Evaluation of a Rapid Manufacturing Approach for Rectangular Waveguide Filters up to 1.1 THz

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***Abstract*—This work explores a rapid design and manufacturing approach to realize complex 3D pillar type filter and transmission line structures for applications in the 220 GHz – 325 GHz range, which cannot be economically reproduced by conventional machining processes or present rapid prototyping methods. The significance of this investigation is that at THz frequencies, the exact conductor shape and surface roughness have a significant electrical effect and any variations result in an important disagreement between the modelled and measured characteristics. This is a proof of concept validation of a multi-stage manufacturing approach that is aimed at paving the way to a range of THz passive waveguide components.**

I. Introduction

MULTIPLE commercial and scientific applications in the millimeter-wave and THz frequency ranges require powerful oscillators and other electrical components, and as the use of this portion of the spectrum is expanded, the need for frequency selectivity would increase. These power generation requirements can be readily met by Backward Wave Oscillators (BWOs) [1]. The double-corrugated waveguide [2] has been proved as an effective Slow Waveguide Structure (SWS) in the THz range. Similar structures, i.e. arrays of closely spaced pillars, have been used as waffle-iron filters at lower frequencies in the past [3], [4].

In this work, filter structures in the 220 GHz – 325 GHz range, consisting of arrays of posts, were designed using the method described in [4]. The effect of the shape, height, and number of pillars was investigated in a 3D FEM simulator (HFSS). Following this, several variants were selected for manufacture through cleanroom-based microfabrication techniques.

The aim was to develop and validate a method for the rapid fabrication of SWS, for the purposes of BWOs at mm-wave and THz frequencies. This method is based on the use of SU-8, a thick negative epoxy-based photoresist [5] for the definition of the pillars, combined with subsequent metallisation. In order to measure these, an H-plane split waveguide block will be used as a housing enclosure.

II. Structure Design

The waffle-iron filters for the 220 GHz – 325 GHz range were designed using the method described in [4] as a starting point, together with the more rigorous analysis in [6]. All the designed filters function as low-pass ones within the band of interest. Once the initial dimensions, detailed in Fig. 1, were calculated, they were then optimised using HFSS for a cut-off frequency (F_c) of 290 GHz.

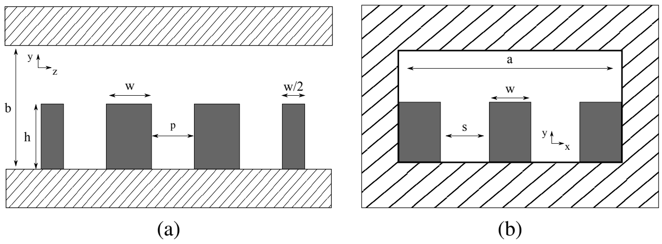

Fig. 1. Waffle-iron filter dimensions (not to scale), along the waveguide (a), and across the waveguide (b).

Four different pillar shapes were evaluated; these are illustrated in Fig. 2. The effect of the number of periods was also investigated in HFSS.

III. Simulation Results

Simulation results from HFSS, showing the expected effect of pillar profile on the filters' S_{21} are presented in Fig. 3, whereas Fig. 4 illustrates how the response changes with an increase in the number of pillar periods N.

It can be seen that the shape of the pillars mainly affects the F_c, with minimal effect on performance in the passband, whereas an increase in the number of periods leads to a sharper filter roll-off.

Overall, these structures are expected to provide a significant frequency selectivity when measured using a Vector Network Analyzer (VNA), allowing for direct comparison with simulation results.

IV. Block Fabrication

The pillar structures were realised via conventional photolithographic process, using SU-8, on a Si host wafer. An important advantage of this method is the possibility to fabricate pillars with arbitrary profile, which is a major limitation

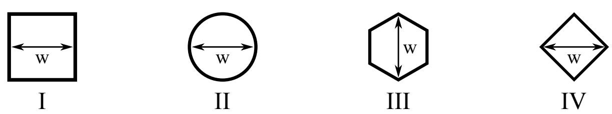

Fig. 2. Pillar profiles investigated. Dimension w kept constant.

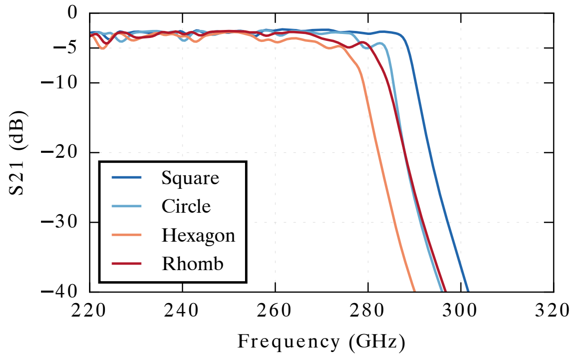

Fig. 3. Effect of pillar shape on S_{21}.

of nano-CNC milling processes. This advantage can be particularly useful to the development of SWS for BWO research [7].

The main challenge with this approach is to obtain the necessary metal thickness on top of the pillars, while maintaining low surface roughness. At the frequency range of interest, around $1\mu m^2$ of metal is required to satisfy the 5 skin depths requirement. Using a combination of sputtered Au seed layer and Au plating with low average plating current density, surfaces with $R_a = 6.21nm$ and $R_q = 7.47$ were obtained, as opposed to $R_a = 5.10nm$ and $R_q = 6.15nm$ for sputtered layers.T his method has been successfully used in the past for other waveguide circuits [8], [9].

Once the structures have been metallised, the wafer can be cut into blocks for VNA measurements. An SEM photograph of such a filter structure with rhomboidal profile is shown in Fig. 5.

V. Conclusions & Future Work

A method for inexpensive and quick fabrication of THz structures using SU-8 has been developed and presented here, and its applicability to waffle-iron filter design demonstrated.

The next step is to report on detailed measurements and their comparison to 3D FEM simulations. In parallel, thin dry film sheets ([10]) will be investigated to facilitate even more rapid and lower cost microfabrication.

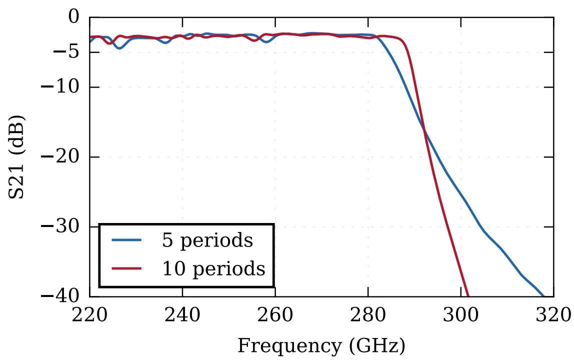

Fig. 4. Effect of number of pillars on S_{21}.

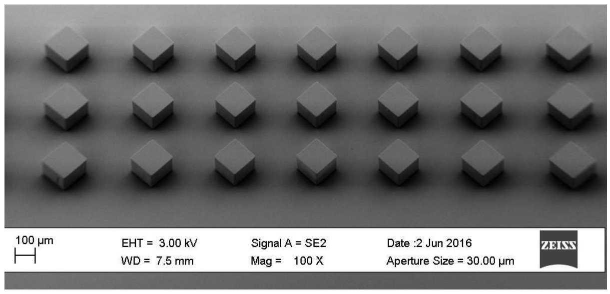

Fig. 5. An SEM image of a filter structure with rhomboidal pillars.

Acknowledgements

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