Effects of Tolerance Fabrication of Extended Interaction Oscillator Based on Pseudospark-sourced Sheet Electron Beam at 0.35 THz

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***Abstract*—A practical numerical approach to the analysis of the effects of tolerances fabrication on the performance of a planar 0.35 THz extended interaction oscillator (EIO) is presented. The planar EIO is to be driven by pseudospark-sourced sheet electron beam. The influence of tolerance on the *Q*-value, resonance frequency, characteristic impedance is demonstrated using an effective value of conductivity of 1.1 x 10^7 S/m to take into account the skin depth and surface roughness. The method of Wire Electrical Discharge Machining (WEDM) is proposed to manufacture the 0.35 THz EIO because of its precision and moderate cost compared with other manufacturing methods such as high speed micro machining, Deep Reactive Ion Etching (DRIE) or Ultra Violet Lithographie, Galvanik, and Abformung (UV LIGA).**

Keywords—extended interaction oscillator, pseudospark discharge, sheet electron beam, sub-terahertz.

I. INTRODUCTION

High frequency and high power radiation sources specically above 100 GHz are in great demand for a wide range of research and technical applications, including high-data rate communications, high resolution radar, molecular spectroscopy, bio-imaging and security screening, etc [1, 2]. Up to date, vacuum electronic technology still remain as the main method to generate kilowatt level high power millimeter wave radiation. As the frequencies move into the sub-terahertz and terahertz region, the size of device reduces dramatically. This brings great difficulties and challenges with regard to the manufacture of the device as well as formation of a high current density electron beam. Therefore a compact and simplified structure is desirable with the pseudospark-sourced (PS) electron beam an ideal cathode for the high power, high frequency source. This is because of the formation of an ion channel following the PS anode, which enables the beam to propagate with no need of a guiding magnetic field [3-11]. Among various VEDs, the EIO as a linear beam vacuum device has gained considerable attention as a promising millimeter wave oscillator due to its high gain per unit length and compact configuration [8-11]. Compared with pencil electron beam VEDs, sheet beam devices have attracted considerable attention as they produce radiation power proportional to the beam width and reduce the electron beam current density, leading to low magnetic field strengths required for beam focusing [11]. The PS-sourced sheet cathode to be used in a plannar EIO has great potential for the development of high power and compact millimeter-wave radiation sources due to the unique properties of PS discharge namely the generation of a high current density sheet electron beam with no applied magnetic field.

However, there are several key issues in the development of sub-terahertz/terahertz VEDs and one of the most critical factors is the precision of components required. When the frequency is greater than or equal to 0.3 THz, the physical dimensions of structure need to be precise as even a quite small error in the geometrical parameters can significantly affect performance. The scale of circuit is commonly as small as tens of microns, which calls for machining process with very high precision. Careful selection of the fabrication technologies is required to meet the criteria in terms of tolerance and surface roughness. To overcome this problem, some advanced approaches have been developed in recent years such as UV LIGA, DRIE, and WEDM [2], which all have made dramatic progress in micro-fabrication. Taking into account the cost of different processing technologies, it is essential and timely to analyse the influences of tolerance on the performance, which is helpful to decide the acceptable tolerance and the most appropriate method of machining.

II. INFLUENCES OF TOLERANCE IN MACHINING

Here, the effects of tolerance of circuit parameters on performance of a single period cavity have been studied. The 3-D model of the ladder-like single period cavity is shown in Fig. 1, which is composed of a gap connected with two coupling cavities on both sides and a beam tunnel passing through the centre of it.

The 3D EM simulation code CST Microwave Studio was employed to study effects of tolerance of the circuit parameters on performance. By simulating the cold (no electron beam present) cavities the various dimensions of the circuit were derived. It was found that a significant effect on the circuit performance are the geometrical dimensions of the interaction gap in the cavity especially the width of gap d and the height of gap gy. The value of characteristic impedance R/Q increases with the larger the tolerance of d and gy as shown in Fig. 2. The R/Q offset is about 4.1% and 1.7% respectively under a 5 μm error of d and gy. The value of unloaded quality factor Q_0 also increases as the tolerance of d grows and decreases as the tolerance of gy increases. The Q_0 offset is about 2.5% and 0.4% respectively with a 5 μm tolerance of d and gy. The characteristic impedance and Q_0 of the cavity are not very sensitive to changes in gy. The resonant frequency falls as the tolerance of d and gy increases. With an error up to ±5 μm of d and gy, the frequency shift is almost 1.5 GHz and 3.5 GHz respectively. Thus, the fabrication technology that is able to achieve a precision of 5 μm or less is preferred.

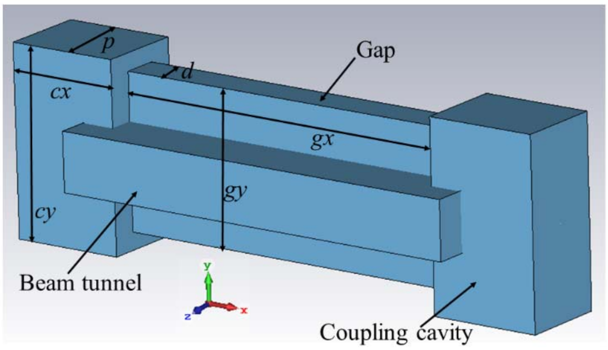

Fig. 1. Schematic of the single period EIO circuit.

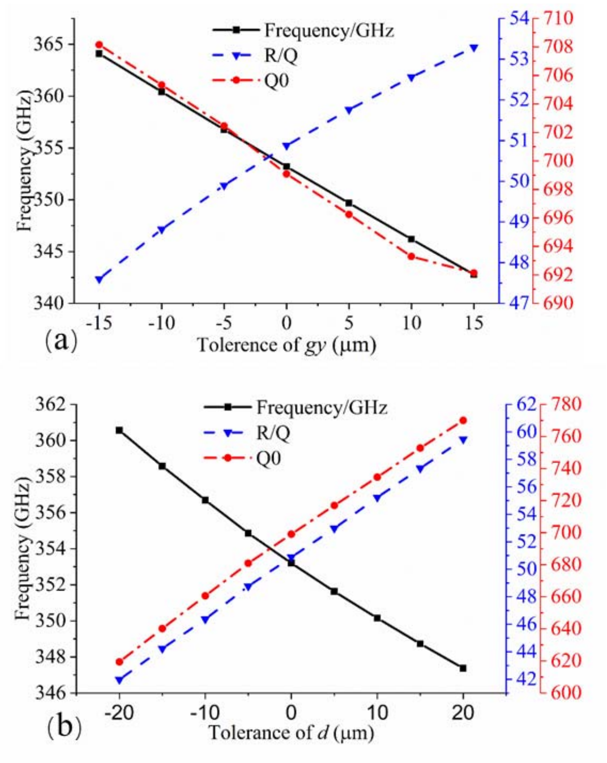

Fig. 2. Influences of tolerance of circuit parameters on performance of cavity.

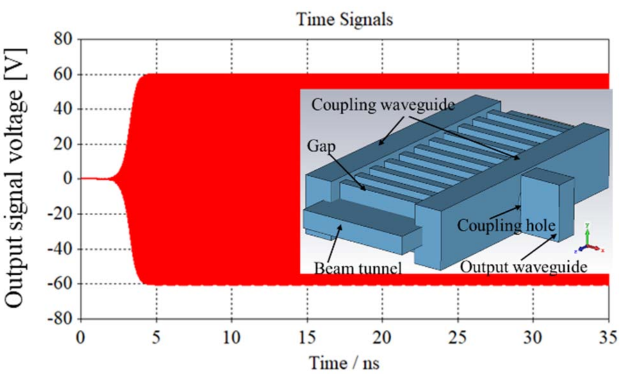

Fig. 3. The output signal voltage. Inset: Layout of the EIO circuit.

Among the advanced fabrication technologies, WEDM is economic and a capable method of machining planar structures [2,12]. It is not as expensive as UV LIGA and the process lends itself well to the manufacture of planar structures.

The 3D PIC simulation code CST Particle Studio was used to study the beam wave interaction of the planar EIO composed of 11 period ladder-like cavities. The conductivity of the background material was set at $\sigma_{Cu}/5$ (σ_{Cu}=5.8 x 10^7 S/m). The RF circuit was driven by a high aspect ratio (8.3:1) PS-sourced sheet electron beam with a voltage of 34 kV and a current of 6 A (0.5 × 10^8 A/m^2 beam current density). The simulation results indicate that a radiation power of 1.8 kW can be achieved at 0.35 THz as shown in Fig. 3.

III. Conclusion

Based on the analysis of potential tolerance in the process of fabrication, the influences of error on circuit performance have been studied. The accepted precision in the manufacture process demands a value of 5 μm or less. The fabrication technology of WEDM has been proposed to machine the device, which is capable of realizing high precision and a relatively straightforward process in the manufacture of planar structures. The PIC simulation results indicate that an EIO with 11 period cavities driven by a PS-sourced sheet electron beam can generate a radiation power of 1.8 kW at 0.35 THz. An experiment to investigate the generation of high power sub-millimeter-waves based on a PS-sourced sheet electron beam is currently being pursued at the University of Strathclyde in collaboration with Queen Mary University of London.

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