# Development of Bright Negative Ion Sources at Culham Laboratory*

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## *Abstract*

This paper describes the present status of the development of high brightness H⁻/D⁻ sources at Culham Laboratory. The performance of the sources are described in terms of the output current, the suppression and trapping of extracted electrons and the beam emittance. Also Langmuir probe data of the plasma is described.

## 1. INTRODUCTION

Sources of $H^-$/$D^-$ ions for accelerator applications are required to have high current and low emittance, to operate cw and be of very high reliability. The magnetic multipole ion source can meet these requirements. We will describe the characteristics of these sources under development at Culham by discussing the performance of a particular one.

## 2. ION SOURCE AND ACCELERATOR

The volume ion source as shown in Figure 1 is a metallic discharge chamber of dimensions 19 x 14 x 10 $cm^2$ with external permanent magnets to increase the plasma density. The discharge is sustained by up to six filaments (or rf from an antenna). The arrangement of magnets is such that a magnetic filter field separates the plasma into two regions. The colder region is adjacent to the extraction aperture where $H^-$ or $D^-$ ions are formed by dissociative attachment of low energy (~1eV) electrons to vibrationally excited molecules of $H_2$ or $D_2$ which have diffused into the region across the magnetic filter[1].

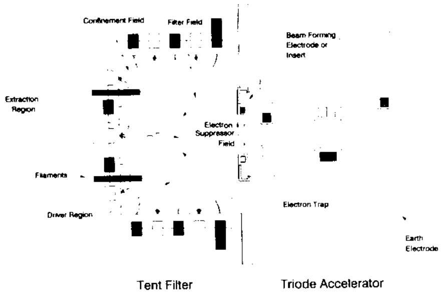

Figure 1. Schematic volume ion source

The source is mounted on the Culham Ion Source Test Stand[2] which is configured as a triode accelerator of energy up to 100keV as shown in Figure 2. Ions and electrons are extracted from the source by the intermediate electrode at voltages up to $V_{ext}$ ~ 20keV. Permanent magnets in the accelerator deflect the co-extracted electrons into a dump region and the ion beam is accelerated to full voltage. Further magnets resteer the ion beam. The ion current is measured downstream by a dc beam transformer at a distance of 0.67m from the source. A deflector magnet ensures there are no electrons in the beam from the accelerator. The source and beam line operate cw. The extraction aperture diameter is 16mm.

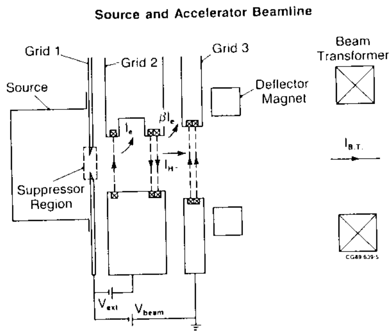

Figure 2. The triode accelerator

## 3. THE SUPPRESSION OF ELECTRONS

The co-extracted electrons present design issues in terms of heat removal, power supply ratings and possibly the beam quality and it is important to ensure as small a flux as possible enters the beam. This is achieved at the plasma/accelerator boundary by the device shown in Figure 3.

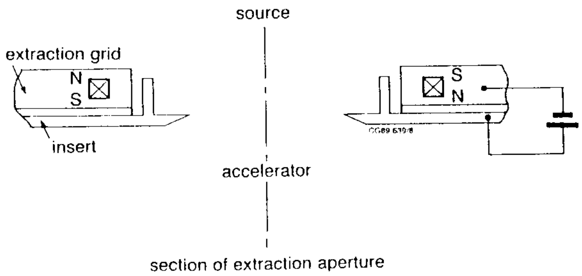

Figure 3. The electron suppressor

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The electrons are trapped on the field lines of the permanent magnets[3] and collected at the extraction electrode which is biased at a voltage $V_{ins}$. Figure 4 shows the dependence on the voltage $V_{ins}$ of the ion and electron currents. The electron current is highly suppressed at a few volts whereas the ion current is relatively independent of $V_{ins}$.

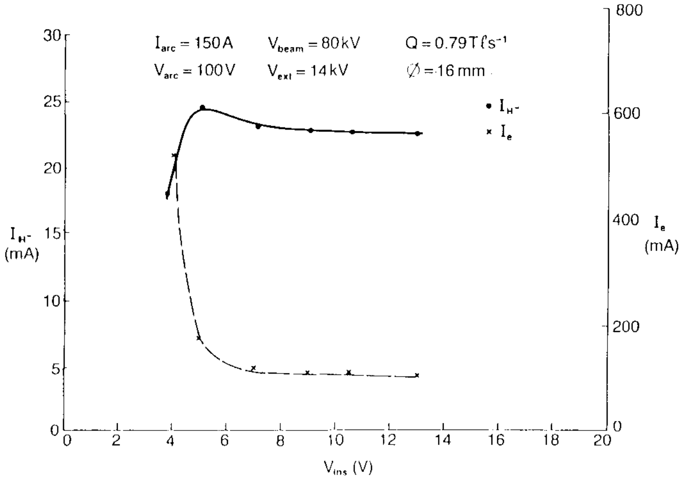

Figure 4. The action of the electron suppressor

## 4. PURE VOLUME PERFORMANCE

Figure 5 shows the measured $H^-$ current from a 16mm diameter extraction aperture as a function of $H_2$ gas flow to the source for different values of arc currents at a beam energy of 92 keV. Currents up to 39mA have been measured and at this current the extracted electron current is 690mA for a suppressor voltage of $V_{ins}$ = 4.9 V

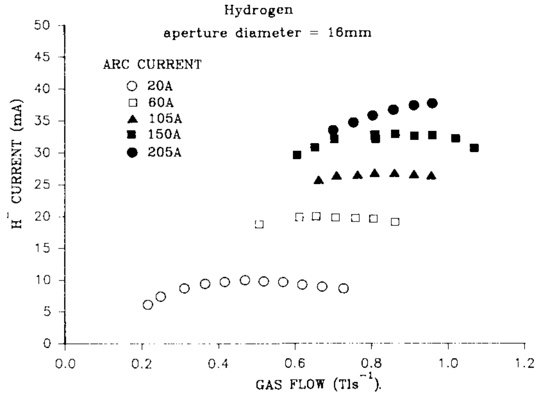

Figure 5. $H^-$ current as a function of gas flow

In Figure 6 we show the $D^-$ current variation as a function of gas flow. From this it can be seen that there is a factor of just more than two reduction compared to the $H^-$ current and the electron to ion ratio has increased, the electron current being about 800mA at the highest $D^-$ current of 14mA even with a higher suppressor voltage of $V_{ins}$ = 5.9 V. The source has not been re-optimised for deuterium operation in terms of the filter field strength and this is known to have an impact on performance.

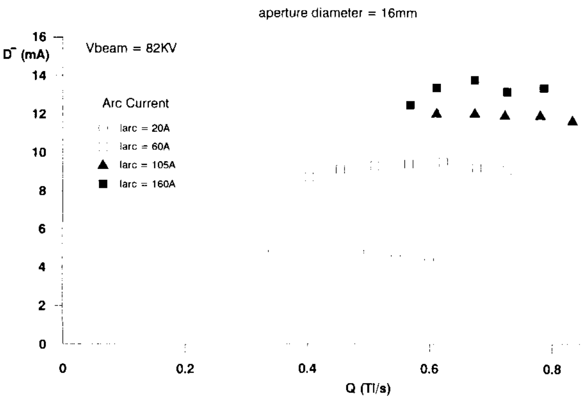

Figure 6. $D^-$ current as a function of gas flow

## 5. CESIATED SOURCE PERFORMANCE

It is well established that trace amounts of cesium added to the discharge enhances beam performance. We added ~ 50mg of cesium by a dispenser and in Figure 7 we show the $H^-$ current as a function of arc current with and without cesium for a gas flow of ~0.7Tℓs⁻¹. There is an enhancement in current with cesium of about a factor of two. Also, the extracted electron current is reduced. The maximum $H^-$ current we measured was 60mA with an electron current of 94mA

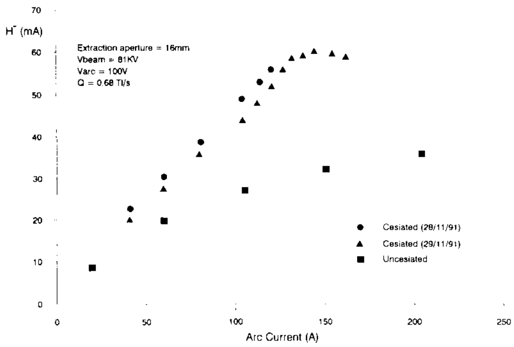

Figure 7. H- current with the addition of cesium

Figure 8 shows the enhancement in deuterium due to the addition of cesium.

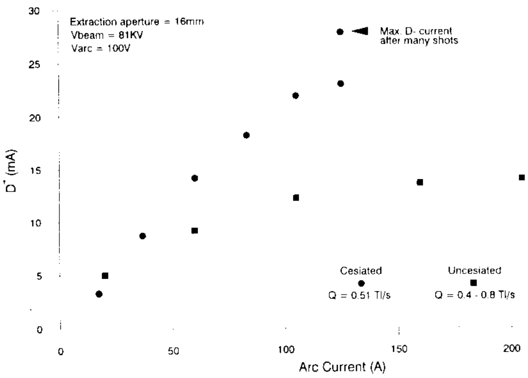

Figure 8. $D^-$ current with the addition of cesium

Again about a factor of two enhancement is observed. For both $H^-$ and $D^-$ cesiated operation at the highest ion currents there is evidence that not all the beam available from the source is being transported by the accelerator. In the case of $H^-$ it is demonstrated by the roll over of current with increasing arc current. In $D^-$ this is indicated by a non saturation of ion current with $V_{ext}$. Thus more current may be forthcoming.

The currents measured here whether the source is operated uncesiated or cesiated represent the highest cw negative ion currents from a single aperture.

## 6. PROBE MEASUREMENTS

A planar Langmuir probe has been installed in both the hot plasma region near the filaments and also in the cold plasma near the extraction apertures. The probes can measure the positive ion current density, electron temperature and plasma potential in the source as a function of arc current and other discharge parameters. In figure 9 is shown $j_+$ for the hot and cold plasma regions as a function of arc current. Both are linear but the hot plasma density attaining 2.5 A/cm$^2$ for a full power discharge picture. The electron temperature and plasma potential for the hot plasma is almost insensitive to arc current and are about 2.5eV and 5.5 volts respectively which the cold plasma has 1.4eV and 4.5 volts for these parameters.

This indicates that a large fraction of the $H^-$ (or $D^-$ ions) may be made in this plasma region in view of the low electron temperature and high density. In comparison with other negative ion sources$^{(5)}$ these results are unusual and offer the possibility of modifying negative ion source to a form which has no magnetic filter and hence possibly lower emittance.

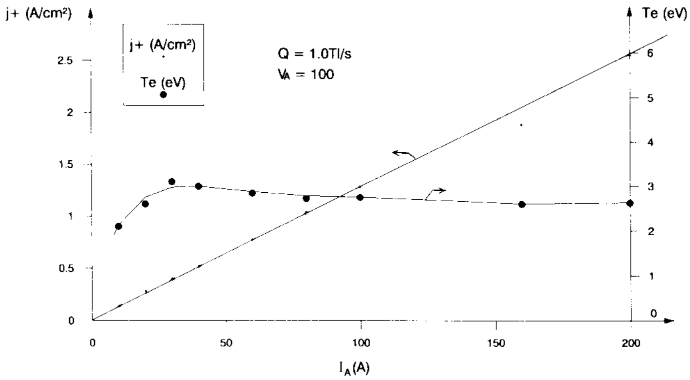

Figure 9. Current Density in Filament Region

## 7. EMITTANCE

The emittance of the beam is measured by an electrostatic sweep emittance diagnostic$^4$ at a distance of 0.82m from the source. The angular resolution of the device is ~ 0.15mrad. The relationship between the normalised emittance $\epsilon_N(F)$ enclosing a beam fraction F for a Gaussian distribution is

$$\epsilon_N(F) = 2\,\epsilon_{RMS}\,\ell n\,(1/(1-F))$$

where $\epsilon_{RMS}$ is the normalised rms emittance. From a plot of $\epsilon_N(F)$ against $\ell n\,(1/(1-F))$ we can obtain $\epsilon_{RMS}$.

For a 30mA $H^-$ beam at 90keV the normalised r.m.s emittance is 0.17π mm mrad as determined by this method Figure 10 shows the phase space contour which contains 97% of the beam and it also shows the contour containing 40% of the heam ; this being the rms contour for a Gaussian distribution. Using the moments formula for the normalised r.m.s emittance,

$$\epsilon = \beta\gamma\,[\overline{x'^2}\,\overline{x^2} - (\overline{xx'})^2\,]^{\frac{1}{2}}$$

we obtain a value of 0.26πmm mrad.

The beam can be seen to have third order abberations at high beam fractions. The central core of the beam, ie at smaller beam fractions, has a very low emittance.

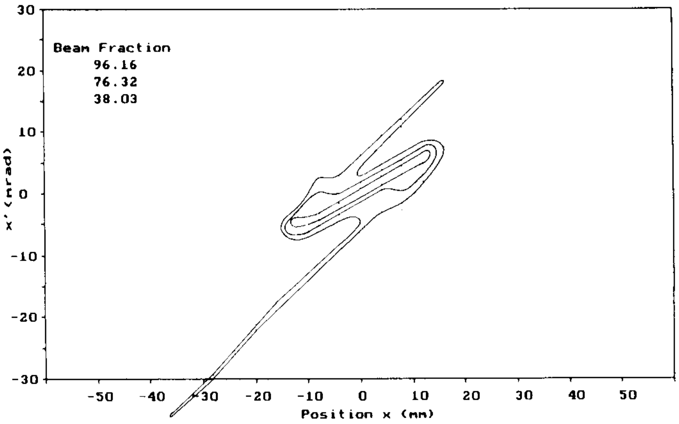

Figure 10. The emittance of a 30mA $H^-$ beam

## 8. REFERENCES

[1] See for example, the papers in Production and Neutralisation of Negative Ions and Beams, 5th International Symposium, Brookhaven, USA, 1989, AIP Conference Proceedings No. 210, 1990.

[2] R McAdams, R F King and A F Newman, "Electron Suppressors for Negative Ion Sources", Rev.Sci.Instr. 61, pp2176-2183, 1990.

[3] F A Haas and A J T Holmes, "Model of Electron Suppression and Negative Ion Enhancement in a Bucket Source", Plas.Phys.Cont.Fus. 33, pp 1197-1211, 1991.

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[5] F A Haas, L M Lea and A J T Holmes, J.Phys. D; Appl.Phys., 24, pp1541-1550, 1991