IMPROVING EFFICIENCY OF PLASMA GENERATION IN H- ION SOURCE WITH SADDLE ANTENNA*

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Abstract

Improving efficiency of plasma generation in RF H^- surface plasma source (SPS) with saddle (SA) RF antenna is considered. Several versions of new plasma generators with different antennas and magnetic field configurations were tested in the SNS small Test Stand. The efficiency of positive ion plasma generation has been improved ~4x times up to 0.18 A/cm^2 per 1 kW of RF power 13.56 MHz. A first prototype SA SPS with AlN chamber was installed in the SNS Test that achieved current of H- ions up to 67 mA with an apparent efficiency of up to 1.6 mA/kW at RF frequency 2 MHz. A new version of the RF assisted triggering plasma source (TPS) has been designed, fabricated and tested. A Saddle antenna SPS with water cooling is being fabricated for high duty factor have been tested.

INTRODUCTION

Development of a high current Surface Plasma H- ion Source (SPS) with plasma generation by RF discharge with Saddle antenna in magnetic fields is described in Refs. 1,2. A prototype of RF H- surface plasma source (SPS) with saddle (SA) RF antenna is developed. Several versions of new plasma generators with a small AlN test chamber and different antennas and magnetic field configurations were tested in the Test Stand. A prototype SA SPS was installed in the Test Stand with a larger, normal sized SNS AlN chamber that achieved peak currents of up to 67 mA with an apparent efficiency up to 1.6 mA/kW at 2 MHz RF frequency. Control experiments with H- beam produced by SNS SPS with internal and external antennas were conducted in similar conditions.

In this period main effort was concentrated on development:

1- more reliable version of the triggering plasma source (TPS);

2- improved efficiency of the plasma generators;

3- saddle antenna SPS with water cooling for high duty factor testing.

RF TRIGGERING PLASMA SOURCE

For fast igniting a powerful pulsed RF discharge at low gas density is used a separate triggering plasma gun (TPG). The hollow-anode dc glow discharge plasma gun (discharge voltage: ~600 V and current ~5 mA), designed at ORNL, has been described previously [3]. It used for injecting H_2 gas and ~20 μA of electrons into the AlN 30-70 kW discharge. It was observed that guns configured with Mo cathodes often failed to ignite after several days. In response to this issue, it was designed and developed a chamber, which is sufficient to ignite the main 2 MHz, of stable operation due to decrease a secondary electron emission.

RF assisted TPG utilizing the existing 13 MHz system. Figure 1 shows a cross-sectional view of the SA SPS with RF TPG which employs a water-cooled Al_2O_3 ($\Phi = 1.3 \times$ length 10 cm) plasma chamber surrounded by a 10-turn Cu antenna. The plasma chamber integrity has been tested up to 1.2 kW of RF power with plasma. Under normal conditions (RF power: 300 W; cathode bias: −250 V; >10 SCCM H_2 flow) about 2 mA of discharge current is supplied to the cathode fabricated from W. This current is then compressed through a circular 2 mm diameter opening in the ceramic plasma chamber to a hollow anode (also fabricated from W). This gun configuration has been found to reliably ignite the main ion source plasma and has been tested coupled to an ion source over several multi-day runs on the test stand. Comparing performance to the Mo, Cu gun, the RF gun produces ~10× electron flux to the ion source with sputtering estimates suggesting ~10^3 less cathode sputtering.

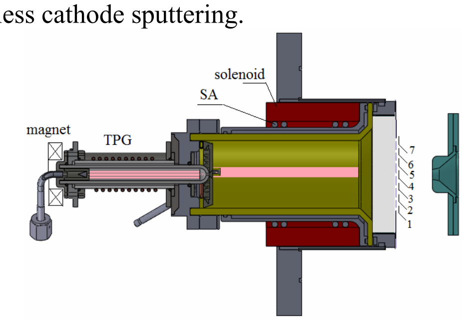

Figure 1: Drawing of the SA Plasma generator with RF TPG and plasma plate with 7 collectors opposite 7 emission apertures of 2 mm diameter (S=3.2 mm^2). Magnetic accelerator electrode is attached for producing of correct magnetic field distribution.

With attached ring permanent magnet the plasma flux from TPG was increased and the minimal gas density, necessary for TPG and pulsed discharge triggering was decreased.

IMPROVING EFFICIENCY OF PLASMA GENERATION

An external antenna source employing solenoidal antenna is under development at the SNS, which was recently described in Ref. 3. The high RF power required for the sources as well as triggering of the pulsed discharge can create problems for very long term operation.

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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 [1]. 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 [1].

The cesiation was improved recently, and appears to be nearly optimal. The probability of extraction of H^- emitted from the collar surface is dependent on the surface collar shape [3], 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. 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].

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 must be low enough to minimize the electron stripping from the extracted H^- ions. This critical gas density is inversely proportional to the emission aperture diameter. For this is necessary to improve a TPG for reliable triggering of pulsed RF discharge at lower gas density.

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.

The schematic of a large RF plasma generator with the AlN ceramic discharge chamber, prototype saddle antenna, and DC solenoid is shown in Fig. 1. The chamber has an ID=68 mm. The saddle antenna in this prototype plasma source with inductance L=1.7 μH was made from copper tube. 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 end of discharge chamber as shown in Fig. 1.

The end plate had seven 2-mm diameter emission apertures which with some addition slits is comparable with surface of the SNS 7-mm diameter ion source outlet.

EXPERIMENTAL RESULTS

In previous experiments the central collector current Ic0 is increased up to 5 times from 10 mA/cm^2 to 50 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.

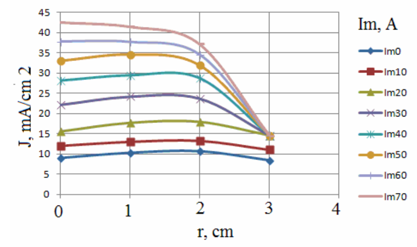

Figure 2: Radial distribution of current density of extracted positive ions for different magnetic fields (coil current I_m), as determined from the 7 collectors.

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 higher. In new experiments, the saddle antenna was moved away from plasma plate back to the back flange ~ 5 cm .

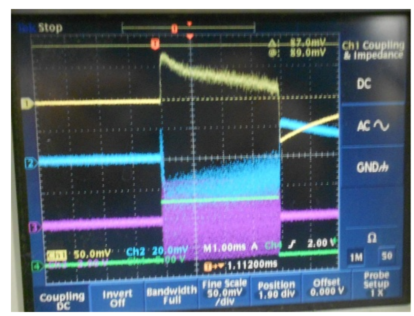

Figure 3: 1- Signal of Ic0 up to 90 mV, 0.5 A/cm^2 with RF power 3kW; 2-Ic1; 3-Antenna current 200A/div.

In result the efficiency of plasma generation was increased up to ~4x times. For plasma generation was used RF discharge with pulsed power Prf=3 kW, RF frequency f=13.56 MHz, pulses T=4 ms , repetition 5 Hz. Discharge was triggered with TPG power Ptpg=300 W, Utpg=0.2 kV, Itpg=5~mA.

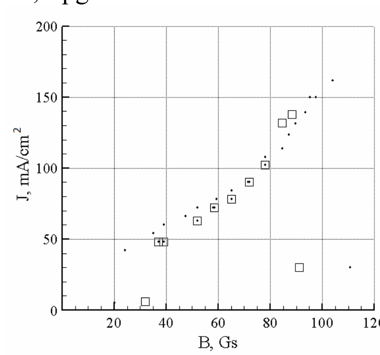

Figure 4: Emission current density Jc1(mA/cm^2) versus magnetic field B (Gauss) at gas flow Q =9.3 sccm (points) and at Q=8.8 sccm (squares) with RF power 1 kW.

The signal of ion current Ic0 from central collector 0 is shown in Fig. 3. The signal differentiation is connected with small inductance of Pearson transformer.The plasma

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density observed by collectors as function of magnetic field B, gas flow Q at different collectors at RF power 1 kW are shown in Figs. 4-6. With gas flow Q=9.3 sccm pulsed discharge can be triggered at magnetic field B>25 G and can be stable supported up to B~112 G. The positive ion emission current increases from 0.004 A/cm^2 to 0.16 A/cm^2 as shown in Fig. 5 (points). With lower gas flow the pulsed discharge need higher magnetic field for triggering and can be supported up to lower critical magnetic field with lower collector maximum current as shown in Fig. 4 (squares). However, at the fixed magnetic field the emission current density increases with decrease the gas flow Q as shown in Fig. 5.

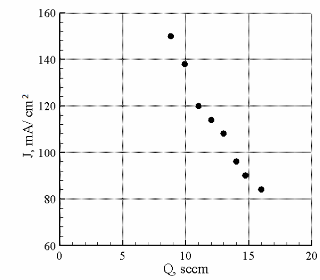

Figure 5: Emission current density Jc1(mA/cm^2) versus gas flow Q (sccm) at magnetic field B=90 Gauss with RF power 1 kW.

Ion current to four collectors (0-3) at magnetic coil current 1 and 80 A and Q=11 sccm are shown in Fig. 6. The highest emission current density Jc0=0.4 A/cm^2 up to 10 times higher than shown in Fig. 2. The current density distribution has higher pick density on the axis than distribution in Fig. 2. By this results were demonstrated than location of antenna in the divergent magnetic field can increase efficiency of plasma generation on the axis of plasma plate.

For utilization of this effect were fabricated short (5 cm) solenoid and new saddle antenna shown in Fig. 7.

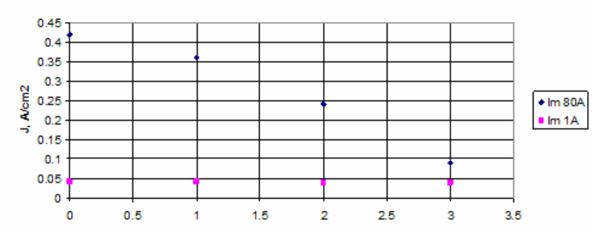

Figure 6: Ion emission current density Jc (A/cm^2) (plasma density) along the radius R (cm) at high magnetic field (blue) and at low magnetic field (pink) with RF power 3 kW.

With this design high efficient plasma production up to 0.5A/ cm^2 per 3kW RF power was reproduced. With 4.5 turns solenoidal antenna similar to SNS external antenna the plasma generation efficiency was ~4 times less with magnetic field and ~10 times less without magnetic field at RF frequency 13.56 MHz.

With RF frequency 2 MHz the pulsed discharge was not triggered without magnetic field up to 6 kW with TPG plasma. With he magnetic field the pulsed discharge was weak and the Ic1 signal was below 1 mV (~6 mA/cm^2).

In CERN replica of DESY RF sources used as proton source, the pulsed discharge is stable ignited with RF power above 20 kW. The emission current density J=240 mA/cm^2 was produced with RF power ~40 kW (~6 mA/cm^2 per 1 kW) [4].

Figure 7: Discharge chamber with a short solenoid and new saddle antenna located out of solenoid.

General design of simplified version of SA SPS with new extraction system shown in Figs. 8 has been prepared.

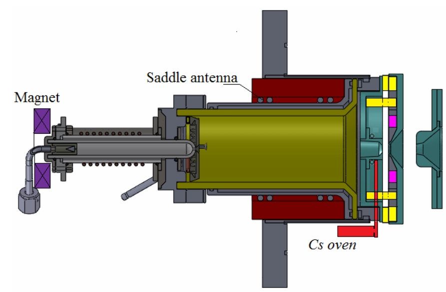

Figure 8: General design of simplified version of SA SPS with new extraction systems and cesium supply.

New version of plasma plate with H- emitting collar was designed, fabricated and assemble. The SA SPS with attached extractor is shown in Fig. 9.

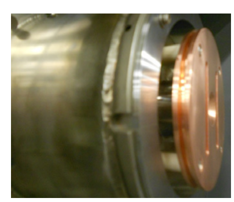

Figure 9: SA SPS with attached extractor.

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