Improved Insertion Loss for a WR-3 Waveguide Using Fully Cross-Linked Two-layer SU8 Processing Technology

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Abstract. Fully cross-linked two-layer SU8 photoresist technology has been successfully developed and used to fabricate a WR-3 waveguide with two back-to-back right-angle bends at both ends. The resulting waveguide is within 0.01 db/mm of a precision machined waveguide, making the SU8 waveguide a very viable proposition for terahertz applications. The right angle bends are designed to facilitate accurate connection with external waveguides for measurement purpose. The insertion loss has shown significant improvement over previous results obtained using four separate SU8 layers. It is believed that elimination of localized air gaps between the fully cross-linked interface of two adjacent SU8 layers contributed to the improvement. The two-layer SU8 processing technology can be extended into multi-layer technology, which will greatly expand the scope of device applications. The technology is particularly useful in devices which consist of isolated regions or weakly joint parts, which is very difficult to fabricate using previously reported separate layer processing technique.

1. Introduction

There is a growing interest in fabricating high performance components at millimetre wave and submillimetre wave frequencies using micromachining technologies. Among many reported so far [1], thick layer SU8 photoresist technology has displayed some important advantages in terms of near vertical sidewalls (aspect ratio >30:1), as well as being relatively cheap to fabricate using standard photolithographic equipment; hence easily accessible to many. In contrast, other competing technologies, such as Si deep reactive ion etching (DRIE) [2] requires an expensive etching machine, while LIGA process [3] requires synchrotron radiation source. In fact, SU8 has been successfully employed by us to make many high frequency components, including WR-3 (220-325 GHz) waveguide, a filter and a slot antenna [4-6].

However, all the SU8 devices made so far are based on separate layers bonded/assembled together. Typically, for example, a waveguide device was split into 4 equally thick layers and all the layers were made in one mask processing. The layers were then released from Si substrate, metal coated and then bonded/assembled together. The drawback of this method is that it is quite difficult to completely avoid localized air gaps between the different layers because the SU8 surfaces are not perfectly flat. When two uneven surfaces come into contact, air gaps will form among the lower surface regions. As is well known, air gaps have deleterious effect on device performance, resulting in current leakage and higher loss.

In this paper, we report results of a 300 GHz waveguide device with two back to back right angle bends obtained through a new fabrication method. The paper is organized as follows: in the next section (2), device details are reported, which is followed by a detailed description of the fabrication method (3). Measurements and discussions will be given in Section 4, which is followed by conclusions in Section 5.

2. Device Details

In order to facilitate measurement of a 300 GHz rectangular waveguide device, two H-plane back to back right angle bends were designed as shown in Fig. 1. This allows for reliable and accurate interconnection with standard waveguide flanges. Fig. 1(b) and (c) shows the top view of layer 1 (and 4) and 2 (and 3). The waveguide is only about 16 mm long by 0.432 mm wide. Each layer is, however, 48 mm long by 24 mm wide in order to fully accommodate all the alignment pin holes as wells as holes for flange screws (more details are given later).

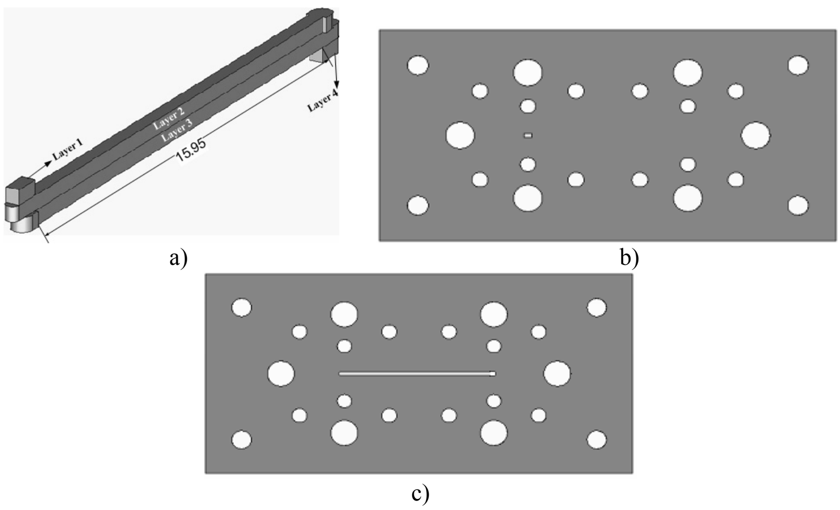


Fig. 1. (a) WR-3 waveguide structure with two right angle bends (unit mm), (b) top view of the first/fourth layer, (c) top view of the second/third layer.

3. Fabrications

Previously this device was fabricated using one mask photolithographic process, in which all four layers were printed onto one mask and processed together in one lithographic step. Each layer i is then individually silver coated and bonded/assembled described in [4]. The disadvantage of such a method is that localized air gaps may form after bonding due to the surface unevenness. These air gaps are likely to lead to increased insertion losses due to current leakage. In order to eliminate the air gaps, we have here developed two-layer SU8 processing technology. Instead of making four separate layers, two layers were processed together to form one half of the waveguide. The final device was formed by combining the two halves together. The fabrication details will be published elsewhere; however here is a brief outline of how it was achieved. Two masks were used instead of one. In mask 1 only the layer 1 and 4 were printed with alignment marks. In mask 2 the layer 2 and 3 printed along with the same alignment marks. Firstly, a 432 μm thick layer of SU8 was spun onto a Si substrate, pre-baked, UV exposed processed with mask 1 and post-baked. Then another 432 μm thick SU8 layer was added onto the top of the layer, pre-baked, UV exposed with mask 2 after careful alignment and post-baked again. During the second UV exposure, both the top and bottom layers were exposed together, hence the second post exposure bake will crosslink the two layers together to form one fully joined piece, hence eliminating the air gaps between the interface. Fig. 2 displays a photo of the processed SU8 device using this new technique where two layers were fully crosslinked together to form a half of the designed waveguide Finally the waveguide was formed by aligning and bonding the two halves together after silver coating.

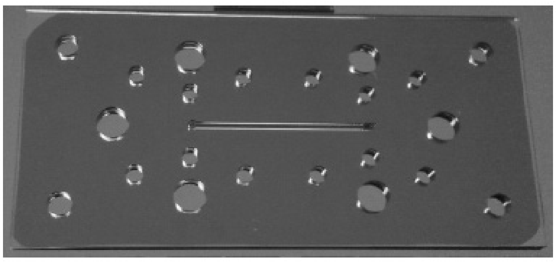


Fig. 2. A photo of the processed SU8 piece where two layers were fully cross-linked together to form a half of the said waveguide.

This method eliminates any air gaps between layer 1/2 and 3/4 interfaces, but it can still leave some air gaps between the middle interface (layer 2/3). However, since the waveguide was designed to split in the E-plane and little current is expected to cross the middle interface, any air gaps there are not expected to have large adverse effect on the device performance.

4. Measurements and discussions

During the measurement, the micromachined waveguide was sandwiched between two brass plates, as shown in Fig. 3. Standard waveguide flanges were inserted into the opening region on the clamping brass to connect directly with the micromachined waveguide circuits [4]. Screws on the flanges go straight through the micromachined waveguide onto nuts at the opposite plate. The alignment pins provide the accuracy to which the two halves are aligned, as well as the accuracy to which the device is aligned to the external flange. The screws are used to clamp the layers together as well as fixing the external flange to the micromachined waveguide. The length of waveguide excluding the bends is 15.95 mm, which is made sufficiently long to allow adequate separation between the flanges of measurement equipment to avoid overlapping of pins and screws from the other side. The measurements were carried out on an Agilent E8361A Network Analyzer with a WR-3 extension T/R module at test port 1 and a receive-only T module at test port 2. Enhanced response calibrations, which combine a one-port calibration and a response calibration were performed before measurements.

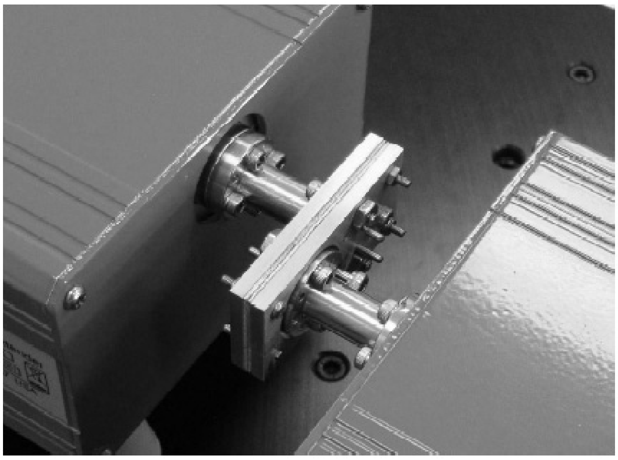
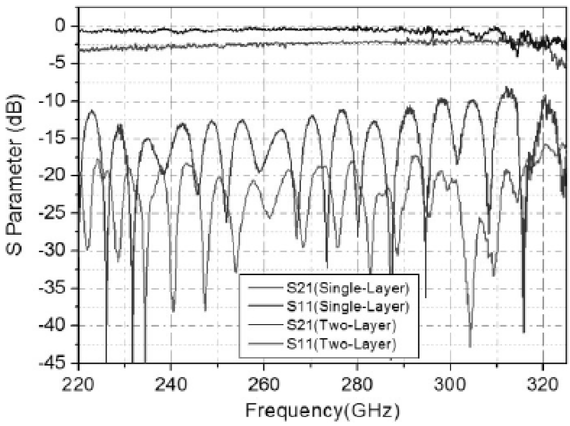


Fig. 3. A photograph of the testing setup.

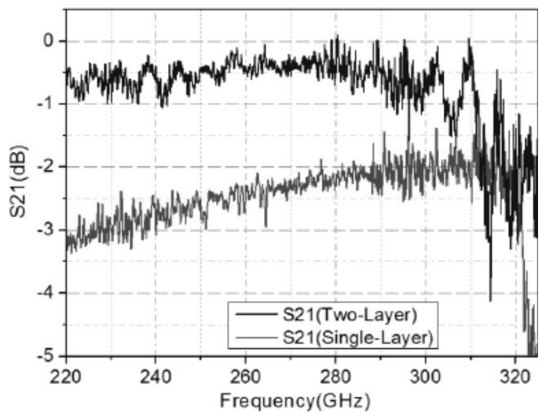
Fig. 4(a) shows the measured S21 and S11 results from the two-layer waveguide device. The previously obtained results based on four single layers are also included for comparison. The improvement in insertion loss (S21) is significant over a wide frequency range from 220 to 300 GHz as shown in the enlargement Figure 4(b).

The average insertion loss is now only around 0.5dB using the newly developed SU8 two-layer process as compared to about 2.3 dB obtained previously through 4 separate layer process in the frequency range of 220 to 300 GHz. The new data represents a loss of only 0.03 dB/mm, which is comparable to the reported performance of around 0.02 dB/mm for the commercially CNC-machined and then gold plated WR-3 metal waveguide [7].

The return loss is very good for this frequency range being better than 10dB in the across the band. This is however worse than the previous results. We are currently trying to find out the reasons for it, but the most likely is dimensional accuracy. At above 300GHz frequency range, the S21 starts to deteriorate, which is possibly due to misalignment and higher mode effect. Currently, the alignment accuracy between layers 1/2 or 3/4 is around 15 μm, which, we believe can be further reduced through process optimization. The insertion loss results, to our best knowledge, are the lowest reported so far from any micromachining technologies.



a)



b)

Fig. 4. (a) Measured S21 and S11 results for WR-3 waveguide obtained with SU8 two-layer processing technique; (b) Measured S21 results for the fully linked two-layer processing technique as compared to the previous 4 separate layer processing technique.

5. Conclusions

A two-layer SU8 processing technique was developed and used to fabricate a WR-3 waveguide device with two back to back right angle bends. The insertion loss performance of the device is found to be greatly improved as compared to the previous method of using 4 separate layers. This is believed to be due to the elimination of localized air gaps because layers 1/2 and 3/4 were fully joined together through inter-layer crosslinking. The new processing technique is likely to expand the scope of device applications for thick SU8 photoresist micromachining technology.

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