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Extracted Current Densities from Surface Conversion Sources of Negative Ions

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ABSTRACT

The condition for extracting a maximum negative ion current density is found when the product of the radius of the negative ion conversion electrode, the cross-section for negative and positive ion recombination, and the density of positive ions in the ion source equals one. The optimum output is obtained at the highest positive ion density and the smallest electrode radius.

High current density sources of negative ions are needed to form compact, cost effective, high energy neutral beam injectors for magnetic fusion reactors. Whereas the beam current density of future beam lines will be limited by constraints established by the ion accelerator (i.e. considerations related to arc suppression, x-rays, sputtering, grid loading, background gas density, etc.), today's limits are imposed by problems within the ion sources themselves.

In these sources negative ions are generated by positive ion bombardment of the cesium-coated conversion electrode (see Fig. 1).

†On assignment from Westinghouse Electric Corporation.

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Because the electrodes are biased at about -150 V with respect to the discharge plasma, they are surrounded by a plasma sheath which accelerates the newly formed negative ions toward the ion exit aperture. The initial current density of negative ions J_1^- is proportional to the positive ion density n^+ in the plasma, i.e.

$$J_1^- = K n^+, \quad (1)$$

in which K is the proportionality constant. At the exit aperture, a distance R from the conversion electrode, the current density has been enhanced by the beam geometry, roughly in proportion to the ratio of the half angle γ which subtends the conversion electrode and the half angle α which encompasses the bulk of the negative ions leaving any point on the conversion electrode surface. The negative ion current meanwhile has been eroded by recombinations between the negative and positive ions.

If σ is the recombination cross-section for 150 V negative ions and the mixture of positive atomic and molecular ions found in the plasma, the extracted negative ion current density must be:

$$J_E^- = K(\gamma/\alpha) n^+ e^{-n^+ \sigma R} . \quad (2)$$

The extracted current density is maximum when

$$n^+ \sigma R = 1 . \quad (3)$$

Assuming that the effective cross section is

$$\sigma = 4 \times 10^{-14} \text{ cm}^2 , \quad (4)$$

the maximum extracted current density is

$$\text{MAX } J_E^- = 0.37 K(\gamma/\alpha) n^+ . \quad (5)$$

or as a function of geometry, from Eq. (3),

$$\text{MAX } J_E^- = (9.25 \times 10^{12}) (K/R) (\gamma/\alpha) . \quad (6)$$

It is interesting to compare the negative ion source developed at the Lawrence Berkeley Laboratory (see Fig. 2) with that developed at the Brookhaven National Laboratory (see Fig. 3). They both use cesium coated negative ion forming electrodes as converters but, as shown in Table I, they operate under very different conditions. Nevertheless, when data taken from the table are introduced into Eq. (6), the value of the proportionality constant K for the two sources is about 2.5×10^{-15} .

When trying to optimize the extracted ion current density of such sources, little can be done to improve the ratio of γ to α . If γ is made too large, it will introduce a significant transverse velocity component into the ion beam which will adversely affect the beam optics. The angle α meanwhile is not subject to external control as it results from the scattering of ions off the converter surface.

Reviewing Eqs. (5) and (6), it is evident that the highest extracted current density is available from the optimized structure designed to operate at the highest ion density and the smallest spacing R. This is the worst possible condition for the conversion electrode as it is subject to the most intense ion bombardment. Special provisions may have to be made to cool the converter and maintain its cesium coverage. (Ref. 3).

References

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3. I. E. Kanter, M. D. Nahemow, J. H. Fink, "A High Current Density, High Temperature, Cesium Emitter," IEEE International Conference on Plasma Science, University of Wisconsin, Madison, Wisconsin, May 19-21, 1980, p. 8.

TABLE I
Ion Source Parameters

	LBL Source (Reference 1)	BNL Source (Reference 2)
R (cm)	6.0	0.375
γ	30^0	37^0
α	15^0	4.6^0
Max J_E ($A\ cm^{-2}$)	0.008	0.5
P (Torr)	$\sim 10^{-3}$	$\sim 10^{-1}$

Figure 1 Surface conversion source of negative ions.

Geometry of the Lawrence Berkeley
Laboratory Negative Ion Source
(Reference 1)
Figure 2

Geometry of the Brookhaven
National Laboratory Negative
Ion Source (Mark III)
(Reference 2).
Figure 3