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Assessment of RDL Technology at Sub-THz Frequencies

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Abstract—This contribution presents the assessment of RDL technology at sub-terahertz frequencies based on polybenzoxazole (PBO) polymers. A stack of two PBO layers of 10 μ m thickness with 3 metallization of 5 μ m copper is being under development. Vias as small as 10 μ m and a separation of 60 μ m are being explored. To assess the materials and capabilities of this technology, GCPW, stripline transmission line structures are being assessed, expecting losses in the order of 1.3dB/mm and 2.1dB/mm respectively. Moreover, two resonators have been designed to enhance the accuracy of the characterization.

I. INTRODUCTION

THE sub-THz frequency spectrum offers promising opportunities for emerging applications, such as high-resolution sensing, short-range wireless link and high-data rates wireless communications, which requires ultra-high-speed data transmission [1]. Full transceivers and radars front-ends MMICs in silicon technology are available thanks to the increase of the f_T/f_{max} towards the higher frequency spectrum [2].

A key challenge at sub-THz frequencies is the integration of integrated circuits (ICs) with antennas, whether on-chip or within the package [3]. Redistribution Layer (RDL) technology, which is widely used at lower frequencies to enable fan-out from the chip to the printed circuit board (PCB), becomes increasingly complex as frequency increases. On one hand, RDL technology must satisfy strict electrical, physical, mechanical, and chemical requirements [4]. On the other hand, a co-design approach between the MMIC and the antennas, both on-chip and in-package, is crucial to achieving efficient interconnections. To achieve ultra-high input/output (I/O) densities, both silicon back-end-of-line (BEOL) [5] and polymer-based RDL solutions have been explored [6]. The latter is particularly advantageous due to its ability to support thicker layers, which are essential to achieve lower transmission line losses in the sub-THz frequency range.

Various polymers have been explored in the literature for RDL applications in the sub-THz spectrum. One approach involves the use of Ajinomoto Build-up Film (ABF)-type laminates on glass substrates, as demonstrated in [7]. These materials enable thicknesses of up to 100 μ m [8]; however, they cannot be patterned using standard lithography processes and require laser ablation. Alternatively, photosensitive polymers such as benzocyclobutene (BCB) and CYCLOTENETM XP80 can be patterned using conventional lithography techniques [9, 10], allowing for higher-resolution features. However, the viscosity of these polymers limits their achievable thickness to around 10-15 μ m.

In this study, we evaluate the electrical properties and the

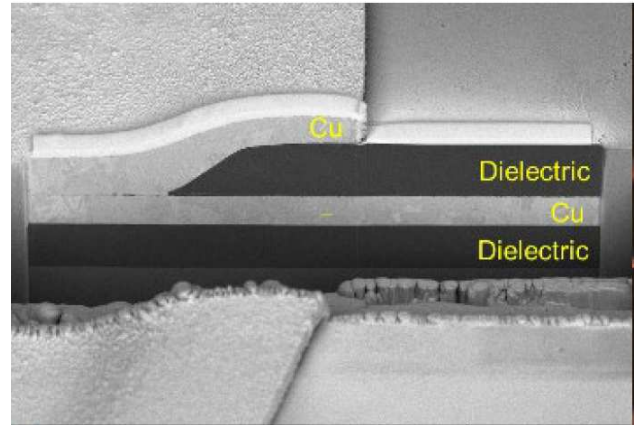


Figure 1: SEM image of a preliminary fabrication samples of RDL using PBO.

vertical interconnect capabilities of a polybenzoxazole (PBO)-based RDL in the 100GHz to 330GHz frequency range. This polymer enables the use of standard lithography processes to achieve high-resolution, high-density vias and transmission lines. The material characteristics and fabrication capabilities will be examined in detail in this work.

II. RDL TECHNOLOGY

In this contribution we evaluate a two layer RDL of PBO fabricated with a Semi-Additive process (SAP) [11]. This technology is based on a chip-first/RDL-last method package [12].

The proposed RDL stack up consists of three metal layers and 2 PBO layers built on top of a glass wafer. The PBO layers are spin-coated on a glass substrate and exposed using lithographic processes. The metallization is realized by first depositing a seed layer of Titanium (100nm) and Copper (200 nm) on the patterned PBO followed by photoresist spin-coating and patterning. Then, the metal layer is completed by using electrolytic copper plating to achieve the desired thickness. After photoresist stripping, the seed layer is removed with a wet etching process. A Scanning Electron Microscope (SEM) image of preliminary fabrication test is shown in Fig. 1.

With this technology we are aiming to allow the fabrication of multi-layer PBO stack with metallization on each interface. Vias as small as 10 μ m diameter with a separation of 60 μ m can be achieved with this technology which, for instance, enables the realization of GCPW without surface wave loss in the sub-terahertz regime.

III. RDL TECHNOLOGY ASSESSMENT

This section explains the structures used to assess the electrical performance of the RDL from 100GHz to 330GHz.

IV. ACKNOWLEDGEMENTS

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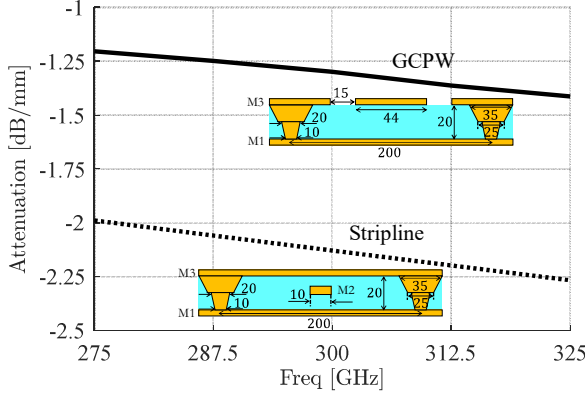


Figure 2: GCPW and stripline transmission line developed in the RDL technology and the expected attenuation around 300GHz. The dimensions in the schematics are in μm .

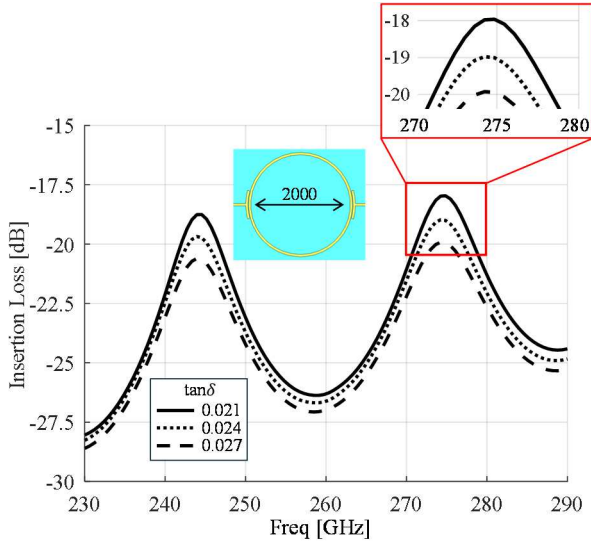


Figure 3: Sensitivity analysis of the $\tan\delta$ showing the transmission coefficient as a function of the frequency of the ring resonator. The dimensions in the schematics are in μm .

Transmission line test structures will be measured on the package through RF waveguide probes and frequency extenders. On one hand, Thru-Reflect-Line structures have been designed to assess the loss of a transmission line. For this, Grounded Coplanar Waveguide (GCPW) lines have been designed, where the signal is in M3 and the ground is in M1, as shown in the cross-section of Fig. 2. The estimated loss is expected to be around 1.3dB/mm at 300GHz assuming a relative permittivity of $\epsilon_r = 3$ and $\tan\delta = 0.024$. Additionally, a stripline transmission line with the signal in M2 and grounds in M1 and M3 is also assessed, expecting a loss of 2.1dB/mm at 300GHz (see Fig. 2). Lastly, microstrip ring resonators have been designed to improve the accuracy of the material technology assessment. In Fig. 3 a first estimation of the sensitivity of the assessment of the PBO loss tangent is shown.

The test structures are currently being fabricated and measurements are expected in the upcoming months.