Compact Sub-terahertz Radiation Sources driven by Pseudospark-produced Electron Beams

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***Abstract*—High quality intense electron beams play an important role in high power millimeter-wave and terahertz radiation generation. To this end, the pseudospark-sourced electron beam has been investigated with their applications in different beam-wave interaction structures. Different structures have been designed and modelled using the particle-in-cell codes MAGIC and CST Particle Studio. The experimental demonstration of the PS-sourced electron beams of sub-millimeter diameter and the coherent millimeter wave radiation generated from PS-sourced electron beams in different beam-wave interaction structures will be presented.**

Keywords—Pseudospark discharge; beam-wave interaction; millimeter wave terahertz radiation.

I. INTRODUCTION

High power radiation sources at the tens to kilowatt level in the terahertz region (0.1-10 THz) are desirable because of the demand in the fields of plasma diagnosis, material science, radiotherapy, spectroscopy and fast speed mobile communications. Vacuum electronic technology, in which electron beam sources have been always crucial, remains as the main method to generate millimetre and terahertz radiation of high power of up to the kilowatt level. Thus the pseudospark (PS) discharge has attracted a lot of interest recently as a promising source of high quality, high intensity electron beam pulses.

II. PS E-BEAM & SUB-TERAHERTZ RADIATION GENERATION

A PS is an axially symmetric, self-sustained, transient, low pressure (typically 50-500 mTorr) gas discharge in a hollow cathode/planar anode configuration, which operates on the low pressure side of the hollow cathode analog to the Paschen curve [1-3]. A useful property of this type of discharge is the formation of an electron beam during the breakdown process [4-8]. During a PS discharge, low temperature plasma is formed as a copious source of electrons and can be regarded as a low work function surface that facilitates electron extraction. Because of the special geometry and discharge mechanism, the electron beam from a PS discharge can propagate without an external magnetic guiding field due to the existence of an ion-focusing channel. The ion-focusing channel is formed due to the background gas ionization by the front of the electron beam itself. For generation of high frequency radiation in the millimeter wave and sub-millimetre wave region this beam is ideal due to its small beam size, compactness and long lifetime. This paper summarises results of some sub-millimetre and terahertz radiation devices based on PS-sourced electron beams of diameter in the micron range both experimentally and numerically [9-16].

Fig.1 shows the schematic experimental setup of a 4-gap PS sourced electron beam that was first used to drive a backward wave oscillator (BWO) and then to drive different beam-wave interactions such as a micro-klystron and an extended interaction oscillator (EIO) in W-band (75 to 110) GHz and G-band (140 to 220) GHz.

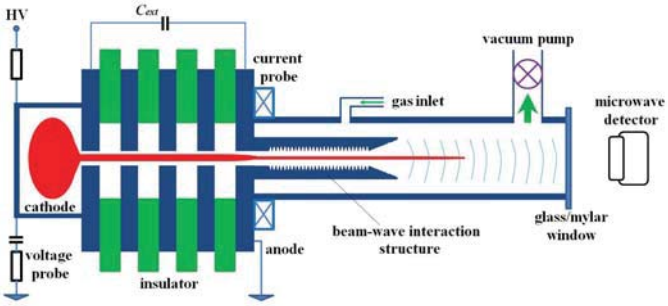

Fig. 1 Schematic experimental setup of a 4-gap pseudospark sourced electron beam used to drive a beam-wave interaction structure.

In order to establish the viability of small-diameter PS-generated electron beams for BWO operation at THz frequencies, micro beams were investigated by using different collimators integrated within the anode of PS device. Collimators with micro-aperture diameters of 1 mm, 500 μm, 200 μm, 100 μm and 70 μm were attached to the PS anode respectively in order to extract micro beams of the corresponding sizes. Images of the generated beams were obtained by inserting a scintillator disk made from 1 μm thickness copper foil coated with scintillation powder (Plano

P47, Agar Scientific Ltd., UK) 60 mm downstream of the anode with pictures taken with a high-speed digital camera located at the end of the drift tube.

A ~500 µm beam image was recorded and is shown in Fig. 2 when a collimator of 500 µm aperture size was used. Images of smaller beams were not recorded because the scintillator/camera combined sensitivity was not high enough, but beam current measurements of the smaller beams confirmed that the PS discharge was scalable to produce micro diameter (70 µm) beams for high frequency radiation applications.

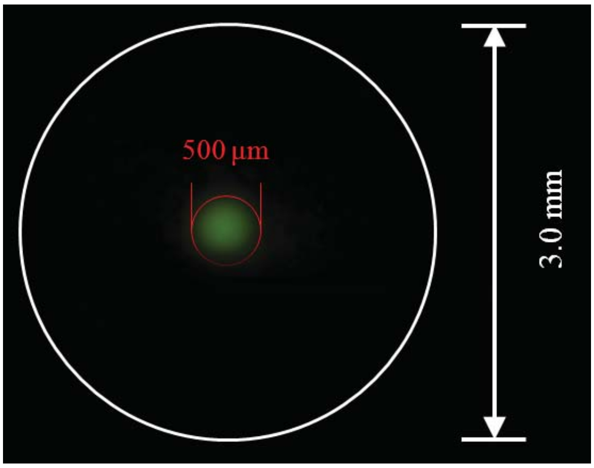

Fig. 2 The cross section image of a 500µm diameter PS beam

A typical microwave output from the G-band BWO experiment was shown in Fig.3, with the repeatable time-correlated electron beam voltage, the discharge current and the millimeter wave pulse together. The electron beam current has a step of about 5 A corresponding to higher voltage and then a peak current of about 10 A to lower voltage. The microwave radiation was mainly generated near this first 5 A step, because the correlated beam voltage has stronger coupling with the BWO structure. The output power was ascertained using the general antenna theorem with the total power from a launching antenna, calculated by integrating its radiated power density over space. The integration was completed by numerically integrating the normalized mode profile of the launching horn and multiplying by the measured maximum power density. In doing so, the total power of the BWO in this frequency range was found to be 20 W.

A W-band EIO simulation and experiment has also been carried. About 38 W of radiation power was measured from the experiment, which agrees well with the simulation [16].

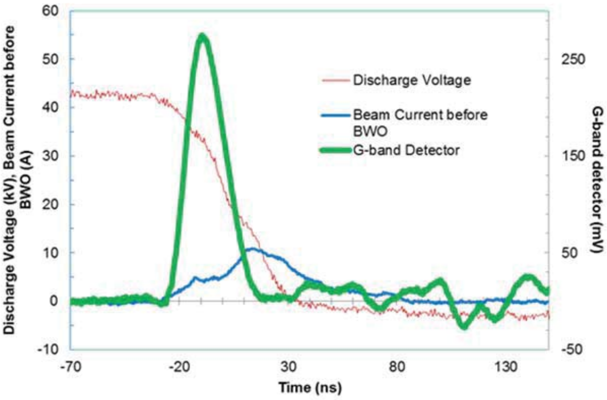

Fig. 3 Time-correlated electron beam current and voltage and the millimeter wave pulse

Experimental results have shown that PS sourced beams have been successfully applied in the generation of millimetre and terahertz radiation. The output power of the devices is estimated in the range of a few watts to a few tens of watts, which agrees well with simulations. This enables the PS-sourced electron beam to be a very promising beam source for compact and cost-effective terahertz sources as well as not requiring the application of an external guide magnetic field to form and propagate the beam.

III. CONCLUSION

Various beam-wave interaction circuits have been studied covering a wide range of frequencies in W-band and G-band to investigate the potential application of pseudospark generated electron beams. Several successful experiments have demonstrated the PS-sourced electron beam to be a very promising beam source in different beam wave interaction regions designed for the generation of terahertz radiation.

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