IMPROVING EFFICIENCY OF IONS PRODUCTION IN ION SOURCE WITH SADDLE ANTENNA*

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Abstract

Extraction of positive and negative ions from a saddle antenna radio-frequency surface plasma source (SA RF SPS) is considered. Several versions of new plasma generators with different antennas and magnetic field configurations were tested in the small Test Stand. The efficiency of positive ion generation in plasma has been improved up to 80 times from 2.5 mA/cm^2 kW to ~0.2 A/cm^2 per 1 kW. For cesiation was used a heating of the cesium chromate cartridges. A small oven for cesium compounds and alloys decomposition by heating was developed and tested. After cesiation a current of negative ions to the collector was increased from ~1 mA to 10 mA with RF power ~ 1.5 kW in the plasma and longitudinal magnetic field B_l~250 Gauss. A specific efficiency of H$^-$ production was increased up to ~ 20 mA/ cm^2 kW from previous ~2.5 mA/ cm^2 kW.

INTRODUCTION

Development of the saddle antenna RF surface plasma source (SA RF SPS) was proposed for improve efficiency of H$^-$ ion production and improve SPS reliability and availability [1-4]. Now RF SPS for accelerators with emission aperture 7 mm have the efficiency of H$^-$ ion generation ~1 mA/kW and RF power ~ 50 kW is needed for 50 mA beam current production [5]. With this efficiency delivered current is enough for 1 MW proton beam production but the high RF power required for the sources can create problems for very long term operation at higher beam power. This efficiency is too low for CW operation with current ~10 mA necessary for Project X and for cyclotrons injection.

In tested version of SA RF SPS the specific efficiency of positive ion generation was increased to ~0.2 A/ cm^2 kW and a specific efficiency of H- production was increased up to ~ 20 mA/cm^2 kW from previous ~2.5 mA/ cm^2 kW.

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 rate of bombarding plasma flux [6,7].

The coefficient of secondary emission of H- is determined by surface properties (proper cesiation) and the spectrum of the plasma particles bombarding the collar/emitter surface around the emission aperture. The cesiation was improved recently [5] and appears to be nearly optimal. The probability of extraction of H$^-$ emitted from the collar surface is dependent on the surface collar shape [4-7], which was optimized recently to improve H$^-$ emission. The problem of 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 [1-4]. 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 negative ions are formed by secondary emission [1-4,6,7].

SA SPS DESIGN

The schematic of a large RF SA SPS with the AlN ceramic discharge chamber, saddle antenna, and DC solenoid is shown in Fig. 1. The chamber has an ID=68 mm. The saddle antenna in this SPS with inductance L=3.5 μH is made from water cooled copper tube. RF assisted triggering plasma gun (TPG) is attached to discharge chamber from left. An extraction system is attached from right side.

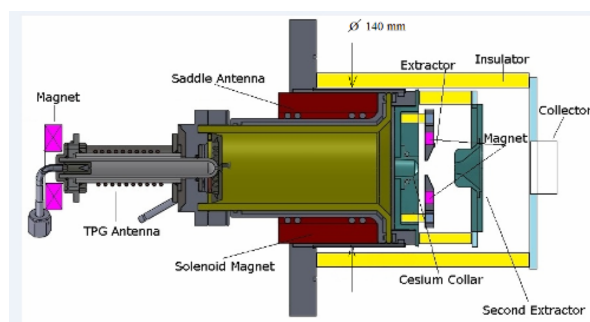

Figure 1: A schematic of the SA SPS with an extraction system and a collector.

Design of the extraction system is shown in Fig. 2. The strong transverse magnetic field (up to 1 kG) is created in the collar (4) by permanent magnets (7) inserted into water cooled extractor (6) attached to the plasma plate (1) through ceramic insulators (5). SA SPS was tested with emission and extractor's apertures of 6 mm diameters.

A Cesium vapor can be delivered to the emitter cone (2)

*Work supported by Contract DE-AC05-00OR22725 and by STTR grant DE-SC0002690.
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from Cs chromate cartridges (4) heated by plasma or from a resistive heated Cs oven (3).

Schematic of ion beam formation is shown in Fig. 3. Ions are extracted from the cone by extraction voltage Uex between the cone and the extractor and accelerated by voltage in the second gape. Co-extracted electrons are well collected to the extractor along magnetic field lines without drift in crossed ExB field.

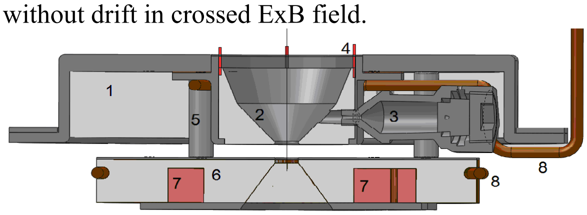


Figure 2: Extraction system of the RF SA SPS. 1- plasma electrode; 2-emitter/converter cone; 3-Cesium oven; 4-Cs cartridges; 5-ceramic insulators; 6- extraction electrode; 7- permanent magnet; 8-cooling tubes.

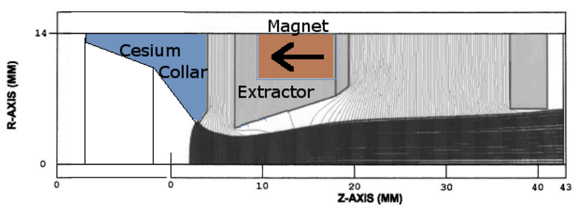


Figure 3: A schematic of ion beam formation (emission aperture is 6 mm diameter).

The strong transverse magnetic field B_t suppress electron collection by collector and the secondary emission is suppressed by magnet attached to the collector.

The RF discharge in the TPG was excited by RF (13.56 MHz) generator with power up to 0.6 kW. For the SA discharge excitation was used RF (13.56 MHz) generator with power up to 2.5 kW. The RF power loss in SA and matching network was ~1 kW and up to ~1.5 kW can be used for plasma generation.

The plasma electrode with Cs collar/cone was grounded. Extractor, accelerator electrode and collector were biased by high voltages Uex up to 15 kV and Uc up to 15 kV. Pulsed currents to these electrodes were registered by Pearson transformers with sensitivity 1 V/A.

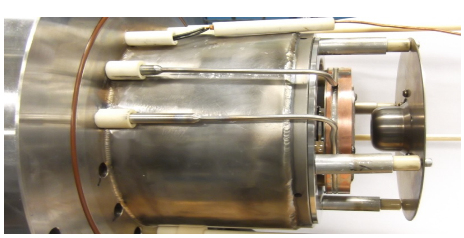


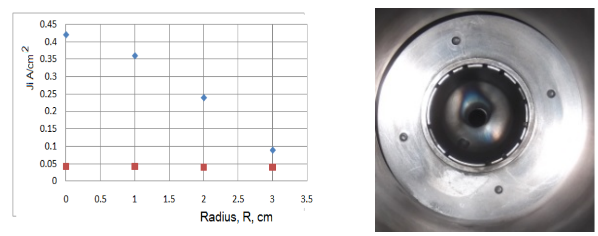
Figure 4: SA SPS with extractor and collector.

A photo of assembled SA SPS with extractor is shown in Fig. 4.

The magnetic field B_l up to 250 G is created by solenoid exited by current Im up to 70 A with voltage Um up to 8 V. A hydrogen gas flow was controlled by MKS mass flow controller.

EXPERIMENTAL RESULTS

Several versions of plasma generators with different antennas and magnetic field configurations were fabricated and tested in the test stand. A pulsed RF (13.56 MHz) discharges with duration 1-2 ms, up to 60Hz and power up to 1.5 kW in the plasma were tested. Produced positive ion emission current density distribution along the radius R is shown in Fig. 5.



a b

Figure 5: a) Ion emission current density Ji (A/cm^2) (plasma density) along the radius R (cm) at high magnetic field (blue) and at low magnetic field (brown) with RF power 1.5 kW in the plasma (observed by small collectors) without transverse magnetic field Bt. b) Trace of plasma flux on the collar converter wall with transverse magnetic field Bt~1 kG concentrated up to 8 mm of diameter.

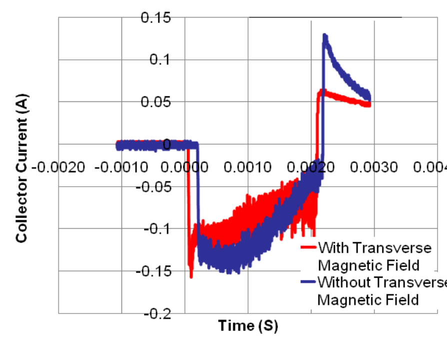


Figure 6: Traces of positive ion current to the collector with and without transverse magnetic field.

Up to 100 mA of positive ion was extracted with emission aperture 6 mm at RF power ~1.5 kW in plasma as shown in Fig. 6.

After cesiaion the negative ion current to the collector Ic was increased from 1 mA to 10 mA and electron current to the extractor Iex was reduced from 0.15 A to 0.1 A.

Examples of Ic and Iex signals are shown in Fig. 7.

Dependences of Ic on RF power in the plasma Prf is shown in Fig. 8 (upper scale). Dependences of Ic on the solenoid voltage Um is shown in Fig. 9. Dependences of Ic on the extraction voltage is shown in Fig. 10. The collector current I_c increases by a factor of 7 as the longitudinal magnetic field Bl increases from 0 to 250 G. and increases with the extraction voltage. The extraction electrode was biased up to Uex~15 kV and collector was biased up to Uc~15 kV. SA SPS can operate at the gas flow decreased down to Q=8.3 sccm (standard cm^3/minute), while the H^- current increased up to 10 mA at P_{rf}=1.5 kW (H^- generation efficiency was up to I_c/P_{rf} = 6 mA/kW with cesiation).

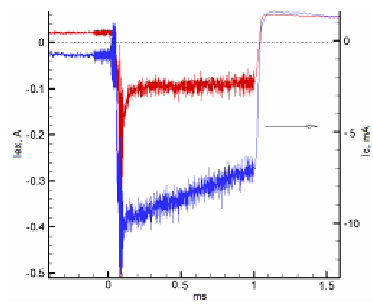


Figure 7: Signals from extractor Iex=0.1A (electron current, red) left scale and signal from collector Ic=10mA (negative ion current, blue) right scale. Signal slope connected with a low inductance of the Pearson transformer.

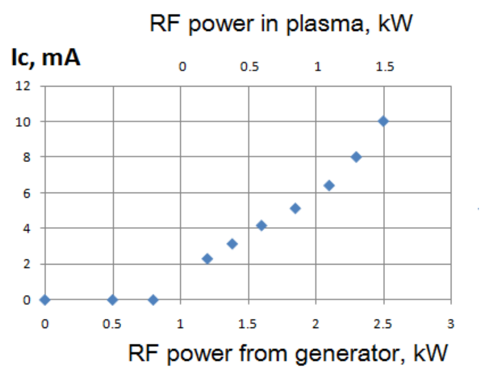


Figure 8: Dependence of Ic on RF power in the plasma Prf (upper scale) and from generator (bottom scale).

The longitudinal magnetic field from the solenoid at the emission aperture is below 50 G and does not change the suppression and deflection of co-extracted electrons by the transverse magnetic field Bt~1 kG.. However, the optimal cesiation was not reached because the extractor current Iex is high. Most efficient and stable cesiation was produced with a dark (carbon) film deposition on the emitter cone (2) in Fig.2.

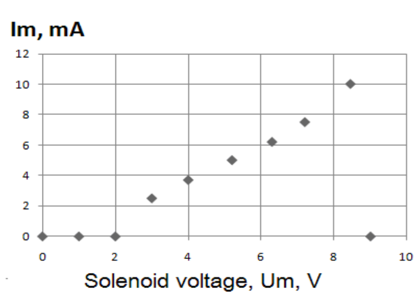


Figure 9: Dependence of Ic on the solenoid voltage Um.

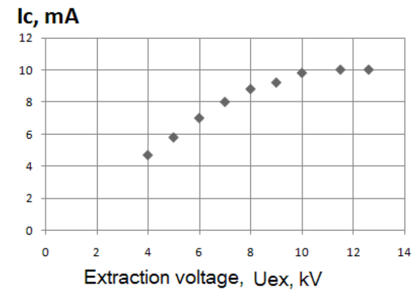


Figure 10: Dependence of the collector current Ic on the extraction voltage Uex. RF power in the plasma Prf=1.5 kW, the solenoid voltage Um=8.3 V. Gas flow Q=8.6 sccm.

Extraction current has a significant level of noise with frequencies fn~1-2 MHz. Ion beam shape is indicated by sputtering traces on the Molybdenum plate of the extractor electrode, on the accelerating electrode and on the collector as shown in Fig. 11.

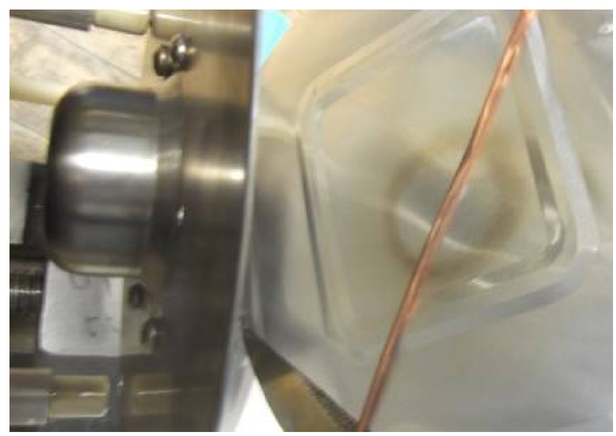


Figure 11: Accelerating electrode and a collector with a trace of sputtering by negative ion beams.

With demonstrated efficiency ~20 mA/cm2 kW it is enough ~10 kW of RF power for 60 mA of H- production, necessary for SNS operation with beam power 1.4 MW. RF SPS for CW operation with beam current ~10-15 mA can be developed with manageable RF power ~ 2 kW.

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