SUPPRESSION OF THE e^- COEXTRACTED FROM A PENNING SURFACE-PLASMA H^- SOURCE*

H. Vernon Smith, Jr. and Paul Allison
AT-10, Mail Stop H818
Los Alamos National Laboratory
Los Alamos, NM 87545 USA

Abstract

The ratio of electrons to negative ions extracted from Penning surface-plasma sources (SPS) such as the 8X source is low even before any steps are taken to suppress the electrons. For the 8X source the e^-/H^- ratio is typically four or five to one for H^- operation and nine to one for D^- operation. Because the coextracted e^- present a power-loading problem to the 8X-source extraction system, methods to dissipate and/or reduce the power in the e^- beam must be developed before extracting a dc H^- or D^- beam. Thus, we conducted this study to determine whether a collar installed in the near-extraction region of the 8X source suppresses the electrons extracted from that source.

Introduction

The 8X source is presently under development for use in the neutral-particle-beam (NPB) program. The pulsed-8X-source design and measured performance are described in Ref. 1. We are developing a cooled version of the 8X source that can operate with dc arc and with dc H^- beam extraction [2]. The key issue that we address in this paper is whether or not the e^-/H^- ratio in the extracted beams can be reduced by simple changes in the 8X-source geometry.

Experimental Method

McAdams et al. [3] used a collar to reduce the electron current extracted from a volume source. Leung et al. [4] and Debiak et al. [5] varied the geometry of a collar to lower the e^-/H^- ratio in the beams extracted from a volume source. We varied the geometry of a collar installed in the 8X source and measured the e^- and H^- currents as well as the H^- beam emittance. Figure 1 shows the geometry of the 8X source collar arrangement. The collar is constructed from a single piece of molybdenum. Its length along the beam direction is L; its diameter is 2R (perpendicular to the beam direction). Set screws (not shown) are used to clamp the collars in the 24-mm-diam by 8.0-mm-long drift region of the 8X source. We then measured the performance with all 12 different L and R combinations with L = 1.0, 2.4, 4.8, and 8.0 mm and R = 1.5, 3.2, and 4.5 mm, and also without a collar. The measurements without a collar reproduced the results reported in [1].

We measured the H^- current with a Faraday cup, and determined the e^- current by subtracting the H^- current from the drain current (Fig. 2). We make the assumption that the drain current is comprised only of the H^- and e^- current; that is, no other negative ions are extracted and no positive ions cross the gap in the reverse direction. The H^- beam emittance is measured with electrostatic sweep scanners [6] located 12 cm from the emitter. All of the measurements reported in this paper were obtained using the high-current test stand.

The extraction system uses an emission-aperture diameter of 2.6 mm, an extraction gap of 3.0 mm, and an extraction-aperture diameter of 3.0 mm. Typical source parameters are discharge voltage V_d = 90 V, discharge current I_d = 440 A, H_2 gas flow = 0.25 Tl/s, N_2 gas flow = 0.006 Tl/s, and arc magnetic field B_x = 360 G. The discharge pulse length is 1.2 ms; the pulse repetition rate is 5 Hz.

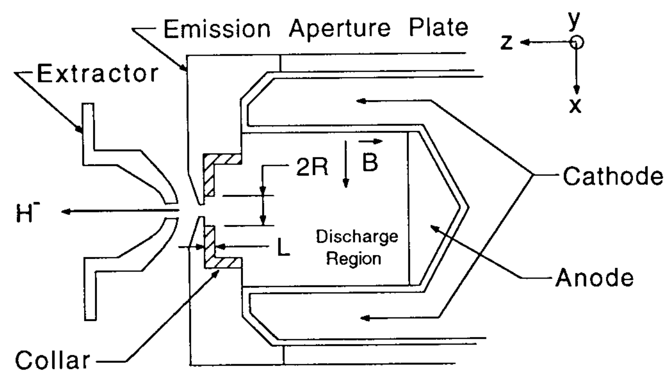

Fig. 1 The 8X-source collar geometry. The cylindrical collar insert (hatched area) is placed in the drift region between the emission aperture and the discharge region. The collar's length is L and its diameter is 2R.

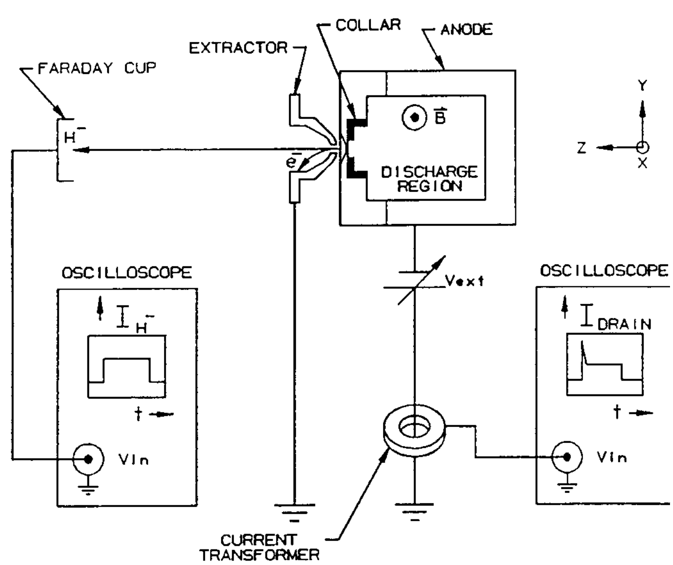

Fig. 2 Schematic of the H^- and e^- current measurements. The H^- current is measured directly with a Faraday cup. Because the e^- are deflected into the extractor electrode by the stray, transverse magnetic field, the e^- current is the difference between the drain current and the H^- current.

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Results

Figure 3a shows the electron current vs the collar length L for fixed collar radius R. The e^- current with no collar, 182 mA, is the circle. The general trend is that the larger the L (for a fixed R), the lower the e^- current. For a fixed L, the smaller the R, the lower the e^- current. For the H^- current (Fig. 3b), there is at first a slight rise, or at least a plateau region, with increasing L, then a fall-off with collar length that is slower than the e^- current. At fixed collar lengths ≥2.4 mm, the H^- current drops with decreasing collar radius.

The e^- to H^- current ratio as a function of collar length for a fixed collar radius is shown in Fig. 4. The e^-/H^- ratio decreases with increasing L (at fixed R) and with decreasing R (at fixed L). Because the e^- current falls off faster with L and R than the H^- current, a large reduction in the e^-/H^- ratio is accompanied by only a small reduction in the H^- current. For example, at L = 4.8 mm and R = 4.5 mm, the H^- current drops by 20% (from 38 to 31 mA, Fig. 3b), while the e^- current drops by more than a factor of 4 (from 182 to 42 mA, Fig. 3a), resulting in an e^- to H^- ratio near 1/1.

The extracted H^- current varies by an order of magnitude for the measurements shown in Fig. 3b. The largest H^- current recorded is 41 mA for a collar with L = 1.0 mm and R = 3.2 mm; the smallest is 3.0 mA for L = 8.0 mm and R = 1.5 mm. To make meaningful comparisons between emittance measurements for different collars, we adjusted the

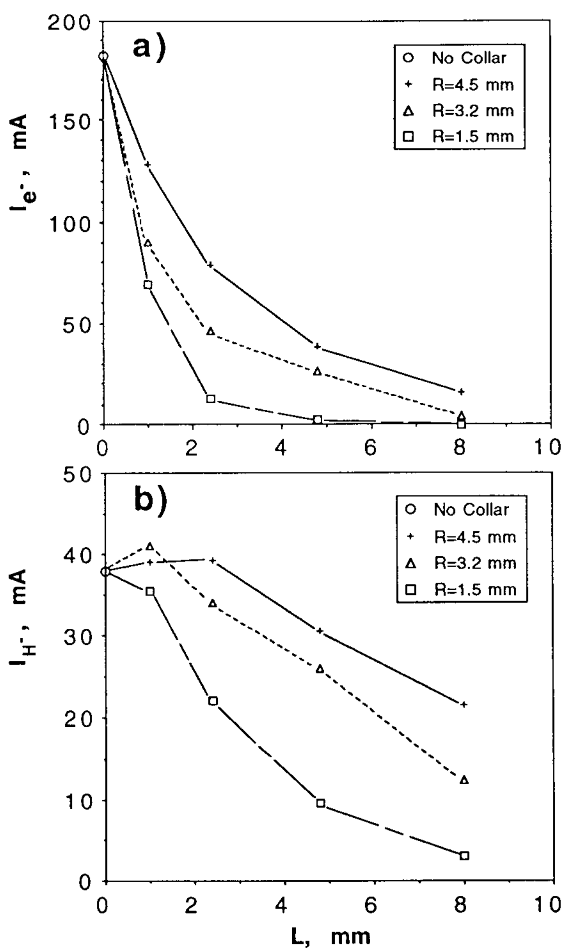

Fig. 3 a) The electron current I_{e^-} vs the collar length L for fixed collar radius R. The circle is I_{e^-} for no collar. b) The H^- current I_{H^-} vs the collar length L for fixed collar radius R. The circle is I_{H^-} for no collar. The lines connect the data points.

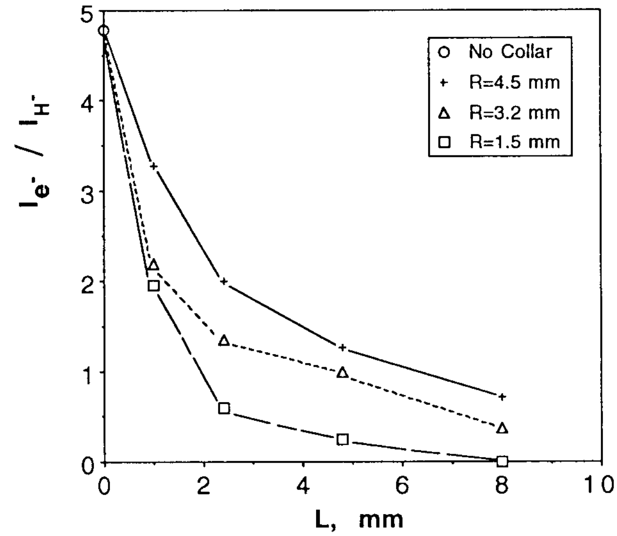

Fig. 4 The e^- to H^- current ratio I_{e^-}/I_{H^-} vs the collar length L for fixed collar radius R. The lines connect the data points.

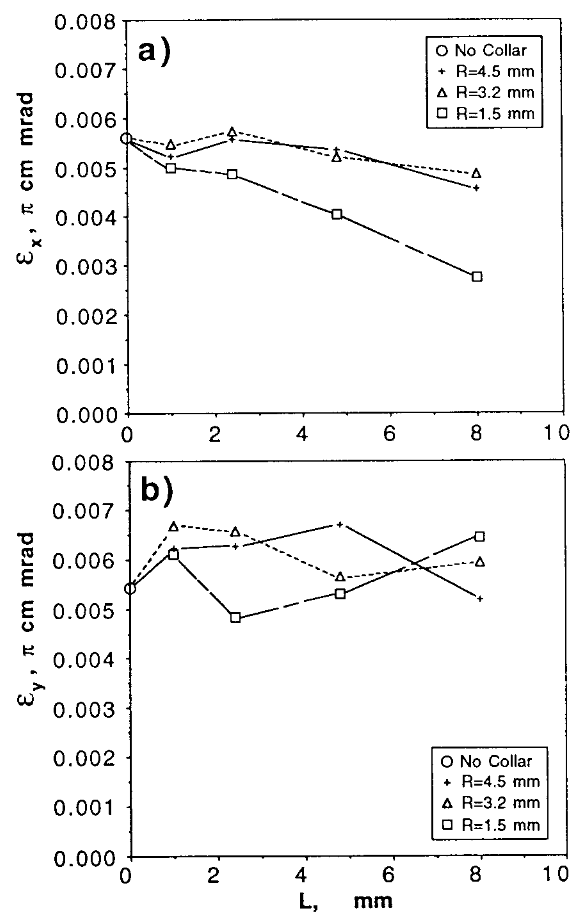

Fig. 5 a) The rms normalized emittance ε_x vs the collar length L for fixed collar radius R. b) Same as a), except ε_y vs L. The lines connect the data points.

electron-equivalent H^- beam perveance P to 0.4 μPerv {$P = [(m_{H^-}/m_{e^-})^{1/2}(I_{H^-}/V^{3/2})]$} by choosing the correct value of the extraction voltage V. Figure 5a shows ε_x as a function of L for fixed R, and Fig. 5b shows ε_y as a function of L for fixed R. With the exception of the R = 1.5 mm data at L = 4.8 and 8.0 mm, ε_x is remarkably constant with L and R. There is more scatter in the ε_y data, but ε_y also appears to be independent of L and R.

Discussion

Bel'chenko et al. [7] point out that for electrons transported along z, across the magnetic field lines, in a SPS the electron density should decay exponentially as a constant times z/δ, where δ is the distance between two parallel plates whose surfaces are perpendicular to the magnetic field (B and δ are in the x direction, Fig. 1). They considered suppression of e^- by the rectangular slit edges in the ion-optical system of their SPS. By replacing z with L and δ with 1.70R (the average distance parallel to B_x inside the collar), we get $I_{e^-}(L,R) \approx I_{e^-} \exp(-CL/R)$, where $C = (\pi/1.70)\, |D_{\parallel}/D_{\perp}|^{1/2}$. For classical diffusion, $D_{\parallel}/D_{\perp} \approx [(m_e/M_i)\,(1 + \omega_{ce}{}^2\tau^2)]$, where ω_{ce} is the electron cyclotron frequency and τ^{-1} is the collision frequency. We estimate that τ^{-1} is 86 MHz for electrons on H_2, giving $D_{\parallel}/D_{\perp} \approx 3$, so the magnetic field does inhibit transport of the electrons across the magnetic field lines. This leads to $I_{e^-}(L,R) \approx I_{e^-} \exp(-3.2\ L/R)$.

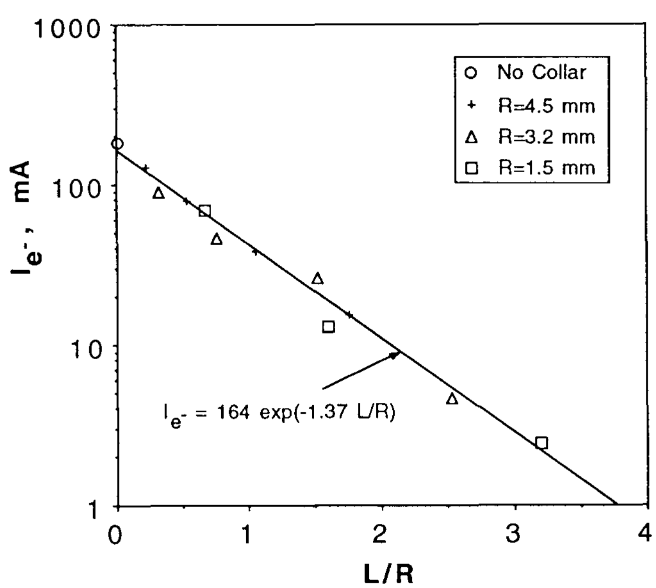

Fig. 6 A plot of I_{e^-} vs L/R, the ratio of the collar length L to the collar radius R. The line is a least-squares fit to the data.

Haas and Holmes developed a hydrodynamical model of a volume source with a collar geometry similar to ours. They arrive at an expression for I_{e^-} that also has an exponential dependence on -L/R [8].

Figure 6 shows a semi-log plot of I_{e^-} as a function of L/R for our collar geometry. The e^- current follows the "universal" curve I_{e^-} (mA) = 164 exp[-1.37 (L/R)] shown on Fig. 6. Uncertainties in our approximate expression for $I_{e^-}(L,R)$ include the assumption of classical diffusion, the assumption that the electron diffusion across the magnetic field is due solely to collisions with H_2 molecules, and the calculation of the H_2 density from the H_2 gas flow through the emitter of known size. In view of these uncertainties, the discrepancy between the calculated (3.2) and measured (1.37) values of the exponent is not surprising.

Conclusion

A collar can be used to suppress the electrons extracted from the 8X source with little sacrifice of H^- beam current. Presumably, the reduction in I_{e^-} arises from the electrons being drained off on the collar edges (by diffusion parallel to the magnetic field) before they can diffuse across the magnetic field lines and be extracted from the source. This result will facilitate the design and implementation of an electron collector for the CW 8X source beam extraction system.

Acknowledgments

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References

[1] H.V. Smith, Jr., et al., "Penning Surface-Plasma Source Scaling Laws - Theory and Practice," Proc. of the Sixth International Symposium on the Production and Neutralization of Negative Ions and Beams, Brookhaven National Laboratory, November 9-13, 1992 (to be published).

[2] H.V. Smith, Jr., et al., "CW 8X Source Development," in Ref. [1] (to be published).

[3] R. McAdams, R. F. King, and A. F. Newman, Rev. Sci. Instrum. **61**, 2176 (1990).

[4] K. N. Leung, C. A. Hauck, W. B. Kunkel, and S. R. Walther, Rev. Sci. Instrum. **61**, 1110 (1990).

[5] T. W. Debiak, L. Solensten, J. Sredniawski, and Y. C. Ng, "Comparison of Negative Ion Beam Output Characteristics for Various Extractor Geometries of the LBL Small Volume Source," Grumman Aerospace Corporation report, 1990. Also, J. Sredniawski, "Experiments with Electron Suppression on the LBL Small Volume Source," Grumman Aerospace Corporation Technical Note No:89-32 (December 1989).

[6] P. W. Allison, J. D. Sherman, and D. B. Holtkamp, IEEE Trans. Nucl. Sci. **NS-30**, 2204 (1983).

[7] Yu. I. Bel'chenko, G. I. Dimov, and V. G. Dudnikov, "Physical Principles of the Surface Plasma Method for Producing Beams of Negative Ions," proc. Symp. on the Production and Neutralization of Negative Hydrogen Ions and Beams (Brookhaven National Laboratory report No. BNL 50727, 1978) pp 79-96.

[8] F. A. Haas and A. J. T. Holmes, Plasma Physics and Controlled Fusion **33**, 1197 (1991).