DEVELOPMENT OF A COMPACT HIGH INTENSITY ION SOURCE FOR LIGHT IONS AT CEA-SACLAY

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Abstract

During the past 5 years, a R&D program has been launched to improve the beam quality of ECR 2.45 GHz high intensity light ion sources for high power accelerators. The main goal was to minimize the divergence and emittance growth of intense beams due to the space charge as early as possible on the low energy transfer line for a better injection in the second stage of acceleration (RFQ). This has been achieved by reducing the length of the extraction system, to be able to put the first solenoid as close as possible to the extraction aperture. This was performed with the ALISES [1] concept (Advanced Light Ion Source Extraction System). Encouraging results have been obtained in 2012 but with limitations due to Penning discharges in the accelerating column. Taking advantages of ALISES geometry, intensive studies and simulations have been undertaken to eliminate the discharge phenomena. An Innovative and compact source geometry has been found and the source has been fabricated. This new prototype and its performances will be described, as well as magnetic field configuration studies and its influence on the extracted beam.

INTRODUCTION

The ALISES concept developed at CEA/Saclay is based on the use of the stray field of a solenoid located downstream the extraction system to produce the ECR resonance in the plasma chamber. The other characteristic of ALISES source is that the insulating structure between the source potential and the LEBT potential is located upstream of the plasma electrode. The design of the accelerator column (Fig. 1), reversed compared to standard high current light ions sources like SILHI [2] or IFMIF [3] source, allows a gain of several tens of cm on LEBT length. This also gives available space at the beginning of the LEBT, to put focalizing and/or guiding elements as early as possible to adjust the beam dimensions and angle, in order to minimize the emittance growth due to the beam space charge effects. The ALISES source has produced about 18 mA extracted from a 6mm diameter plasma extraction hole at 23 keV during the commissioning in 2011-2012 [4], but strong limitations were observed [5] due to Penning discharge in the accelerator column.

After two years of intensive work on electromagnetic simulations and design improvement to eliminate the penning discharge process, an innovative and compact source geometry has been developed, fabricated and successfully tested on BETSI [6] test bench in 2015.

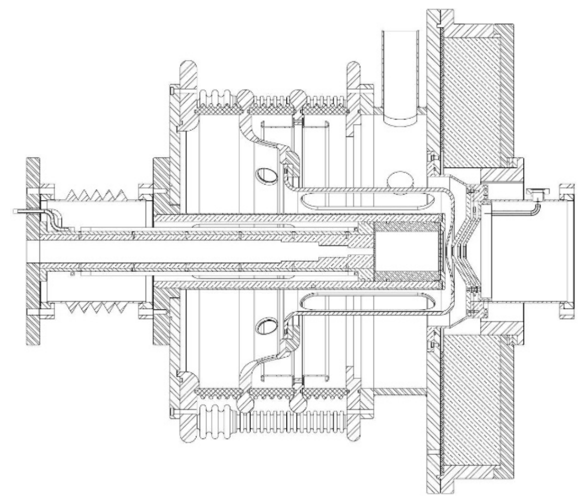

Figure 1: ALISES source geometry characteristic.

ALISES II* INOVATIVE ION SOURCE

The undesirable Penning discharge occurred at different locations in the ALISES accelerator column due to favorable combination of electromagnetic and electrostatic field lines. This was due first, to electrode shape with alternative parts along axial direction and radial direction, and second to higher magnetic field value in the system compare to standard source configuration, because of increasing field from the RF injection up to the extraction end. At the location of changes in direction of electrode shape, Penning trap electromagnetic configuration can occur. Then, at several locations, electrons are accelerated up to several kilovolts and trapped with enough energy to ionize the residual gas, leading to the Penning discharge.

The Insulating structure used for ALISES source was a spare part of SILHI source with a large 410mm internal diameter. In this big volume of vacuum, the electrodes geometry have been designed with smooth shape and sufficient space in between, to prevent from electrostatic sparks, especially the shape of the puller electrode between the plasma chamber at 100 kV, and the first grounded electrode, but not for Penning discharge reason. To eliminate all the sources of Penning discharge, the idea was to reduce the vacuum part as much as possible where they could appear. The main characteristic of this source

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is that now the insulating structure, initially 155mm away from the outer part of the plasma chamber, is now directly in contact with the source body. From the initial ALISES source, the pumping port has been suppressed, but the same solenoid is used as well as the extraction chamber. This chamber hosts the two grounded electrodes, which are cooled, with the repeller electrode in between.

SOURCE ASSEMBLY

Main Parts

The new source ALISES II is a compact system as we can see on Fig. 2 and Fig. 3. A first copper cylinder (A) has been machined to form the plasma chamber (A1) and the RF entrance ridged guide (A2) in one piece. A smooth ceramic cylinder (B) built in two concentric parts realizes the insulating structure, and is in contact of the copper body. Both the ceramic and the source body are screwed on a copper flange (C) and connected to the RF guide. The plasma electrode (D) is fixed on the copper cylinder extremity to close the plasma chamber with an appropriate extraction hole. The puller electrode (E) is fixed to the source body by the mean of an intermediate ring shaped ceramic part (F). During the machining, a collar (G) has been realized on the external part of the insulating structure, to allow the structure to be assembled with the magnetic system (H) and the extraction chamber (I) by the mean of a dedicated flange (J).

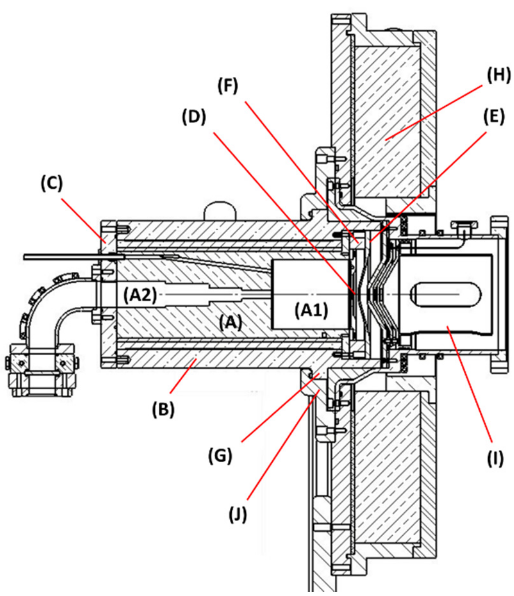

Figure 2: ALISES II source assembly.

The geometry of the five electrode extraction system is now greatly simplified. Electrodes shape is reduced to simple cones that ensure electric field line more or less parallel to the magnetic field lines avoiding any Penning trap problem. The assembly is also easier. The Extraction system has been initially design for high current and high voltage (100mA@100kV) with a 9mm diameter plasma electrode.

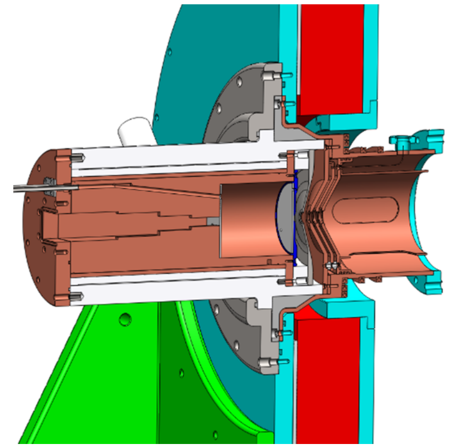

Figure 3: 3D cut of ALISES II source.

Puller Electrode Connection

To connect the puller electrode to high voltage (Fig. 4), a groove has been machined longitudinally on the external surface of the internal ceramic cylinder, and a hole has been drilled radially on the external ceramic cylinder (Fig. 4). The wire goes in the hole (K), then in the groove (L), cross the collar (M) of the source body, pass through the ceramic ring (F) and is plugged on the puller electrode (E) by a screw. Because the source body is at 100 kV, and the wire is at intermediate potential around 70 kV, the wire is inserted in a glass tube when crossing the copper collar, which extend in the ceramic part enough to prevent electrical sparks.

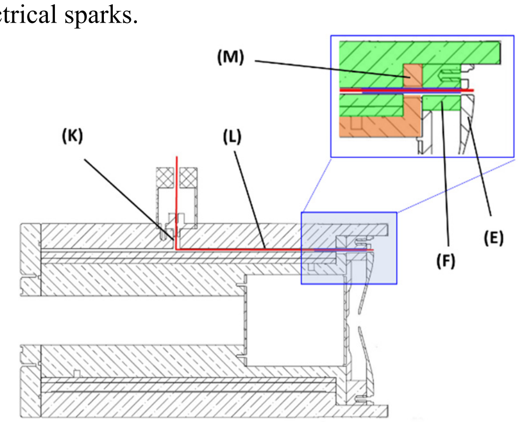

Figure 4: Repeller electrode connection.

COMMISSIONING ON BETSI

The source has been first tested without RF power to verify the lack of Penning discharge by increasing the high voltage, with the magnetic field adjusted at resonance value of 875 Gauss for the 2.45 GHz microwave generation. We observed that no output current occurs on high voltage power supplies, which means that no particle hit the electrodes to induce any fall of the voltage.

ALISES II has then been installed on BETSI test bench in March 2015 (Fig. 5) and has produced its first proton beam very easily with 18mA@35kV in pulsed mode (500ms each s) with a 6mm extraction hole diameter.

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After optimization with the same extraction, the source has produced end of March, a proton beam of 35mA@50 kV in continuous mode with gas injection of 1.65sccm, and a RF power of 980 W. We couldn't explore higher extraction voltage because of High voltage limitation to 50 kV on BETSI.

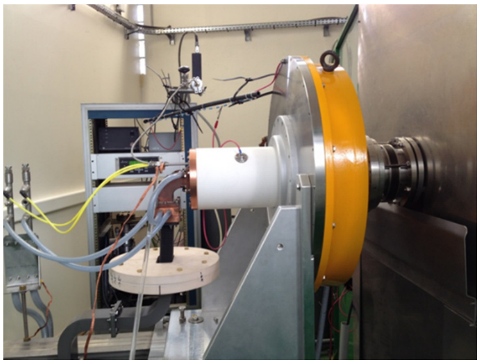

Figure 5: ALISES II on BETSI.

MAGNETIC FIELD PROFILE STUDY

A major characteristic of this source is that over a large range of magnetic field value, the source is producing about the same current even in off-resonance mode inside the plasma chamber (Fig. 6).

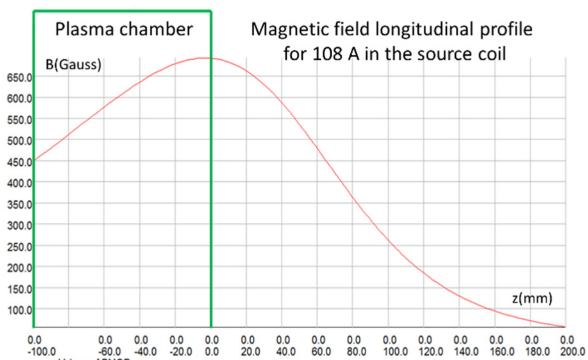

Figure 6: Best magnetic field B(z) for 22.5mA@30kV extracted beam.

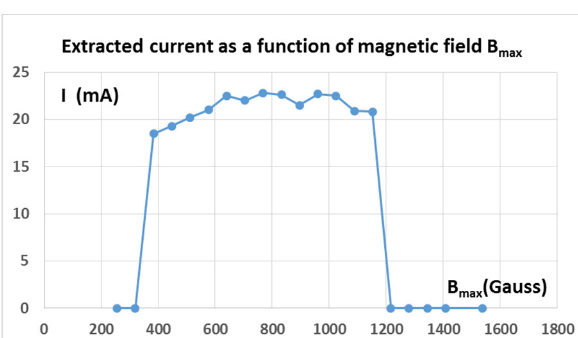

Figure 7: Extracted current function of B_{max} (extraction).

The resonance zone is usually positioned just in front of the RF entrance. To obtain 875 Gauss at this location, the corresponding current in the coil is 181A with Bmax=1150 Gauss at the extraction. As we can see on Fig. 7, we can produce a beam between 18mA to 23mA from Bmax=400 Gauss (I=60A) to Bmax=1150 Gauss, when extraction stops.

As the dimensions of the source body has been dramatically reduced, we tried to understand this production mode by adding a second coil (SILHI type) installed around the ceramic structure (Fig. 8). With the 2 coils, we could test different magnetic profiles, including the SILHI one. The same results were obtained, with the best tuning under the resonance. The latest result was obtained with a current of only 104A in the additional coil, the theoretically current for resonance at the RF entrance being 140A. The extracted beam current was 48.5mA@50kV with 2.1sscm gas and 700W power in continuous mode. Additional work is necessary to understand clearly the mechanism of ion production.

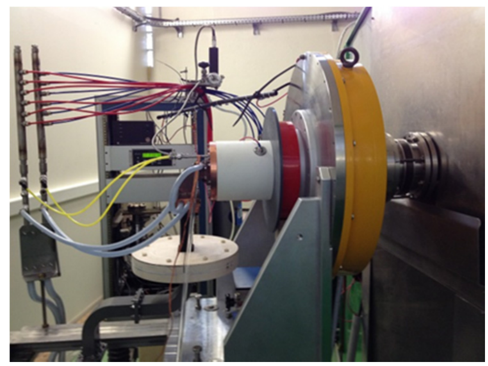

Figure 8: Addition of a second coil surrounding the ceramic and the plasma chamber.

CONCLUSION AND FUTURE WORK

ALISES II ECR light ion source has been successfully tested at Saclay at 50 kV. The BETSI upgrade to 100 kV at the end of this year will give the possibility of higher extraction voltage and performance improvements. Wien filter and Allison scanner will be ready to analyze the beam proton fraction and the beam emittance. Due to the compactness of this source given by its innovative conception, we can now use a small coil around the source body instead of the large initial solenoid. Drawings of ALISES III taking also into account some improvements for an easy plug of the source on the LEBT without any support, have already been realized and fabrications launched. Assembly is foreseen by the end of this year.

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