RADIO FREQUENCY SURFACE PLASMA SOURCE WITH SOLENOIDAL MAGNETIC FIELD *

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Abstract

Operation of Radio Frequency Surface Plasma Sources (RF SPS) with a solenoidal magnetic field are described. RF SPS with solenoidal and saddle antennas are discussed. Dependences of beam current and extraction current on RF power, gas flow, solenoidal magnetic field and filter magnetic field are presented.

INTRODUCTION

Efficiency of plasma generation in Radio Frequency (RF) ion source can be increased by application of a solenoidal magnetic field [1-9]. A specific efficiency of positive ion generation was improved by the solenoidal magnetic field from 5 mA/cm^2 kW to 200 mA/cm^2 kW [8, 9]. Chen [10] present explanation for concentration of a plasma density near the axis by magnetic field through a short circuit in a plasma plate. Additional concentration factor can be a secondary ion-electron emission initiated by high positive potential of plasma relative the plasma plate. The secondary emission can be increased by cesiation-injection of cesium for increase of the secondary negative ion emission [11-14], increasing a secondary electron and photo emission.

RF ION SOURCE IN SNS TEST STAND

RF ion source was installed in Spallation Neutron Source (SNS) test stand. A design of ion source and Low Energy Transportation channel (LEBT) is shown in Fig. 1. The RF ion source consist of AlN ceramic chamber with a cooling jacket from keep. At a left side is attached an RF assisted Triggering Plasma Gun (TPG). At a right side is attached a plasma electrode with an extraction system. The discharge chamber is surrounded by a saddle (or solenoidal) antenna. The LEBT at right side consist of accelerator electrode and two electrostatic lenses focusing a beam into a hole of 7.5 mm diameter in a chopper target. The second lens consists of four electrically insulated quadrants, which allow for chopping the beam to form an extraction gap inside the accumulator ring. In addition, the voltages on the quadrants can be varied individually to steer the beam for improving the transmission through the RFQ [15]. In more detail extraction system is presented in Fig. 2. The plasma plate (1) have a collar (2) with a conical converter surface. Cs oven (3) for decomposition of Cs_2CrO_4 cartridges is attached to the collar. The extractor electrode (5) is attached to the plasma plate through ceramic insulator (4). Permanent magnet bars (6) is inserted into the water cooled plasma electrode (5). A ferromagnetic insert (8) can be used for shaping the magnetic field. Accelerating electrode (7) is used for accelerating of extracted ions up to 65 keV.

A plasma is generated by a current in antenna. Solenoidal magnetic field is concentrate the plasma on the axis. A transverse magnetic field generated by permanent magnet (6) located inside the water cooled extractor (5), bend the plasma flux, preventing electrons to escape the plasma. A configuration of the transverse magnetic field is shown in Fig. 1 (below). The plasma outside a 6 mm diameter impacts on the conical surface of a Mo converter, where H- ions are formed. The H- production is enhanced by lowering the Mo work function by adding a partial monolayer of Cs. Negative ions that drift into the source outlet are extracted by its potential of the extractor-electron dump. The extractor, which has a 6 mm aperture, is have a potential up to 8 kV. The 1 kG dipole field integrated into the extractor drives the co-extracted electrons sideways. Most of them are intercepted by the electron dump, which is kept near -57 kV with a +8 kV supply located on the -65 kV platform. The -65 keV H- beam emerges from the extractor and is focused by two electrostatic lenses into the hole of diameter 7.5 mm in a chopper target.

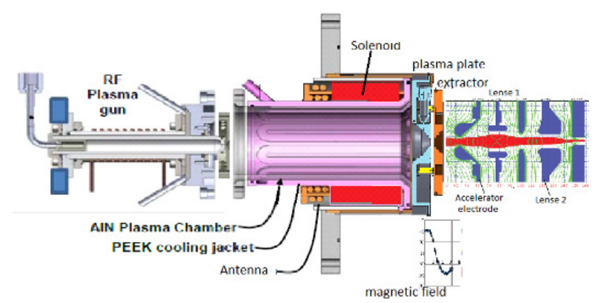

Figure 1: Design of RF Ion Source and LEBT.

EXPERIMENTAL RESULTS

Typically, 200 W from a 600 W, 13 MHz amplifier generates a TPG continuous low-power plasma. Cathode TPG is biased at 310 V with a current ~10 mA. The high current beam pulses 1 ms, up to 60 Hz are generated by up to 50 kW from a pulsed 80 kW, 2 Mz amplifier, connected to the antenna through insulating transformer and matching network. A discharge is triggered at pulsed power Prf= 3.8 kW, antenna current Iant=120 A, antenna voltage Uant=6.5 kV (at 13.56 MHz discharge start from Prf=0.5 kW, Iant=14 A, Uant=1.2kV).

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Cesiation is started after 3 hours conditioning by discharge. The Cs oven is slowly heated up to 550 ºC. Faraday cup current is increases in and of pulse as shown in Fig. 3. The optical spectrum is transformed as shown in Fig. 4.

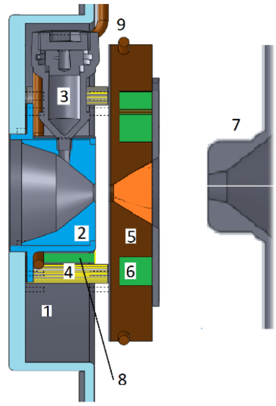

Figure 2: Design of extraction system. 1- plasma electrode (PE), 2- conical collar with emission aperture, 3- Cs oven, 4- ceramic insulators, 5-extractor electrode, 6- permanent bar magnets, 7- accelerating electrode, 8- ferromagnetic insert, 9- water cooling lines.

After cesiation an extractor current decreases up to 4 mA from 120 mA at RF power Prf=50 kW. Faraday cup current Ifc increases up to 25 mA at Prf=50 kW from RF generator.

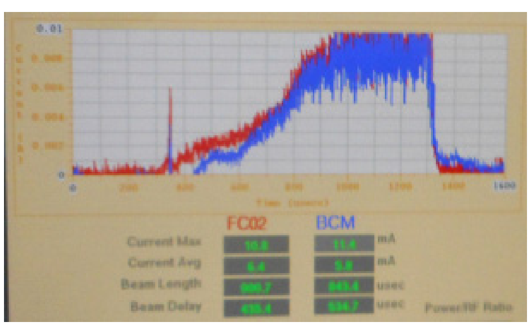

Figure 3: Increase of the Faraday cup current during cesiation.

After ion source opening a white film of CsH was observed on the discharge chamber wall, not bombarded by the plasma as shown in Fig. 5. With a solenoidal antenna Ifc is increases up to Um=4 V and decreases after 5 V, because plasma is concentrated up to emission aperture. Extractor -e dump current is increases monotonically

Dependents of Faraday cup current Ifc on magnetic solenoid voltage Um with a solenoidal antenna and Bt=1000 gauss is shown in Fig. 6.

With a saddle antenna and Bt=600 Gauss Ifc is increases from 2 mA to 11.6 mA with increase Um from 0 to 6 V, as shown in Fig. 7.

Negative ion extraction was tested with transverse magnetic field of Bt=200 G. Ifc reach 70 mA at RF power Prf=50 kW (6 kW in the plasma). Experiment with He gas in discharge chamber show that electrons accelerating and transported by LEBT to Faraday cup.

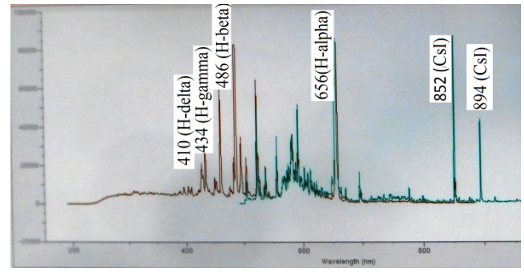

Figure 4: Optical spectrum of plasma during cesiation. Cs 852 nm and Cs 894 nm lines are increasing and new lines are increasing.

A simulation of beam extraction shows that at Bt=200 Gauss electrons are leaking through e-dump and can be transported by the LEBT to the Faraday cup. At Bt>400 Gauss electrons could not leaking through e-dump. Testing a discharge with He shows the transportation of electrons to FC at Bt=200 Gauss and trapping of electrons by e-dump at Bt>330 Gauss.

Figure 5: CsH film on the wall of the discharge chamber.

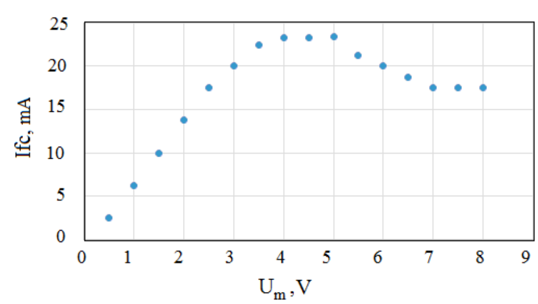

Figure 6: Dependents of Faraday cup current Ifc on the magnetic solenoid voltage Um with solenoidal antenna Bt=1000 Gauss. RF power 50 kW from generator (6 kW in the plasma).

ESTIMATION EFFICIENCY OF H-BEAM GENERATION

Forwarded RF power from the RF generator is measured by a directional coupler and calculated by the following formula: Prf=45 x $\langle I \rangle^2$ kW, where <I> rms is rms current in V. Before triggering discharge, all power is dissipated in the insulating transformer, antenna and matching network. For our case it is <I>=0.293 V, 3.86 kW, antenna current <I>ant= 83.3 A, antenna voltage V=6,480 V. Active resistance of network + antenna is

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$R=2P/\langle I\rangle^2ant = 2*3860/(83.3)^2=1.1$ Ohm. For discharge with $\langle I\rangle = 0.599$ V the power Prf=16 kW is dissipated in discharge Pd, in antenna+network Pant and in surrounding antenna solenoid Psol: Prf=Pd+Pant+Psol. For $\langle I\rangle ant1=136$ A $Pant=R\langle I\rangle^2 ant/2=10$ kW.

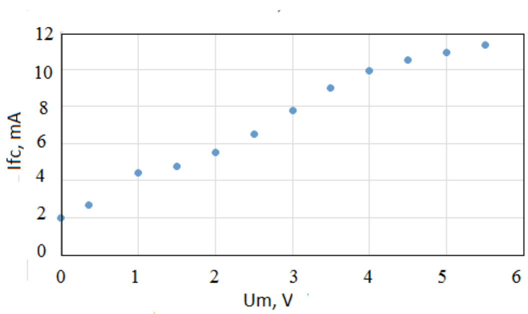

Figure 7: Dependents of Faraday cup current Ifc on the magnetic solenoid voltage Um with saddle antenna. RF power 21.5 kW from generator (4 kW in the plasma).

Temperature of solenoid with RF is Tsol=53C. Without RF but with solenoid at voltage Um=2.11 V, Tsol =35C. Active resistance of solenoid Rsol=0.15 Ohm.

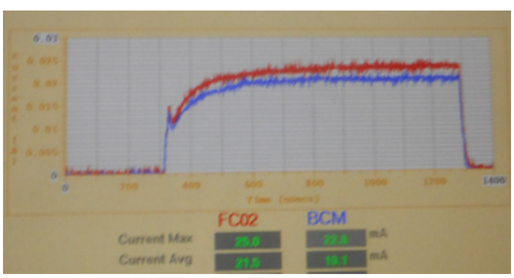

Figure 8: Current of Faraday cup 25 mA.

After switching off solenoid current Tsol=32C. Power from solenoid current is $Um^2/Rsol=29.7$ W, and increases the solenoid water temperature by 3C. To increase Tsol by 28C, an average power of Psol=280 W is necessary, and pulsed power 4.7 kW. Pd=16-10-4.7=1.3 kW. For Faraday current Ifc=17 mA, the efficiency of current generation is $\lambda=13$ mA/kW at Um=2.11 V.

At $\langle I\rangle=0.872$ V, Prf=34 kW. $\langle I\rangle ant =194.4$ A. Pant=20 kW. Psol=5 kW. Pd=34-20-5=9 kW. Ifc=16 mA, $\lambda=16/9=1.7$ mA/kW at Um=0. At $\langle I\rangle=0.963$ V, Prf=41.7 kW. $\langle I\rangle ant =250$ A. Pant=34.3 kW. Psol=6 kW. Pd=41.7-34.3-6=1.4 kW. Ifc=25 mA, $\lambda=25/1.4=17.8$ mA/kW at Um=3.2 V. Current of extractor power supply is up to 40 mA. Current of Faraday cup 25 mA (Fig. 8).

Volume of the collar is 29 cm^3. Mass of the collar is 290 g. A specific thermal permeability of Mo is C=0.255 J/gK. Thermal permeability of collar is 75 J/c. A speed of the collar cooling after switch of discharge is 0.7 $^oC/s$. A power loss from the collar is 52 W (pulsed power 868 W from Prf=34.2 kW from RF generator at Um=1.68 V). Slow cesiation: increase of Faraday cup current (mA) in time during cesiation from 3 mA to 13 mA at constant RF power 40% (10 kW in plasma, antenna, network and solenoid; blue max current, green-average current) is shown in Fig. 9. Ifc is increased with decrease of Q. An efficiency of plasma generation and a stability of discharge can be increased by control of plasma potential [16].

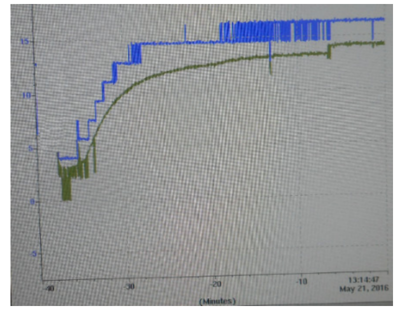

Figure 9: Cesiation is an increase of Faraday cup current (mA) in time during cesiation from 3 mA to 13 mA at constant RF power 40%.

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