UV-LIGA Microfabrication of 0.3 THz Double Corrugated Waveguide

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***Abstract*— A microfabrication process has been developed by using ultraviolet photolithography (UV-LIGA) with multi-layer SU-8 photoresist to create high aspect ratio Slow Wave Structures (SWS) for millimeter waves and THz vacuum electron devices. The main steps of the process will be described, applied to the fabrication of a double corrugated waveguide at 300 GHz.**

Keywords*— *BWO; double corrugated waveguide; UV-LIGA; microfabrication; sub-THz vacuum electron devices; SU8.

I. Introduction

Recent years have witnessed a significant interest for advancement of vacuum electron devices (VEDs), in particular the fabrication of millimeter waves and terahertz (THz) slow-wave circuits. This interest is in line with recent advances in microfabrication technology, with the aim of fabricating novel high power and bandwidth devices operating at millimeter wave and THz frequencies, as well as high aspect ratio structures for a variety of applications [1, 2]. While it is well known that VEDs are scalable with frequency, miniaturization of these devices is still challenging. To accommodate the increase in frequency, 3D metal structures need to be realized with high dimensional accuracy, within a few microns. Several fabrication technologies have been demonstrated as suitable for the realization of high frequency (sub-THz region) VEDs in the past few decades, such as Deep Reactive Ion Etching (DRIE) [3], X-ray LIGA, UV LIGA, high precision Computer Numerical Control (CNC) milling [4] and Direct Metal Laser Sintering (DMLS) [5]. However, the quality of the surface finish and the dimensional accuracy of the finished structure remain critical challenges in fabrication of high frequency VEDs.

At sub-THz frequencies, photolithography techniques have proven to be a suitable approach for microfabrication of high aspect ratio 3D metallic structures. DRIE is one of the photolithographic techniques that is used to fabricate metal-coated structures with very good electrical characteristics, however, these structures are associated with poor thermal dissipation. Microfabrication based on LIGA technology, such as X-ray LIGA and UV LIGA, can be used to fabricate all metal structures and have both seen wide use. While X-ray LIGA is associated with high cost, UV LIGA is affordable while still allowing high accuracy and high aspect ratio structures to be fabricated.

It is important to fully control the process parameters used in UV-LIGA, to achieve the high dimensional accuracy and a surface roughness well below the skin depth, to reduce the ohmic losses [6].

This paper describes progress towards multi-layer UV-LIGA fabrication, using SU-8 photoresist [7], of millimeter waves and THz waveguides for use as slow wave structures (SWS) in VEDs [8].

II. Multi-layer UV-LIGA Processes

The fabrication process described below is applied to the realization of a 300 GHz double corrugated waveguide (DCW) [9]. The 300 GHz DCW pillars are 160 microns tall and have a square profile with 70 micron sides. The two main steps are creating the SU-8 mold and growing the copper structure and ground plane. The main challenges of the process are ensuring that the pillars are all fabricated with uniform height, and controlling the electroplating process to ensure low surface roughness surfaces and high dimensional accuracy. The pillars are grown from a metallized silicon wafer, which is coated with SU-8. Using a two-step electroplating process, the pillars are grown from their top towards the ground plane, allowing the height of the pillars to be controlled by the thickness of SU-8, before a copper ground plane is grown on the surface of the SU-8 mold. Fig. 1 shows an illustration of a sample before release from the SU-8 mold.

All microfabrication steps were performed in the class 1000 and class 100 cleanrooms.

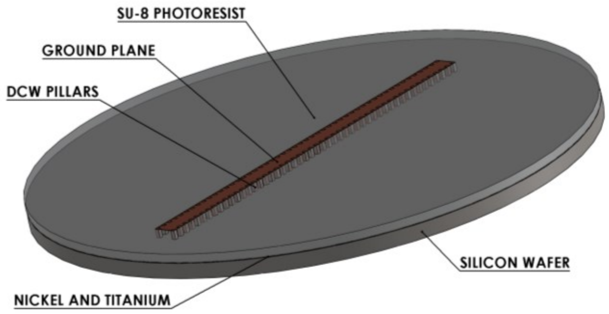

Fig. 1 – An illustration of a wafer after photolithography of SU-8 and electroforming of copper.

A. *Thermal evaporation process*

A 40 nm titanium (Ti) film is deposited by thermal evaporation on the surface of a 2-inch diameter silicon wafer, followed by a 200 nm nickel (Ni) seed layer for the electroforming process. Ti was chosen to improve the adhesion of Ni to the wafer, while Ni is used as seed layer due to its poor adhesion with copper, to ease removal of the metal structure when completed.

B. *SU8 spin-coating*

SU-8 photoresist is deposited on the metallized wafer, with a thickness equal to the height of the DCW pillars (160 µm). The SU-8 is spin deposited with a proper spin speed to achive the desired thickness given the viscosity of the SU-8. It has previously been shown [8] that for thick layers (>100 µm) a multi-layer process helps in avoiding an uneven surface and reduces the size of edge beads after spin coating. In this work two layers, with a thickness of 80 µm each, were deposited to create the mold. A spin rate of 2000 rpm was used, followed by at least 30 minutes of relaxation between the application of the layers.

C. *UV exposure and developing*

An MJB4 mask aligner (from SUSS Microtec) is used for the alignment and exposure with a hard contact to improve the homogeneity of the exposure and the verticality of the mold walls. After exposure to UV, the sample is allowed to relax at room temperature for at least 10 minutes. Post-exposure baking is then carried out at 120°C for 40 minutes, followed by a 5-minute development process using ultrasonic agitation.

D. *Electroforming*

The last phase is the electroforming of copper to form the DCW pillars. When the pillars are fully formed, another thermal evaporation step is required to deposit a copper seed layer, for the ground plane, on the surface of the SU-8. This permits the electroforming of the ground plane.

After completion of the ground plane, the SU-8 is removed using Reactive-Ion Etching (RIE), allowing the copper structure to be lifted off the wafer. Fig. 2 shows the details of the final DCW pillars after SU8 removal. Some pillars were bent during release from the mold, but new samples, using improved parameters to prevent this, are in fabrication. Fig. 3 illustrates the reflection of copper pillars on the ground plane that demonstrates a very low surface roughness.

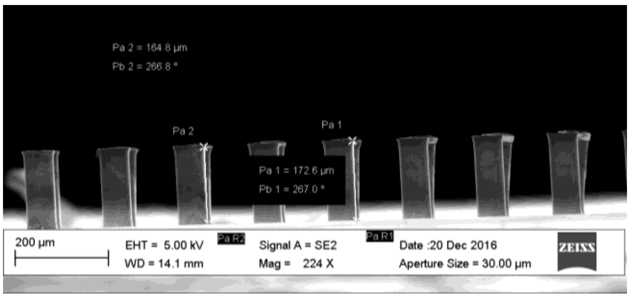

Fig. 2 – Profile image of the DCW pillars after removal from SU-8.

III. Conclusions

This work has demonstrated a UV-LIGA process that is suitable for fabrication of metal DCW for sub-THz VEDs. A great deal of effort was devoted to calibrating the process parameters to ensure uniform and accurate height of the pillars. Further improvements are being made, for full removal of the SU-8 and to achieve very low surface roughness.

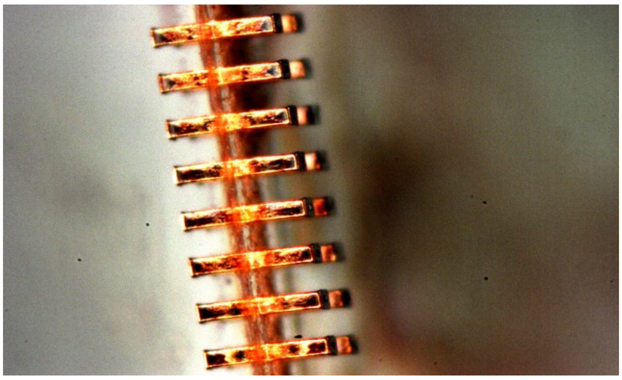

Fig. 3 – Profile microscopic image of a DCW. The reflections on the ground plane is visible.

Acknowledgment

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