Comparative Analysis on DRIE and LIGA Fabrications for Millimeter-Wave Backward-Wave Oscillators

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***Abstract*— For the generation of millimeter wave from vacuum electron devices, the microfabrication of an interaction circuit is one of the key factors. Two different technologies, a deep etch x-ray lithography (x-ray LIGA) and a deep reactive ion etching (DRIE), were employed for the comparative study and the realization of a backward-wave oscillator. Both methods showed accurate and reliable results, which enabled the integration of the interaction circuit for millimeter-wave backward-wave oscillators.**

I. INTRODUCTION

There have been many technologies for the fabrication of vacuum electron devices (VEDs) operating in microwave region from a few hundred megahertz to several tens of gigahertz. For example, milling, electrical discharge machining (EDM), electro-forming, etc. These conventional technologies, however, allows a fabrication tolerance and a surface roughness of over 5 µm. To reach high frequency operation of VEDs from millimeter to sub-millimeter wave or so-called "Terahertz (THz) Gap," a more precise and accurate fabrication technology is strongly required due to shorter wavelength. Here we employed modern technologies of LIGA (German acronym for Lithographie, Galvanoformung Abformung; deep-etch x-ray lithography, electroplating, and molding) and DRIE for the interaction circuit fabrication of coupled-cavity backward-wave oscillators (CCBWOs) operating at 100 GHz.

II. RESULTS

The design of the interaction circuit was prepared using a large-signal code to predict the output power and the operation frequency. As shown in Fig. 1, the dispersion relation of the interaction circuit indicates a tunable resonance with the electron beam near 0.1 THz. The circuit comprises a series of interaction cavities and coupling slots to increase interaction efficiency, which is called as a coupled-cavity backward-wave oscillator (CCBWO). The predicted output peak power is about 5 W maximum when a CW operation of 12-kV, 50-mA electron beam is assumed.

The size of the circuit is near several hundred microns due to the wavelength as shown in Fig. 2(b), so the conventional fabrication technology in microwaves is no more preferable. Also, when we consider high frequency operation more than 0.1 THz, the size of the interaction circuit requires higher precision upto micron tolerance. Thus, the silicon based technology DRIE (Deep Reactive Ion Etching) and LIGA fabrication are considered as proper solutions for the microfabrication of interaction circuits. First, the 2-step DRIE process and the eutectic bonding of silicon wafers were successfully employed for the 3-dimensional interaction circuit. Figure 2 depicts the surface of the wafers after the 500-µm DRIE process. A 1.5-µm gold deposited silicon wafer was prepared, while 200-µm wide solder lines were patterned on the separate wafer for adhesive layers by liftoff process.

Another approach to fabricate the interaction circuit is the LIGA process using deep X-ray lithography. The LIGA process satisfies the microfabrication of complicated structures with high-aspect ratio. The Au-mask for X-ray exposure was combined with the 5 mm-thick PMMA on Cu-substrate by a fixture. Figure 3 shows the LIGA-fabricated interaction circuits with high quality of sub-micron surface roughness.

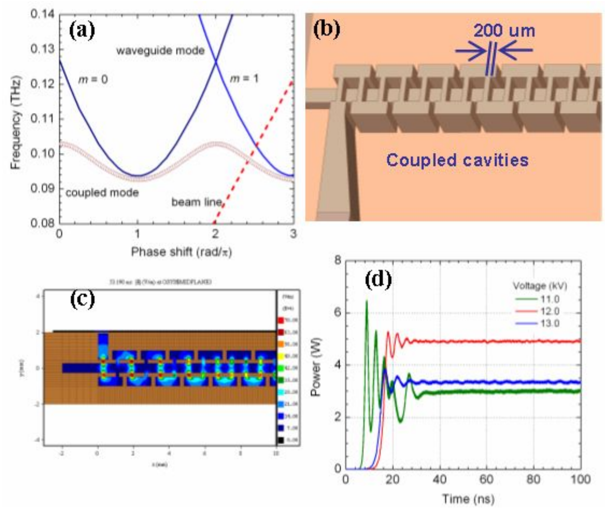

Fig. 1. (a) Dispersion relation, (b) structure of interaction circuit, (c) RF simulation, and (d) growth of output power of the designed 100 GHz CCBWO.

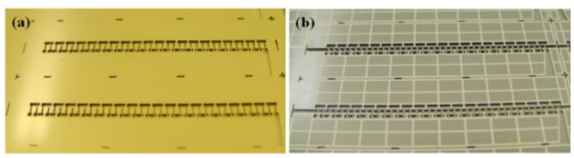

Fig. 2. DRIE-fabricated interaction circuit on silicon wafers. (a) Au-deposited surface for bottom and top layers, and (b) solder line patterned and beam tunnel etched on the intermediate layer.

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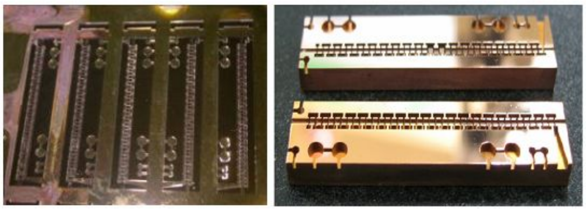

Fig. 3. X-ray LIGA fabricated CCBWO.

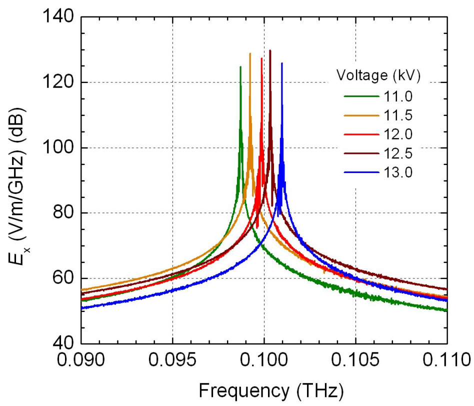

Fig. 4. FFTs of the electric fields (Ex) at different electron beam voltages.

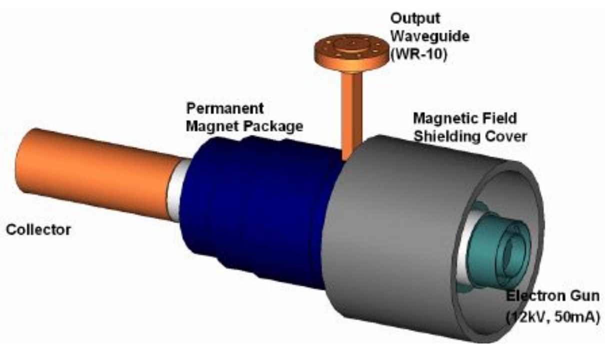

Fig. 5. Assembly for 0.1 THz CCBWO.

For the detailed analysis on the designed interaction circuit, a 3-dimensional particle-in-cell code was used. Figure 4 represents frequency spectra obtained by the fast Fourier transformation (FFT) of the electric fields at the output port of the interaction circuit. A 0.1 THz oscillation frequency was calculated and a narrow bandwidth was predicted. In addition, the center frequency could be precisely tuned when the operating voltage was changed.

Figure 5 shows a conceptually assembled structure of the 0.1 THz CCBWO. Using a permanent magnet package, the electron beam from the cathode will be confined, and a WR-10 type waveguide output port is employed for extracting a generated power at 0.1 THz.

A microfabricated vacuum electron device as a promising source for the realization of high-power coherent radiation in millimeter wave was theoretically designed and experimentally fabricated. We propose two kinds of microfabrication of the interaction circuit for high frequency source development. A comparison between DRIE and LIGA fabrications on the accuracy, tolerance, surface roughness together with insertion loss will be discussed in detail. A detailed study on the THz imaging, especially for detecting various materials together with the highly reliable source is underway.

References

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