Silicon Micromachining Technology for Passive THz Components

Choonsup Lee, Bertrand Thomas, Goutam Chattopadhyay, Alex Peralta, Robert Lin, Cecile Jung, and Imran Mehdi

***Abstract*— Silicon micromachined terahertz passive components such as silicon washers, waveguide blocks for W-band (75-110 GHz) power amplifiers, and waveguides for 325-500 GHz band have been designed, microfabricated, and characterized. Based on these results, an integrated 600 GHz silicon micromachined Radiometer-On-a-Chip (ROC) has been demonstrated for the first time. It reduced in mass by an order of magnitude compared to the conventional metal machining.**

***Index Terms*—Silicon micromachining, Radiometer-On-a-Chip (ROC), waveguide, silicon washer.**

I. Introduction

There is an increasing interest in the millimeter and submillimeter wave frequency range for various applications such as compact range radar, terahertz imaging, and the space [1-2]. The frequency bands for these applications are in the range of 300 GHz to 3 THz corresponding to a wavelength of 1 mm to 100 μm which silicon micromachining can contribute significantly. At submillimeter wave frequency range, the hollow waveguide has been used due to the low loss, and manufactured by conventional milling and drilling machines. However, at frequencies above 500 GHz, waveguides become so small (less than 0.3 by 0.15 mm) that conventional machining technique becomes extremely difficult, expensive, and/or impossible to manufacture. Thus, silicon micromachining technique have been attempted to make passive components below 100 GHz. [3]. Silicon micromachining technique is capable of achieving micron feature size with excellent process control such as high aspect-ratio, uniformity, and surface quality. While there have been several demonstrations of waveguide circuits fabricated with silicon micromachining and other techniques, few if any of these circuits have been subjected to any significant electrical testing [3-4]. In this paper, we have demonstrated THz passive components such as silicon washer, waveguide blocks for W-band amplifiers, and waveguides for the 325-500 GHz band, and applied it to 600 GHz ROC for the first time ever.

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II. Implementation and Results

A common hurdle to date to test these components has been the eventual interface of the Si pieces with the metallic waveguide. We have developed a silicon washer where the surface of the Si wafer is used to make the Si-metal interface. It showed the same behavior as metal washer (Figure 1).

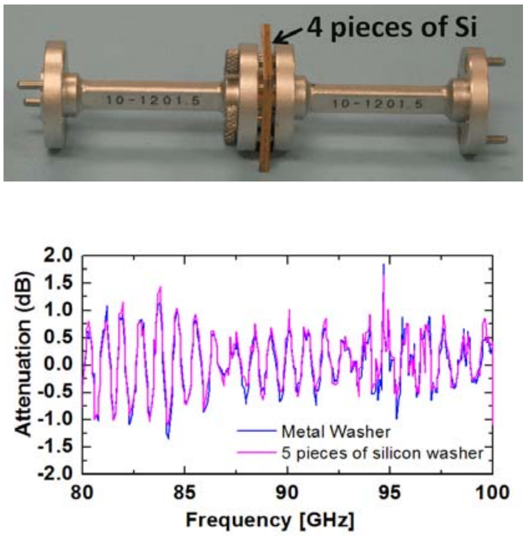
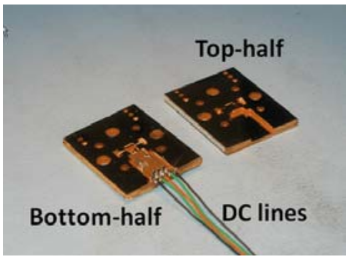
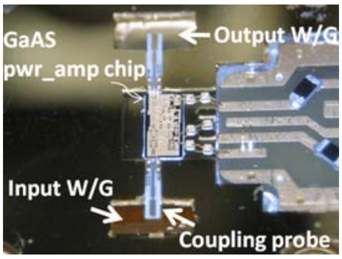


Figure 1. Measured attenuation data plot of both 2.5 mm-thick metal and 2.5 mm-thick silicon washers. Si washer is composed of 4 pieces of wafers. It shows almost identical behavior.

Subsequently, we have designed and microfabricated a silicon based W-band (75-110 GHz) power amplifier module (Figure 2). This circuit is based on a stack of four Si wafers and provides the standard UG-387 flange for interface to metallic waveguides. The performance of the silicon block is similar to a block fabricated using conventional metal machining (Figure 3).



(a)



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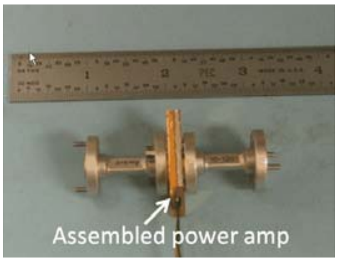


(c)

Figure 2. (a)View of top and bottom half of the silicon blocks. (b) It shows the GaAs power amplifier sitting on the channel in silicon micromachined waveguide. (c) Photograph of assembled GaAs power amplifier using silicon micromachined waveguide block.

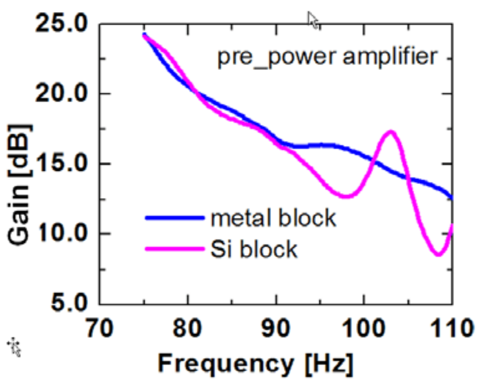
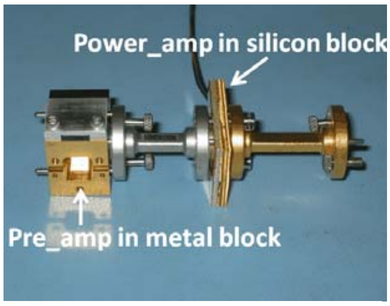


Figure 3. Measured data plot of GaAs pre-power amplifiers assembled in both metal and silicon blocks. It shows similar behavior.

The pre-power amplifier assembled in metal module and the power amplifier assembled in silicon module are connected in a cascade (Figure 4). We have demonstrated over 140 mW at 94 GHz from the cascaded power amplifiers (Figure 4).



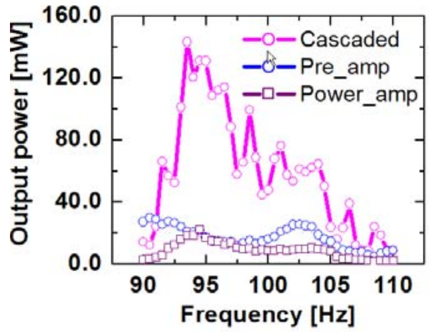
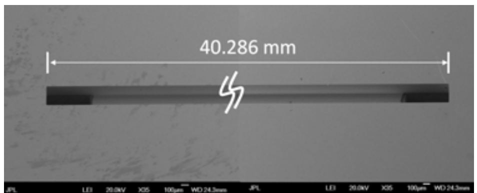


Figure 4. (left) Photograph of cascaded pre-amplifier and power amplifier (right) Measured output power of cascaded power amplifiers. Over 140 mW has been achieved.

Furthermore, we have developed silicon micromachined waveguide components in WR-2.2 (325-500 GHz) band (Figure 5). We used a 40mm straight section of waveguide with two two-step H-plane bends bringing the waveguide flanges on top surface of the silicon. We measured approximately 5-6 dB of loss at 350 GHz for the guide, which also includes 8 mm of waveguide length of the testing fixture (Figure 5). These results are consistent with theoretical simulations and demonstrate that this approach can be used for building passive THz components.



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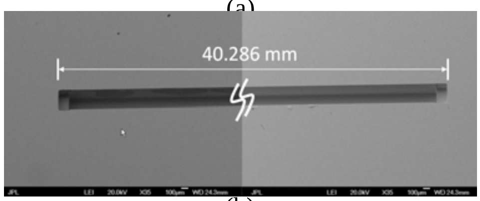


(b)

(c)

Figure 5. SEM images of 325-500 GHz waveguide. (a) bottom half of Si waveguide (b) top half of Si waveguide. (c) assembled waveguide.

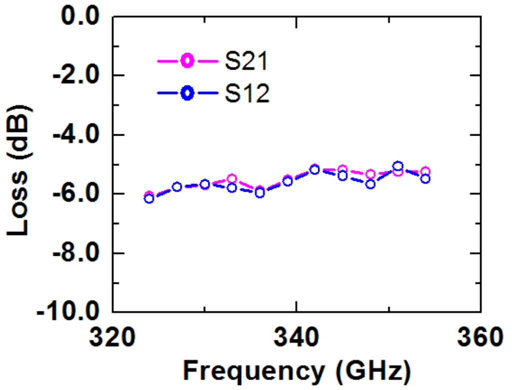
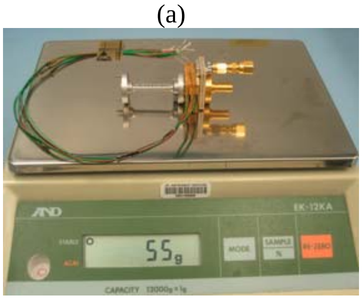


Figure 6. Measured data plot of 325-500 GHz waveguide block. The loss is about 5-6 dB according to HFSS simulation. It matches the measurement results.

(a)



(b)

Figure 7. (a) Conventional machined 600 GHz receiver (b) silicon micromachined 600 GHz receiver. It reduces an order of magnitude in weight.

Finally, we have applied silicon micromachining techniques to build a 600 GHz integrated heterodyne receiver. Double Side Band (BDS) receiver noise temperature of 4200 K and 13 dB conversion losses have been measured at 540 GHz. It dramatically reduced both mass and size (Figure 7).

III. Conclusion

This is the very first demonstration of a novel receiver using silicon micromachining techniques. This architecture will open the new door for the development of large arrays of receivers in the sub-millimeter wave range.

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