# EXTRACTION OF A STEADY STATE ELECTRON BEAM FROM HCD PLASMAS FOR EBIS APPLICATIONS*

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## Abstract

Experiments to extract high brightness electron beams from hollow cathode discharge plasmas are now in progress. A unique feature of these plasmas, which in principle can facilitate the extraction of large current low emittance electron beams, is the existence of a relatively high energy electron population with a very narrow energy spread. This electron population was identified in a self-extraction experiment, which yielded a 35 eV, 600 mA electron beam with parallel energy spread of less than 0.5 eV. Preliminary, crude application of 2.5 kV extraction voltage yielded a steady state electron beam current of 1.2 A. The end result of this endeavor would be an EBIS with an electron beam current of 6 A

## Introduction

Tentative long-range plans for the BNL heavy ion program call for the development of an electron beam ion source (EBIS) with an electron beam current of 6 A. Present day EBIS devices operate with electron beam currents of less than 1 A. These beams operate steady state (or with very long pulses), and they have low emittance. Because of the latter requirement, no serious considerations were given to electrons extracted from plasmas. Plasma cathodes can easily yield multi-amperes of electrons, however at a very high emittance. Therefore this type of electron beams have very limited use (mostly used to excite molecules in powerful gas lasers). For almost all other applications, electron beams are injected from guns utilizing either thermionic cathodes, or photocathodes. These surface emitted electrons have energy spreads of about 0.5 eV or less (as compared to plasma electrons with energy spreads of a few eV at least). But, space charge problems pose severe limitations on the total steady state (or long pulse) electron current that can be extracted from the various surface emitters. Other surface emitters, e.g., semiconductor photoemitters have an inherent limitation to very short pulses only at high current outputs.

Hollow cathode discharge (HCD) plasmas have two electron populations: the bulk electrons with a density of up to (and/or slightly above) $10^{14}$ cm$^{-3}$ with a temperature of several eV, and fast primary electrons having a density of about $10^{11}$ cm$^{-3}$ or less with an energy corresponding to the cathode potential and a thermal spread which is close to the cathode temperature of 0.17 eV. (In order to avoid confusion in terminology, it is important to note that most European researchers refer to this type of discharges as hollow cathode arcs HCA). Existence of fast electron in HCD plasmas was either postulated[1] to explain properties of external plasmas in HCD's, or accepted as a possibility[2] that some electrons emitted from a hollow cathode surface could survive their "trip" to the anode without loss of energy.

To date, there is no theory which can account for thermalization of the surface emitted electrons, or a theory which could predict whether the electron population is a Maxwellian with a long superthermal tail, or whether there are two distinct electron populations.

We gambled on the existence of two distinct groups of electrons. Initial results indicate that at higher operating pressures the electron population is most likely thermal with a long superthermal tail, while at lower operating background pressures there are two electron populations, one of which has a narrow energy spread. Self extraction of this population yielded a beam current of 600 mA with a parallel energy spread of less than 0.5 eV. Application of an extraction voltage of 2.5 kV yielded 1.2 A.

## Experimental Set-up and Results

In principle, this scheme is based on extracting the energetic electrons only. Schematically, the experimental configuration[3] relied on repelling the bulk (thermal) electrons with a negatively biased grid and further selection was to be done with a magnetic mirror in case the discharge would not operate properly without a magnetic field. Fortunately, we obtained very encouraging results with unmagnetized discharges. After numerous experiments and changes our present experimental configuration has evolved to that which is shown in Figure 1. The plasma is generated in a 3 mm Ta hollow cathode.

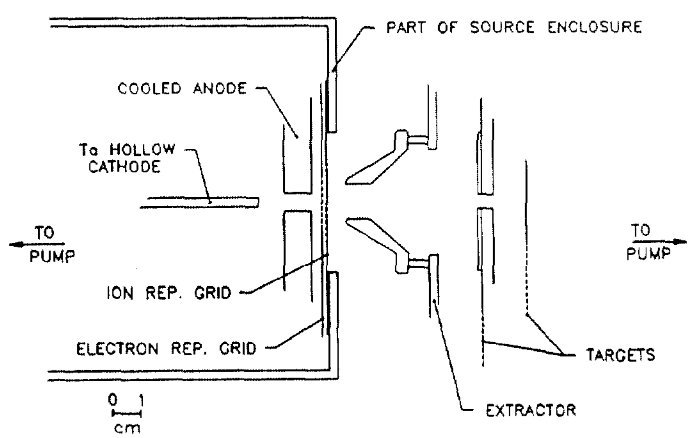


Fig. 1. Schematic of the electron selection and extraction system.

The length of the discharge, i.e., the cathode to anode distance, is 9 mm. This distance should be made as short as practically possible to minimize velocity space relaxation due to multiple small angle scattering of the fast electrons by the plasma

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particles. The hollow anode is followed by a negatively biased grid designed to repell the bulk electrons. Next, we have a positively biased ion repelling grid, which proved the necessary in self-extraction experiments by preventing ions from reaching the target. The whole source is enclosed in a differentially pumped cylinder which is negatively biased. The extractor and target are at ground potential.

A large number of measurements failed to show the existence of a distinct fast electron population with a narrow energy spread for "normal" modes of operation[4] with a background pressure in the $10^{-4}$ Torr range. The electron current on the targets was supposed to show a very sharp drop or rise as the electron repelling grid bias was increased or decreased. This sharp transition was expected at a grid bias close to the arc voltage (the cathode potential). With the background pressure at about $10^{-4}$ Torr (or even as low as $7.2 \times 10^{-5}$ Torr), target-current repelling-grid-voltage characteristics showed a gradual response. This was indicative of either a larger than expected thermal spread, or of the existence of a velocity distribution with a very long tail. Finally, when the background pressure in the discharge was reduced to $1.8 \times 10^{-5}$ Torr, the desired behavior was observed. Figure 2 is a plot (on an x-y recorder) of the target current as a function of the bias on the electron repelling grid. The very sharp rise extends for 600 mA (off scale in Fig. 2). The resolution is about 0.5 V, hence the parallel energy spread is about or less than 0.5 eV. Furthermore, this sharp transition did occur at an electron-repelling grid bias of -33 V which roughly equalled the arc voltage. The plasma current was 18 A and the bias on the ion repelling grid was +42 V.

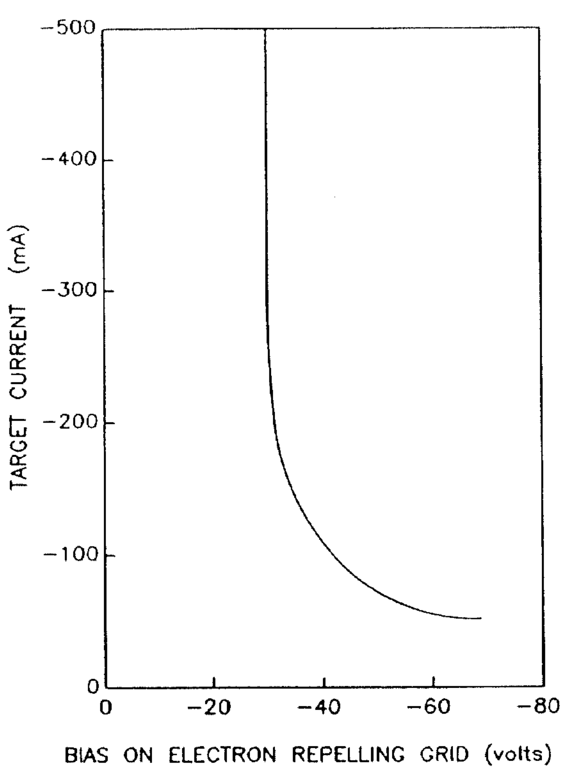


Fig. 2. Self-extracted electron current versus bias on the electron repelling grid.

High voltage extraction started less than two weeks before the beginning of this conference. The experimental configuration was identical to that shown in Figure 1 except for the omission of the ion repelling grid. About 1.2 A of electron current was extracted at 2.5 kV, and its dependence on the electron repelling grid voltage exhibited the sharp increase/decrease characteristics. However, due to lack of cooling on the grid and extraction system, the measurements were not reproducible as a result of damage to both the grid and extractor. An additional limitation in this run was reduced pumping which forced operation at twice the optimum pressure.

## Future Plans

Initial results are encouraging. They strongly suggest the existence of a fast electron population with a narrow energy spread. Next we plan to reinstall the ion repelling grid and improve the pumping. After the results of the self-extraction experiments are repeated with high voltage extraction, emittance measurements are to be done. If the electron beam meets the requirements for an EBIS, experiments with long-life hollow cathodes will be performed.

## References

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