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A 200 GHz Millimetre-Wave Source Driven by a Small Diameter Pseudospark Electron Beam

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Abstract: Small-scale pseudospark discharges are under investigation for their applications for millimetre wave to terahertz radiation generation. A 10 kV voltage was applied to a single-gap pseudospark having a 1mm cathode aperture, 1mm anode aperture and 6mm gap separation. At a pressure of 100 mTorr, an output current of 4 A was measured which corresponded to a current density of 500 A cm^{-2} and is similar scale to that observed in previous 3 mm aperture experiments. Based on the pseudospark–sourced electron beam, a 200 GHz microklystron was designed and simulated using the particle-in-cell (PIC) code MAGIC. In a four cavity microklystron, MAGIC-2D results predicted a strong amplification signal with a peak power output of 5 W with an RF input power of 25 mW when the Q-factors were 730, 1600, 1600 and 1600 for the cavities, respectively. This corresponded to a device gain of 23 dB and efficiency of 20%.

Introduction

Terahertz radiation (0.1-10 THz) has wide potential applications in both scientific research and commercial uses, including plasma diagnosis, radiotherapy and advanced communications. All these applications require compact and inexpensive terahertz power sources. The klystron is an ideal choice for THz generation, due to its high gain, high efficiency and robustness as well as the fact that it may be scaled in size in order to achieve higher frequency operation [1]. Due to the decrease in size as the frequency is increased, there is a need for the electron beam current density to increase in order to achieve reasonable output powers. A pseudospark (PS) discharge is a viable option to address this requirement, due to the emitted linear beam's characteristic properties, such as high current density and high brightness, as well as the benefit of electrostatic self-focusing negating the requirement for an external magnetic guiding field. Therefore a pseudospark driven microklystron can be a compact and simple device.

1 mm Aperture PS Electron Beam Experiments

Discovered thirty years ago, the pseudospark discharge continues to be studied with regard to its discharge physics and applications as a high quality electron beam source and as a high power pulsed switch [2]. A pseudospark is an axially symmetric, self-sustained, transient, low pressure (typically 50-500 mTorr) gas discharge in a hollow cathode / planar anode configuration and operates on the left-hand side (with respect to the minimum) of the hollow-cathode analogue to the Paschen curve. A potentially useful property of this type of discharge is the formation of an electron beam during the breakdown process [3-6]. Pseudospark experiments have previously been undertaken at the University of Strathclyde and recently single-gap experiments were performed in an effort to show the effects of scaling down the size of the pseudospark discharge on beam performance.

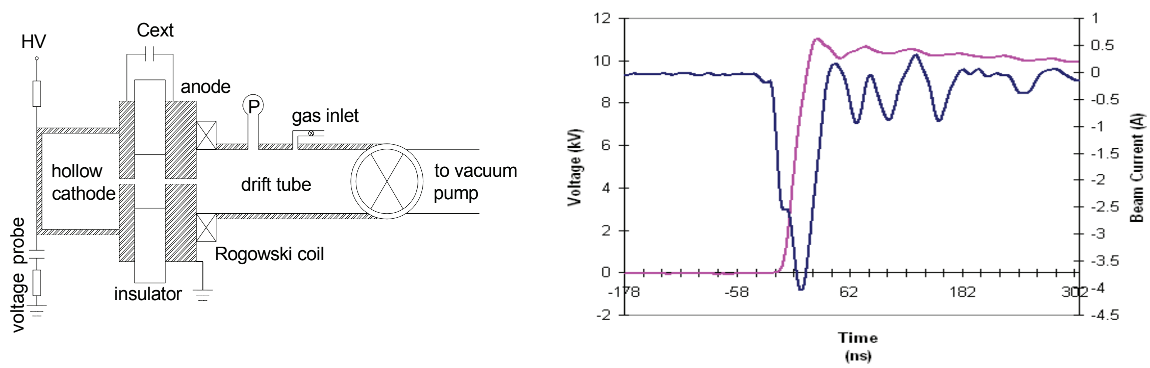

Fig. 1. Experimental setup (left) and electron beam measurement (right) from a PS configuration of 1mm axial aperture.

A 10 kV voltage was applied to a pseudospark having the configuration: 1mm cathode aperture, 1mm anode aperture and 6mm gap separation as shown in the left hand diagram of Fig.1. At a pressure of 100 mTorr, an output current of 4 A was measured as shown in the right hand diagram of Fig. 1, which demonstrates an output current density of a similar scale to that observed in previous 3 mm aperture experiments [7-11]. This also shows the potential to further scale down the pseudospark to become a micron sized discharge to drive a microklystron.

200GHz Microklystron Simulations

A four-cavity klystron with an operating frequency of 200 GHz was designed and simulated using the particle-in-cell (PIC) code MAGIC. As shown in Fig. 2 (top left), the microklystron consists of four cavities with same size of 430 μm width and 400 μm radius with interaction gap widths of 100 μm. The cavities are evenly positioned with a distance of 3.15 mm. The drift tube has a radius of 35 μm and a length of 11 mm in total. An 8 kV electron beam of 25 μm radius and 3.1 mA current, with a 1.58 mA RF modulated current was focused by a 0.4 T magnetic field. MAGIC-2D results revealed a strong amplification signal with a peak power output of 5 W at an RF input power of 25 mW when the Q-factors were 730, 1600, 1600 and 1600 from the input cavity to output cavity respectively, as shown in Fig. 2 (bottom left). This corresponded to a device gain of 23 dB and efficiency of 20%. The increase of the electron power and the beam current is shown in Fig. 2.

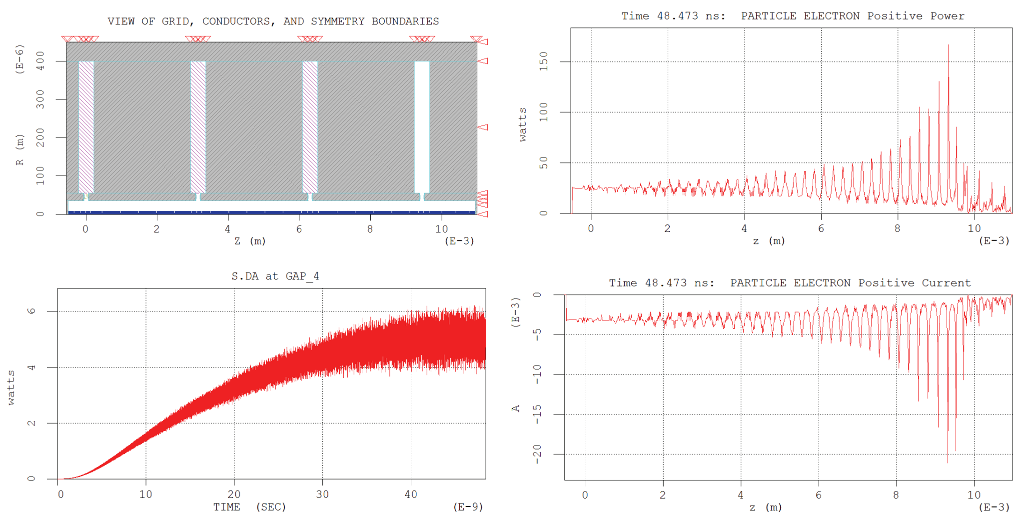

Fig. 2. MAGIC-2D representation of the 200GHz four-cavity klystron geometry (top left), power flow as a function of time at output gap (bottom left), electron power (top right) and current (bottom right) as a function of position

MEMS Manufacturing Process

In the past, the upper limits of the klystron operating frequency were limited due to constraints in the manufacturing processes available to engineers. The advent of microelectromechanical systems (MEMS) [12,13] has opened new avenues of performance. A process has been devised by Duke University to allow the construction of the 200 GHz klystron by means of deep reactive-ion etching (DRIE), chemical mechanical polishing (CMP) and silicon fusion bonding. A sputtered/electroplated copper layer of 1 μm will be applied to the micromanufactured device structure before the cavity and drift tube layers are combined to form the completed device. A possible four-cavity klystron interaction region has been designed for fabrication by MEMS with a single-gap pseudospark electron beam source being integrated into the system during the fabrication process.

Discussion and Conclusion

Recent pseudospark experiments producing electron beams of 1 mm in diameter have shown the possibility of being further scaled down in size to drive a microklystron in the terahertz frequency region. Simulations of a 200 GHz microklystron were carried out using MAGIC and have shown strong amplification in a four-cavity klystron structure. In order to increase the device gain and efficiency, an energy recovery system is to be simulated and designed. The fabrication of the whole device will be realized using the MEMS technique to integrate both the pseudospark beam source, the interaction region and the beam energy recovery system together.

Acknowledgements

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