1991 Particle Accelerator Conf., San Francisco, CA, 5/6-9/91.

Conf-910505--182

BNL--45445

DE91 013592

THE BNL TOROIDAL VOLUME H^- SOURCE*

J.G. Alessi and K. Prelec
AGS Department, Brookhaven National Laboratory
Upton, New York 11973

Abstract

The BNL toroidal volume H^- ion source, in pulsed operation, is now producing up to 35 mA with an electron to H^- ratio of less than 5, and a ratio of less than 3 for currents up to 20 mA. This improvement came about by increasing the strength of the conical filter field. The source has also been operated steady state at low arc currents, where up to 6 mA of H^- was extracted. The electron to H^- ratio is 2-3 times larger for dc operation. For dc currents up to 5 mA, the arc power efficiency was 5 mA/kW. Pulsed performance with Ta and W filaments were very similar, except for the large gas pumping observed with the Ta filament. In dc operation, the Ta filament performed somewhat better than W. Extraction from 7 apertures having a total area of 1 cm^2 produced the same results as a single 1 cm^2 aperture.

Introduction

Studies have been in progress at BNL since 1988 on a volume H^- ion source of unique design. While surface production H^- sources are still used on most high energy accelerators, volume sources have the attractive feature that cesium is not required for H^- production. Volume H^- sources have two plasma regions, separated by a magnetic "filter field". In this type source, the hydrogen discharge results in the production of highly vibrationally excited H_2 molecules. H^- ions are then produced by dissociative attachment of the excited H_2 with slow electrons. The filter field separates the plasma generation region, which requires fast electrons, from the H^- production region, where slow electrons are required for the dissociative attachment process and fast electrons are detrimental in that they result in destruction of H^-. The novel feature in the BNL source is the conical shape of this magnetic filter field.

Previously reported parametric studies of the source[1,2] included the effect of filament position and size, gas pressure, plasma electrode bias, anode aperture diameter, and filter field strength. We have also reported on emittance measurements,[3] operation with deuterium[4] (D^- production), and the effect of cesium on source performance.[4] In this paper, new results will be presented on filter field effects, a comparison of operation with tantalum and tungsten filaments, operation with a multiaperture extraction system, and steady state operation of the source.

Source Geometry and Measurement Setup

Figure 1 shows the source schematically. The source has a cylindrical discharge chamber, 6 cm long and 20 cm i.d. SmCo magnets are arranged around the outside of the source to produce circular cusp magnetic fields as shown in the figure. A SmCo disk magnet opposite the extraction aperture produces the conical filter field. The filament is a single loop of wire located outside the filter region. The cathode voltage is applied to the filament. All results given below are with the plasma electrode grounded. Floating the plasma electrode generally resulted in a slight (<10%) increase in H^- current, accompanied by a large increase in the extracted electron current.

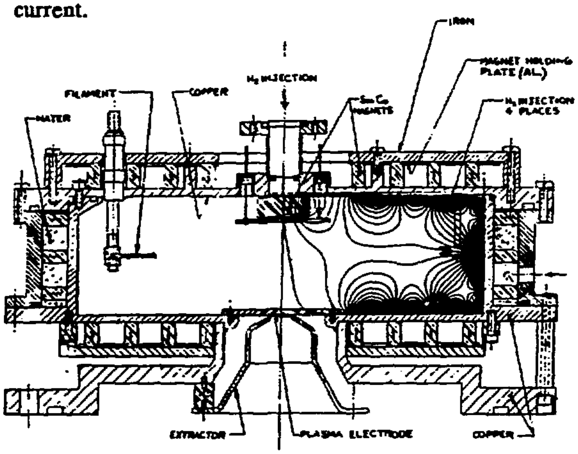

Fig. 1. Cross section of the BNL volume H^- source. The calculated magnetic field is also shown.

For all but the dc operation discussed below, the source was operated with a pulsed discharge of ≈1.2 ms, at a repetition rate of 0.5-1.3 Hz. The gas was pulsed, and the extraction voltage was dc. Beam current was measured on a Faraday cup located 10 cm from the source. A strong dipole field between the extractor and Faraday cup prevented any electrons from hitting the cup. A current transformer on the output of the extractor supply measured the total supply drain current. The

---

*Work performed under the auspices of the U.S. Department of Energy.

difference between the H$^-$ current measured on the Faraday cup and the total supply current is assumed to be electrons.

Filament Studies

In previous studies with a tungsten filament, it was found that a smaller (9 cm) filament loop diameter (filament closer to the center of the source) gave a better H$^-$ output than a 16 cm loop.[2] However, with the small loop diameter, the arc current was limited to 150 A due to the small emitting area. A filament (1.25 mm wire diameter) was therefore tried with the 9 cm loop diameter, but with waves bent into the filament parallel to the cylindrical chamber axis. In this way, we were able to increase the total length of the filament by a factor of 2-3 while keeping the filament at the optimum location with respect to the axis of the source. The H$^-$ output with this filament was the same as with the loop without waves, but we were able to push the arc current to > 350 A without the filament burning out, and the filament lifetime for operation at lower arc currents should be improved. (Life tests have not yet been done).

The source was also tested with a tantalum filament with a shape identical to the W filament described above. While the evaporation rate of Ta is higher than that of W at a given temperature, the electron emission rate is also higher for Ta. The net effect, for operation at the same electron emission rate, is very similar evaporation rates for the two. When compared, the H$^-$ output under optimum conditions was very similar for Ta and W, as was the electron/H$^-$ ratio for the two. With Ta, however, there was more conditioning required when first starting the source, before the optimum current could be reached. A strong pumping effect was also observed when the Ta filament was used. As the source ran with Ta, the discharge would become gas starved, and the gas pulsed into the source would have to be increased. Observation of the pressure outside the source chamber showed that the pressure was actually dropping as the filament current was increased, and increasing the pulsed gas restored it to its original pressure. It is known that Ta pumps hydrogen very well. (It has a sticking probability for hydrogen of 0.48 at 330 K).[5] From the observed pressure changes, we estimate that the Ta depositing on the source walls from the filament gave 30-40 l/s of pumping for hydrogen during the gas pulse. Some slight pumping was also observed with the tungsten filament.

Filter Field Studies

The dependence of the H$^-$ and electron outputs on the strength of the conical filter field had been studied previously by placing a small pulsed coil in the source in place of the SmCo disk magnet.[2] It was found that the electron current was very sensitive to the strength of this field, while the H$^-$ current had a fairly broad optimum. This experiment had presented practical difficulties, so normal operation continued to be with the disk magnet. We are able, however, to increase the strength of the filter field slightly by appropriate placement of some small SmCo magnets outside the source. Figure 2 shows the H$^-$ current and e$^-$/H$^-$ ratio as a function of arc current, with and without the external magnets. The addition of these magnets (20-30% increase in filter field strength) has allowed us to now run routinely with e$^-$/H$^-$ ratios lower than we had previously reported. Figure 3 is a plot of the e$^-$/H$^-$ ratio as a function of H$^-$ current, showing the source performance under many different conditions (W and Ta filaments, 1 and 2 cm^2 apertures). This electron-to-H$^-$ ratio is now at least an order of magnitude smaller than what others typically obtain from Cs-free volume H$^-$ sources.

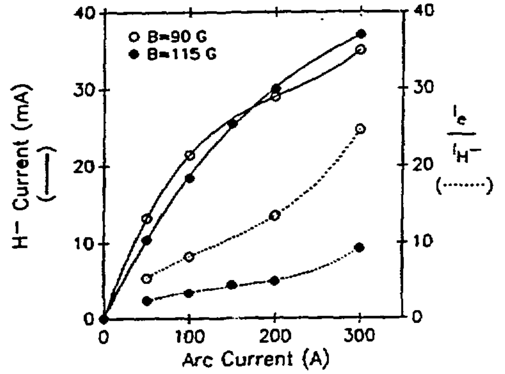

Fig. 2. H$^-$ current and electron-to-H$^-$ ratio vs. arc current for filter field strengths of ~ 90 G and ~ 115 G (W filament, 2 cm^2 aperture).

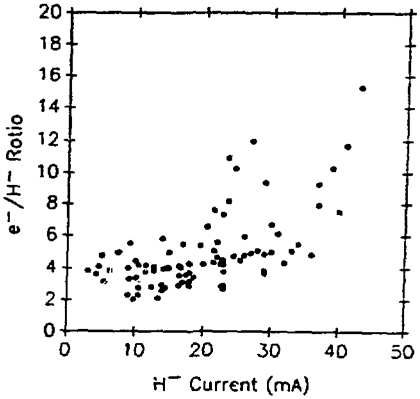

Fig. 3. Electron-to-H$^-$ ratio vs. H$^-$ current for various pulsed operating conditions and source geometries (W and Ta filaments, 1 cm^2 and 2 cm^2 apertures).

Single and Multiaperture Extraction

Figure 4 shows the H⁻ current vs. arc current obtained for 1 cm^2 and 2 cm^2 apertures. A saturation in output as arc current increases is typically seen, and the H⁻ output does not scale well with increasing extraction aperture. A multiaperture extraction system was tried and is also shown in Figure 4. Both the anode and extraction electrode had 7 apertures of 0.44 cm diameter each (total extraction area of 1.06 cm^2), spaced within a 1.54 cm total diameter. The extraction gap was 0.76 cm. The H⁻ current and e⁻/H⁻ from this extractor was the same as that from the single 1 cm^2 extractor. We have not yet tested to see how the H⁻ current scales with total extraction area for multiaperture extraction.

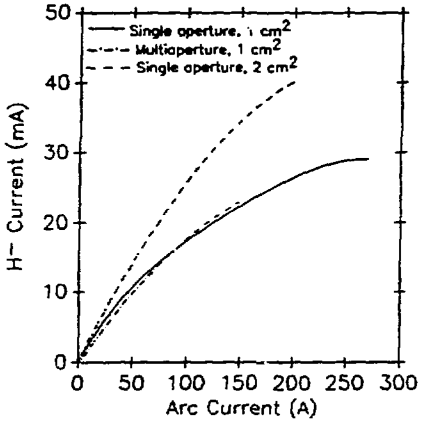

Fig. 4. H⁻ current vs. arc current for single apertures of 1 cm^2 and 2 cm^2, and a seven-aperture extractor of 1 cm^2 total area (Ta filament).

Steady State Operation

Although the source was initially designed for pulsed operation, the addition of one cooling loop and some modifications to the filament feedthroughs allowed us to operate it dc at reduced arc powers. For these tests, the arc and gas were steady state, but the extraction voltage was pulsed (1.2 ms) in order to reduce the power on the extraction electrode and Faraday cup. The anode and extraction electrode were 1.13 cm diameter (1 cm^2 area).

Running steady state, we were able to measure up to 6 mA of H⁻ at the maximum arc current we attempted of 20 A and 150 V. This current was essentially the same as that obtained at 20 A arc for pulsed operation. However, the e⁻/H⁻ ratio for dc operation was 2-3 times that obtained when running pulsed. (A test with a pulsed arc but dc gas flow gave the same performance as normal pulsed operation). In pulsed operation, as the source pressure was varied, the minimum e⁻/H⁻ ratio occurred at about the same pressure as the maximum H⁻ current. When running dc, the minimum in e⁻/H⁻ occurred at about half the pressure of that giving the maximum H⁻. Also unlike pulsed operation, the dc performance was somewhat better with the Ta filament when compared with W. Measured gas flows for dc operation were typically in the range of 15-30 sccm, which is consistent with estimates based on previously measured pressures of 5-15 mT in the source for pulsed operation.

In pulsed operation, the source is typically operated with arc voltages of 200-350 V for arc currents of 50-300 A. There, the arc voltage is used to optimize H⁻ current without regard for power efficiency. When running dc, however, we did not push the discharge voltage above 150 V. For H⁻ currents up to 5 mA, the arc power efficiency was 5 mA/kW. The combination of the H⁻ current not scaling linearly with arc current, and higher arc voltages being required at higher arc currents, leads to a much worse (5-10 times lower) power efficiency when producing 10's of mA's in pulsed operation.

Acknowledgements

We would like to thank D. McCafferty for the excellent job he has done in carrying out the many modifications to the source required for these studies, and K. Welch, for helpful discussions on the pumping of hydrogen by tantalum. One of us (JA) would like to thank R. York of LANL for advice on filament shapes and fabrication, and multiaperture extraction.

References

[1] K. Prelec, Proc. 1989 IEEE Part. Accel. Conf. (Catalog No. 89CH2669-0), 340.
[2] K. Prelec, Proc. Fifth International Symp. on the Production and Neutralization of Negative Ions and Beams, AIP Conf. Proc. No. 210, 304 (1990).
[3] J.G. Alessi, Proc. Fifth International Symp. on the Production and Neutralization of Negative Ions and Beams, AIP Conf. Proc. No. 210, 526 (1990).
[4] J.G. Alessi and K. Prelec, Proc. Second European Part. Accel. Conf., Nice, France, 656 (1990).
[5] D.O. Hayward and N. Taylor, Proc. Fourth International Vac. Cong., 115 (1968).