Electron Beam Generation from a Superemissive Cathode*

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Abstract

An experimental study of electron beams produced by a superemissive cathode in the Back-Lighted Thyratron (BLT) and the pseudospark is presented. This work is motivated by experiments demonstrating very high current densites (≥10 kA/cm^2 over an area of 1 cm^2) from the pseudospark and BLT cathode. This high-density current is produced by field-enhanced thermionic emission from the ion beam-heated surface of a molybdenum cathode. This work reports the use of this cathode as a beam source, and is to be distinguished from previous work reporting hollow cathode-produced electron beams. An electron beam of more than 260 A peak current has been produced with 15 kV applied voltage. An efficiency of ≈10% is estimated. These experimental results encourage further investigation of the super-emissive cathode as an intense electron beam source for applications including accelerator technology.

I. INTRODUCTION

Pulsed electron beams have been produced by the pseudospark structure, and an intense electron beam of 1 kA peak current, 10^5 A/cm^2 current density, and 10-100 ns duration has been reported[1-3]. These reports of pseudospark-produced electron beams concentrated on the energetic, transient phase beams generated during and briefly before voltage breakdown, and related to hollow cathode (HC) emission.[4] Here we investigate the electron beams generated by the back-lighted thyratron (BLT) during the superemissive cathode (SEC) phase which follows the HC phase.[5-7] The BLT has an electrode structure similar to the pseudospark switch. The superemissive cathode in the BLT is self-heated, very robust, and produces extremely high, uniform current. In the low pressure glow discharge mode, typical of the BLT and the pseudospark, high current density ≥ 10 kA/cm^2 over an area of 1 cm^2 has been observed.[8-10] The heating of cathode surface by ion bombardment during the current build up is responsible for the observed high current density during the SEC phase. During the conduction phase of the BLT, the voltage across the gap is of few hundred volts. Most of this voltage is across the cathode fall region, which is a thin layer of few microns thickness on the cathode surface. The electrons generated by the superemissive cathode are accelerated across the cathode fall region and some of them pass through the anode center hole. Modeling by Bauer and Gundersen suggests that the electrons can be extracted from the BLT.[11,12] We report here experiments to investigate the electron beams generated by this superemissive cathode.

II. EXPERIMENT

A. Setup

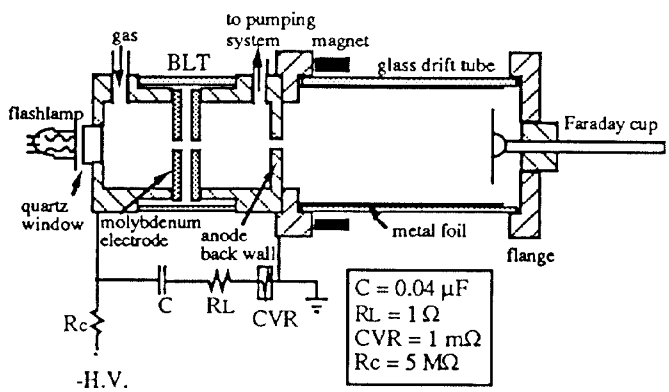

Figure 1. The experiment setup for BLT-produced electron beam diagnostics.

Figure 1 shows the experiment setup. The BLT has molybdenum electrodes with center holes of 5 mm diameter separated by a gap of 5 mm. The o-ring sealed BLT is electrically connected in parallel to a charging capacitor of 0.04 μF and a one-ohm load resistor. The cathode side is charged to a negative high potential through a 5 MΩ resistor unit and the anode side is at the ground potential. A one-miliohm current viewing resistor (CVR) is inserted for monitoring the circuit current pulse. The BLT was triggered by a UV flashlamp at the back of the cathode operating at one Hertz. There is a 5 mm diameter center hole on the back wall of the BLT anode bulk body for extracting the electron beam. The anode back wall is then connected to the diagnostic region through a glass tube which serves as the drift region for the electron beam. The beam current is monitored from the diagnostic port by a Faraday cup which is attached to the other end of the glass tube through a flange. The o-ring seal between the Faraday cup and the flange enables the anode-cup distance to be adjusted over a 10 cm range. For measurements, permanent magnets are

*This work was supported by the Army Research Office, and the Strategic Defense Initiative through the Office of Naval Research.

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0-7803-0135-8/91$01.00 ©IEEE

placed transverse the drift tube to deflect the electron beam. A grounded metal layer is attached to the inside of the tube wall to collect the deflected electrons. The diagnostic port is sometimes replaced by a CRT screen with a decaying time of few microseconds. The minimum energy for electrons to excite the phosphor serves as a threshold to screen low energy electrons. A fiber bundle is used to couple the luminescence light onto a photodiode head. The photodiode signal is used to monitor the temporal behavior of beam electrons with energies above the threshold energy. Luminescence shows the beam shape and has been used to estimate the beam energy when combining with the use of transverse magnetic field and to measure beam emittance. The signals from the CVR and the Faraday cup are displayed by a fast digitizing oscilloscope which is outside the screen room surrounding the experiment setup.

B. Results and Discussion

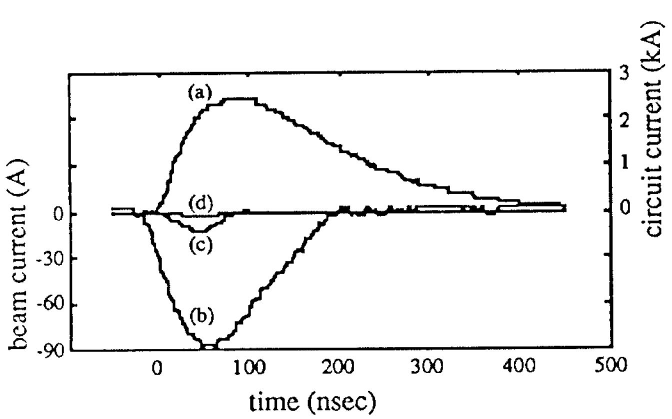

Figure 2. (a) The main discharge current and the beam currents at 7 cm downstream when (b) no magnet, (c) one pair of magnets, and (d) two pair of magnets are applied.

With argon gas at 55 mTorr, and 20 kV applied voltage, an electron beam of 90 A peak current, 120 ns duration was measured 7 cm downstream (figure 2b). The Faraday cup signal extended well into the falling portion of the CVR signal (main circuit current, figure 2a) indicating a beam generated by the superemissive cathode. These electrons are injected from the cathode fall region of the BLT during the high-current conduction phase. The penetration of these electrons into the bulk plasma and the hollow anode back space is possible and has been predicted by Bauer and Gundersen.[11,12] Two components of beam current were observed. The first component is a low current (<5 A), high electron energy, transient phase pulse of ~20 ns which begins before and shortly after the main discharge. The second component is a high current (>70 A), low electron energy, conducting phase pulse of >80 ns which is associated with the superemissive discharge. The two components are hard to distinguish in Figure 2 because of the second component of much higher current superimposing on the first component. 80 and 160 Gauss transverse magnetic fields were applied outside the drift tube to deflect the beam and a much smaller signal was obtained from the Faraday cup, as shown in figure 2c and 2d. The reduced signal indicates that the high energy electrons are created before and during the voltage breakdown. A simple calculation shows that most of the beam electrons have energy of few keV or less. Experiments also show that the beam current increases with applied voltage and with decreasing gas pressure. This suggests that the voltage holdoff capability of the BLT, thus the SEC-produced beam current, can be scaled by a multiple-gap structure.[13] The increase of beam current with decrease gas pressure is further studied by a differential pumping scheme.

The differential pumping effect on the electron beam has been investigated by changing the position of the gas pumping outlet of the system to the diagnostic port. The differential pumping effect comes from the center holes of the electrodes and the anode back wall. At drift tube gas pressure of 10 mTorr and 20 kV applied voltage, an electron beam current of 260 A peak current, 200 ns duration was measured 9 cm downstream (as compared to beam current of 105 A peak current, 120 ns duration without differential pumping). The large increase of beam current and duration with differential pumping is explained by the reduction in the numbers of collisions of beam electrons with neutral gas and plasma in the drift region.[11,12] Application of transverse magnetic field has dimmed the light coming out from the drift tube significantly, indicating bending of the beam electrons into the tube wall before they ionize the neutral gas. In principle the electron beam diagnostics in vacuum should be easily implemented with several stages of differential pumping. A two-stage differential pumping scheme is underway.

With a CRT screen 23 cm downstream, a luminescence light ~3.5 cm in diameter is seen on the screen center. The luminescence light is displaced and distorted into a more triangular shape when the transverse magnetic field is applied. This distortion of beam shape may result because the magnetic field is not uniform across the drift tube and the electron energies are decreasing outward from beam center. Figure 3 shows the detailed structure of the luminescence generated from the phosphor. The luminescence actually begins ~120 ns before the main discharge occurs indicating a beam with runaway electrons of energies comparable to applied voltage.[3] This portion of beam did not show in figure 2 because of its small current. Trace 3(c) represents the luminescence generated from the discharge of the self-capacitance of the BLT (no external capacitor). The electron beam corresponding to this is closely related to the initiation of hollow cathode discharge (HCD). Trace 3(b) represents the luminescence of the phosphor when external capacitor of 16 nF and load resistor of one ohm are connected. The interval between the two peaks on trace 3(b) is the electron beam from the HCD. The emittance of electron beam generated by the HCD is measured by a pepper pot mask and the phosphor screen. The normalized emittance is estimated to be about 20 π mm-mrad. The detailed experiment and the characteristics of the HCD-produced electron beam will be discussed in a separate paper. The second peak on trace 3(b) is evidence of the electron beam in the beginning of the superemissive discharge which also temporally coincides with the rising part of the discharge current. The voltage across the gap between the electrodes is dropping to the cathode fall voltage during the rise of the discharge current. Electrons with energies of the cathode fall are not likely to excite the phosphor and produce luminescence. Collisions experienced by the beam electrons propagating in the drift tube further reduce the beam energy. These two factors may explain why the luminescence trace did not follow the discharge current trace after the current maximum. The electron energies are estimated from the transverse magnetic field strength, the length of the interaction region, the distance between the screen and the interaction region, and the displacement of luminescence light on the screen. The electron energies at beam center and edge are estimated to be ~10 keV and ~600 eV at applied voltage of 15 kV. Because of the fringe effect of the magnets and the ununiformity of the magnetic field, the estimation is accurate only to an order of magnitude.

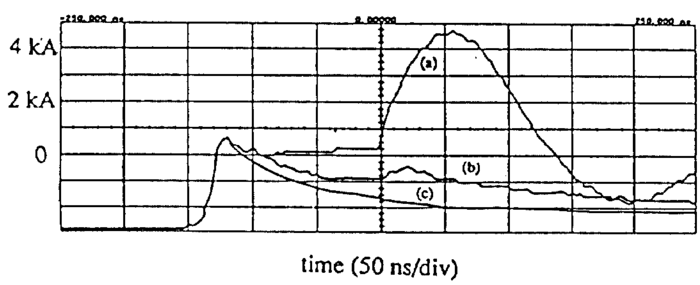

Figure 3. The temporal behavior of (a) the discharge current, and the luminescence from phosphor (b) with and (c) without an external capacitor connected.

III. CONCLUSIONS

Experimental evidence for electron beam production by the superemissive cathode in the BLT is reported. An electron beam of more than 260 A peak current has been extracted. The beam current can be scaled by adjusting the external circuit, using a multiple-gap BLT structure, and changing the gas pressure. With the multiple-gap BLT structure, the scaling of voltage holdoff capability from 10^4 volts to 10^5 or 10^6 volts is possible. The electron beam extraction into vacuum can be achieved by differential pumping. The electrode shape also is a factor affecting the beam generation and will be studied in the future work. These results show that the superemissive cathode in the BLT and pseudospark is potentially an important source for producing high current, high current density electron beams. The simple trigger, compact, and robust nature of the BLT and the data indicate that the superemissive cathode is a beam source that deserves further study for applications such as accelerators and high power klystrons.

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