High Power, High Brightness Electron Beam Generation in a Pulse-Line Driven Pseudospark Discharge

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Abstract

High brightness ($\sim 3 \times 10^{10}$ A/m^{2}rad^2), high power density ($\sim 10^{10}$ W/cm^2) electron beams have been generated by the mating of a hollow-cathode discharge device operating in the pseudospark regime to the output of a high power pulse line accelerator. Very small diameter ($\sim$ 1 mm) electron beams with currents in the range 500-1000 A and energies in the range 150-300 keV have been generated with measured effective emittances of about 85 mm-mrad. Such emittances are comparable to those achieved in conventional electron beam sources at current densities several orders of magnitude lower than those observed in these experiments.

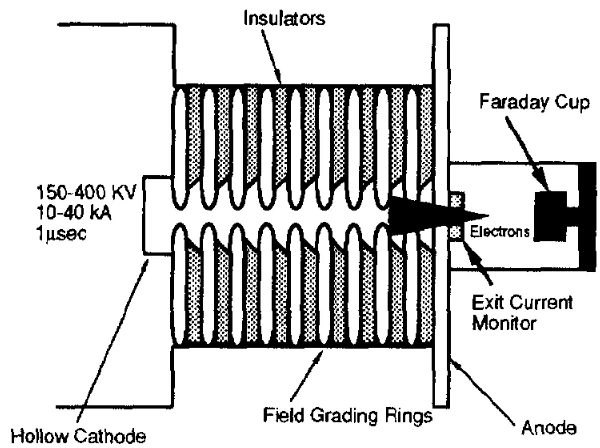

Figure 1: Basic experimental configuration.

I. INTRODUCTION

During the last decade, considerable research has been conducted on pseudospark discharges of the type first explored by Christiansen and Schultheiss[1] in 1978. Interest in this novel discharge configuration has been driven by potential applications of such discharges to such areas as high power switch development.[2] In addition, the observation of high current density electron beams generated by such discharges has spurred interest in their possible application as high brightness electron beam sources for such diverse uses as electron beam lithography, plasma processing, Free Electron Lasers, and next-generation accelerators.

Over the last decade, several experiments have been reported in which high-brightness electron beams have been produced in pseudospark devices operating in the voltage range 20-50 kV.[3-5] Ion-focused electron beams with normalized brightness values as high as 10^{12} A/m^{2}rad^2 have been observed to propagate out from the discharge region in these experiments. Although these studies have been encouraging, the extraction of such ion-focused beams into vacuum for possible applications is complicated by the low energy and very high current density of the beam. In this report, we detail initial experiments in which a high-power pulse line accelerator has been mated to a hollow cathode discharge experiment operating in the pseudospark regime in an attempt to reproduce the attractive beam qualities observed in low voltage experiments at electron energies in the range 150-300 keV.

II. EXPERIMENTS

The experimental configuration is shown schematically in Figure 1. A pulse line accelerator which normally operates at 200-800 kV, 40-120 kA, 100 ns was modified to produce a longer pulse duration by eliminating the output pulse forming switch and connecting the load directly to the output of the pulse transformer via a water coax section. The resulting pulser is capable of routine operation at 150-600 kV, 5-40 kA, 1 μsec. A multigap hollow cathode discharge device was connected to the output of the pulser in series with a 10 Ω resistor to ensure that the pulser would be well matched should the hollow cathode discharge impedance short out late in the discharge cycle. The multigap hollow cathode device consists of ten sets of electrodes and insulators as shown with an effective gap between electrodes

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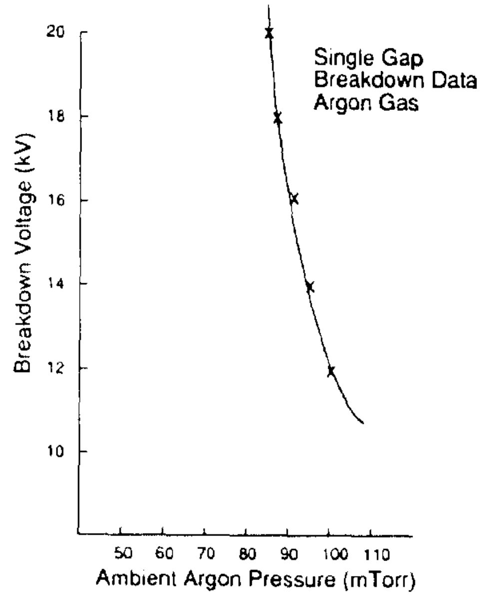

Figure 2: Single gap hollow cathode breakdown data.

of about 1 cm. An on-axis aperture 0.63 cm in diameter was drilled in the electrodes and electrons generated in the hollow cathode region were accelerated through these apertures to the extraction point on the anode side of the device. The discharge was initiated in Argon gas with ambient gas pressures in the range 30-100 mTorr.

In order to ensure that the multigap hollow cathode device would operate in the pseudospark regime, single gap breakdown characteristics were measured using a 20 kV pulser with a pulse duration similar to the 1 μsec pulse of the modified pulse line accelerator. Data from these studies, shown in Figure 2, indicates that operation of the multigap device in the pseudospark regime is possible at voltages of 100-300 kV with ambient Argon gas pressures in the range 50-100 mTorr, providing that the breakdown voltage of the multigap device is approximately that of a single gap times the number of gaps employed.

Typical pulse line voltage and current waveforms observed upstream of the multigap hollow cathode discharge device are shown in Figure 3. The voltage is seen to rise smoothly to a maximum of about 200 kV prior to voltage collapse, and a peak line current of greater than 20 kA is observed after the collapse occurs with the expected pulse duration (100 ns) equal to the electrical length of the coaxial line feeding the device. A typical ejected electron beam current waveform measured with the exit current

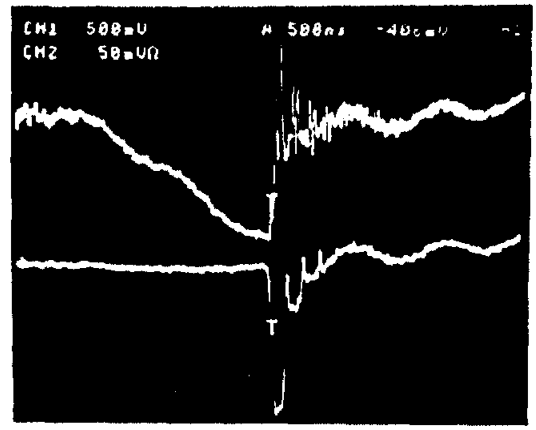

Figure 3: Typical pulse line voltage (top, 92.5 kV/div) and current (bottom, 3.7 kA/div) waveforms.

monitor is shown in Figure 4a. It is readily seen that the ejected beam current begins to rise about 20 ns prior to the onset of voltage collapse (which occurs at $t = 0$ on the scale accompanying the waveform) to a current of about 2 kA, and then increases to about 3 kA after voltage collapse. The peak ejected electron beam current, therefore, is seen to be a small fraction of the observed line current, an indication that most of the post-collapse current flows from electrode to electrode and is returned to ground at the anode. The post-collapse electron beam current, moreover, is comprised almost entirely of low energy electrons. Thus the high voltage electrons are produced in a short burst of approximately 20 ns duration prior to voltage collapse. To confirm this interpretation of the ejected beam current waveform, the ejected beam was then passed through a thin copper foil calculated to cut off all electrons below 140 keV. The current waveform obtained downstream of the foil is shown in Figure 4b, and it is readily seen that only that part of the ejected beam pulse that was initiated before voltage collapse had sufficient energy to penetrate the foil. It is therefore expected that the electrons that produced the current pulse shown in Figure 4b were accelerated to energies comparable to those associated with the full anode-cathode voltage (200 keV) prior to voltage collapse. The measured post-foil beam current of 120 A is consistent with range-energy theoretical expectations for a 1 kA, 200 keV electron beam passing through a foil of sufficient thickness to stop 140 keV electrons.

Both the damage pattern on the copper stopping foil and the image left by the beam on a heat sensi-

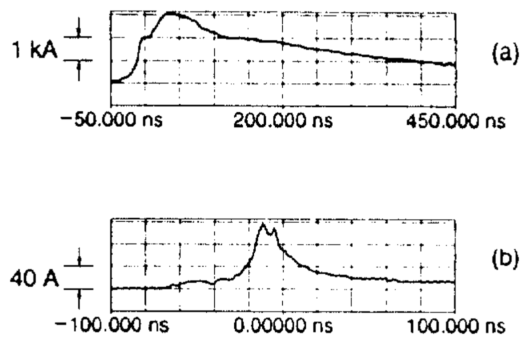

Figure 4: (a) Typical ejected beam current waveform. (b) Current waveform downstream of copper stopping foil. In both cases, t = 0 is the time when voltage collapse begins.

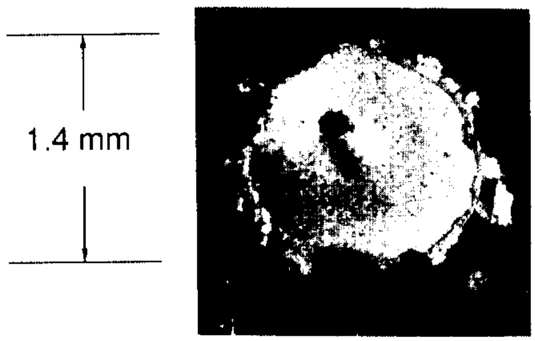

Figure 5: Photograph of typical beam damage pattern on copper foil. The dark spot in the damage pattern is a hole 0.17 mm in diameter produced by the beam.

tive polycarbonate sheet placed on the downstream side of the copper stopping foil were used to provide a simple means of estimating the diameter of the high energy component of the electron beam. These measurements were typically obtained 3.5 cm downstream of the anode plate, although similar measurements have been obtained at distances as great as 12 cm downstream of the anode. The measured beam diameter obtained from these experiments was in the range 0.2–1.4 mm. A microscope photograph of a typical damage pattern is shown in Fig. 5.

In a previous report[6], the measurements of beam energy, current and diameter were used to estimate the effective ($4\times$ rms) emittance and corresponding normalized brightness of the high energy component of the beam. Assuming a beam energy of 200 keV, I = 1 kA, and full charge neutralization, the effective emittance was calculated to be $\leq$ 174 mm-mrad for a beam radius of 0.5 mm. Recent measurements of beam emittance made by passing the beam through a multi-slit aperture and recording the beam image on an electron-sensitive film 2 cm downstream of the aperture yield an actual measured effective emittance of about 85 mm-mrad. Normalized brightness is calculated to be 3×10^{10} A/m^{2}rad^2.

Future studies are planned to explore the scaling laws that determine beam parameters and to explore their injection into vacuum in the presence of confining magnetic fields. In addition, methods of delaying voltage collapse in the hope of increasing the high energy beam pulse duration are also under study.

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