Pseudospark-sourced sheet electron beam for application in high power millimeter wave radiation generation

H. Yin[1], G. Shu[2], L. Zhang[1], W. He[1], J. Zhao[3], A.D.R. Phelps[1], and A.W. Cross[1]
[1]Department of Physics, SUPA, University of Strathclyde, Glasgow, G4 0NG, Scotland, UK
[2]College of Electronic Science and Technology, Shenzhen University, Shenzhen, 518060, China
[3]HighVoltage Division, School of Electrical Engineering, Xi’an Jiaotong University, Xi’an, 710049, China

Abstract— **This paper presents the plasma-sourced sheet electron beam generation based on a pseudospark discharge. This beam source has advantages of high current density, ion-channel assisted beam focus, long life and simplicity with no external guiding magnetic field needed for beam transportation. A collimator of cross section size of 2.0mm × 0.25mm is used in the sheet beam generation and propagation experiments. Sheet beam currents in the range of 6A to 21 A (~10^4 A/cm^2 current density) and peak voltage of ~32 kV were measured after the sheet beam has propagated a distance of 10-mm without any external focusing magnetic field. Furthermore the pseudospark-sourced sheet electron beams were successfully used to drive both a W-band (75-110 GHz) and a G-band (200 GHz) planar extended interaction oscillator (EIO), with beam tunnel of approximately 2.8mm × 0.5mm and 1.0 mm × 0.17 mm in cross sectional size respectively.**

I. INTRODUCTION AND BACKGROUND

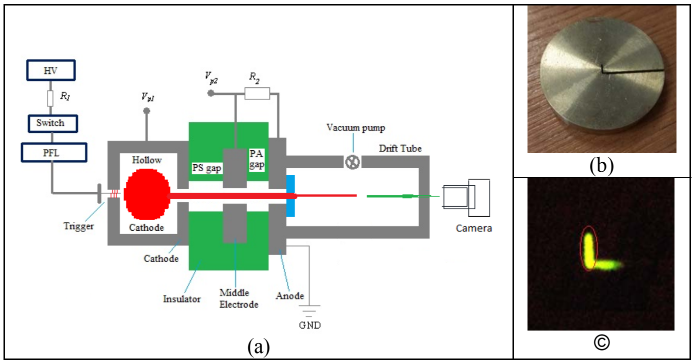
As radiation frequency goes up into the millimeter wave range, a sheet-shaped electron beam displays much better performance compared with a pencil-shaped beam. This is because a sheet beam is of larger cross section than a pencil beam so that a higher sheet beam current can be achieved. However the formation and focusing and propagation of a sheet electron beam is challenging especially when the beam has to be transported down through a structure of small transverse cross-section in the sub-millimeter range. For this reason, a pseudospark discharge has been recently investigated for high current sheet electron beam generation on the basis that it has shown to be an excellent pencil electron beam source in various experiments [1-7]. This is because a PS-sourced electron beam has the ability to self-focus due to the unique structure and the formation of an ion channel generated by the beam front, which makes it an excellent electron beam source for desirable compact millimeter wave devices.

II. EXPERIMENTS AND RESULTS

Fig.1 shows the pseudospark sheet beam generation system that consisted of a pseudospark discharge section and a post-acceleration unit [3,8,9]. It was composed of a brass hollow cathode cavity of 26 mm in diameter and 12 mm in length, a perspex insulator of 16 mm thickness, a brass post-acceleration electrode, a perspex insulator of 6 mm thickness and a brass planar anode to form a pseudospark discharge gap and a post-acceleration gap. When the high voltage pulse from the PFL generator is applied between the trigger electrode and the grounded anode, the voltage will distribute on the stray capacitance C_t of the trigger discharge gap, the stray capacitance C_{ps} of the pseudospark discharge gap, and the resistor R_2. Because C_t is much smaller than C_{ps}, most of the voltage will drop on the trigger gap before the breakdown of the pseudospark discharge gap. Although within the operating pressure range of the pseudospark discharge the pd of the trigger gap is much lower than the pd of the pseudospark discharge gap and the hold-off voltage of the trigger gap should be much higher than that of the pseudospark discharge gap, the electrical field strength is extremely high due to the very small gap separation and the field emission of the electrons dominates the discharge process in the trigger gap. So the breakdown voltage of the trigger gap is actually much lower than that of the pseudospark discharge gap and the first breakdown definitely takes place in the trigger gap when a sufficiently high voltage is applied over the whole structure. Because the trigger gap is connected in the structure in series, all of the discharge current will pass through the discharge channel during the discharge and produces sufficient seed electrons to start the pseudospark discharge.

At the early stage of the pseudospark discharge, the discharge current is very limited and the voltage on resistor R_2 is much smaller than the voltage of the driving voltage pulse, so most of the voltage drops on the pseudospark discharge gap. In the conductive stage of the pseudospark discharge, because the voltage across the pseudospark gap has collapsed, the voltage across the gap remains at a very low level of hundreds volts and then the total voltage is nearly all applied on the resistor R_2 across the accelerated gap before its breakdown. The resistor R_2 is a key component in the device to ensure the pseudospark gap discharging prior to any discharge in the acceleration gap and the voltage drops mainly on the trigger gap and the pseudospark gap. Meanwhile, it limits the voltage on the acceleration gap to a low level during this period to limit the discharge and initial plasma in the acceleration gap before the conductive stage of the pseudospark discharge. The resistance of R_2 needs to be much higher than the characteristic impedance to maintain the PFL generator output with a voltage of 2 times the charging voltage during the post-acceleration of the electron beam. Because this resistor also controls the whole discharge current it greatly influences the beam generation and post-acceleration.

The generated pencil pseudospark electron beam would propagate from the hollow cathode cavity to the anode through an on-axis aperture of 3 mm diameter. Attached with the anode is a collimator disc with different slot dimensions. A typical size of 2.0 mm×0.25 mm is shown in Fig.1b. This collimator forms the sheet beam. Because of the gas background in the beam drifting area, the high energy beam front from the second hollow cathode stage ionizes the gas along its path to form an ion-channel for later beam electrons to propagate. Therefore, there is no need for an external guiding magnetic field for the beam transportation. Fig. 1c show the cross-section image of a typical sheet beam of about 21 A peak beam current and 32 kV peak beam voltage that was generated and transported with no external magnetic field.



(a) (b) ©

Fig. 1 Pseudospark-sourced sheet electron beam generation experiment (a) experimental setup; (b) collimator (c) cross sectional image of the sheet beam of 2.0 mm×0.25 mm

Fig. 2 shows the time-correlated total discharge voltage, the post-acceleration voltage and the electron beam current experimentally measured after the collimator of rectangular shape of 2.0 mm×0.25 mm. It can be seen from Fig.2 that the post-acceleration voltage pulse has a shorter pulse width compared with the total discharge voltage, indicating that the post-acceleration unit works well and the beam is indeed post accelerated to a higher energy level with reducing energy spread at the mean time. The maximum electron beam current is 21.5 A, corresponding to a very competitively high current density of ~1.24×10^4 A/cm^2. With this advanced pseudospark discharge combined with a post-acceleration technique, the experimentally measured pseudospark sheet electron beam achieves a combined beam energy of >30 keV and high beam current in the range of 6A to 21 A, which makes it an excellent sheet electron beam source for planar millimeter wave structures.

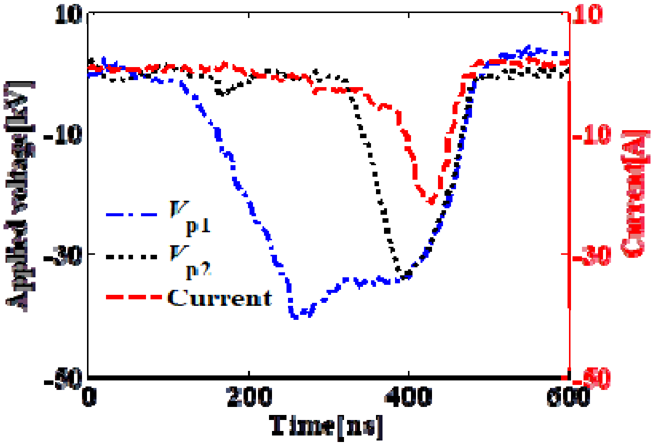


Fig. 2 Typical time-correlated total discharge voltage, the post-acceleration voltage and the electron beam current experimentally measured after the collimator of rectangular shape of 2.0 mm×0.25 mm

Two planar sheet beam EIO structures, one in W-band and one in G-band were both simulated and designed to be driven by the pseudospark-sourced sheet electron beam by replacing the collimator in Fig.1 with a planar EIO slow wave structure [10,11]. Initial experimental results demonstrated that an output power of 1.2 kW and 10 W, respectively, was achieved from the W-band and G-band planar EIOs. Since the beam voltage or the beam current of the pseudospark-sourced sheet electron beam is sweeping with respect to time, the planar EIO slow wave structures can be further optimized and the pseudospark-sourced sheet beam can be experimentally adjusted to achieve the optimal operation. This opens exciting future applications of pseudospark-sourced sheet beams in the generation of high power millimeter wave terahertz radiation in a very compact manner.

III. CONCLUSIONS

Experiments show that high current density high quality pseudospark-sourced sheet electron beam can be extracted from a compact structure of a pseudospark discharge unit combined with a post-acceleration unit. Initial experimental results show that powerful terahertz radiation can be generated by using the pseudospark-sourced sheet electron beam to drive a planar EIO slow wave structure. Future studies will focus on the improvement of the stability and efficiency of the EIO and the application of this pseudospark-sourced sheet beam in higher frequency EIOs.

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