220 GHz Folded Waveguide Circuits for High Power Amplifiers

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Abstract: *Folded waveguide interaction circuits for a vacuum electronic amplifier have been designed. Microfabrication efforts to produce the FWGs are underway and preliminary analysis of the properties of these slow wave circuits has been completed.*

Keywords: Folded waveguides; deep reactive ion etching; DRIE; LIGA; microfabrication.

Introduction

As part of DARPA's High Frequency Integrated Vacuum Electronics (HiFIVE) program, robust folded waveguide (FWG) circuits are being developed to achieve a compact 50 W amplifier operating at 220 GHz. Realization of a fully-integrated high power amplifier based on microfabricated circuits will have a significant impact on a variety of defense applications including covert, high data-rate communication, airborne collision avoidance systems, and high resolution radar imaging.

Slow wave circuit designs have been completed for both single and multiple FWG circuits capable of achieving >50 W CW at 220 GHz based on CHRISTINE simulations and impedance calculations with HFSS. The expected gain is above 30 dB, so 50 mW of drive power should be sufficient to drive the amplifier into saturation. Figure 1 shows the power and gain of the single FWG circuit as a function of frequency.

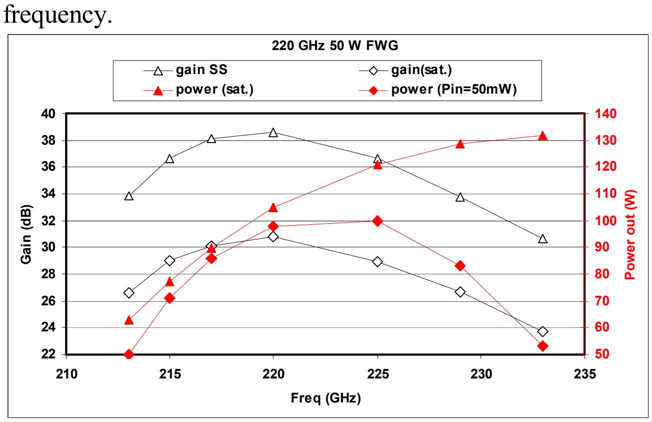

Figure 1. Power and gain vs. frequency for a single FWG.

While simulations predict that a single FWG with a circular pencil electron beam can achieve the HiFIVE goals, thermal issues associated with CW operation may limit the RF performance. Power combining of multiple FWG circuits requires the proper design of a input splitter and output combiner to minimize reflections and phase errors. Less beam current is required in each individual FWG in a power combined scheme resulting in a lower beam tunnel fill factor reducing the chance for beam interception. For the case of a 5-way combined circuit, the expected peak circuit temperature is 70 ^{o}C, three times less than that for a single beam FWG.

Microfabrication Techniques

With either amplifier design (single or multiple FWG), the overall dimensions of structures are consistent with consistent with fabrication techniques based on DRIE and UV-LIGA using an SU-8 resist. Both lithographic techniques have been employed to fabricate FWGs for cold testing of the circuit properties.

Previously, Teledyne Scientific and Imaging developed the processes required for fabricating 650 GHz waveguides by aligned bonding of two mirrored wafers, each having metallized FWGs formed by Si DRIE of the substrates. This technology was developed to meet the following challenging specifications: waveguide aspect ratio (~8:1), height/width dimensional accuracy (1%), height uniformity (<1%), sidewall smoothness (<50nm) and top-to-bottom half alignment accuracy (<2 µm). Circuit fabrication constraints, such as those associated with surface roughness and alignment of the circuit halves, will be significantly easier to satisfy at 220 GHz than at 650 GHz. The key differences that may require technology optimization of the DRIE process are the larger waveguide height and the thicker waveguide sidewall metallizations. The larger waveguide height requires etching deeper Si trenches, to depths of ~400 µm. Initial etching experiments exhibit a 5-6 µm variation in the etched depth of the FWG, and efforts are underway to reduce the amount of variation.

Thermal management issues due to beam interception and high RF power levels may require the use of all-metal

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circuits in the HiFIVE amplifier. Creatv MicroTech has developed UV-based LIGA microfabrication techniques for producing the high efficiency interaction circuits. SU-8, a negative-tone photoresist, is attractive for applications in high-aspect-ratio microfabrication because of its high sensitivity to UV radiation and good resolution. After exposure and development, Cu is electroplated around the SU-8 mold forming the FWG.

Optimization of the UV/SU-8 LIGA processing to achieve the desired dimensional tolerances is in process. One such key area is the planarization to achieve parallelism between the bottom of the folded waveguide and the top surface of the circuit die. Failure to maintain parallelism will result in a structure with a varying phase velocity along the length of the circuit. While maintaining parallelism, the FWG height must be accurate such that the device operates at the desired beam voltage. An example of multiple FWGs microfabricated by the UV/SU-8 LIGA process is shown in Figure 2.

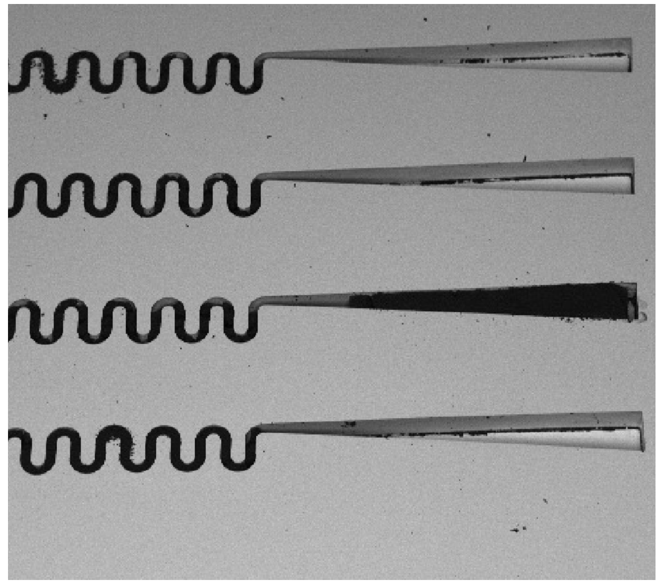

Figure 2. UV/SU-8 LIGA produced FWG structures shown with the SU-8 photoresist partially removed.

Conclusion

NGC has designed single and multiple FWG circuits for use in 220 GHz amplifiers as part of DARPA's HiFIVE program. Microfabrication of the circuits is proceeding on parallel paths: Cu-coated DRIE Si and the all Cu on Cu FWGs produced by UV/SU-8 LIGA. FWGs microfabricated by both methods are currently being evaluated for use in high power amplifiers and the results will be reported.

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