PSEUDOSPARK-SOURCED BEAMS OF ELECTRONS AND IONS

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Abstract

Since its discovery in the late 1970's, the pseudospark discharge has undergone intensive studies with regard to its unusual and interesting discharge properties. In the last fifteen years the pseudospark discharge has attracted significant attention from diverse fields such as pulsed-power switching, electron beam generation, free electron masers, ion beam generation, extreme-ultraviolet radiation sources and microthrusters. This paper will present experiments and measurements of pseudospark-sourced electron beams for accelerator applications. The pseudospark discharge can also be used to produce ion beams. In this paper the production of pulsed electron beams with current intensity over 10^8 Am^{-2}, high brightness up to 10^{12} A m^{-2} rad^{-2} and emittance of tens of mm mrad from a multi-gap pseudospark discharge is presented. The transportation of the high peak current, high quality, high-brightness pseudospark electron beam is also discussed.

INTRODUCTION

A pseudospark (PS) [1-3] 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 analogy to the Paschen curve. A potentially useful property of this type of discharge is the formation of an electron beam during the breakdown process. During a pseudospark discharge, a low temperature plasma is formed which acts as a copious source of electrons and can be regarded as a low work function surface that facilitates electron extraction. The PS research at Strathclyde has been focused on PS-sourced electron beam generation and its applications [4-6].

PS E-BEAM EXPERIMENTAL STUDIES

The initial study of electron beam production was carried out on a single-gap pseudospark system for a wide range of parameters, including cathode cavity length, cathode hole size, applied voltage, external capacitance and the inductance in the discharge circuit, as shown in Figure 1.

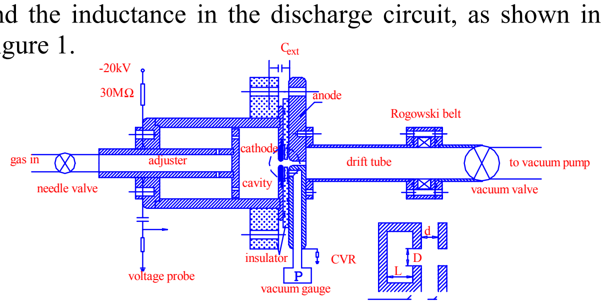

Figure 1: Pseudospark discharge and beam extraction experiments

Further electron beam experiments were conducted using a three-gap pseudospark discharge chamber. The temporal evolution of the beam produced is shown in Figure 2. The dependence of the discharge current and e-beam current on the hollow cathode cavity length *L* was studied. It was found that when the hollow cathode cavity length *L* was less than 3 mm, which was equal to the cathode aperture diameter *D*, the beam current was small while the discharge current was high. Both the discharge and beam current were insensitive to the hollow cathode cavity length when it was larger than 3 mm. At the extreme situation when the cathode cavity length was close to 0 mm (no hollow cathode region), both the discharge and beam current were small. The pseudospark configuration, which produced the best beam current pulse, was when the aperture size (3mm) was equal to anode-cathode gap separation d (5mm) with the hollow cathode cavity length L (30mm) approximately a factor 10 greater than the aperture diameter. The cross-section image of the electron beam, taken by a fast-speed digital camera using a scintillation technique, is shown in Figure 3. The dependence of the electron beam current on the axial distance from the anode was investigated, it was found that without any guiding B-field about 10 percent of the beam propagated as far as 20 cm from the anode, as shown in Figure 4.

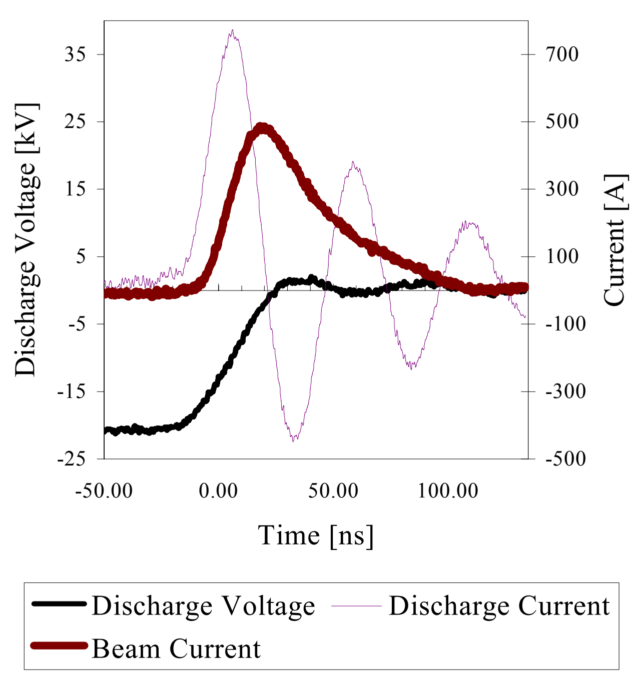

Figure 2: A temporal evolution of the beam produced from a three-gap pseudospark discharge chamber

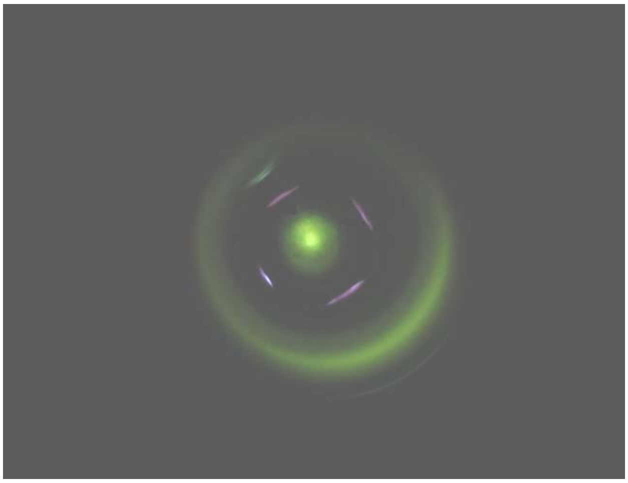

Figure 3: Image of electron beam imprint on phosphor scintillator (3 pulse integration), electron beam diameter (represented by central bright spot) was 3 mm

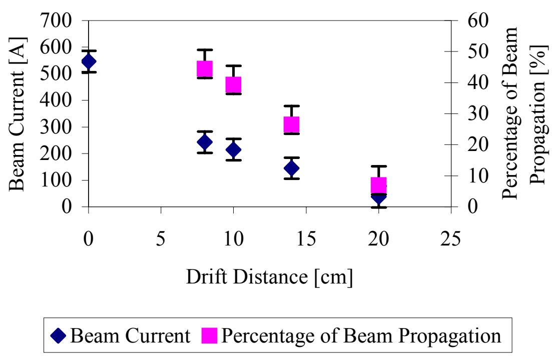

Figure 4: Electron beam current and its propagation percentage along the axis after the anode

The brightness of the e-beam was measured using a magnetic-field-free collimator technique. The collimator length was 5 cm. A time dependent beam brightness of up to 10^{11-12} Am^{-2} rad^{-2}, measured using the magnetic-field-free collimator technique is shown in Figure 5. This beam has a higher combined current density and brightness as compared to electron beams formed from any other known type of electron source (figure 6).

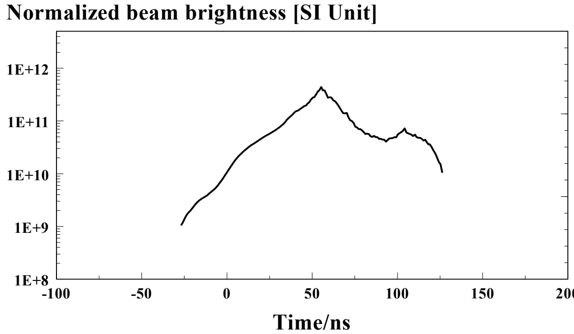

Figure 5: Measured beam brightness from a 3-gap pseudospark discharge

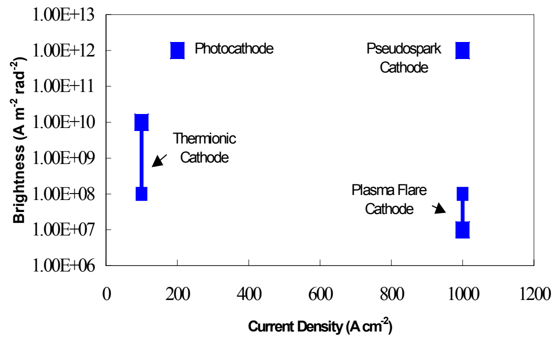

Figure 6: Brightness as a function of current density for various electron beam sources

POST-ACCELERATION EXPERIMENT

A schematic outline of the experimental setup for the study of the propagation and the post-acceleration of the pseudospark-sourced beam is shown in Figure 7. The electron beam was extracted from a three-gap pseudospark discharge chamber. The acceleration gap was formed using a single perspex cylinder of inner diameter 5 mm, outer diameter 300 mm and 26-mm thickness. A recess was machined in the Perspex cylinder resulting in an acceleration gap separation of 5-mm.

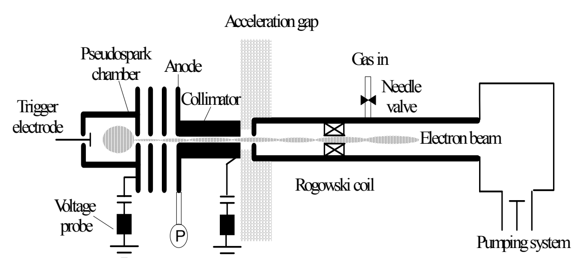

Figure 7: Schematic diagram for the post-acceleration experiment of the pseudospark electron beam

The pseudospark discharge was powered by a dc power supply. The hollow cathode was connected through a 30 MΩ charging resistor to a negative voltage source (-30 kV, 1 mA DC power supply), the charging voltage was measured using a capacitive voltage probe. The external energy storage capacitance was 600 pF. The acceleration unit was driven by a 40 kV, 125 ns voltage pulse produced by a cable Blumlein and the acceleration voltage was measured by another capacitive voltage probe. In the post-acceleration experiment a 30 mm long collimator of 3.5 mm internal diameter was inserted after the anode of the pseudospark discharge chamber with the acceleration unit located immediately after the collimator to achieve a gas pressure gradient and to optimise beam current. The beam acceleration experiments showed that careful adjustment of the trigger system could ensure synchronization between the beam propagation and the application of the acceleration voltage. A 100 A, 40 kV electron beam pulse was measured at a distance of 120 mm from the acceleration gap without a magnetic guiding field, as shown in Figure 8.

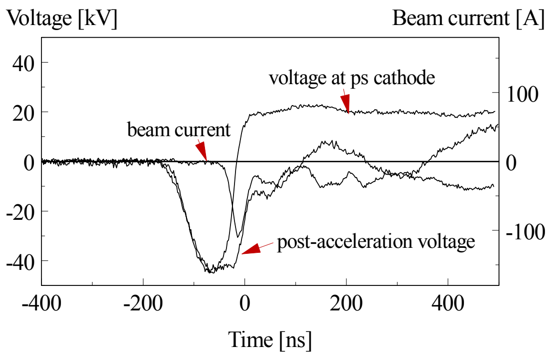

Figure 8: Typical record of the time-correlated pseudospark discharge voltage, beam current and the acceleration voltage pulse

However in Fig.8 some beam loading effect was evident where it can be seen that as the beam current increased the post acceleration voltage decreased with duration of the flat top portion of the post accelerated voltage signal reduced. During the experiments, the beam loading effect was mitigated by reducing the internal impedance of the cable pulser from 50 Ω to 14 Ω. It is possible to further reduce the beam loading effect by continuing to decrease the internal impedance of the cable Blumlein or by using an alternative lower impedance pulse forming line. Beam propagation across the acceleration gap and further along the beam channel was simulated using the finite difference time domain Particle-In-Cell (PIC) code MAGIC (Figure 9).

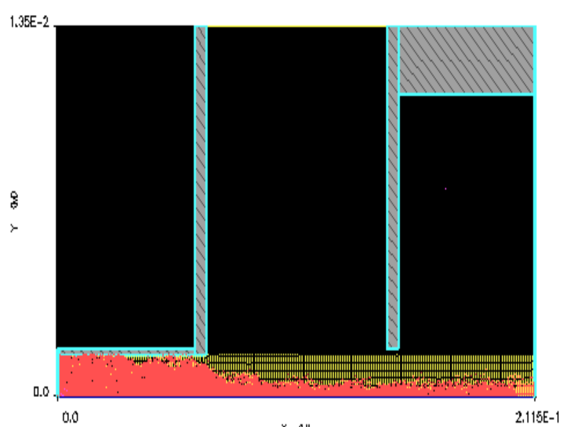

Figure 9: Beam propagation with a plasma of density 6 x10^{12}cm^{-3} filling the channel beam 200A, 200V, red electrons, yellow- plasma.

SUMMARY AND FUTURE WORK

A three-gap pseudospark-sourced electron beam was carefully studied to determine its beam quality as well as its ease of propagation and suitability for post-acceleration. Electron beams of up to 500 A were measured at the anode from the three-gap pseudospark discharge. It was found that the electron beam brightness could be as high as 10^{12}A m^{-2} rad^{-2}.

In the post-acceleration experiments a 100 A, 40 kV electron beam pulse was measured at a distance of 120 mm from the acceleration gap without a guide magnetic field. Comparing this with the simulation implies that a favourable ion background exists along the beam channel and the acceleration gap. At the start of the pseudospark discharge the initial high-energy electrons ionises the background gas. When the electron beam generated by the PS discharge is then injected into the plasma channel the space charge of the beam expels the channel electrons while the much more massive ions remain relatively fixed. The resulting positive ion channel acts to focus and guide the PS electron beam.

Future studies aim to improve the performance of the pseudospark discharge with respect to generation of both long (100 ns) and short (< 1 ns) high quality electron beam pulses. The ultimate goal of the research is to produce electron beam pulses, which offer very favourable comparison of their brightness with the very brightest available photocathode electron sources while at the same time possessing higher current densities.

A pseudospark discharge can also be used to produce ion beams from its hollow anode by the application of a positive voltage.

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