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Bowes, D. and Yin, H. and Cross, A.W. and He, W. and Phelps, A.D.R. and Ronald, K. and Chen, Xiaodong and Li, Daohui (2014) Investigation of a klystron with a pseudospark-sourced electron beam. Journal of Physics: Conference Series, 511 (1). ISSN 1742-6588 , <http://dx.doi.org/10.1088/1742-6596/511/1/012020>

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Investigation of a klystron with a pseudospark-sourced electron beam

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Abstract. Investigation has been undertaken at the University of Strathclyde to simulate, design and construct a klystron amplifier with an operating frequency of 94 GHz. A novel beam source shall be utilized in the form of a pseudospark discharge, a form of low-pressure, high-current plasma discharge which produces an electron beam possessing high brightness as well as self-focusing properties. The seed signal for the klystron will be fed in using a tapered dielectric-lined iris coupling system.

1. Introduction

Extremely high frequency (EHF) radiation (30-300GHz) has wide potential applications in both scientific research and commercial use, including plasma diagnosis, medical imaging and advanced communications, etc. All these applications require compact and inexpensive radiation sources. The klystron is an excellent choice for EHF 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 discharge is a viable possibility in this respect, due to the emitted linear beam's characteristic properties such as high current density and high brightness as well as being self-focusing during its propagation. A pseudospark driven microklystron will be a compact and simple device as no external magnetic guiding field is required.

2. Pseudospark beam experiments

A pseudospark is an axially symmetric, self-sustained, transient, low pressure (typically 50-500 mTorr) gas discharge in a hollow cathode / planar anode configuration with the potentially useful property of the formation of an electron beam during the breakdown process [2-3]. During a pseudospark discharge, low temperature plasma is formed as an abundant electron and ion source and may be classed as a low work function surface that facilitates electron/ion extraction by voltage application at different polarities. A 10kV voltage was applied to a pseudospark of configuration: 1mm cathode aperture, 1mm anode aperture and 6mm gap separation as shown in figure 1. The anode was grounded and there was no external applied guide magnetic field.



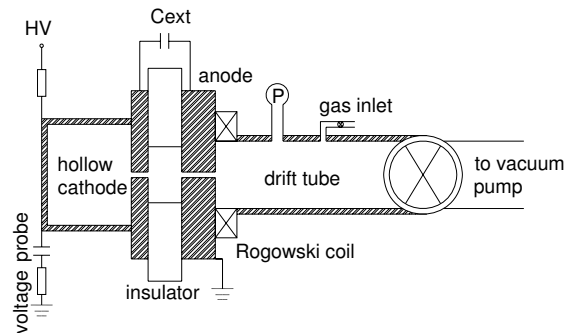


Figure 1: Experimental setup of pseudospark beam experiment.

At a pressure of 100mTorr, an output current of 4 A was measured as shown in figure 2, which demonstrates an output current of a similar scale to that observed in previous 3 mm aperture experiments [4-10]. This also shows the possibility to further scale down the pseudospark to become a micron sized discharge to drive a microklystron.

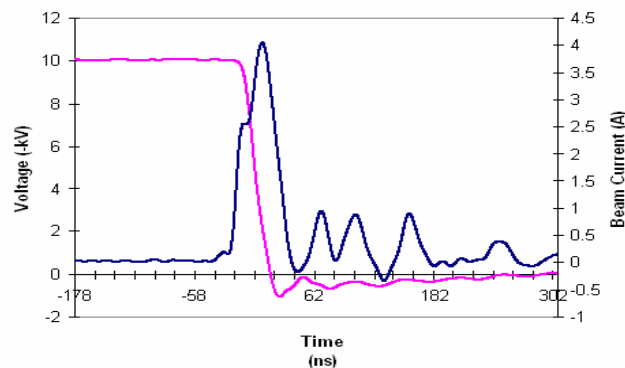


Figure 2: Current and voltage traces of single-gap pseudospark discharge.

3. Klystron simulations

The klystron is a linear-beam vacuum device which operates via using an input RF signal in order to velocity modulate a beam progressing along a length of drift tube. This seed signal induces signal amplification at the cavity resonant frequency coupled to the beam which may then be extracted via an output cavity further along the drift tube.

A multi-cavity klystron with an operating frequency of 94 GHz was designed and simulated using the particle-in-cell (PiC) code MAGIC. An 8 kV electron beam of 15 mA dc current modulated with an input RF signal of 200 mW was focused by a 0.6 T magnetic field. MAGIC-2D results revealed a strong amplification signal with a peak power output of 19.3 W at a millimetre wave input power of 200 mW, corresponding to a device gain of 19 dB and efficiency of 16%.

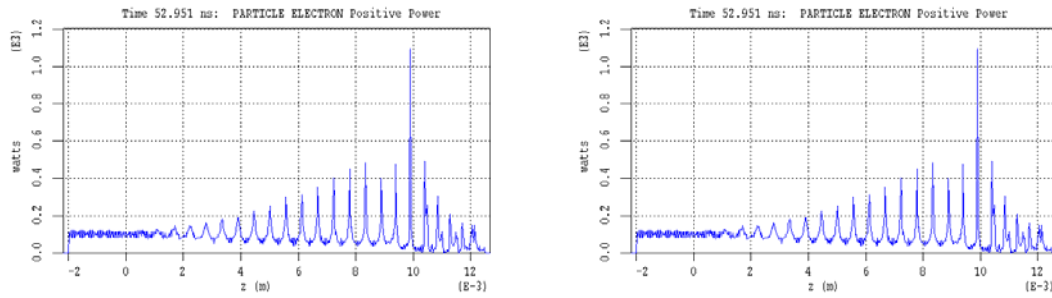


Figure 3: Electron positive power along length of beam.

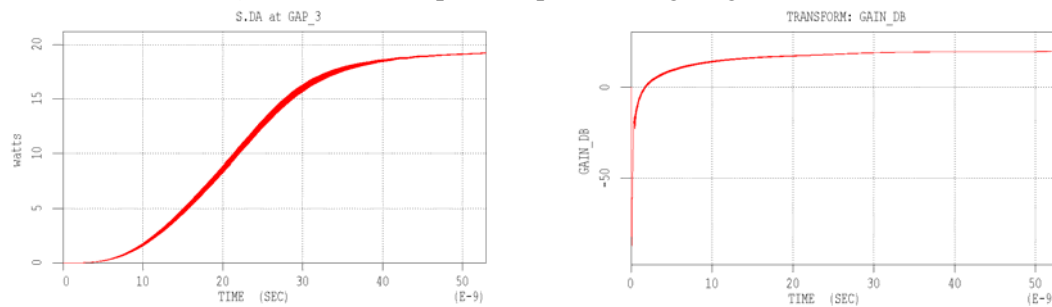


Figure 4: MAGIC-2D simulated output power, left, and gain.

Simulations were also performed using a modified current and voltage pulse in an attempt to better model device performance with a realistic pseudospark pulse. Voltage was stepped down to an average of 8 kV for 15ns before dropping to zero, whilst a current pulse of peak current 15 mA was timed to coincide with the voltage step, as shown in figure 5.

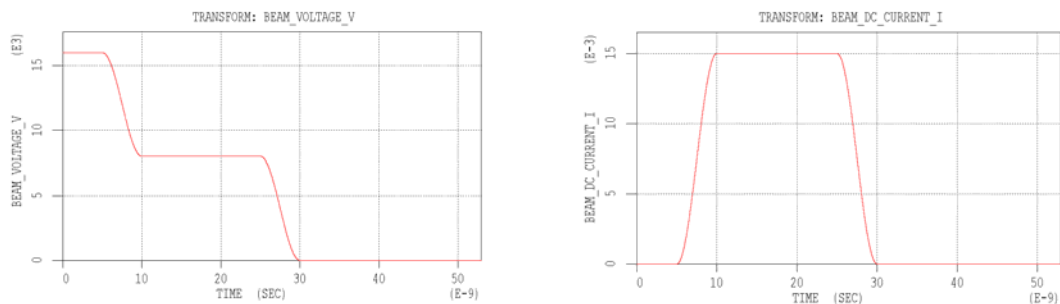


Figure 5: Pulsed current and voltage traces, 15 ns duration.

By varying the device interaction length a peak output power of 8.86 W was observed, coinciding with a device efficiency and gain of 7.4% and 16.5 dB respectively.

4. Coupler design

Owing to the precise dimensions involved with high-frequency klystron design and manufacture, coupling was an issue due to the cavities possessing dimensions significantly smaller than waveguide of corresponding frequencies. A solution has been proposed via coupling the input and output cavities to a tapered length of waveguide, gradually increasing to standard waveguide dimensions. In order to compensate for the difference in cutoff frequency, the taper is lined with a dielectric material, thus altering the effective cutoff frequency along the length of the coupler. The proposed structure was then modeled in CST Microwave Studio.

5. Summary and ongoing work

A three-cavity klystron which operates at a frequency of 94 GHz, using a pseudospark discharge as a beam source, is currently under investigation. Through the use of the EM modeling packages MAGIC-2D and CST Microwave Studio, it has been possible to construct a realistic model of device performance. Manufacturing and experimental measurements shall begin soon on the 94 GHz klystron, as well as testing of the coupling system and the use of a puffed-gas input system for pseudospark discharges.

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