ADVANCED LARGE VOLUME SURFACE PLASMA H^-/D^- SOURCE FOR NEUTRAL BEAM INJECTORS

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The design of an Advanced Large Volume Surface Plasma Source (LV SPS) for Neutral Beam Injectors is presented and discussed. The LV SPS will be assembled from a set of modules. Every module consists of a plasma generator with an RF saddle antenna injecting plasma and hyperthermal atoms into the expander chamber. The plasma electrode with multi-slit extraction system and localized magnetic filter is attached to the bottom flange of the expander chamber. The plasma will be generated by an RF discharge using a saddle antenna in an optimized longitudinal magnetic field. This type of discharge is very efficient for dense plasma generation. The magnetic field is used to suppress plasma diffusion to the wall, improve the efficiency of plasma generation and decrease the thermal flux to the plasma generator wall. The expanded flux of ions and hyperthermal atoms bombards uniformly the plasma electrodes of the extraction system and produces an intense beam of negative ions. With improved cooling, the average discharge power can be increased significantly above that of any existing SPS. With smaller slit emission apertures, it is possible to suppress H^- stripping after extraction. These conditions are promising for reliable production of higher emission current density up to ~40-50 mA/cm^2 with corresponding decrease of SPS dimensions and cost.

I. INTRODUCTION

The problem of intense, high brightness negative ion beam production for accelerators and for neutral beam injection for Controlled Fusion was solved, in general, by a small admixture of cesium vapor into gas discharge ion sources[1]. In subsequent experiments[2], it was demonstrated that cesium adsorption decreases the surface work function which enhances secondary emission of negative ions caused by the interaction of plasma with the electrode surface. Ion sources based on this process have been named surface-plasma negative ion sources (SPS). For practical SPS operation it is important that cesium admixture decreases significantly the current of co-extracted electrons. The SPS with H^-/D^- beam intensity about 1 A was described in one of the first publications[3]. Later, the H^- beam current was increased up to 11 A in a semiplanotron SPS with geometrical focusing[4]. With more development, the intensity of LV SPS for neutral Beam Injectors (NBI) was increased up to 40 A with emission current density up to 30 mA/cm^2.

II. SPS FOR NBI WITH RF DISCHARGES

Performances of LV SPS were improved recently by using inductive RF discharge for plasma generation[5]. Further improvements of LV SPS performance can be reached by increased efficiency of H^-/D^- generation in the interaction of the plasma particles with an optimized plasma electrode surface and improved secondary ion emission properties. An improved discharge configuration and better insulators with enhanced thermal conductivity, such as aluminum nitride (AlN), will be used for this purpose. Source lifetime and beam intensity will be improved by better suppression of the cesium loss with an optimized temperature distribution and by suppression of back accelerated positive ions, which are the main reason of electrode erosion and flake formation. The LV SPS will be assembled from a set of modules as in Ref. 5. Every module (shown in Fig. 1) will consist of a plasma generator with an RF saddle antenna injecting plasma and hyperthermal atoms to the expander chamber. The plasma electrode with multi-slit extraction system and magnetic system for electron emission suppression is attached to the bottom flange of the expanding chamber. The plasma will be generated by an RF discharge using a saddle antenna in an optimized longitudinal magnetic field created by a set of coils. This type of discharge is very efficient for dense plasma generation[6]. The magnetic field is used to suppress plasma diffusion to the wall, improve the efficiency of plasma generation and decrease the thermal flux to the plasma generator wall. The expanded flux of ions and hyperthermal atoms bombards uniformly the plasma electrodes of the extraction system and produces an intense beam of negative ions.

With improved cooling, the average discharge power can be increased significantly above that of existing SPS. With smaller slit emission apertures, it is possible to suppress H- stripping after extraction. These conditions are promising for production of higher emission current density up to ~40-50 mA/cm^2 with corresponding decrease of SPS dimensions.

According to surface-plasma production theory the negative ions are produced predominantly by conversion of hydrogen atoms on the cesiated plasma grid surface[7]. It is well known that the dissociation of the hydrogen molecules and ionization are more efficient in dense plasma because there is higher probability of electron interaction with excited particles.

The wall recombination of the atoms and ions are lower on the ceramic surface. Although the positive ions contribute less to the negative ion production they are important for the neutralization of the space charge created by the negative ions. There is no need for electrons in Surface plasma generation if H^- and the electrons could be extracted from the plasma along the magnetic field lines. In the existing LV SPS the flow of the hydrogen atoms as well as of the positive ions saturates at high power, it is not surprising that this is observed also with the negative ions.

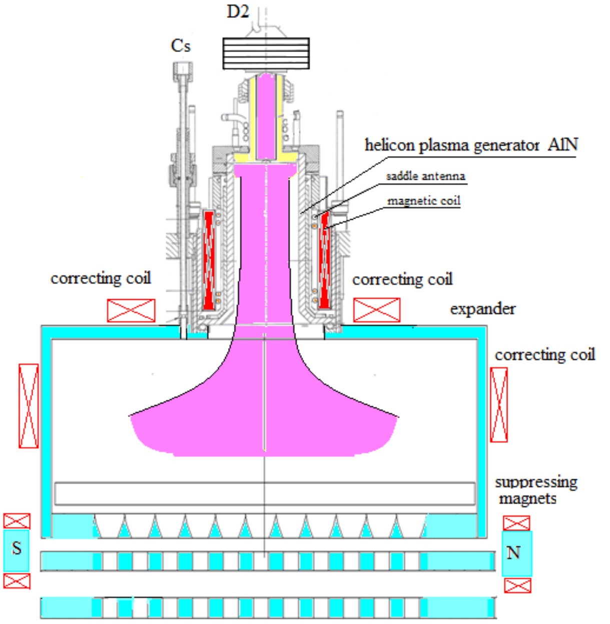

Fig. 1: Schematic of LV SPS for Neutral Beam Injection that uses RF discharge with saddle antenna into an AlN discharge chamber (18 cm Diameter for 50 kW of RF power). A multislit extraction system with localized magnetic field is used for electron emission suppression. Correcting coils are used for magnetic (and plasma) flux redistribution.

One way to avoid such "saturation effects" would be to improve the plasma generation in RF discharge with the saddle antenna and AlN discharge chamber. Because the existing LV SPS cesium vapor is released into the source by a nozzle in the back plate at the side of the driver the cesium handling is determined by the very time-consuming distribution of the Cs onto the plasma grid. A more distributed Cs supply with improved cesium trapping on the plasma grid surface would improve this procedure and increase efficiency of cesiation.

II.A. Surface Plasma Interaction and H^- beam extraction

The plasma particle interaction with the electrode surfaces is very important for negative ion generation and for ion source lifetime. The H^- generation efficiency depends on the energy of plasma particles bombarding the plasma grid ionization surface. Cesium adsorption lowers the surface work function thus increasing the probability of sputtered and reflected particles escaping in the form of negative ions. This probability increases as the work function decreases and the velocity of particles moving away from the electrode surface increases. The theory of negative ionization of particles interacting with an electrode surface has been presented in Ref. [8]. Figure 2 shows the calculated dependence of the H^- formation probability on the initial particle velocity for different work functions and on the work function for different initial velocities.

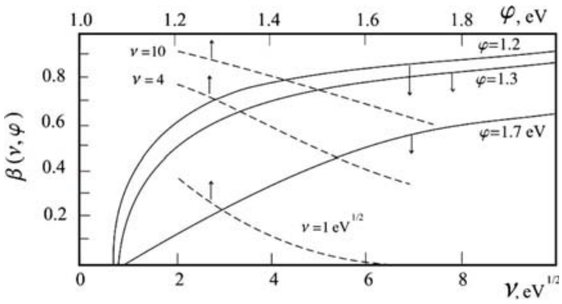

Fig. 2: Calculated negative ionization coefficient vs. the initial velocity and work function [8].

Increasing the plasma electrode negative potential enhances the negative ion emission because the energy and intensity of positive ions bombarding the electrode surface become higher and the number of sputtered and reflected particles is increased along with the velocity of their movement away from the electrode surface. The potential drop near the electrode accelerates emitted negative ions without a space charge limitation. It also increases the mean path traveled by ions in the plasma without destruction and allows better ion extraction through the emission aperture. Cesium is trapped on the negative electrode surface as it comes back from the plasma in the form of ions. The electrode surfaces with potential close to that of the plasma are also bombarded by fast plasma particles and emit negative ions. The efficiency of negative ion generation on these electrode surfaces is lower than that on the electrodes with negative potential but it can still be higher than the volume generation efficiency of extracted H^- ions.

The efficiency of extracting of H^- ions emitted from the surface can be improved by optimization of the surface near the emission aperture. In a Cs-free discharge with a current of up to 400 A and a very high plasma density, H^- current grew as the plasma electrode (collar) thickness was increased up to 10 mm (Ref. 9). In discharges with Cs, the discharge current and plasma density are much lower. It should then be possible to extract H^- ions emitted from the surfaces located farther away from the emission aperture. Plasma electrode rods up to 25 mm thick with magnetic material inserts may be useful as illustrated in Fig. 1.

For high efficiency of H^- generation it is useful to use plasma particles with energy of several eV because the probability of reflection is high for these. For long lifetime it is important that the sputtering rate of hydrogen ions with these energies is very low.

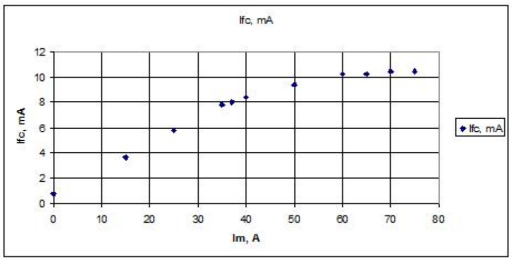

Fig. 3: Evolution of H^- beam intensity of the saddle antenna RF LV SPS (1 aperture 7mm diameter) with increase of magnetic coil current Im.

For low aberration beam formation in a magnetic field, a slit extraction system is very suitable. This property of slit extractors has been used for the measurement of the transverse temperature of positive and negative ions with good preservation of low ion temperature (0.2 eV) along the slit. In the perpendicular direction, it is more difficult to eliminate aberrations. However, this problem is the same as in extractors with circular aperture. Decreasing the emission slit dimension, d, along the magnetic field, (and increasing of effective wall thickness *h*) is very effective for suppression of co-extracted electron flow. Minimizing the electron current *Ie* is very important for maintaining high brightness and for prevention of breakdown. The optimization of the configuration of the extraction electrodes and operating at the proper emission current density for a given extraction voltage helps to minimize the aberrations and effective ion temperature in the small size direction. To maintain the brightness, it is very important to have noiseless discharge and noiseless beam formation and transportation, which can be reached with slit extraction as in many versions of the SPS. The design of the LV RF SPS with the slit extraction is shown in Fig. 1. The plasma flux generated in the cylindrical ceramic chamber by RF discharge with saddle antenna is concentrated near the axis and guided to the plasma electrode convertor by a longitudinal magnetic field created by coils. An external magnet creates a strong transverse magnetic field near the plasma grid and extractor grid with a magnetic insert for suppression and deflection of co-extracted electrons.

II.B. LV SPS with Saddle Antenna

H^- ion generation in the RF LV SPS with the saddle antenna was tested in Ref. 6. The H- beam current increases significantly with increase of the magnetic coil current in this RF LV SPS is shown in Fig. 3. After starting the discharge without cracking the cesium ampoule, the efficiency of H^- beam generation increases 5 times during 3 hours of activation. We believe that perfect "cesiation" was produced (without additional Cs) by the collection and trapping of traces of cesium compound 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.

Beam H- ions with an emission current density up to ~200 mA/cm^2 was extracted from LV SPS with saddle antenna.

It is possible to produce the emission current density up to 50 mA/cm^2 from LV SPS with the multislit extraction system.

III. CONCLUSIONS

Advances of LV SPS for NBI can be improved by using a helicon discharge with a saddle antenna for plasma generation and by using a slit extraction for H^-/D^- formation and beam extraction.

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