Micromachined ridge gap waveguide for sub millimeter and millimeter wave applications

MICROMACHINED RIDGE GAP WAVEGUIDE FOR SUB MILLIMETER AND MILLIMETER WAVE APPLICATIONS

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***Abstract* — High-frequency waveguide technology has become a field of great interest lately. In this paper we present a ridge gap waveguide with two** 90 *degree* **bends and a ridge gap waveguide resonator, both fabricated with MEMS technology. It is the first time the ridge gap waveguides have been fabricated for millimeter waves. The ridge gap waveguides is realized of two conducting plates, one of them with a texture, and can provide low transmission losses without any requirements to alignment between the two plates, and with neither conductive joints nor sidewalls. The Ridge gap waveguide makes use of a "bed of nails" structure which acts as a magnetic conductor and creates a cut-off for parallel plate modes between the two plates. Thereby, wave propagation is confined to the electric conducting ridge, without making use of electrically conducting sidewalls. MEMS technology can provide precision machining which makes it possible to go up in higher frequency bands than with conventional machining. The purpose of this paper is to describe the the fabrication process of the surface textured with pins and ridge.**

Keywords: **GHz, High-frequency, MEMS, RF, Waveguide**

I – Introduction

Sub millimeter and millimeter waveguide technology is an expanding new field. Conventionally solid rectangular waveguides and coaxial transmission lines are use due to their low losses at high frequencies. However they experience some practical problems when integrated in a high-frequency system. Other waveguides have been introduced but often requires electrically conductive sidewalls and good alignment. Even though some structures do not require solid walls they are still in need for electrical contact between separately manufactured pieces. Recently, a ridge gap waveguide has been introduced [1], constructed, manufactured by milling, and verified to work between 10 and 20 GHz [2]. The fabrication method by milling is impossible when dimensions are decreased to achieve higher frequencies, and in particular above 100 GHz. On the other hand, MEMS technology can offer precision machining and open up a new frontier of high frequency microwave components. In this paper, we present for the first time a ridge gap waveguide and a ridge gap resonator for the range of 210-340 GHz fabricated with MEMS technology.

Ridge gap waveguides use metamaterial to confine the electromagnetic wave without using solid or conductive walls. At the operation frequency the metamaterial will act as an Artificial Magnetically Conducting (AMC) surface. Thereby, it creates together an overlying parallel electric conducting surface a cutofffor parallel-plate modes. By surrounding the conducting ridge with the AMC surface, the electromagnetic wave will follow the ridge and is forbidden to propagate in any other direction due to the parallel-plate cutoff. The ridge gap waveguide has the benefit of low losses at the same time as being easier to manufacture, and allowing more freedom in assembly, alignment and fabrication than other lowloss waveguide technologies.

II – Structure & Design

Here in this work a ridge gap waveguide (figure 1) and an ridge gap resonator (figure 2) has been

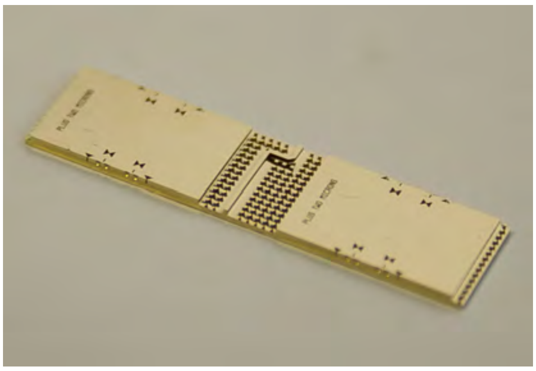

Figure 1: *The waveguide chip*

fabricated using MEMS technology. By having a electric conducting surface parallel to an AMC surface with a distance smaller than one fourth of the wavelength, the wave is prohibited from propagating between these two surfaces [3]. In this structure a conductive ridge is embedded in the AMC surface allowing the electromagnetic wave to propagate between the ridge and the smooth electric conductor above. The AMC is obtained by a structure known as "bed of nails" [4]. Here the "bed of nails" structure

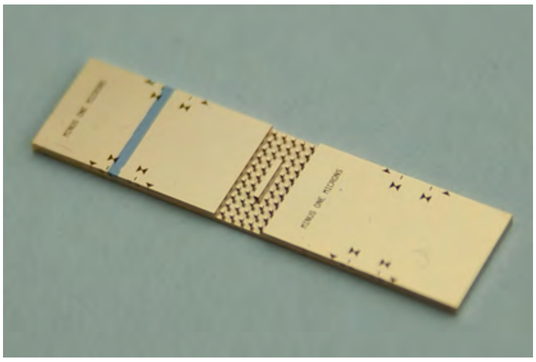

Figure 2: *The resonator chip*

is constructed with micromachined pillars. The pillar height is around 277 μm, the active area of the ridge gap waveguide chip is 5.290 $mm \times 3.5$ mm and for the ridge gap resonator it is 4.95 $mm \times 2.28$ mm. The electrically conducting lid over the ridge gap waveguide has a height of 55 μm above the ridge and the lid over the resonator is placed $167 \mu m$ above.

The ridge gap waveguide has a ridge with two 90° bends which show that the electromagnetic wave follows the ridge. To obtain a signal a rectangular waveguide situated in a measuring flange needs to be attached. A surrounding copper package, figure 3, is milled to support the chip when the measuring flange is connected to it. The copper package has besides support two more purposes. 1) It provides the smooth electric conducting lid above the ridge as seen in enlarged area of figure 3 with the AMC surface at a fix distance from it. 2) It has a transition interface structure for the electromagnetic wave to transfer from the ridge gap waveguide to the rectangular waveguide in the measuring flange. The transition is done with a staircase structure, milled into the copper package connected to the ridge figure 4.

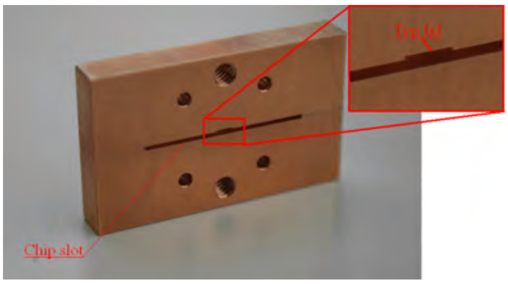

Figure 3: *The copper support package. The enlargement show the milled area which will act as a conducting lid over the chip.*

The resonator consists only of a single ridge surrounded with the "Bed of nails" structure from every direction. The resonator is weakly coupled to the measuring flange and therefore there is no need for a transition interface structure. The rectangular waveguide is simply connected to the short side of the resonator and there are fewer requirements for a perfect connection.

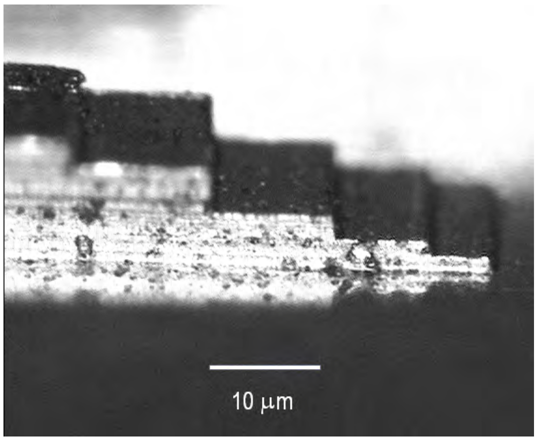

Figure 4: *The transition structure from the ridge waveguide to the rectangular waveguide*

III – Fabrication Process

The process for fabricating the waveguide and the resonator is shown in the schematic process plan in figure 5. Both devices have the same pillar height and therefore the same processplan is used. A more detailed description will follow.

A 0.5 μm thick aluminum layer was sputtered on a silicon wafer to act as a hard mask during etching. Aluminum was used and not silicon dioxide because it gives a better lateral resolution than an oxide hard mask when etching. The etch selectivity for Al/Si is higher than for SiO_2/Si. Since Aluminum is used as a hard mask, a thin photoresist is sufficient when etching. In contrast when using oxide with the given equipment, a thick resist layer would have been needed to compensate for the reduced selectivity.

To achieve vertical walls, deep reactive ion etching was used. Similar work has been done in [5]. Here the etch rate was up to 3 $\mu m/min$. The height of the pillars were aimed to be in the range of 277 μm to achieve the operation frequencies of 210-340GHz. When etched slower black silicon was observed in the trenches.

The aluminum and the remaining photoresist is stripped of the wafer. Thereafter the wafer was diced into strips to ease the electroplating of gold. Gold is used to make the surface conducting and needs to be 5-6 times thicker than the skin depth at 270 GHz which results in a requirement of an approximately 1 μm thick gold layer. First a 50 nm layer was sputtered as a seed layer on all sides to achieve electrical contact

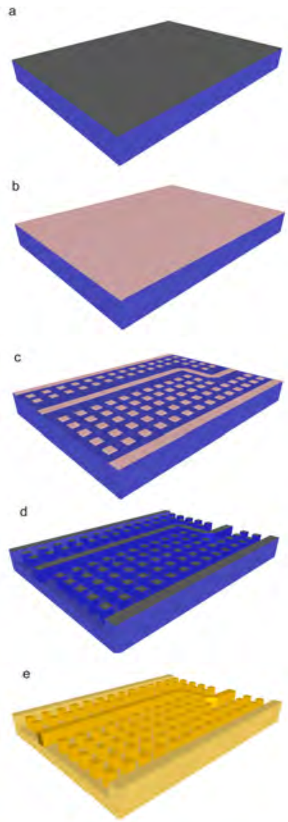

Figure 5: *Process plan for both the waveguide and the resonator. a) A* 0.5μ*m layer of Al is sputtered, b) a thin photoresist layer is spun on top, c) the photoresist is developed and the exposed Al is etched, d) Deep reactive ion etching is used to etch the pillars and the Al and remaining resist is stripped, e)* 1 μ*m gold is sputtered and electroplated*

to the package. The line of unplated surface visible in figure 2 is a consequence of the clamp used when electroplating. Electroplating is used to give a better step coverage and a more even distribution compared to if the entire layer was only sputtered. The strips are also sputtered and electroplated on the sides to achieve electrical contact with the copper package.

IV – Measurement specification

Measurements will be done using three basic components [6] i) a performance network analyzer (Agilent E836x system), ii) a millimeter wave test set controller (Agilent N526x), iii) a waveguide module. Here the module is the flange WR03 used for the range 220-325 GHz 6.

V – Results & Conclusions

Simulations for the ridge gap waveguide including the rectangular waveguide transition shown in figure 7 show how the electric field is propagating over the ridge gap waveguide at different frequency points. The simulation takes into consideration of the rectangular waveguide transition point. The propagation is

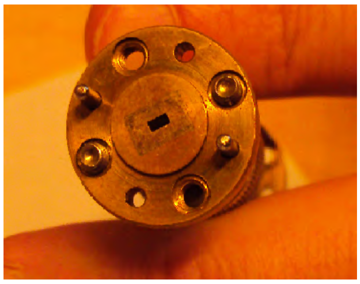

Figure 6: *The measuring flange with the inner rectangular waveguide of the dimension* 0.846×0.432 *mm*

concentrated along the ridge and it is restrained in all other directions by the pins surface within the operation frequency range, between 210 GHz and 340 GHz. Outside the frequency range, the electromagnetic field starts to spread all around the structure, as shown from the color plots (figure 7) at 180 GHz and 350 GHz.

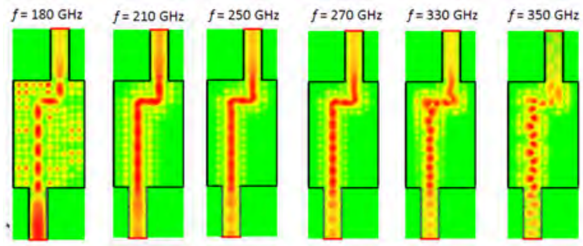

Figure 7: *Figure 7 shows 2D color plots of the simulated absolute value of E-field for the ridge gap waveguide at each frequency point, including rectangular waveguide transitions.*

The same simulations are done for the ridge gap resonator. Figure 8 shows the simulated electric field over the resonator. The third order mode is propagating over the ridge gap along the ridge, and the pins surface stops the field propagation in all other directions inside the cavity.

The simulated transmission and reflection coefficients, S2 respectively S1 , for the ridge gap waveguide including rectangular waveguide transitions can be shown in figure 9. The return loss is below -15 dB between 240 GHz and 340 GHz for the straight ridge case. The oral presentation will also show the measured S-parameters.

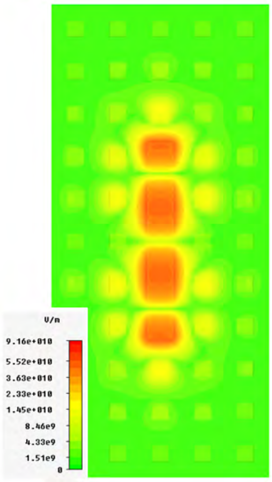

Figure 8: *This Figure shows 2D color plot of the simulated absolute value of the electric field for the open circuit ridge gap waveguide resonator.*

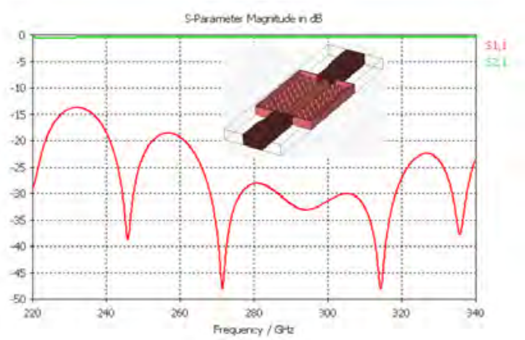

Figure 9: *The simulated reflection- (S2) and the transmission- (S1) coefficient for the straight ridge gap waveguide case*

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