HELICON PLASMA GENERATOR-ASSISTED H⁻ ION SOURCE DEVELOPMENT AT LOS ALAMOS NEUTRON SCIENCE CENTER*

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Abstract

The aim of the helicon plasma generator-assisted negative ion source development at Los Alamos Neutron Science Center (LANSCE) is to use high-density helicon plasmas for producing intense beams of H^- ions. Our work consists of two development paths, construction of a hybrid ion source (long-term goal) and replacement of the LANSCE surface converter ion source filaments by a helicon plasma generator (short-term goal). The hybrid ion source is a combination of a long-life plasma cathode, sustained by a helicon plasma generator, with a stationary, pulsed main discharge (multi-cusp H^- production chamber) directly coupled to each other. The electrons are transferred from the helicon plasma to the cusp-chamber by thermal flow process to ignite and sustain the main discharge. Replacing the filaments of the ion source based on surface conversion process by a helicon plasma generator is a low-cost solution, building upon the well-proven converter-type ion sources. Both development paths are aimed at meeting the beam production goals of the LANSCE 800 MeV linear accelerator refurbishment project. This article provides a brief comparison of these approaches and describes the design and the status of the helicon-driven surface conversion H^- ion source.

INTRODUCTION

The current converter-type negative ion source employed at Los Alamos Neutron Science Center is based on cesium enhanced surface production of H^- ion beams in a filament-driven discharge. Figure 1 presents a schematic of the current LANSCE surface conversion H^- ion source (the other end plate with filament omitted for illustration purposes). In this kind of an ion source the extracted H^- beam current is limited by the achievable plasma density. The plasma density is strongly affected by the electron emission current from the filaments and can be increased by increasing the filament heating power (see figure 2 in the following section). Unfortunately, this leads not only to shorter filament lifetime but also to an increase in metal evaporation rate from the filaments, which degrades the performance of the H^- conversion surface due to tungsten deposition and consequently higher work function. Therefore it is highly questionable if the performance limit of the filament-driven LANSCE surface conversion source can ever be pushed over 20 mA keeping the emittance of extracted H^- beam at values less than 1.1 π·mm·mrad (normalized area emittance, 95 % of the beam current).

*Work supported by the US Department of Energy under contract DE-AC52-06NA25396
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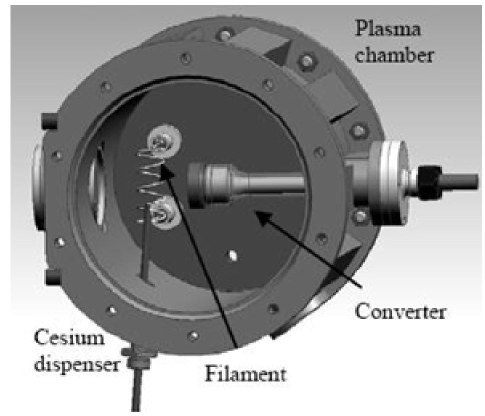

Figure 1 : Schematic of the LANSCE filament-driven surface conversion H^- ion source

Helicon plasma generators are widely used for plasma processing applications due to their long life-time and capability of efficiently producing high density (up to $n_e = 10^{13}$ cm-3 for hydrogen [1]), low-temperature (2-10 eV) plasmas in suitable magnetic fields. In order to overcome the limitations of the filament-driven surface conversion H^- source we have started a project aiming at utilizing helicon plasma generators for producing intense H^- ion beams. We expect that this technology will significantly improve the performance and reliability of H^- ion sources at LANSCE.

BRIEF COMPARISON OF HYBRID ION SOURCE AND HELICON-DRIVEN SURFACE CONVERSION ION SOURCE

The helicon driven H^- ion source development work at LANSCE consists of two paths, construction of a hybrid ion source (long-term goal) and replacement of the LANSCE surface converter ion source filaments by a helicon plasma generator (short-term goal).

Hybrid Ion Source

The hybrid ion source (hybris) [2] is a combination of a long-life plasma cathode, sustained by a helicon plasma generator, with a stationary, pulsed main discharge (multi-cusp H^- production chamber) directly coupled to each other. The electrons are transferred from the helicon plasma to the cusp-chamber by thermal flow process to ignite and sustain the main discharge. Furthermore the H^- ions are produced on the surface of an SNS-type cesium collar [3] separated from the main plasma by a dipole filter. This type of configuration will enable us to optimize the RF-plasma production and negative ion beam production simultaneously which, according to current understanding, cannot be obtained in a single-stage source.

The design of the helicon driven LANL-hybris can be found from reference [4]. The helicon plasma generator for the LANL-hybris was built in 2006 and recently it was decided that the cusp-chamber of the six-filament version of the LANSCE surface conversion source [5] will be used as the main chamber for the LANL-hybris.

Helicon-Driven Surface Conversion Ion Source

In the recent past the effort of pursuing the helicon technology for H^- production at LANSCE has been concentrated on building a helicon-driven surface conversion source i.e. replacing the filaments of the LANSCE surface conversion source by an RF-antenna aimed at exciting helicon wave-mode. Due to enhanced plasma density we expect this type of an ion source to be capable of producing an extracted H^- ion beam with a current of 25 mA without causing significant emittance growth compared to the filament-driven LANSCE surface conversion sources. The main difference between this source type and the LANL-hybris source is that the surface conversion source is relying on achieving favorable plasma and surface conditions for H^- production simultaneously in a single chamber while the LANL-hybris utilizes a cold plasma cathode.

DESIGN AND STATUS OF THE HELICON-DRIVEN SURFACE CONVERSION SOURCE

The main limitation of the filament-driven surface conversion H^- ion sources is the achievable plasma density. The extracted H^- beam current of the LANSCE sources increases with increasing filament heating power i.e. filament temperature. However, the filament heating power cannot be increased significantly over 1.1 kW without jeopardizing their required life-time. This fact gave us the motivation to characterize typical hydrogen plasmas produced by a filament-driven source (without cesium injection) and, furthermore, compare the obtained plasma parameters with a typical helicon discharge. Measurements were performed with a Langmuir-probe positioned 19 mm from the converter on the beam axis. Figure 2 shows the measured plasma density as a function of filament heating power (error bars are based on standard deviation). For the probe data analysis it was assumed that dominant ion species in the plasma is H_2^{+}.

The plasma density was observed to increase almost linearly with increasing filament heating power while the electron temperature remained practically unchanged, namely 3-5 eV. The collected data also revealed a presence of two electron populations, low-energy population (3-5 eV) and a population with significantly higher temperature due to acceleration in the plasma sheath formed by biasing the filaments during the 1 ms pulses (so-called arc-voltage). A double-Maxwellian fit to the the measured probe-traces indicates that the low-energy electron contribution to the overall electron density is 85-90%. The plasma potential was observed to be 5-7 V. The feed rate of hydrogen did not have any significant effect on the plasma parameters while the plasma density increased slightly with increasing (negative) converter voltage. The probe-measurement results were observed to be independent of the source duty factor i.e. pulsing frequency and pulse length (less than 1.2 ms).

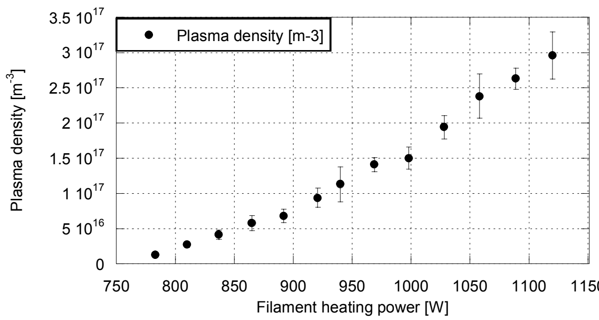

Figure 2 : Plasma density of the LANSCE filament-driven surface conversion H^- ion source (hydrogen plasma, no cesium)

The plasma density measurements encouraged us to start developing a helicon-driven version of the surface conversion source because helicon plasma generators have been proven to produce higher plasma densities [6] compared to densities shown in figure 2 at neutral pressures of 3-7 mtorr, which is the operational pressure range of the filament-driven surface conversion sources [7]. After some development work we have come up with the design of the first prototype ion source presented in figure 3 (schematic, cross-section shown for illustration purposes).

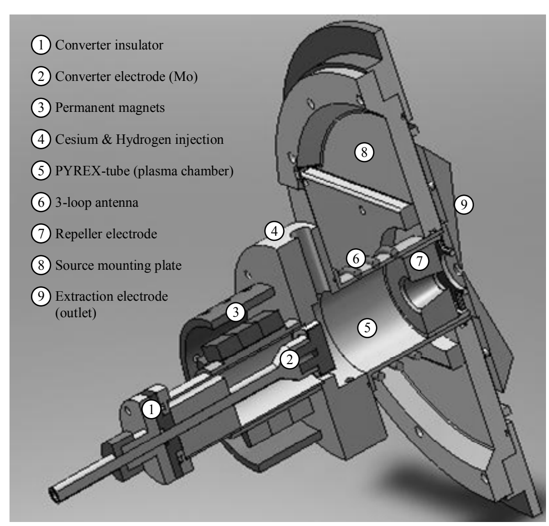

Figure 3 : Prototype of the helicon-driven surface conversion H^- ion source.

The design of the prototype source is partly based on the filament-driven sources i.e. the mounting flange, extraction electrodes, converter electrode and repeller (magnetic + electrostatic) are identical to the parts used in the filament-driven sources. The development for the helicon-driven version was initially started with solenoids producing the magnetic field (required for exciting the helicon mode) but finally permanent magnets were chosen because the RF-antenna can be placed in the fringe field of the magnets and therefore the problems of coupling RF-power to the solenoids can be avoided. In the prototype design the permanent magnet array consists of 18 magnet blocks normally used for producing the cusp-field of the LANSCE filament-driven sources i.e. the magnets were readily available. The magnetic field profile on the axis of the source is shown in figure 4 together with electrode and antenna positions.

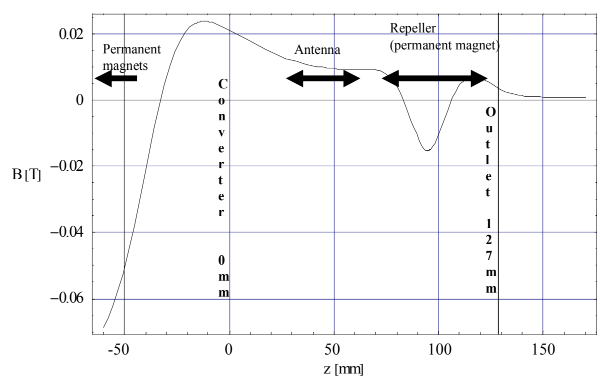

Figure 4 : The magnetic field on the axis of the source.

The magnetic field strength at the antenna region is about 0.01 T, which has been demonstrated to be adequate for exciting the helicon mode [8]. The 3-loop antenna design was chosen because the ratio of the length and diameter of the Pyrex-tube is too small for optimized helical antenna design (the distance from the converter to the outlet is 127 mm leaving roughly 60mm for the antenna while the tube radius is 75 mm). The RF-power is fed to the antenna through a capacitive matching circuit. It has been shown that, for a given RF-power, a magnetostatic field applied to inductively coupled plasma increases the electron density by a factor of four due to m=0 helicon wave mode excitation and makes it easier to operate the discharge at low neutral pressures (in the order of 1-5 mtorr) with a loop antenna [8,9].

The initial experiments with the prototype source have demonstrated converter currents (positive ion current) up to 1.06 A at RF-power of 775 W (coupled to the plasma) and at converter voltage of -275 V without cesium injection, which is close to the converter currents (1.1–1.5 A) typically observed during the filament-driven source operation without cesium. However, the effective ion collection area of the converter is twofold in the filament source due to insulator geometry. The ions can hit only the face of the converter in the helicon source while in the filament source they are also collected by the sides of the converter not contributing to the extracted beam current. Therefore 1 A of converter current probably corresponds to 1.5-2 A in the case of the filament source depending on the plasma distribution and uniformity in the filament source. During the preliminary measurements it has been shown that the source prototype can be operated without cesium at neutral pressures of 5-10 mtorr. The converter current has been observed to be practically independent of the pressure with a duty factor of 6 % (1 ms pulses at 60 Hz) with proper matching. At this time we have not yet extracted any H^- from the device.

Our near future plans include the following steps to further develop the source prototype: (1) Operation and converter current measurements with cesium injection and possibly implementing a new design for the cesium oven. (2) Operating the source prototype at higher RF-power (up to 5 kW). (3) Shortening the distance from the converter to the outlet by redesigning the repeller electrode (the mean free path of H^- @ 5 mtorr of H_2 neutral pressure is about 10 cm). (4) Simulating the effect of magnetic field gradient and converter surface curvature on the beam extraction in order to optimize the magnetic field design. (5) Implementing a control for the converter surface temperature, which has been shown to be an important factor for improving the surface production of H^- ion beams [10,11] due to lower work function of cesiated molybdenum converter in low-pressure hydrogen atmosphere at elevated temperatures (~ 250 ºC) [12]. (6) Operating the helicon-driven surface conversion source at the LANSCE ion source test stand [7] and studying the properties of extracted H^- ion beams (current and emittance).

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