Fabrication of G-band Double Corrugated Waveguide by Precision Cutting

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***Abstract*—Fabrication of sub-THz slow wave structures usually requires expensive high precision equipment. A low cost fabrication method for the double corrugated waveguide at sub-THz frequencies is proposed. The use of the precision cutting machine permits to quickly produce square pillars with dimensions in the range of hundreds of microns or smaller with good precision. A double corrugated waveguide has been simulated at G-band (275 - 305 GHz) with the geometry modification to keep into account the cutting profile produced by the cutting wheel. A first sample of pillars with cross section 70 x 70 microns by using the precision cutting has been demonstrated. The preliminary results are promising making the process a possible alternative to CNC milling or UV-LIGA.**

***Index Terms*—G-band, D-band, TWT, double corrugated waveguide, slow wave structure**

I. Introduction

The main challenge for 5G and 6G networks is the availability of state of the art power amplifiers for revolutionizing the distribution of high data rate outdoor at sub-THz frequencies [1], so far limited by the high link attenuation at those frequencies.

Traveling wave tubes (TWTs) have recently gained interest to provide power over the wide frequency bands of the sub-THz spectrum above 100 GHz [1], [2]. The fabrication of TWT at the verge of the 300 GHz range is a formidable task with the need of innovative fabrication solutions. [3].

Only a few G-band TWTs realized and tested at different level are reported in literature [2], [4], [5]. A double corrugated waveguide (DCW) for a G-band (210 - 250 GHz) TWT was designed with pillar with cross section 70 x 70 microns [6].

This paper reports the first test of a new fabrication method using a precision cutting machine to produce pillars for sub-THz double corrugated waveguides applicable to D-band and G-band TWTs.

II. G-band Double Corrugated Waveguide Design and Fabrication

The fabrication of the slow wave structure for D-band [7] and G-band [6] TWTs is a formidable and expensive task due to the small dimensions of the features. Most of the TWTs so far reported at G-band use the folded waveguide [2], that are usually fabricated by lithographic process (UV-LIGA). A double corrugated waveguide (DCW) was designed for a 275 - 305 GHz TWT with pillars with 65 x 65 microns cross section. The fabrication of pillars with this dimension has been demonstrated both by CNC milling [8] and UV-LIGA process [9]. However, both the processes have their own specific challenges.

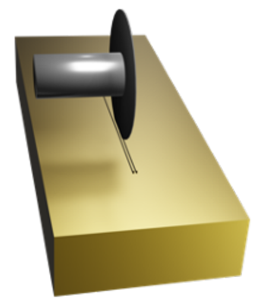

Fig. 1. Working principle of high precision cutting machine

A. Fabrication challenges

CNC milling for sub-THz slow wave structures is very time consuming due to the use of small tooling (less than 200 microns diameter) and very slow feed rate [3]. UV-LIGA with electroforming permits to build structures with features of tens of microns by a relatively simple process of exposing a layer of given thickness of photoresist (SU-8) to UV-light by a mask with the pattern to build. Then the metal structure is growth by electroforming. The UV-LIGA is an affordable fabrication process in term of equipment and allows large volume production, but it needs a long electroforming time and carefull removal of the SU-8.

B. High precision cutting fabrication

A new process based on the use of a high precision cutting machine is in development. The process is promising and low cost since the pillars, instead to be machined by CNC milling, are cut by a high speed cutting wheel on one metal block, as shown in the rendering in Fig. 1. The cutting is much faster than CNC milling since the cutting wheel works in straight lines and remove high quantity of material. In addition, the using of the cutting wheel permits avoiding very low diameter toolings that are expensive, of fast degradation of cutting

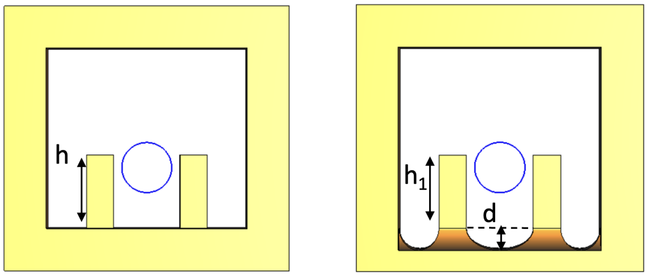

Fig. 2. Schematic of the original DCW (left) and modified (right) DCW including the cutting profile (the blue circle represents the electron beam).

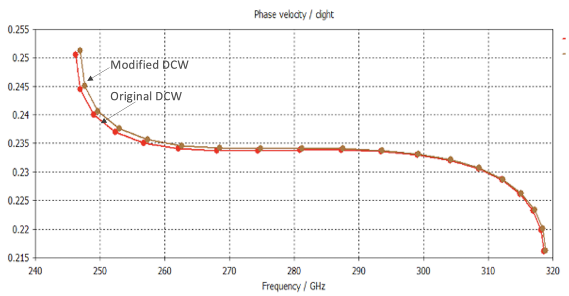

Fig. 3. Comparison of the dispersion curve of the DCW in Fig. 2.

performance and need a very long time machining to produce pillars. In our knowledge the minimum thickness of the cutting wheel available in the market is 150 microns suitable for the channel width of a G-band DCW (160 microns).

The first step to built the pillars is to produce a high quality surface copper substrate. A rib with width equal to the sum of the two pillars width and the channel width is produced by CNC milling, with the length of the DCW to produce. A first cut along the longitudinal axis of the rib produces the beam channel. In case of pillar for the G-band TWT, a 150 microns cutting wheel is used. The pillars are then produced by using a 250 microns cutting wheel working at 90 degrees with the axis of the rib. The second block with the waveguide to enclose the pillars will be produced by CNC milling.

The difference in comparison to the CNC milling is that the wheel cut produces a round profile at the base of the pillars (Fig. 2). This additional shape determines a different electrical behaviour that has to be considered in the design phase. A redesign of the DCW was performed to find the dimensions to have the same performance of the DCW fabricated by CNC milling. Reducing the height (h) of the pillars of a quantity equal to d the depth of the cut, so that the new height ($h_1 + d$) is approximately equal to the original h, the same cold parameters are achieved. The depth of the cut is obtained by experimental observation. The comparison of dispersion between the original DCW and the modified DCW to be fabricated by precision cutting is shown in Fig. 3. The resulting cold parameters are substantially identical.

Figure 4 shows a first proof of concept of pillars with about 70 x 70 microns cross section by precision cutting. A post process polishing is needed to improve the surface roughness. The precision cutting process is in development to produce a full DCW for a complete characterization.

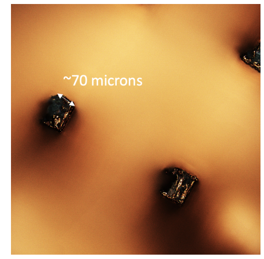

Fig. 4. Photo of the pillars realized by precision cutting.

CONCLUSIONS

A preliminary test of feasibility for a low cost fabrication process suitable for G-band and D-band double corrugated waveguides for sub-THz TWTs has been discussed. The use of precision cutting to produce the pillars is fast and low cost. The method needs further refinements and test, but the results obtained are very promising as complement to CNC milling and UV-LIGA fabrication.

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