High current density hollow cathode electron beam source

J. J. Rocca, B. Szapiro, and T. Verhey
Electrical Engineering Department, Colorado State University, Fort Collins, Colorado 80523

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An electron beam with current density greater than 30 A/cm^2 and total current of 92 A has been generated in 5 μs pulses by accelerating the electrons from a glow discharge in a narrow gap between two grids. The ratio of the extracted electron beam current to discharge current is approximately 1. The gun also operates in a dc mode.

Plasma cathodes that do not suffer diode closure (collapse of the anode-cathode gap) are of particular interest in the generation of high current density electron beam pulses with duration $> 1\ \mu$s. Glow discharges have been previously used to produce electron beams at current densities < 2 A/cm^2.[1-4] Humpries *et al.* obtained electron beam current densities up to 15 A/cm^2 at energies < 300 eV from a spark generated, grid controlled plasma cathode.[5] Recently, an electron beam current of 30 A (60 A/cm^2) was reported from a grid-stabilized plasma emitter.[6]

Here we report the generation of a high current density (> 32 A/cm^2) electron beam with a total current of 92 A by accelerating the electrons of a hollow cathode glow discharge in the narrow gap between two grids at energies up to 2 keV. The current of energetic beam electrons was measured at 15 cm from the acceleration grid, and does not include the electrons accelerated in the gap, but intercepted by the 40% opaque acceleration grid. The electron current density emitted by the plasma source is larger and approaches 45 A/cm^2.

Our experimental setup is schematically illustrated in Fig. 1. The plasma source is a 5-cm-diam stainless-steel hol-

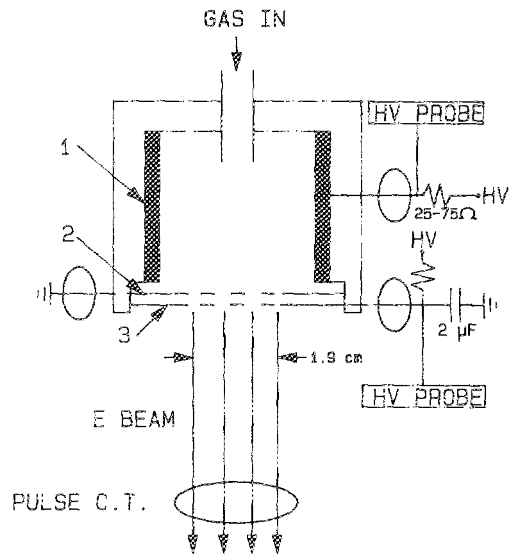

FIG. 1. Experimental setup. The vacuum chamber is not shown. The circles represent pulse current transformers. (1) The 5 cm i.d. hollow cathode, (2) the anode electrode, and (3) the acceleration electrode are indicated. The 25–75 Ω discharge ballast resistor was only used in the high current experiments, in series with a 50-nF capacitor.

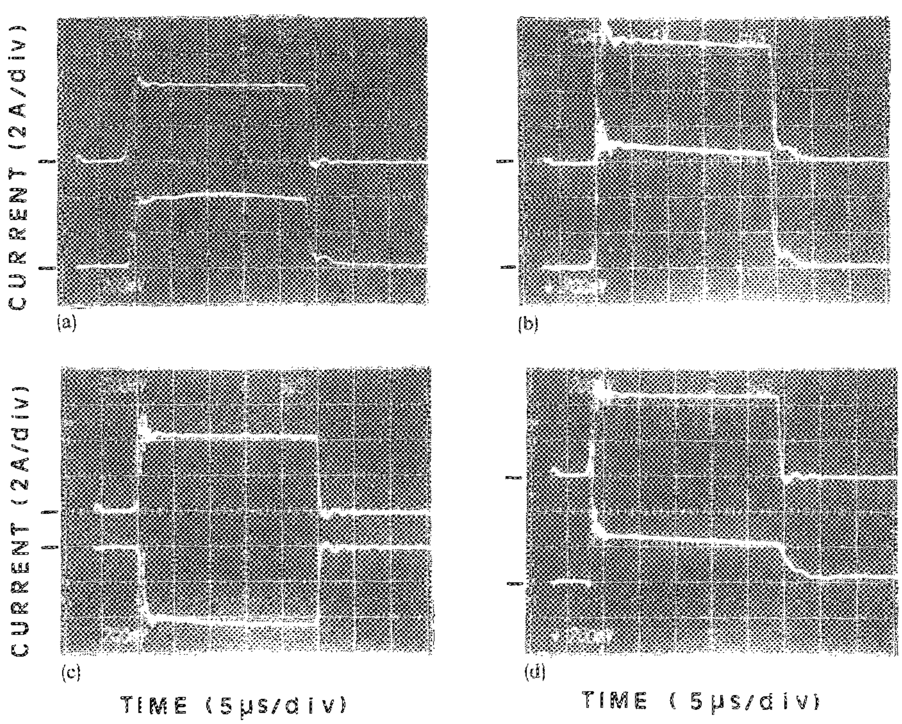

FIG. 2. (a) Upper trace: discharge current; lower trace: electron beam current. Acceleration voltage $V_{accel} = 2$ kV. (b) Upper trace: sum of discharge and anode grid currents; lower trace: sum of electron beam and acceleration grid currents. (c) Upper trace: discharge current; bottom trace: anode grid current for $V_{accel} = 0$ kV. (d) Upper trace: discharge current; lower trace: anode grid current for $V_{accel} = 2$ kV. All vertical scales are 2 A/div, with the zero level indicated in the left margin. The helium pressure was 0.45 Torr.

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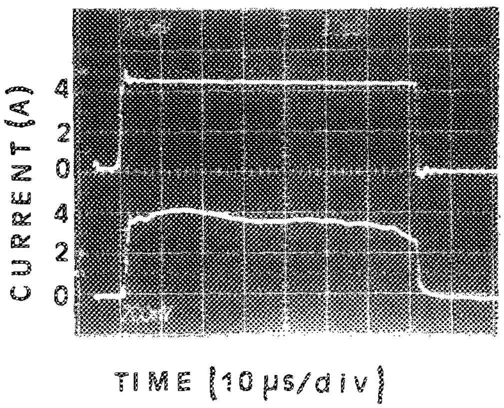

FIG. 3. Upper trace: discharge current; lower trace: electron beam current. $V_{accel} = 2$ kV. The background helium pressure was 0.45 Torr. The slight current decrease at the end of the electron beam pulse is a consequence of the decrease in the accelerating voltage due to the charge lost by the biasing capacitor. Since the beam current is measured at 15 cm from the gun, a reduction in accelerating voltage results in increasing scattering leading to the slight current reduction.

low cathode discharge that was operated in helium. Emission is confined to the inner walls of the cylindrical cathode by a Teflon embodiment that surrounds the cathode. The Teflon piece also supports two grids that form the 2.5-mm-wide electron acceleration gap. Both the internal anode grid and the acceleration grid are made of number 42 stainless-steel mesh, having a transmissivity of approximately 60%. The grids are mounted in supporting stainless-steel plates having an orifice 19 mm in diameter that defines the diameter of the extracted beam. The entire electron gun structure was enclosed in a vacuum chamber and evacuated to a pressure of 10^{-3} Torr. Helium was continuously introduced inside the electron gun and evacuated through the grids by a rotatory pump connected to the vacuum chamber. The helium flow caused the pressure inside the electron gun structure to be approximately 1.2 times higher than that in the electron beam drift region of the vacuum chamber. The electron gun was operated at vacuum chamber pressures between 0.1 and 1 Torr. The hollow cathode discharge was excited with a pulse forming network and a high voltage pulsed transformer giving negative voltages up to 6 kV. The maximum current this source can provide is 7 A. In experiments at larger currents the hollow cathode discharge was initiated and maintained by discharging a 50-nF capacitor negatively charged up to 8 kV through a series spark gap. In the later case a ballast resistor (25–75 Ω) was connected in series with the discharge circuit. The anode grid was grounded and the acceleration grid was directly connected to a 2-μF capacitor charged to provide the desired electron beam energy (0–2 keV). No limiting resistor was added in series with the acceleration grid circuit. The cathode current and the grid currents were monitored with current transformers. The electron beam current was measured by monitoring the current flowing through another current transformer placed coaxial with the beam at 15 cm from the extraction grid. The voltage drop across the glow discharge and the acceleration gap were also simultaneously measured using commercially available high voltage dividers.

The ratio of the electron beam current to the discharge current is close to 1 as shown in Fig. 2(a). The sum of the electron beam current and extraction grid current was observed to be as high as 1.4 times the cathode current. The sum of the former two was measured to exactly match the sum of the discharge current and anode current [Fig. 2(b)]. When no acceleration voltage is applied a negligible current is collected by the acceleration grid, and the pulse of electron current collected by the anode grid is a good reproduction of

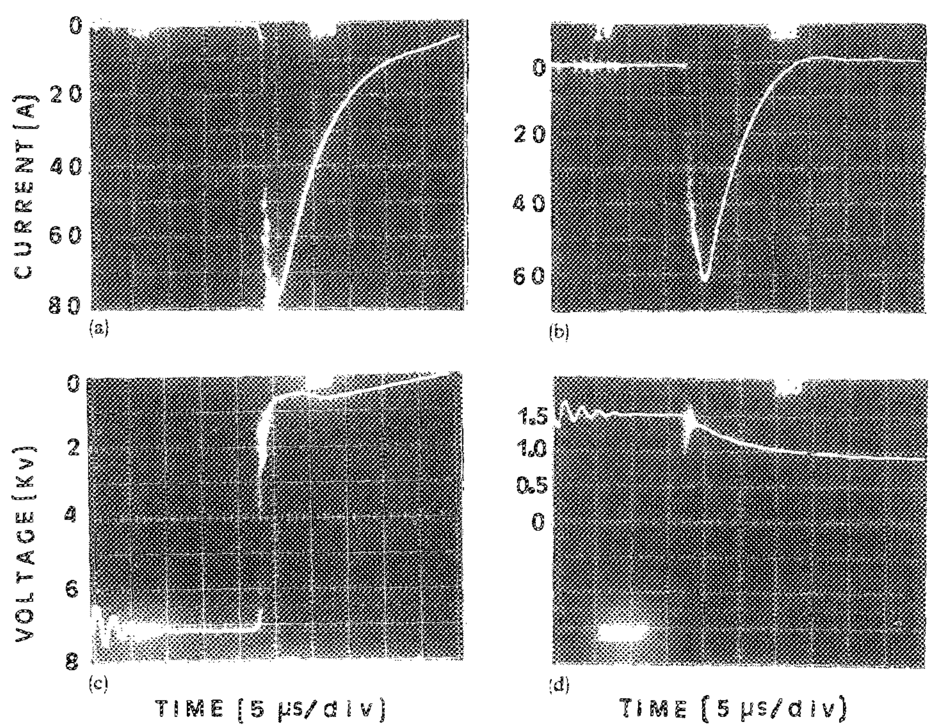

FIG. 4. (a) Discharge current. (b) Electron beam current. (c) Discharge voltage. (d) Acceleration voltage. The background helium pressure was 0.2 Torr. A 75-Ω ballast resistor was used in series with the hollow cathode discharge current.

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the cathode current pulse [Fig. 2(c)]. However, when an acceleration voltage greater than 60 V is applied across the gap, the anode current reverses sign and becomes an ion current as shown in Fig. 2(d). This behavior corresponds to that of grid-controlled plasma cathodes in which the wire spacing in the grids is larger than the width of the space-charge layer near the anode, and is consistent with the theory of Zharinov *et al.*[7]

The discharge current was observed to be practically unperturbed by the application of an acceleration voltage and the resulting electron beam extraction. Consequently, the electron beam current and energy can be controlled independently. Closure of the acceleration gap does not occur and long electron beam pulses can be obtained. Figure 3 shows a 70-μs discharge pulse and the corresponding 2-keV electron beam pulse. The gun was also operated in a dc mode at electron beam currents of 50 mA.

Figures 4(a) and 4(b) show a 75-A discharge pulse and a 62-A (20 A/cm^2) electron beam pulse obtained charging the discharge capacitor to 7.2 kV. The voltage drop across the hollow cathode discharge is approximately 600 V, as shown by Fig. 4(c). The potential of the acceleration grid [Fig. 4(d)] is observed to decrease smoothly from 1.5 to 1 kV during the electron beam pulse due to the charge lost by the biasing capacitor. Electron beam current pulses as high as 92 A (32 A/cm^2) were obtained operating the gun at a background helium pressure of 0.2 Torr and an applied cathode voltage of 8 kV.

In conclusion, we have demonstrated the operation of a simple plasma gun at current densities >30 A/cm^2 in 5 μs pulses. The beam current was source limited and even larger beam currents should be possible. The gun does not present diode closure and was also operated at reduced currents in the dc mode.

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