MICROMACHINING APPROACH IN FABRICATING OF THZ WAVEGUIDE COMPONENTS

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ABSTRACT

The modern radio astronomy has high demands for submillimeter receivers. Approach, employing fine mechanical machining, successfully used for longer wavelengths, reaches its margin at about half-millimeter wavelength. New techniques for fabricating submillimeter and THz waveguide components are required. With this paper, we describe our progress in micromachining of a waveguide structure for 1.3 THz.

1. INTRODUCTION

The world largest radio astronomy instrumentation projects, ALMA [1], as well as its "pathfinder" APEX [2], both include submillimeter bands based on heterodyne receivers. We develop the APEX 1250 – 1390 GHz band balanced receiver. The mixer is based on waveguide technology, where electromagnetic waves are guided by rectangular waveguide with dimensions approximately ${}^{\lambda}/_{2} \times {}^{\lambda}/_{4}$, where λ is a wavelength. Therefore, waveguide dimensions for 1.3 THz are 200 × 100 μm^2 only. One of receiver's key elements is a four-port 3 dB quadrature directional waveguide coupler. The coupler consists of two parallel waveguides coupled through a series of branched apertures. Progress in submillimeter technique faces the need of producing waveguide structures with dimensions of few tens of microns and a very high precision in dimensions, surface quality and repeatability.

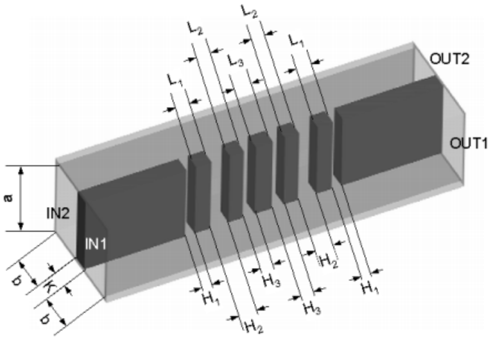


Fig. 1. Design of waveguide hybrid with a 6 branches coupler. The main waveguide height $b = a/2$ is fixed to be $b = 100$ μm.

2. WAVEGUIDE DESIGN AND REQUIRED FABRICATING ACCURACY

Fig.1 shows drawing of such a structure with 6 sections. The design variables are: the heights of the branches (H_n), the spacing between branches (L_n), and the distance between the main waveguides (K). The limit on branch guide height H_n is chosen as 20 μm. In our design we have kept the main guides at the full height ($b = a/2$) with fixed $b = 100$ μm. Therefore, for each half of split block, the aperture sides should be 100 μm long. We have

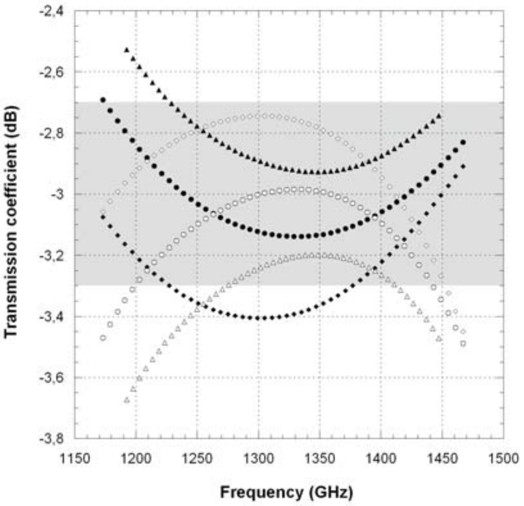


Fig. 2. HFSS™ simulated transmission coefficients for the 6 branches coupler. Each of the curve pairs (● and ○, ♦ and ◊, ▲ and Δ) demonstrates transmission parameters from IN$_1$ to OUT$_1$ and IN$_1$ to OUT$_2$ respectively. Curves ● and ○ are corresponded to the optimized configuration of design variables (K=41 μm, H_1=24 μm, H_2=46 μm, H_3=30 μm, L_1=38 μm, L_2=35 μm, L_3=42 μm). The others curves indicate the situation when all structure dimensions are shifted up (curves ▲ and Δ) and down (curves ♦ and ◊) from the optimized level by 1 μm. Gray shaded area shows required transmission coefficient range of 3±0.3 dB.

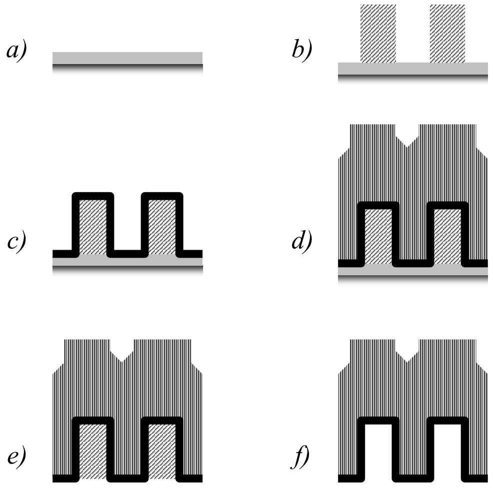


Fig. 3. Waveguide structure fabricating scheme.

optimized the bandwidth, coupling, and return loss using High Frequency Structure Simulator, HFSS™ [3].

Since the required manufacturing accuracy influences the choice of a fabricating method, we have proceeded with analysis of the required accuracy. To examine the accuracy, the dimensions of the structure have been varied and the corresponding electromagnetic performance has been simulated. The results of the simulations for different values of the design variables are represented in Fig.2. Optimal configuration of the coupler has been achieved with the design variables as follows K=41 µm, H_1=24 µm, H_2=46 µm, H_3=30 µm, L_1=38 µm, L_2=35 µm, L_3=42 µm. The transmission parameters from IN_1 to OUT_1 and IN_1 to OUT_2 of the coupler in the case of optimal design are shown by solid curves ● and ○ respectively. The curves pairs ▲ , Δ and ♦ , ◊ reflect cases if design variables are shrunk or enlarged by 1 µm from the optimized values.

The accuracy analysis shows that the manufacturing should be accurate with linear error below 1 µm in order to achieve the required hybrid performance. Additionally, THz frequency places high demand on the surface quality. The surface roughness should be below 0.1 µm (skin depth at 1.3 THz); the surface impedance should be the lowest.

Summarizing, the required sub-100 µm dimensions along with the linear error below 1 µm and surface quality prompt using a fabricating method other than fine mechanical machining.

3. MICROMACHINING APPROACH

Taking into account the requirements discussed above, we decided to employ the photolithography combined with electroplating for fabricating of the waveguide structure (Fig. 3).

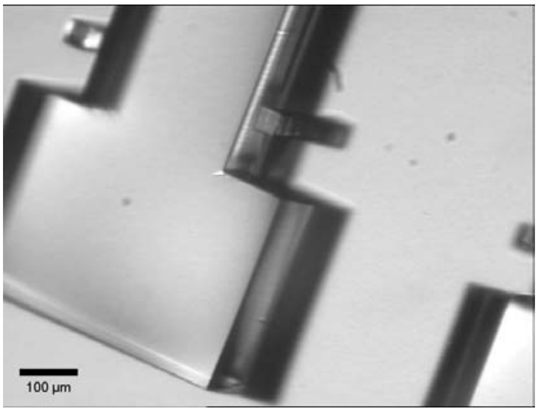


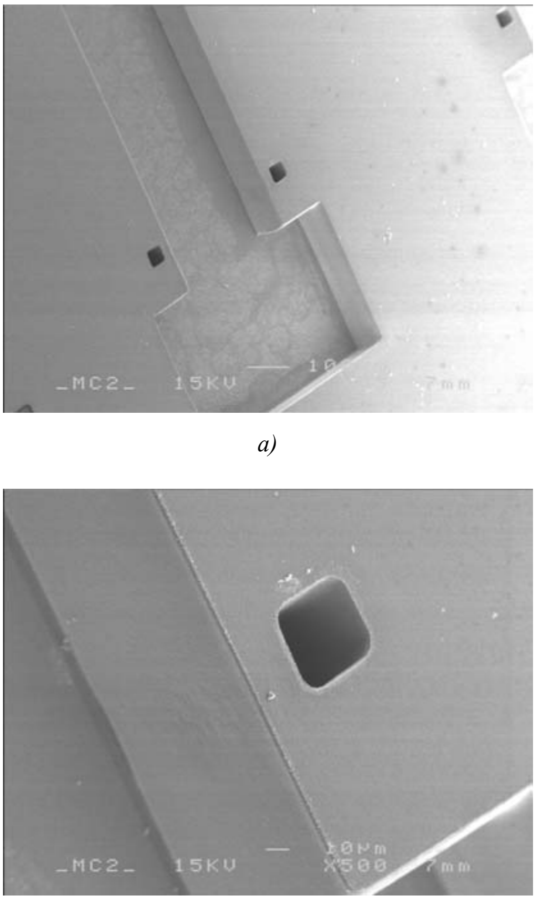
Fig. 4. Photograph of the test pattern fabricated in 100 µm thick SU8-2035 resist.

In the processing, a 2” silicon wafer was used as a substrate. Release layer of PiRL-III [4] has been applied first at 3000 rpm spin and baked at 200°C for 5 minutes (Fig. 3a). Thick SU8-2035 [5] has been applied afterwards. We found the subsequent spinning of the two layers at 2000 rpm with intermediate baking at 65°C for 20 minutes provides the best resist uniformity. We applied soft baking at 65°C for 20 minutes followed by 95°C 20. A pattern has been exposed with a contact mode i-line mask aligner with wavelengths shorter than 350 nm filtered out. Post-exposure baking at 65°C for 5 minutes and subsequently 95°C 10 minutes followed by developing in XP-SU developer for about 10 minutes have been carried out (Fig. 3b). Fig.4 shows the obtained resist pattern.

In order to get higher conductivity of the waveguide walls and to provide conductive seeding layer for subsequent electroplating, the 0.5 µm layer of Au, Pd or Al/Pd has been deposited by magnetron sputtering (Fig. 3c).

Copper plating has been carried out with a *dc* power feed in proprietary solutions [6]. We have plated in two steps, firstly, slow plating for fine gap filling, 20 µm at 0.5 A/cm^2, secondly, thick plating, 500 µm at 2 A/cm^2 (Fig. 3d). After completion of the plating, we have detached the silicon substrate by dissolving of the release layer at 60°C in an ultrasonic bath of alkaline developer (Fig. 3e).

To strip SU8 resist (Fig. 3f) we have tried Piranha (sulfuric acid + 2% of hydrogen peroxide) wet etching at 60°C and microwave plasma ashing in oxygen at 1 mbar with temperature kept below 120°C. Both methods provided reasonable results, but Piranha etching better removed resist from the narrowest gaps (Fig. 5).



a)

b)

Fig. 5. SEM micrograph of produced test pattern after copper plating and stripping of SU8 resist.

4. CONCLUSION

We have successfully demonstrated processing technology for fabricating of the waveguide hybrid for 1.3 THz heterodyne receiver. Fabricating of the test pattern with characteristic dimension of 30 μm proved that the suggested technology meets the requirements on the precision for the patterned geometry and the surface quality. The results of the waveguide hybrid machining will be presented at the Conference.

5. ACKNOWLEDGEMENTS

Authors would like to acknowledge Galvanord and Dr.B. Okholm for providing excellent possibilities for electroplating. Authors are thankful to Dr. A. Bogdanov for his idea of using SU8 thick photoresist for micromachining of the hybrid. This work is part of APEX Project and is supported by Swedish Research Council and Wallenberg Foundation by their respective grants.

6. REFERENCES

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