SURFACE PLASMA H$^-$ SOURCE WITH SADDLE RF ANTENNA PLASMA GENERATOR*

V. Dudnikov#, R. P. Johnson, Muons, Inc., 552 N. Batavia Ave., Batavia, IL 60510, U.S.A.
S. Murray, T. Pennisi, M. Santana, M. Stockli, R. Welton, ORNL, Oak Ridge, TN 37831, U.S.A.

Abstract

A prototype of RF H$^-$ surface plasma source (SPS) with saddle (SA) RF antenna is developed which will provide better power efficiency for high pulsed and average current, higher brightness with longer lifetime and higher reliability and availability. Several versions of new plasma generators with a small AlN test chamber and different antennas and magnetic field configurations were tested in the SNS ion source Test Stand. A prototype SA SPS was installed in the Test Stand with a larger, normal-sized SNS AlN chamber that achieved unanalyzed peak currents of up to 67 mA with an apparent efficiency of 1.6 mA/kW. Control experiments with H$^-$ beam produced by SNS SPS with internal and external antennas were conducted. A new version of the RF assisted triggering plasma source (TPS) has been designed. A saddle antenna SPS with water cooling is being fabricated for high duty factor testing.

INTRODUCTION

Typical RF sources for H$^-$ generation have a coil antenna, which creates an RF magnetic field along the axis of the source. After significant modifications, the SNS internal antenna H$^-$ source now routinely produces the 38 mA LINAC beam current. The status of this source is presented in [1, 2]. Occasional failures of the internal antenna limit the source service cycle and the availability of the source when operating with 50-60 kW of RF power. Recently an increased rate of internal antenna failures has temporarily reduced this availability The ion source and LEBT yield a combined availability of ~90%. In order to further increase their availability, several design efforts are ongoing to improve weak points of the system [1].

An external solenoid antenna source is under development at the SNS, which was recently reviewed in [3, 4]. The necessary RF power for these sources is higher and pulsed discharge triggering at low gas density creates problems for very long-term SPS operation [4].

The total efficiency of the surface plasma produced fraction of the H$^-$ beam is a product of the probability of secondary emission of H$^-$ caused by plasma bombardment of the collar surface around the emission aperture, the probability of extraction of emitted H$^-$, and the efficiency of generation of plasma flux bombarding

The coefficient of secondary emission of H$^-$ is determined by surface properties (proper cesiation) and the spectrum of the plasma particles bombarding the collar surface around the emission aperture.

The cesiation was improved recently [1, 6] and appears to be nearly optimal (improving of cesiation is always important). The probability of extraction of H$^-$ emitted from the collar surface is dependent on the surface collar shape [1], which was optimized recently to improve H$^-$ emission. The problem efficient plasma generation is being addressed by the development of new RF plasma generators with higher plasma generation efficiency and better concentration of useful plasma flux onto the internal surfaces of the collar around the emission aperture for lower RF power [5-7]. In this project, we use the saddle antenna, which has its RF magnetic field transverse to the source axis, combined with an axial DC magnetic field, to concentrate the plasma on the collar where the ions are formed [5].

The strong transverse magnetic field (up to 1.6 kG) created in the collar emission aperture by permanent dumping magnets should be enough to suppress and filter out the fast electrons from the discharge plasma and to decrease the number of escaping co-extracted electrons. The gas density in the discharge plasma must be low enough to minimize the electron stripping of the extracted H$^-$ ions. This critical gas density is inversely proportional to the emission aperture dimension. The gas density in the extraction-acceleration region was decreased by improving the gas pumping but a further decrease is desirable to reduce the ~7% stripping losses in the SNS low energy beam transport section. For this is necessary to improve a triggering plasma gun for reliable triggering of pulsed RF discharge at lower gas density.

RF PLASMA GENERATORS

Several versions of plasma generators with different antennas and magnetic field configurations were fabricated and tested in the test stand with useful plasma flux generation improvements up to 5 times by increasing the DC magnetic field.

Small RF Plasma Generators

Discharges in small (~23 mm ID) AlN ceramic discharge chambers with coil and saddle antennas were studied in pulsed mode. An RF generator with frequency f=13.56 MHz, output power up to P=1.2 kW, pulse 3 ms, 5 Hz was used. The ion current extracted through a small (2 mm diameter) emission aperture with extraction voltage -3kV was measured as a function of H_2 gas flow and RF power.

Use of a permanent ring magnet near the extraction aperture and in 12 cm from the aperture was tested with small coil and saddle type antennas. The ring magnetic

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#vadim@muonsinc.com

field increases the plasma density and decreases significantly (up to 20 times) the gas density necessary for pulsed discharge triggering (self-triggering without external plasma generator). The emission current density to the collector was as high as $J_c \sim 60$ mA/cm^2 at $P_{rf} \sim 1$ kW, which is up to 5 times higher than without the ring's magnetic field. These plasma sources can be used for pulsed discharge triggering at very low gas density.

Large RF Plasma Generators

The schematic of a large RF plasma generator with the AlN ceramic discharge chamber, prototype saddle antenna, and DC magnetic coil is shown in Fig. 1. The chamber has an ID=6.8 cm. The saddle antenna in this prototype plasma source with inductance L=2.7 μH was made from Litz type wire.

The plasma density distribution was measured by collectors extracting the ion beam current through small emission apertures locating along a radius in the end plate attached to the discharge chamber.

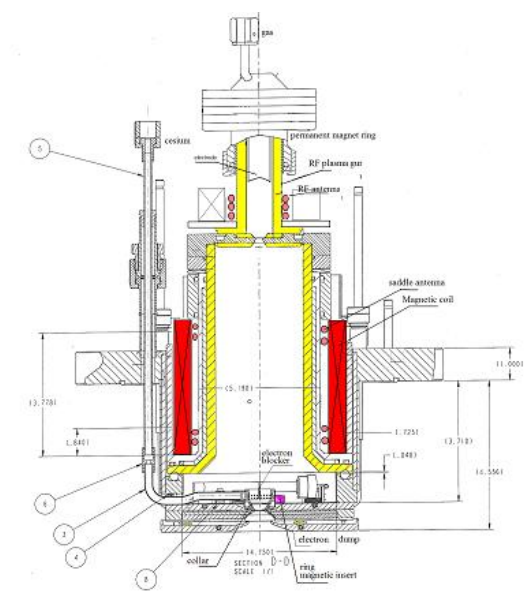

Figure 1: Upgraded design of the Advanced RF Saddle antenna SPS with RF plasma gun for pulsed RF discharge triggering (yellow-ceramic AlN; red-magnetic coil; orange-saddle antenna; magenta-magnetic insert ring).

The end plate had seven 2-mm diameter emission apertures so that is about half that of the SNS 7-mm diameter ion source outlet. The longitudinal magnetic field was created by a magnetic coil wound from a copper tube of 4-mm OD in two layers with 25 turns per layer.

Experimental Results

The collector current increased up to 5 times from 12 mA/cm^2 to 60 mA/cm^2 as the magnetic field increased from 0 to 250 G.. The ion current density distributions for different magnetic fields are shown in Fig. 2. For low magnetic field (I_m up to 20A) the radial distribution of plasma density is flat. For higher magnetic fields, the plasma density inside 2 cm radius is much higher. The same increase of ion current density on the axis with increasing magnetic field was observed in saddle antenna discharges at f=5 MHz.

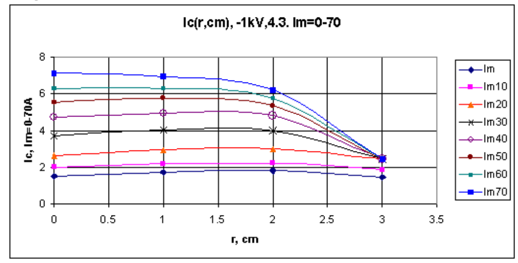

Figure 2: Radial distribution of current density of extracted positive ions for different magnetic fields (coil current I_m), as determined from the 7 collectors.

SA RF SPS IN THE TEST STAND

The prototype of the saddle antenna RF H^- SPS (SA RF SPS) was tested in the SNS test stand as shown in Fig. 3. The first tests used a plasma plate with a molybdenum conical collar with a 300 G magnetic filter and a 1.6 kG electron dumping magnet. The DC magnetic coil was excited by a manually regulated current supply (I_m =0 to 74 A) and was cooled by water flow. A plasma gun with DC glow discharge was used for the pulsed RF discharge triggering at low gas density.

A pulsed RF (2 MHz) discharge with duration 0.4 ms, 10Hz and power up to 56 kW was used. Stable, reproducible generation of H^- beam was reached. The beam pulse shape depends on gas flow, magnetic field, and RF matching network tuning.

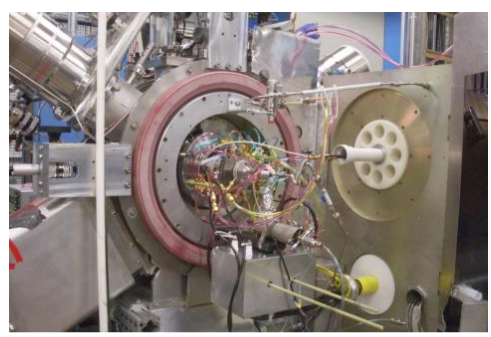

Figure 3: RF SPS saddle antenna, magnetic coil, and external Cs source attached to the test stand.

The H^- current measured by the Faraday cup I_{fc} increased by a factor of ten as the longitudinal magnetic field B was increased from 0 to 250 G. The plasma gun operated as the gas flow was decreased down to Q=8.8 sccm (standard cm^3/minute), while the H^- current increased up to 15 mA at P_{rf}=15 kW (H^- generation efficiency I_{fc}/P_{rf} = 1 mA/kW before cesiation).

The magnetic field from the DC coil is below 50 G at the emission aperture and does not change the suppression and deflection of co-extracted electrons by the dumping magnetic field at B_d=1.6 kG

After "partial" cesiation by cracking the Cs ampoule, I_{fc} increased by about 50% instead of the expected typical increase of a factor of 3 or 4.

In the next experiments, the magnetic filter was removed and ferromagnetic inserts were located around the collar to improve the concentration of plasma flux into the collar. The evolution of H^- beam intensity with variation of RF power and magnetic field is shown in Fig. 5. After starting the RF discharge with P_{rf}=25 kW the initial beam current I_{fc}=8 mA started growing and increased up to 42 mA over 4 hours without cracking the cesium ampoule, mostly likely due to collection of residual Cs from the previous experiment. Stable operation of the prototype of RF H^- SPS with the saddle antenna and longitudinal magnetic field was successfully demonstrated up to RF power 56 kW, 0.4 ms, 10 Hz.

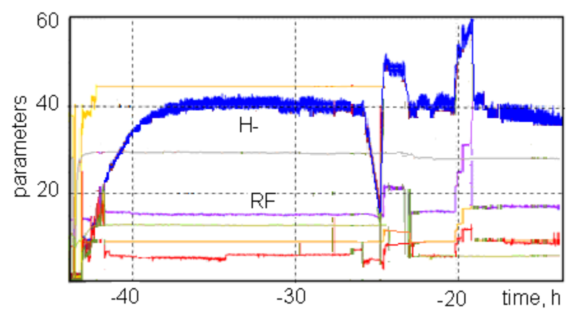

Figure 4: Evolution of H- beam intensity with variation of RF power and magnetic field.

The dependence of beam current versus RF power is shown in Fig. 5. Without cracking the cesium ampoule, but likely with Cs from the previous experiment, the efficiency ratio achieved I_{fc}/P_{rf} ~ 1.6 mA/kW, which is comparable with SNS RF discharges in similar conditions. We believe that perfect cesiation was produced (without additional Cs) by the collection and trapping of traces of cesium remnants from SPS surfaces. Long conditioning is necessary because cesium is only slowly recovered from remnants. This slow accumulation demonstrates that the lifetime of these catalytic impurities in the collar can be very long. Nanograms of impurities are enough for enhancement of secondary emission of negative ions from the collar surface.

The beam intensity increases significantly with decreased gas flow Q below 9 sccm, but the plasma gun discharge became unstable for Q<19 sccm. For operation at lower Q a small RF triggering plasma gun (TPG) has been designed. The SA SPS with RF TPG is shown in Fig. 1. Pulsed operation with a fast gas valve [8] is under preparation for testing. All measurements of beam intensity and RF power were collected in the same conditions as for recent measurements with other SNS RF SPS for correct comparison of efficiency. In control experiments with SNS external antenna SPS unanalyzed peak currents of up to 42 mA with RF power 55 kW was typical with optimized cesiation.

SA SPS was inspected after testing. Some impurities were detected on the collar surface.

SPS with a water cooled saddle antenna was prepared for high duty factor testing as shown in Fig. 7.

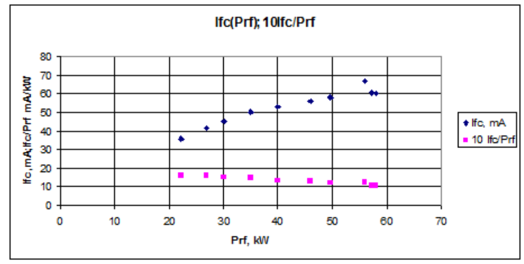

Figure 5: Evolution of the Faraday cup current I_{fc} and ratio I_{fc}/P_{rf} as function of P_{rf} during cesiation. The efficiency of I_{fc} generation increased with decreased gas flow Q from 20 sccm to 17.2 sccm.

Figure 6: Water cooled saddle antenna and magnetic coil for high duty factor operation.

Further design and operation optimization of the SA RF SPS will improve the source efficiency, average current and lifetime. Cesium control and diagnostics will be improved with using of spectroscopy and lasers [9].

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