RECENT DEVELOPMENT ON RF-DRIVEN MULTICUSP H⁻ ION SOURCES

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ABSTRACT

The radio-frequency (rf) driven multicusp source was originally developed for use in the Superconducting Super Collider injector. The source routinely provided 35 keV, 30 mA of beam at 0.1% duty factor. By using a new cesium dispensing system, beam current in excess of 100 mA and e/H^- ~1 have been observed. For pulse mode operation, the rf discharge can be started by means of a xenon flash lamp. Extracted electrons in the beam can be efficiently removed by employing a permanent-magnet insert structure. Chopping of the H^- beam can be accomplished by applying a pulsed positive voltage on the plasma electrode.

1. INTRODUCTION

H^- ions have found important applications in particle accelerators and in generating energetic neutral beams for heating and for current drive in fusion plasmas. It has been demonstrated that a multicusp source can be used to generate volume-produced H^- ions in pure hydrogen discharge. Most recently, the SSC rf-driven H^- source was modified to enhance the H^- output by adding cesium to the discharge.

With a new cesium dispensing system, H^- beam current in excess of 100 mA and e/H^- ratio close to one have been observed [1]. For pulsed mode operation, it has been demonstrated that a xenon flash lamp can replace a tungsten filament as a starter for the rf discharge [2]. If the duty factor is low, the electrons in the extracted beam can be removed by means of a specially designed permanent-magnet insert structure. Experimental results showed that >98% of electrons can be separated from the H^- beam without any significant deterioration of the H^- ion output [3]. The H^- beam can be chopped periodically by applying a positive bias voltage on the plasma electrode. A fast electronic switch is being developed and preliminary results of the beam-chopping experiment are presented.

2. EXPERIMENTAL SETUP

Figure 1 shows the schematic diagram of the rf multicusp ion source. The source chamber is a thin-walled (4-mm-thick) copper cylinder (10-cm-diam by 10-cm-long) surrounded by 20 columns of samarium-cobalt magnets which form a longitudinal line-cusp configuration for plasma confinement. The magnets in turn are enclosed by an anodized aluminum cylinder, with the cooling water circulating around the source between the magnets and the inner housing wall. A pair of permanent-magnet filter rods is installed near the plasma electrode to enhance the production of volume-generated H^- ions. The back flange has four rows of magnets cooled by drilled water passages and contains a gas inlet, an antenna feedthrough, and a 1-cm-diam opening for a quartz rod serving as a light pipe or window.

In most applications, a two turn copper coil antenna is employed. The antenna is normally coated with a thin layer of porcelain material. For pulsed mode, the porcelain coating can surrvive months of operation without any significant deterioration. For high duty factor or cw operations, care must be taken to avoid high voltge breakdown across the porcelain coating. A study of the antenna lifetime at high rf powers is still in progress. Currently, the antenna at LBNL has been operated at 10 kW for over 20 h without any pitting or damage to the porcelain coating. For rf power in the range of 4 kW, antenna lifetime in excess of 200 h has been achieved at Northrop Grumman Corporation [4].

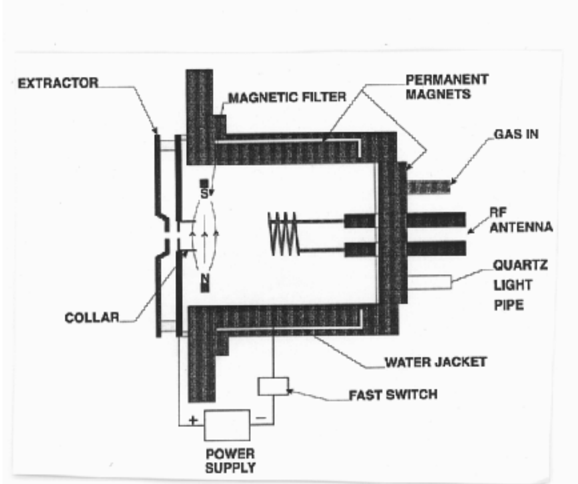

Fig. 1 Schematic of the rf-driven multicusp H^- ion source.

3. EXPERIMENTAL RESULTS

3.1 H^- Ion Current Enhancement

A multicusp source can be operated with a rf induction discharge to generate volume-produced H^- ions. The SSC rf-driven source routinely provided 35 kV, >35 mA

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H⁻ beams with normalized rms emittance ($e_{n\text{-rms}}$) < 0.1 π-mm-mrad. The source was typically operated with a 100 μs beam pulse width at a 10 Hz repetition rate.

The H⁻ output current of a rf-driven multicusp ion source can be increased by introducing a trace amount of cesium into its collar region [5]. Most recently, the SSC rf-driven H⁻ source was modified to enhance the H⁻ output for testing a high current LINAC. A collar with eight cesium dispensers was installed at the exit aperture. A plasma grid heater element controls the temperature of the cesiated surfaces and the rate of cesium dispensation. With this arrangement, beam current in excess of 100 mA and e/H⁻ ratios close to one have been observed [1]. Emittance measurements at 70 mA suggest a 20% increase over uncesiated emittance values [1].

With the new cesium dispensing arrangement, high H⁻ currents could be achieved quickly and maintained. This enhancement in H⁻ beam current is accompanied by a dramatic reduction of electron current. Figure 2 shows the time development of the H⁻ and electron output currents. In about 10 minutes, the H⁻ beam current reaches 100mA and can be maintained at that level for over hundreds of minutes [6]. The e/H⁻ ratio in this case is about 3.

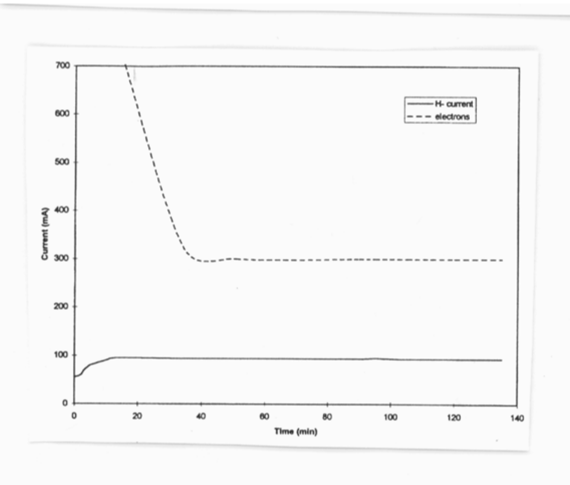

Fig. 2 Time development of the H⁻ ion and electron output current after cesium is added to the rf-driven multicusp source.

3.2 Ion Source Opeation and Start-Up

When the rf multicusp source is operated in pulsed mode, a small tungsten filament can be used to generate some electrons to aid in plasma ignition. However, the filament has a limited lifetime and contributes tungsten impurities to the plasma. It has been demonstrated that the ultraviolet light from a nitrogen laser impinging upon a magnesium target can provide enough photo emission electrons to ignite the plasma [7]. Recently, it is shown that the more expensive laser could be abandoned in favor of an inexpensive xenon flash lamp [2].

The pulse width of the xenon flash lamp was about 25 μs with a broadband energy of ~20 mJ. The flash bulb was mounted at one focus of an elliptical mirror and the light pipe was mounted at the other. For maximum transmission of the ultraviolet light, a light pipe made of fused silica was employeds (Fig. 1). The timing of the flash with respect to the rf pulse affects the plasma starting. In normal operation, the rf amplifier and the flash lamp are triggered at the same time. This will enable the plasma to be formed at the very beginning of the pulse and thus avoid the porcelain coating to be damaged by high rf antenna voltages.

3.3 Beam Electron Dumping

The extraction of H⁻ ions is accompanied by a large amount of electrons, which must be removed from the beam before further acceleration. The remaining H⁻ ion beam must be focused properly to match the acceptance of the next element of the accelerator system, e.g., a radio-frequency quadrupole (RFQ).

Recently, a permanent-magnet insert structure for the removal of electrons from pulsed, extracted negative ion beams has been developed at LBNL [3]. A previously performed computational modeling of the extracted beam defined the necessary magnetic field strength, the aperture diameter, the extraction voltage and the gap separation between the first and second electrode [8]. The simulated output of Fig. 3 shows that the electrons are removed from the H⁻ beam and made to impinge on the second electrode. The trajectories of the H⁻ ions are not noticeably perturbed.

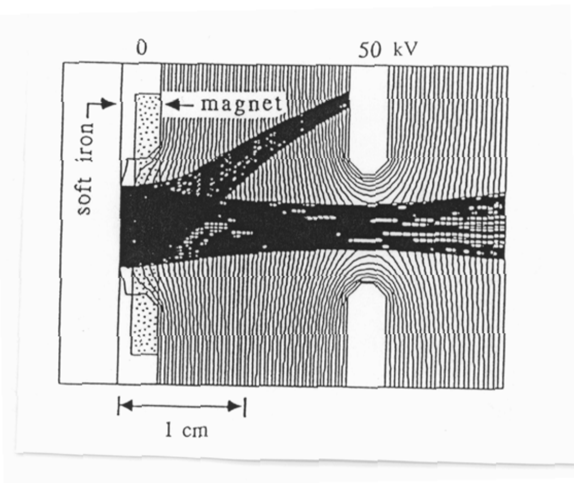

Fig. 3 Planar calculation showing the effect on the extracted electrons due to a pair of permanent-magnets located inside the first electrode.

The ion source was operated at a repetition rate of 5 Hz and pulse widths ~ 500 μs for a duty factor of ~ 0.25%. When the extraction voltage was varied between 14 to 19 kV, the electron removal efficiency of the magnetic collar was found to be almost 100% while being less than 0.5% for the case when the magnetic collar is replaced by a dummy copper of similar size. This efficiency is defined as the ratio of removed electrons to total electrons present in the extracted beam. Experimental results also demonstrated that the small permanent-magnet pair did not affect the H^- output current [3].

3.4 H^- Beam Chopping at the Source

Spallation neutron sources such as the NSNS require 200 ns gaps or holes in the beam. The holes are required for turn-on time of the extraction kicker when the beam is ejected for transport to the neutron-production target. Traveling-wave beam chopping systems have been developed and operated successfully at both the Brookhaven AGS and LAMPF. Beam chopping has also been tested at the volume-production type H^- ion source at LANL [9]. Modulating the beam intensity at the source would make final beam chopping easier by reducing the space-charge effect.

Recently we have studied beam chopping with the multicusp H^- source. A dc power supply and a fast electronic switch is installed between the plasma electrode and the source chamber wall. In normal operation, the plasma electrode is connected to the anode walls (Fig. 1). If a positive voltage (~100 V) pulse is suddenly applied to the plasma electrode, the plasma in front of the exit aperture is pushed away by the electrostatic field and the H^- current disappears. This effect is illustrated in Fig. 4 in which a hole of approximately 40 μs wide with 100% beam current suppression is generated within the much longer H^- current pulse. The time response of the beam intensity follows closely to the applied voltage. In order to improve the beam turn on and off times, we are now developing a voltage modulator with rise/fall time less than 100 ns. Results of this fast beam modulation testing will be reported in the near future.

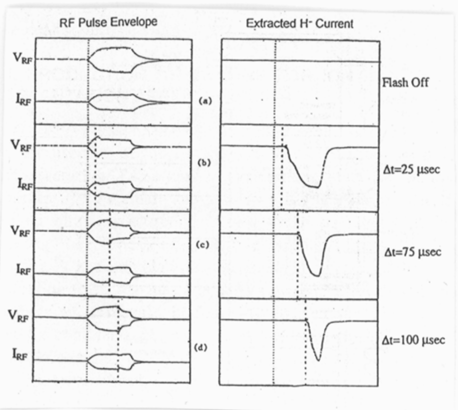

Fig. 4 Oscilloscope trace showing the modulated H^- ion beam current when a positive voltage pulse is applied on the plasma electrode.

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