MICROMACHINED WAVEGUIDE COMPONENTS FOR SUBMILLIMETER-WAVE APPLICATIONS

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Abstract - The high cost of fabricating waveguide components is one of the primary factors limiting the development of terahertz technology. This paper reviews the development of an inexpensive micromachining technology that is suitable for the frequency range from 500 GHz through 5 THz. Our first effort was a 585 GHz direct detector that allowed us to measure the beam patterns of our new micromachined horn antenna. The results were quite good and matched both theoretical predictions and the patterns of a low frequency scaled model of the horn. More recently, a high quality 585 GHz mixer was assembled and tested. The performance was equivalent to that obtained from a traditionally machined block, $T_{mix,dsb}$ = 1,200K. We are now extending this technology to 1.6 THz. A sideband generator and a mixer circuit are being fabricated and the first circuits demonstrate excellent control of the critical features. This paper overviews the new micromachined block fabrication process, summarizes our measurements at 585 GHz and shows the first fabrication results at 1.6 THz.

I. THE FABRICATION PROCESS

The block fabrication process presented here is a modified version of the process reported in several previous conference publications [1,2,3]. As in the previous work, our new process begins with the formation of a modified diagonal horn by selective crystal etching of a silicon wafer through a silicon dioxide masking layer. This etch creates a very suitable horn structure with easily controlled flare angle and aperture and very good (>90%) Gaussian coupling efficiency [4]. Next, a thin layer of photoresist is spun onto the wafer and exposed to mark the precise position of the waveguide. An automatic dicing saw is then used to slit-cut the waveguide for each half of the block. The photoresist and oxide layers are then removed.

The next step is to form the microstrip circuit channel that runs perpendicular to the waveguide. This is achieved with an ultra thick photoresist known as SU-8 [5]. This resist can be exposed by standard UV lithography to depths of up to 1 mm. The SU-8 layer is intentionally made thicker than our desired channel depth. This resist is then exposed through a mask that protects the horn, waveguide and channel areas. The wafer is then developed to clear the unexposed resist and the wafer is hard-baked. This cures the SU-8 into a plastic layer that remains as a permanent part of our mixer. This plastic is then lapped to the desired thickness on a commercial wafer lapping system. Lapping allows control of the depth of the channel to within a few microns and eliminates any problem with the planarity of the original SU-8 surface.

Alignment grooves are then diced into the wafer, the sample is coated with metal by a combination of sputtering and electroplating and the individual components are diced. Both the dicing and alignment grooves are patterned in the SU-8 layer to facilitate proper alignment on the wafer. A three-inch process wafer yielded twelve complete waveguide pairs. The result is shown in Fig 1. Note that the features are much sharper than is possible with traditional machining and the fixed backshort is defined with lithographic precision.

II. MIXER ASSEMBLY AND TESTING

To assemble the mixer, a quartz microstrip circuit with an IF filter, a waveguide probe and an integrated GaAs diode is placed in the microstrip channel [6]. Bond wires attached to the circuit are then attached to the block for the IF return and to the center pin of the coaxial IF connection. Metal shims are placed in the alignment grooves and these shims guide the two halves precisely into place. This yields excellent alignment and the flat SU-8 surface formed by lapping yields no visible gap between the halves.

A molecular gas laser provides an LO source at 585 GHz and a hot/cold load source is used as a calibrated signal. The LO and signal are spatially combined in a diplexer and coupled to the horn through an off-axis parabolic mirror. The lowest system noise temperature measured was 1,700K and a graph of the system noise temperature versus the input noise temperature of the IF amplifier indicated a mixer noise temperature of 1,200K and conversion loss of 8dB (all DSB). The system noise temperature is plotted versus LO power in Fig. 2. The mixer requires about 1 mW of power for optimum performance and the performance is still quite good down to 0.2 mW. These are essentially the same values obtained when a similar integrated mixer circuit was tested in a traditionally machined metal block [6]. The antenna pattern of the micromachined horn is shown in Fig. 3. There is a slight asymmetry in the beam but this can be corrected by adjusting the depth of the horn etch.

III. FIRST TRIALS AT 1.6 THZ

The success achieved at 585 GHz has encouraged us to use this fabrication process at higher frequencies. Both a 1.6 THz mixer with an integrated GaAs-on-quartz diode circuit and a whisker-contacted sideband generator are planned. The sideband generator uses a novel varactor diode architecture that has been shown to generate unprecedented power and efficiency at this frequency, > 50 _W and —14 dB respectively[7]. The result of the first fabrication trial is shown in Fig. 4. The features are again very crisp and the control of all critical dimensions is better than we have obtained from the best commercial suppliers of traditional metal blocks. Our next goal is to test the performance of these circuits.

IV. DISCUSSION

We have fabricated split block mixer housings for 585 GHz and 1.6 THz with standard semiconductor processing techniques including crystallographic silicon etching, ultra-thick photoresist, automatic dicing and wafer lapping. The results indicate better dimensional control and sharper features than have been demonstrated with traditional machining. The 585 GHz mixers have been RF tested and yield essentially the same performance as the traditional blocks with a diagonal horn antenna. The 1.6 THz designs have not yet been tested, but the dimensional quality is exceptional. This process is readily scaled to even higher frequencies and these blocks have survived rapid immersion in liquid nitrogen with no degradation. Thus, we believe this technology can potentially be used for SIS, HEB and Schottky, mixers throughout the terahertz band. Thus, micromachining has been demonstrated as a viable solution to greatly reduce the costs of submillimeter-wave receiver components.

ACKNOWLEDGEMENTS

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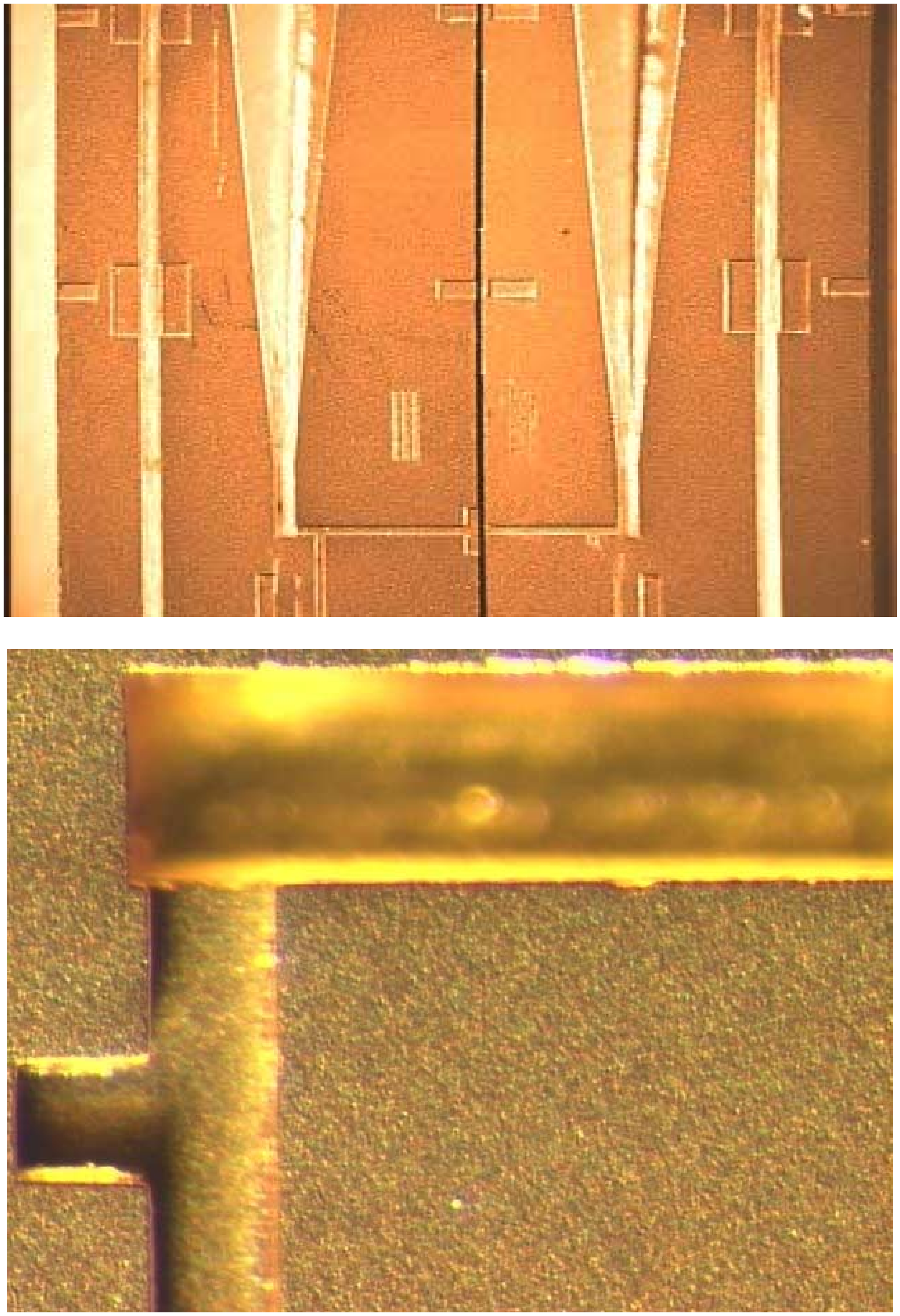

Fig. 1: Two views of the 585 GHz split-block mixer, top: the flared horn, waveguide and microstrip channel, and bottom: a view of the waveguide, backshort and part of the channel. Note the extremely sharp features. Also, the bottom of the channel is the metallized silicon surface. The microstrip channel width is 120 μm.

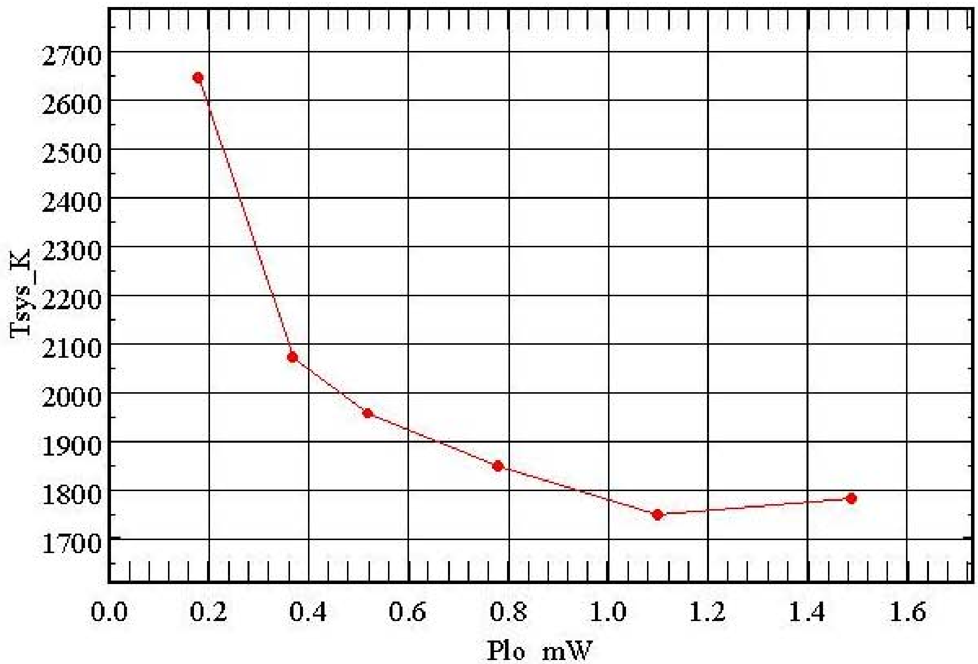

Fig. 2: A graph of system noise temperature versus LO power. The best measured result was 1,700K (DSB).

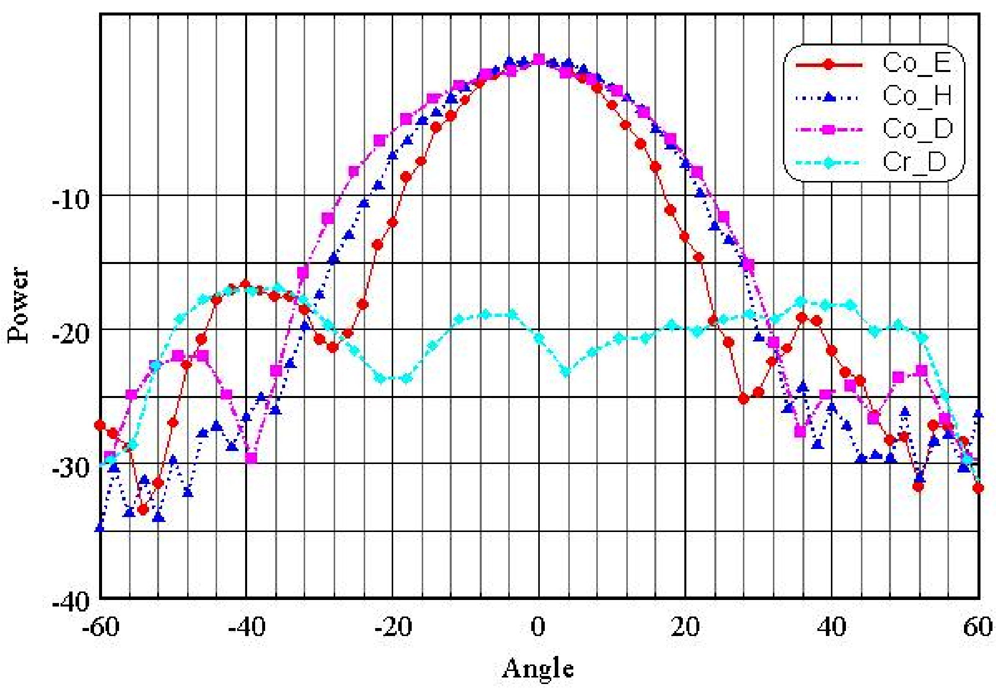

Fig. 3: The measured antenna pattern of the 585 GHz mixer. The slight asymmetry can be removed with a better selection of the silicon etch depth.

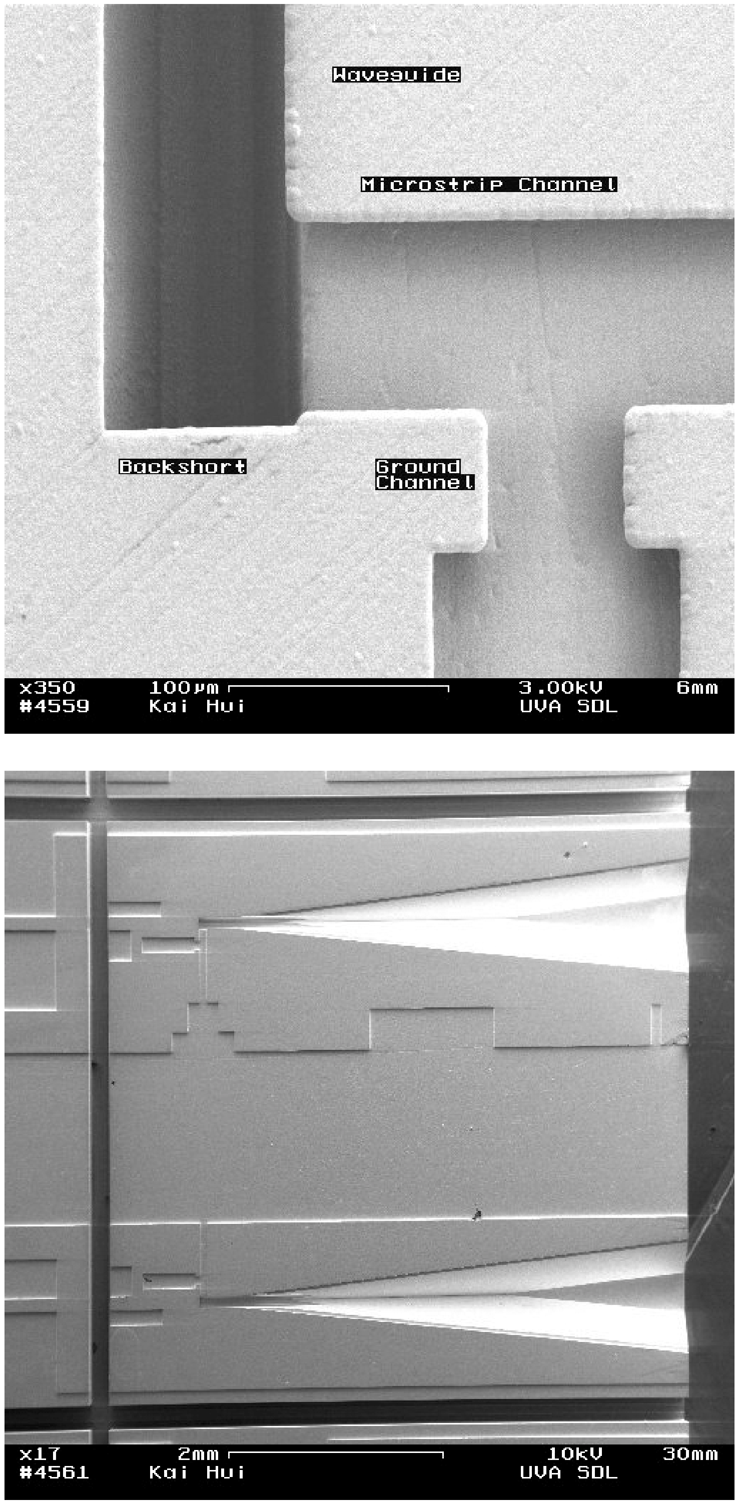

Fig. 4: The first 1.6 THz micromachined waveguide components. The microstrip channel is 60 m wide and 25 micron deep.