Results of the CEA/Saclay H electron cyclotron resonance ion source, ECRIN

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A 2.45 GHz electron cyclotron resonance test stand based on a pure volume H^- (negative) ion production is actually under development at CEA Saclay. The negative ion source is working in a pulsed mode, 2 ms at 5 –10 Hz. The first H^- ions have been observed at the beginning of 2002 with a poor efficiency: only a few microamperes were produced. Several changes inside the plasma chamber have increased the production rate of negative ions up to several milliamperes. A biased grid separates the plasma chamber into two regions. In the first part, we produce excited H_2 molecules that are necessary for producing in the second zone H^- ions by a dissociative attachment process located near the extraction zone. Qualitative and quantitative beam diagnostics allow measuring several beam parameters and analyzing the effect of gas mixing or materials on the H^- production rate. © *2006 American Institute of Physics.* (DOI: 10.1063/1.2163277)

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I. INTRODUCTION

Neutral beam injection (NBI) based on a negative ion source is one of the most promising candidates for heating and current drive in future fusion reactors. A long duty factor, high-current, and high-quality H^- beams are also required for injection into compressor rings of machines such as the Spallation Neutron Source (SNS) or European spalation source (ESS) and neutrino factories. The latter facilities have been planned to work in a pulsed mode (roughly 1 -2.5 ms at a frequency ranging from 15 to 50 Hz). Many existing machines such as HERA, ISIS, proton acceleration in Los Almos (LANCSE), and others are also interested in source developments. So there is a strong desire for reliable and efficient H^- ion production and also for source development. For several years, CEA has undertaken an important research and development program on H^- ions source development. In this paper the electron cyclotron resonance (ECR) ion source ECRIN will be described and, second, some results will be presented. Finally, present and future technological improvements will be reported for this source in order to increase microwave frequency for a future ECR source at 10 GHz.

II. ECRIN, CEA/SACLAY NEGATIVE ION SOURCE

A. Description

The ECRIN ion source (see Fig. 1) is composed of a rectangular chamber of 34x72 mm and 200 mm long (WR284), where the rf wave is longitudinally injected. Around this chamber a solenoidal field is generated by two magnetic coils that deliver a 0.2 T field. The rf is generated by a pulsed magnetron of 2.45 GHz, from 1 to 20 ms at 10 Hz, to avoid plasma electrode heating. At this frequency plasma electrons are accelerated on the 875 G isomodul magnetic surface. For usual operation the source voltage is up to −10 kV for negative ion extraction. The pressure inside the plasma chamber is of great influence on the plasma characteristics such as species temperature. The vacuum is implemented by a 1000 l/s turbomolecular pump. The plasma chamber is pumped through the extraction system with a 5 mm diam plasma electrode aperture.

B. Beam diagnostics

After the plasma chamber there is a diagnostic chamber where an electrostatic extraction is located and two different kinds of diagnostics can be used. All are at ground potential:

A qualitative one, that allows us to ensure the production of H^- ions. This diagnostic is composed of a bending magnet and a Faraday cup behind it to collect selected charges. The magnet is calibrated with positive ions. That allows us to be entirely sure of producing and extracting H^- out of the source. But that measurement does not allow us to measure the entire extracted beam.

For that reason we use a quantitative diagnostic composed of a larger Faraday cup that collects all extracted beams.

Several hours are necessary to change the diagnostic, as we need to break the vacuum inside the source. In order to collect only negative ions inside the quantitative Faraday cup, an electron steerer has been placed just near extraction hole for bending electron trajectories. The collected beam is free of electrons, composed of negative particles, in our case mostly of H^- ions.

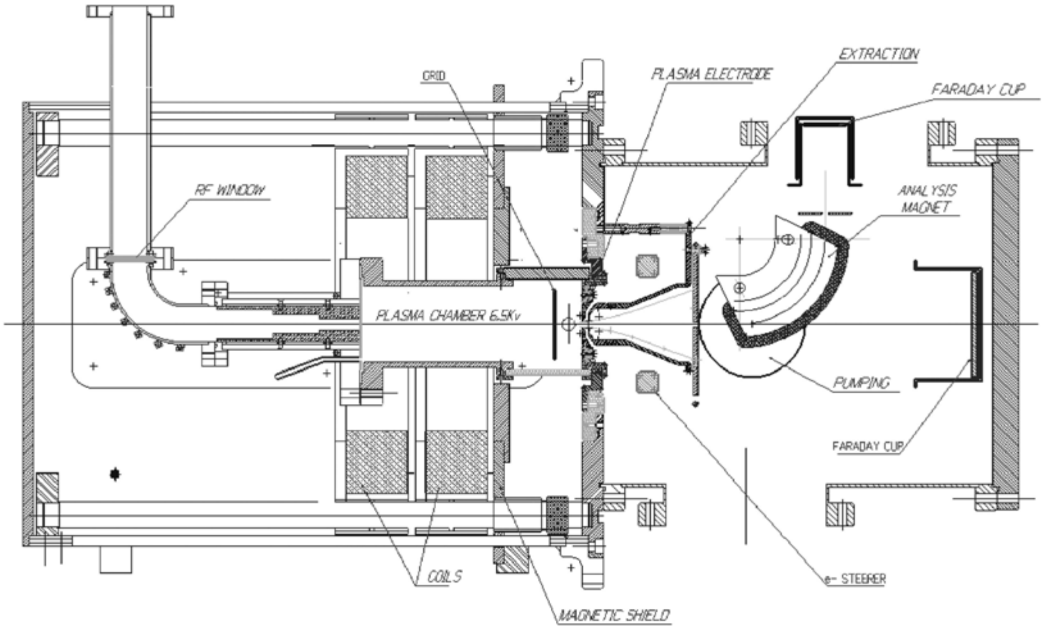

FIG. 1. ECRIN source with the qualitative diagnostic.

C. Polarized grid

The main process to produce H^- ions is the so-called dissociative attachment process (DA):[1]

$$e_{\text{cold}} + H_2(v \sim 5) \rightarrow H + H^- .$$

The radio-frequency (rf) wave produces high-energy electrons (hot electrons ~10 eV) needed for molecules excitation, which lead to H^- production. Unfortunately too much rf power produces too many atomic species that are able to deexcite $H_2(v \sim 5)$ molecules and neutralize negative ions. In order to separate the hot and cold electronic population we use a biased grid installed at about 3 cm from the extraction plasma electrode.[2,3]

It realizes an electrostatic barrier that acts like a high-pass filter. Sufficiently high energetic electrons can pass over it and are decelerated on the other side of the grid.

The mesh of this grid has been optimized to be a reflector for the incoming rf wave.[4] Thus there is no electric field behind the grid, no heating zone that could produce energetic electrons.

The potential usually applied varies between −20 and up to −120 V, considered from the high voltage of the source (−10 kV).

D. Magnetic measurements

We plotted extracted current versus the electron steerer's vertical transverse magnetic field intensity. We noticed a variation of this current with magnetic field intensity. With a gauss meter we measured the B_y magnetic component on the source axis. We noticed that magnetic coils generate a slight transverse component inside the production zone, and that the B_y vertical magnetic component generated by the electron steerer leaks well inside the production zone. Its orientation considered to the one of coils (opposite or additive) has a great influence on the production and extraction of H^- ions.

The quantitative diagnostic allows us to measure H^- current versus the field intensity applied with the electron steerer. One can see in Fig. 2 when the steerer field is off a large amount of negative charges are collected, mostly electrons. As we increase the steerer-field intensity, the extracted current drops until we compensate completely the coils' vertical component with the electron steerer's vertical component. H^- ions are only extracted and transported from the source from then: we can see a sort of "plateau." The hatch region (in Fig. 2) is where H^- ions are detected with the qualitative diagnostic. We can conclude that transverse field produced by the coils must be lowered as far as possible on the source axis. The best result obtained with that configuration is 2.8 mA of extracted H^-.

III. GAS-MIXING EXPERIMENT

Some authors[5] have noticed in the case of filament-driven negative ion sources that an the adjunction of a heavy

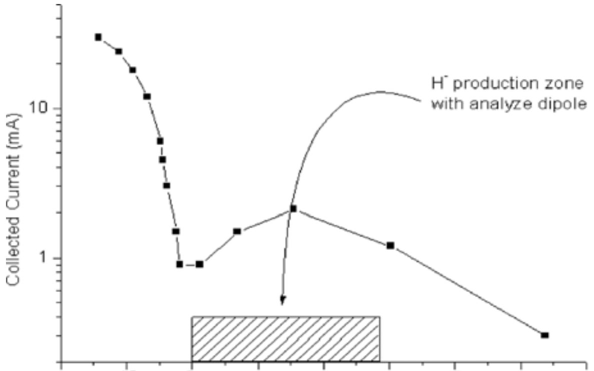

FIG. 2. Negative current vs steerer-field intensity through the quantitative diagnostic.

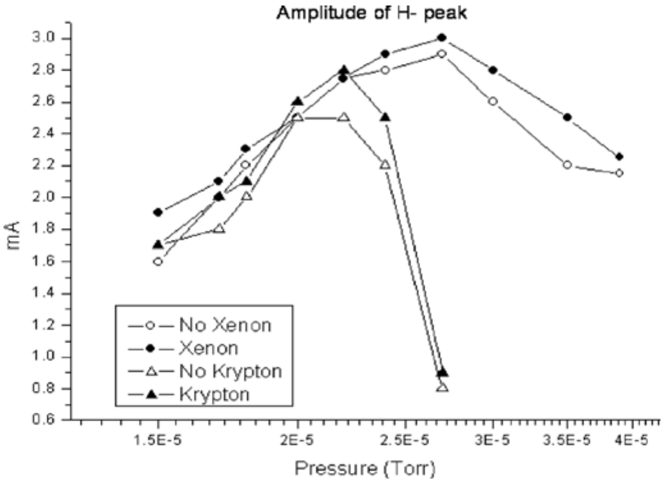

FIG. 3. H–-extraction current vs pressure when adding xenon and krypton gas.

noble gas allows an increase of negative ion production by respectively increasing and lowering the electron density and temperature. Several noble gases were added with a second controlled valve. The variation of the pressure inside the chamber was monitored and special attention was made on the reflected rf power in order to keep it constant as the noble gas was added. The pressure is mainly due to the H_2 gas. Two kind of behaviors were observed: for heavy gases like xenon and krypton, a slight well-reproducible increase was noticed (Fig. 3), but nothing has been detected or improved with argon gas.[6] It was noticed that it is harder to get to a stabilized regime with lighter gas; this may explain the difficulties of operating with argon injection. We can see that the range of pressure is much lower for krypton than for xenon. No explanations have been found yet to explain the behavior with argon gas

IV. FUTURE IMPROVEMENTS

For increasing ion production with volume process, several technological options have been chosen and are about to be carried out. Magnetic coils generate an almost longitudinal field on all sections of the coils. Thus electrons are also confined in the center of the chamber. Magnetic rings composed of permanent magnets, in Halbach[7,8] geometry, generate a multipolar field. Several configurations have been modeled with two different software.[9,10] A difference of 3% has been observed between both simulations located near high-field regions, i.e., at the magnet surface.[11] The role of this multipole is to confine electrons near the border of plasma chamber near the resonance zone, which is located 33 mm from the axis and keeps the center of the source for negative ion production. The second change concerns the length of the resonance zone inside the plasma chamber. As the main process occurs inside the volume, we can estimate that an optimum length exists. A short resonance zone is not sufficient to produce enough hot electrons, which is the first step of the H^- ion production process. A too long resonance zone one is useless because too much collisions occurs between the cre-ation of H_2 excited molecules and the production zone. Several magnetic rings will be placed to vary the resonance length, and also a plasma chamber will be used with a variable length. The latter will have a cylindrical geometry to fit better to the resonance zone geometry. Four windows near the production zone will allow the insertion of plasma diagnostics (see Fig. 4). Those technological changes are the first step toward a future H^- ECR ion source operating at 10 GHz frequency.

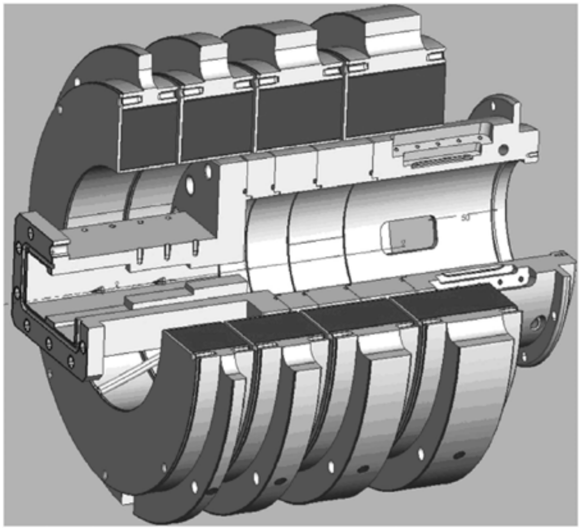

FIG. 4. Design of the next ECRIN ion source at CEA Saclay.

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