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Low Cost Fabrication for W-band Slow Waves Structures for Wireless Communications Traveling Wave Tubes

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Abstract: *The fabrication of slow wave structures for millimeter wave Traveling Wave Tubes (TWT) poses significant difficulties and requires high accuracy processes. The EU H2020 TWEETHER project proposes a Point to Multipoint (PmP) distribution wireless W-band (92 -95 GHz) system for backhaul for small cells in the future 5G scenario and fixed access, based on a folded waveguide W-band TWT. The cost of TWTs and feasible high volume production are key parameters for millimeter wave network front ends. This paper explores possible new approaches for reducing the fabrication cost of millimeter wave slow wave structures for TWTs based on the SU-8 casting and low cost CNC milling process.*

Keywords: millimeter wave; W-band; TWT; casting; double corrugated waveguide; SU-8

Introduction

The H2020 TWEETHER project is introducing, for the first time, traveling wave tubes as enabling devices for point to point (PmP) wireless networks at W-band (92 -95 GHz) for 5G small cell backhaul and access [1, 2]. The high atmospheric attenuation and the low power available from solid state devices at millimeter waves has so far made it difficult to implement PmP distribution, which is based on low gain antennas for distributing the signal over wide sectorial areas. The high frequency does not allow the use of conventional helix TWTs due to the small dimensions of the slow wave structures (SWS). The folded waveguide (FWG) is a very good compromise in terms of fabrication and performance, but needs very high precision CNC milling. A folded waveguide 92-95 GHz TWT is in the final fabrication phase to produce about 40 W [3].

One of the requirements for the wireless market is providing affordable equipment to network operators. Due to the tight mechanical tolerances, fabrication time and steps, the fabrication of SWSs contributes to the overall cost of a millimeter wave TWT. This paper explores possible processes to lower the fabrication cost of millimeter wave SWSs, with the possibility of using them in high volume production.

Casting of SU-8 molds for folded waveguides and low cost CNC milling for double corrugated waveguides [4] will be discussed.

Casting of SU-8 for folded waveguides

Folded waveguide circuits are usually built in two halves, due to the difficulty of constructing the beam channel in a single block. CNC milling is the preferred process to build FWGs, but it requires very high dimensional accuracy, due to the tight tolerances in the alignment of split-block circuits, typical of high end, and high cost, CNC milling machines. The LIGA process has been demonstrated for fabrication of W-band folded waveguide [5]. However, the deposition of thick layers of SU-8 is challenging and needs a very accurate control of the process parameters, including the instability of SU-8 over time. SU-8 thickness is usually controlled by spinning at a given angular speed, depending on its viscosity. At W-band, the thickness required to build one half of folded waveguide is close to 1 mm, requiring the use of highly viscous SU-8, which is difficult to spin properly, or multiple layers, complicating the process.

Casting is a process where a liquid material (usually melted metal), is poured into a hollow cavity with a given shape where it solidifies. An analogous process can be applied to SU-8. Instead of spinning the SU-8, it is poured on a flat surface, which may be surrounded by a hollow cavity to set the height of the mold, or lapping may be used to set the height after metallization. Under the influence of gravity, the SU-8 self-levels with the correct thickness and can then be baked and exposed to UV light, to build the mold for electroforming.

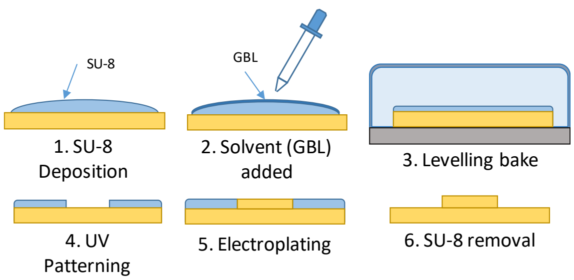

Figure 1. SU-8 casting process

The proposed SU-8 casting process for a W-band folded waveguide is illustrated in Figure 1 and can be summarized as follows: SU-8 is poured evenly across a pre-heated copper substrate. The change in weight is used to estimate the final thickness of the layer with the known density and solid content of GM1070 SU-8. The levelling process is accelerated by adding a small amount of the principal solvent used in SU-8, and allowing the sample to sit under cover for 30 minutes.

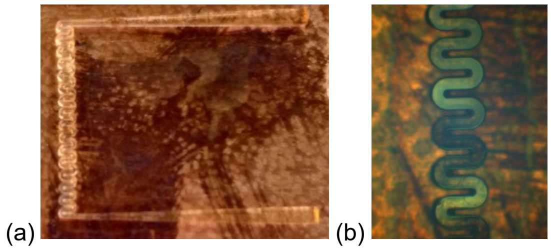

Figure 2. Folded Waveguide SU-8 mold a) top view; b) microscopic view, showing the well-defined waveguide

A standard lithographic process produces the mold: pre-exposure baking to remove the solvents from the photoresist, followed by UV exposure, pulsed to reduce post-development cracking. A post-exposure bake helps accelerate the crosslinking process that forms the SU-8 mold. Development is carried out overnight. Figure 2 shows the resulting SU-8 negative FWG mold. The copper waveguide structure will be built using pulsed electroplating in a copper sulfate-based acid bath. Optimization is ongoing to improve the quality and speed of the electroplating. The process seems very promising and could be a potential complement to CNC milling.

High speed CNC milling

The double corrugated waveguide (DCW) is a simple, robust SWS that could be considered for W-band TWTs. The DCW does not require high precision alignment. This makes it suitable for manufacturing using medium accuracy CNC milling machines, which typically, even if the accuracy if sufficient for the purpose, have spindle rotational speeds below 10000 rpm. Their low spindle speeds cannot produce the low surface roughness necessary for low losses. The skin depth at W-band is 200 nm, and the surface roughness must be well below this.

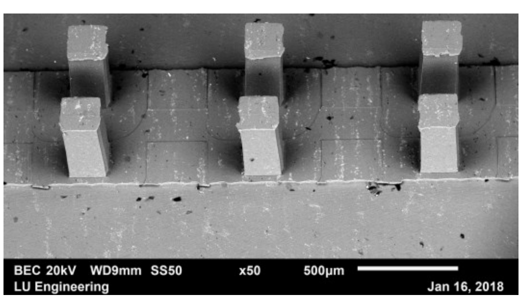

Figure 3. W-band double corrugated waveguide, each pillar is 190x190x500 µm

To overcome this problem, as a possible solution, an affordable air turbine spindle, which interfaces seamlessly with the existing tool chuck, was installed in an XYZ Machine Tools 710 CNC Vertical Milling Center, to raise the spindle speed from 8000 rpm to 50000 rpm, to improve the surface finish. Initial tests in aluminum have been carried out at W-band, using the air turbine spindle and specially coated tooling, with very good results. Figure 3 shows an SEM image of a W-band DCW, demonstrating excellent surface quality and dimensional accuracy. The DCW pillars have a square section with a 190x190 µm profile and 500 µm height. The beam tunnel is 200 µm wide.

Several test circuits have been fabricated for cold testing between 80 and 110 GHz. The transmission characteristics are compared with Ansoft HFSS simulations in Figure 5 and a photo of the DCW is included as an inset. The simulations were carried out using a conductivity of 1×10^7 S/m, to account for losses due to surface roughness. Further improvements to the fabrication process are in progress, but the surface finish is already suitable for millimeter wave SWSs.

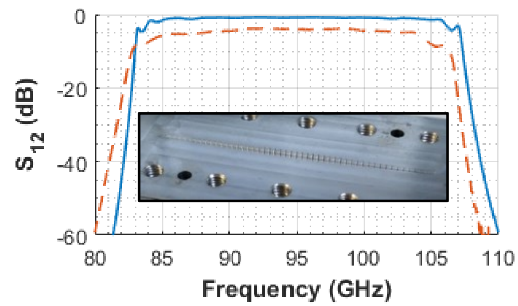

Figure 4. Measured (dashed) and simulated (solid) S_{12} of W-band DCW; inset: photo of the tested structure

Conclusions

Two low cost approaches for fabrication of millimeter wave SWSs for TWTs have been presented. SU-8 casting is very promising for large structures. A substantial improvement is expected for the next samples and the first metal folded waveguide will be built by electroforming.

The use of a high speed air turbine spindle enables the use of low cost, medium accuracy CNC milling for fabrication of millimeter wave SWSs up to 100 GHz.

Acknowledgements

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