Development of W-band Backward-Wave Oscillator

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Abstract: *The precise patterning of periodic slow-wave structures can be successfully accomplished by modern photolithography technology on flat substrates in high frequency regime (>100 GHz). When the aspect ratio of the structure between in-plane and out-of-plane dimensions becomes higher than unity, however, controlled MEMS (micro-electromechanical systems) technologies are strongly required to achieve accurate depth profiles of slow-wave beam-wave interaction circuits. Here we report a W-band backward-wave oscillator using micro-fabrication technologies by which a fully 3-dimensional slow-wave interaction circuit is successfully employed on multi-bonded silicon wafers. The return loss measurement of the circuit appears to be very similar to the simulation, which indicates not only the dimensions but also the surface roughness is under control. A more detailed discussion on the design, fabrication, and RF test result will also be included.*

Keywords: Backward-wave oscillators, slow-wave structures, photolithography, MEMS, beam-wave interaction, W-band.

Introduction

Increasing demand for high-frequency, high-power, coherent electromagnetic-wave sources has brought about a new challenge in search of highly precise fabrication technologies enabling sophisticated slow-wave interaction circuits. Due to decreasing physical dimension of the circuit, the conventional machining technologies (e.g., wire EDM) on high conductivity bulk metals have shown many mechanical or thermal drawbacks. SU-8 lithography, LIGA (German acronym for Lithographie, Galvanoformung Abformung; deep etch x-ray lithography, electroplating, and molding), deep RIE(reactive ion etching), etc, therefore, have been introduced for terahertz (>0.1 THz) beam-wave interaction circuits [1, 2]. Previous studies have also proved that the deep RIE microfabrication is one of good candidates satisfying the requirements of dimensional tolerances, surface finish, and alignment of the structures [3]. Here we employed the deep RIE fabrication method for W-band backward-wave oscillators (BWOs). In particular, the return loss measurement shows a good performance as predicted by FEM (finite element method) simulation. The interaction circuit is fully integrated with thermionic electron gun, collector, WR-10 waveguide, RF window, etc in vacuum sealed tube. The preliminary RF test result is also discussed.

Design

The realization of the W-band BWO is presented in Fig. 1, which shows the detailed engineering design of the assembly. A 12-kV electron beam from the thermionic cathode is employed with two 3 l/s ion pumps at both ends of the assembly. The slow-wave interaction circuit has been designed and studied as described in previous report [4] and now we have a newly revised circuit design for efficient beam-wave interaction with optimized wave coupling structures to the output port. Figure 2 represents the BWO circuit similar to folded-waveguide structures. The physical dimension of each cell is several hundred microns. The gap for beam-wave interaction on the beam tunnel is chosen to be 300 microns.

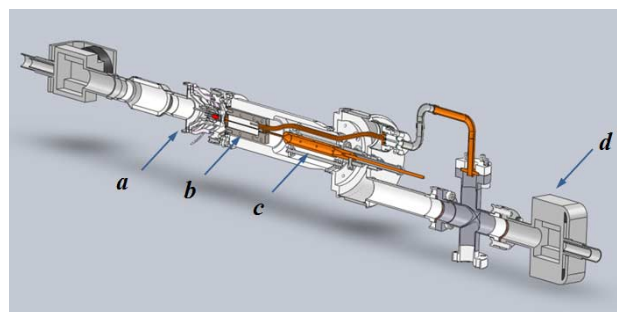

Figure 1. Assembly design of W-band BWO. Electron gun (a), slow-wave interaction circuit (b), beam collector (c), and ion pump (d) are shown.

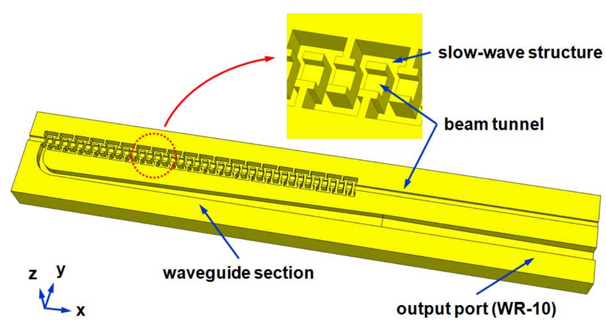

Figure 2. Slow-wave interaction circuit for backward-wave oscillation.

Fabrication

As shown in Fig. 3, the deep RIE microfabrication is applied on 6-inch silicon wafers. The fully 3-dimensional circuit structure on silicon wafers requires more than 2-step fabrications because of different depths between the beam tunnel and the slow-wave structure. To enhance the return loss characteristics, 4-wafer multi-bonding fabrication is applied after the process of photolithography, deep-RIE, metal evaporation, etc. as shown in Fig. 3(b) which indicates the side view of the beam tunnel.

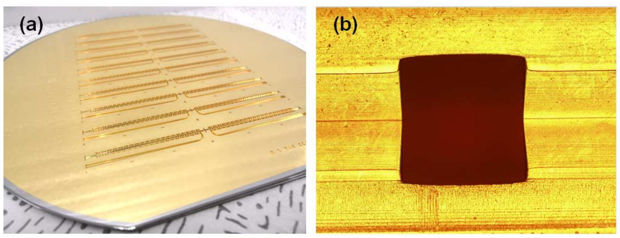

Figure 3. (a) Lithographically prepared interaction circuit on silicon wafer. (b) Entrance of beam tunnel.

Measurement

Figure 4 shows the return loss characteristics of 3 different cases: (1) FEM simulation (e.g. HFSS) of the circuit according to the design shown in Fig. 2, (2) measurement using a vector network analyzer (VNA) of the circuit, and (3) VNA measurement of the fully-integrated circuit with a WR-10 waveguide and the vacuum window in the sealed tube as shown in Fig. 5. The RF resonances from 96 to 110 GHz were successfully observed and the RF loss along the entire assembly was not significantly measured. In addition, the vacuum window including the WR-10 waveguide in the tube has little influence on the circuit performance. The several oscillations observed near 93 GHz are under the cutoff from the circuit dimensions, and they are considered as the low frequency oscillations between the tapered and bended waveguide section and the entrance of the slow-wave structure.

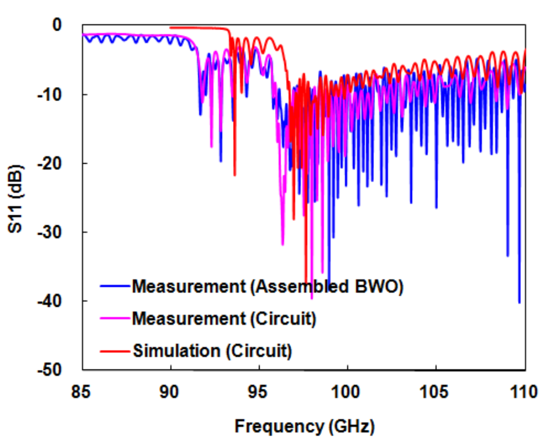

Figure 4. Return loss measurement and simulation.

The fully integrated sealed BWO tube is shown in Figure 5. Currently, it is under bakeout process and will soon be RF tested using an RF detector with a spectrum analyzer.

Figure 5. Vacuum-sealed W-band backward-wave oscillator.

References

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