Silicon Laser Micromachining for the Development of Planar Waveguide-Based THz Structures

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Abstract – This paper describes an approach toward the development of low cost terahertz components. The approach utilizes laser micromachining on a silicon substrate to form rectangular waveguide structures. We discuss the design and fabrication of a 600 GHz bandpass filter employing the laser micromachining technique. We will discuss the measurement plan to produce the first measurement of a laser micromachined waveguide bandpass filter at 600 GHz.

Introduction

Increasing focus has been placed on the use of Terahertz (THz) frequency signals. Currently the frequency range is used mostly for astronomy purposes, but has great promise in imaging, especially in medical imaging as THz signals do not have the harmful effects associated with traditional X-Rays. In order to bring this technology to the forefront, an in-expensive and highly repeatable production of THz components needs to be established. While some of the components may be fabricated using traditional metallic waveguide or by using established etching techniques on silicon to form the waveguide, none offer the accuracy, versatility or potential inexpensive production as does the laser micromachined approach.

Laser Machining

Although very small metallic waveguide structures can be manufactured using mechanical machining techniques, they can be costly and could be difficult for mass production and could be come impossible to manufacture as frequency increases and the size of the waveguide and associated components decrease. The alternative is to use well developed micromachining techniques to form the needed waveguide. This approach has already been applied [1, 2, 3] section waveguide sizes of WR-10 and WR-4 with measurements reported, but these techniques are limited in the 3-dimensional shapes they can form. What we propose is using laser micromachining [4] as this technique is able to create very small features, different depths of etch and must is not constrained to any crystalline plane and is highly repeatable for frequencies up to ~ 10 THz.

The laser machining technique is based on the illumination of a silicon substrate with an argon-ion laser that locally heats a portion of the substrate inside a chlorine ambient. At the onset of melting, volatile silicon chlorides are formed and, as a result, controlled thin shavings can be removed plane by plane with no change in the etch rate. With this technique, THz waveguide structures that were extremely difficult, if not impossible, to fabricate with classical machining techniques can be developed. The structures can bee three-dimensional and of any shape with an accuracy of one micron.

600 GHz Bandpass Filter

Our efforts to prove the validity of this technique and approach are to initially be proven in the 600 GHz frequency range. This range was selected due in part for its ability to be measured with a network analyzer. For the bandpass filter design we elected to use a classic waveguide cavity filter [5] having 3 poles yielding a 15 GHz (2.5%) bandwidth. These simulations of these were carried out using Ansoft's HFSS simulator. The waveguide size for the filter was selected to be WR-1.4 (14 by 7 mils). The simulation results are shown in figures 1 and 2.

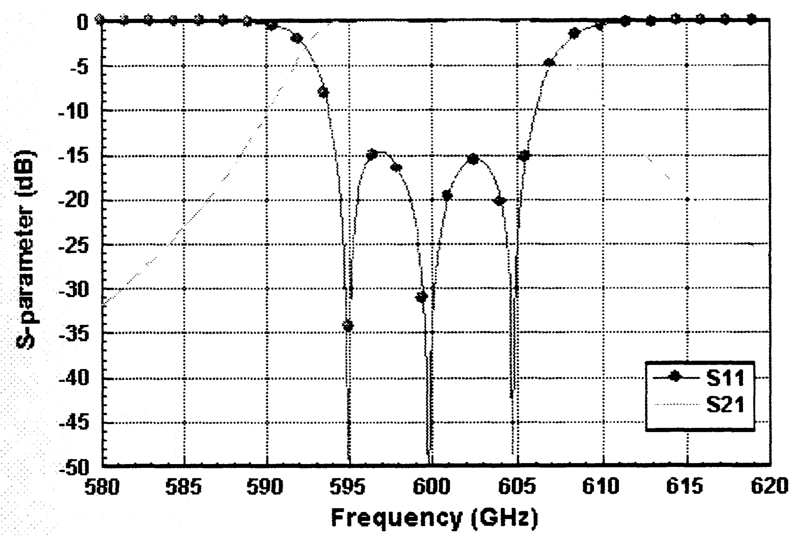

Figure 1 Simulated S-parameters of the 3 pole laser machined waveguide filter.

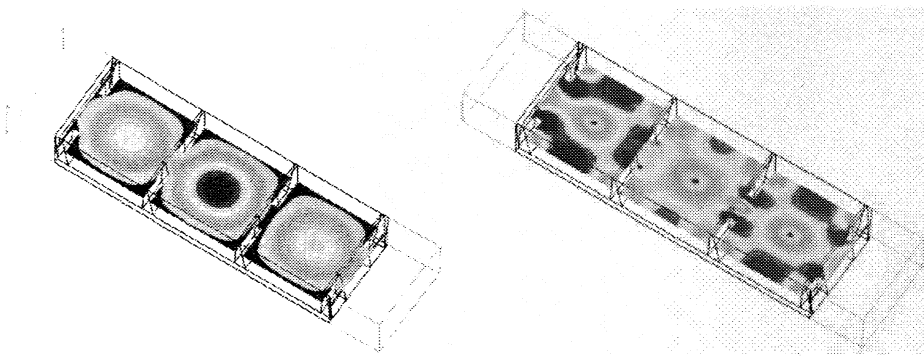

Figure 2 Simulated E-Field (left) and H-Field (right) of the 3 pole laser machined waveguide filter.

The fabrication of the filter using the laser etching technique can potentially be done in two ways, the first by creating two halves or a 'split-block' and bond the two halves together, the second approach is to laser etch the entire waveguide and simply use a 'lid' style approach. We have elected to use the latter approach to avoid any alignment issues. The fabrication results of the filter can be seen in the SEM image from a top view perspective in figure 3 without the lid attached.

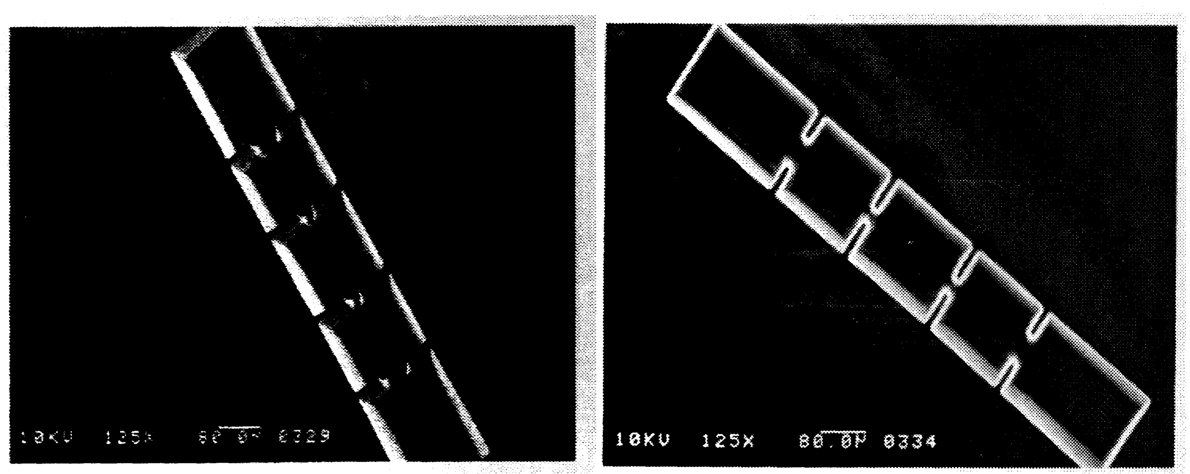

Figure 3 SEM picture of the 3 pole laser machined waveguide filter

After the laser fabrication the filter was sputtered with a titanium layer followed by a gold layer. Additionally the 'lid' for the filter was sputtered with the same combination of metals. These two pieces were then bonded together using a Karl Suss SB6 bonding machine.

Measurement Plan/Results

For the measurement of the 600 GHz bandpass filter, we intend to use the Network Analyzer at Jet Propulsion Laboratories in Pasadena, California. Specially designed metallic waveguide filters have been manufactured in order to select the harmonic content for our frequency band. The difficulties of a measurement at this frequency with alignment issues are compounded by the fact that we are trying to interface a waveguide made in silicon without flanges to a metallic interface. In order to facilitate this interface a custom package will be built around the finished silicon waveguide filter. This will not only provide a rigid package for the filter, helping to avoid handling damage, but will also be outfitted with precision round flanges that will directly interface with the measurement system.

Conclusions

We have discussed laser micromachining of THz components and its advantages over mechanically machined and traditional etched waveguides. A proposed 600 GHz bandpass waveguide filter was proposed for the purpose of proving the laser machining approach. Simulation and initial fabrication results were shown. A measurement plan has been proposed for demonstrating the effectiveness of this approach.

References

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