presented using 130 nm CMOS technology [3] but they exhibit poor electrical performance due to the extremely limited substrate thickness available (~10 μm) in BEOL. Organic substrates like LCP have also been used to develop SIWs in D-band but they suffer from large conductor loss due to the surface roughness (~350 nm) of LCP [4]. Other than surface roughness, large minimum feature sizes of LCP (~10μm) is also a limitation of this platform for mmWave applications. CMOS process compatible SIWs in silicon interposers have been presented in [5] which show good electrical performance in D-band, but cost is a major issue for such solutions due to the use of high resistivity silicon substrates.

To address the limitations of existing packaging technologies, glass-based packaging has gained a lot of attention for supporting mmWave modules due to its ability to support fine feature sizes, ultra-smooth surface, excellent dimensional stability and low cost. Glass-based packages are fabricated by laminating a glass core with thin polymer films on both sides. Lamination enables high density component integration with double sided redistribution layer due to low loss of thru glass vias (TGVs). Glass-based packages achieve silicon-like pitches (~1 μm) at low cost due to large panel processing capability like organics (LCP) [6].

The merits of glass-based packaging make it worthwhile to develop and benchmark the performance of SIWs in glass interposers. In this paper, we report the first results for SIW interconnects in D-band (110 GHz to 170 GHz) embedded in glass interposer. SIWs have been designed and fabricated on ABF/Glass/ABF stack up. The stack up consists of 100 μm thick AGC ENA1 glass with 15 μm ABF films laminated on both sides.

II. DESIGN DETAILS

SIW consists of two metal layers connected by via side walls enclosing the substrate. For cut off frequency for the first mode (TE_{10}), the width of the SIW should be equals to one half of the wavelength corresponding to that frequency. The dielectric constant of ABF/glass/ABF stack up has a relative permittivity of 4.6 [7]. A frequency dependent loss tangent model was used for the loss tangent of the stack up. The loss tangent values used were 0.009, 0.012 and 0.015 at 120 GHz, 140 GHz and 160 GHz, respectively [8]. The width of SIWs was designed to be 900 μm to keep the cut off frequency for first mode (TE_{10}) around 80 GHz. The diameter and pitch of the via side walls were designed to be 100 μm and 150 μm respectively. To feed the designed SIWs, broadband microstrip taper transitions were used. The taper width and length were determined by performing optimization in Ansys HFSS. To probe the designed samples, CBCPW to microstrip transitions were designed. The CBCPW probe pads were designed to be consistent with the probe pitch of Cascade Infinity Probe (75 μm). SIWs with two different waveguide section lengths (4 mm and 8 mm) were designed to eliminate the effect of CBCPW probe pads, transitions, feed lines and microstrip taper. The design and dimensions for material stack up, CBCPW to microstrip transition and SIW are shown in Figure 1.
III. FABRICATION

The designed SIWs were fabricated using a Semi-Additive Process (SAP) [9]. The process flow is described in Figure 2. In the first step Thru Glass Vias (TGVs) were drilled in the glass substrates. Then 15μm thick Ajinomoto Build up films (ABF GL102) were vacuum laminated on glass. The lamination fills the TGVs with the polymer film. Next via in via were drilled in the glass substrates using Cornerstone Laser Machine. Then the 0.4μm thick Cu Seed layer was deposited using electro-less copper deposition. Next, a 7μm thick dry-film positive photoresist was laminated on the seed layer. Then it was exposed using standard photolithography process. Copper was deposited to 7μm by electroplating and then the seed layer was etched by using differential etching.

![Fig. 2 Process Steps for fabrication](image)

The fabricated samples were examined using Zeta Optical Profilometer. The fabricated samples are shown in Figure 3. The fabricated dimensions were over etched by ~4 to 5 μm. The measured dimensions were used in the simulation models to obtain better model to hardware correlation.

![Fig. 3 Fabricated Samples](image)

IV. MEASUREMENTS AND RESULTS

The scattering parameters for the designed SIWs were measured in the D-band (110 GHz to 170 GHz). Agilent vector network analyzer (E8361C) along with millimeter wave controller and frequency extenders (V06VNA2) were used to take the measurements. The samples were probed using Infinity probes 170-S-GSG-75-BT (75μm pitch) by Cascade. Cascade WinCal software was used to perform LRRM calibration to remove the losses from cables, test heads and probes. The simulated and measured scattering parameters of the designed samples are shown in Figure 4. In addition to the response of SIW sections, these results include the loss of CBCPW pads, CBCPW to MS transition, microstrip feed lines and microstrip taper transitions.

To de-embed the response of the SIW section, the insertion loss of the samples were subtracted. The de-embedded \( S_{21} \) response (per mm) is shown in Figure 4c. The measured insertion loss of glass based SIWs is 0.5 dB/mm at 110 GHz and 0.72 dB/mm at 170 GHz. The insertion loss mostly stays within a range of 0.5-0.8 dB/mm for the entire D-band except for a narrow frequency band around 150 GHz. That irregular trend is not captured in simulation and hence it can be attributed to the inaccuracy due to process variations and measurement uncertainties.

V. PERFORMANCE COMPARISON

The performance of glass based SIWs has been compared with SIWs on silicon interposer and LCP. It can be seen in Figure 4c that glass based SIWs perform very close to LCP and silicon interposer. It implies that glass-based packages can be used to take advantages of SIW structure with good electrical performance, while having ability to form silicon like pitch at low cost. Although the loss tangent of LCP is lower (0.009 at 155 GHz) as compared to glass (0.015 at 150 GHz), LCP based SIWs suffers in mmWave region due to its large surface roughness. The performance is also very close to silicon interposers which cost 10x more than the glass interposers.
In this paper, we report first results for SIWs embedded in glass interposer for D-band. The material stack-up consists of 100 μm thick AGC ENA 1 Glass laminated with 15 μm of ABF GL102 on both sides. SIWs have been fed using microstrip taper transitions. Standard semi-additive process has been used to fabricate the designed SIWs. The electrical measurements have been taken for the frequency range 110 GHz to 170 GHz. The insertion loss of SIW varies from 0.5dB/mm to 0.8dB/mm for almost entire D-band. The glass based SIW demonstrates comparable performance to the LCP and Silicon based SIWs. This work can be useful for the development of mmWave modules.

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REFERENCES