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Advanced light ion source extraction system for a new electron cyclotron resonance ion source geometry at Saclay[a)]

O. Delferrière,[b)] R. Gobin, F. Harrault, S. Nyckees, Y. Sauce, and O. Tuske
Commissariat à l'Energie Atomique, CEA/Saclay, DSM/IRFU, 91191 Gif/Yvette, France

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One of the main goal of intense light ion injector projects such as IPHI, IFMIF, or SPIRAL2, is to produce high current beams while keeping transverse emittance as low as possible. To prevent emittance growth induced in a dual solenoid low energy transfer line, its length has to be minimized. This can be performed with the advanced light ion source extraction system concept that we are developing: a new ECR 2.45 GHz type ion source based on the use of an additional low energy beam transport (LEBT) short length solenoid close to the extraction aperture to create the resonance in the plasma chamber. The geometry of the source has been considerably modified to allow easy maintenance of each component and to save space in front of the extraction. The source aims to be very flexible and to be able to extract high current ion beams at energy up to 100 kV. A specific experimental setup for this source is under installation on the BETSI test bench, to compare its performances with sources developed up to now in the laboratory, such as SILHI, IFMIF, or SPIRAL2 ECR sources. This original extraction source concept is presented, as well as electromagnetic simulations with OPERA-2D code. Ion beam extraction in space charge compensation regime with AXCEL, and beam dynamics simulation with SOLMAXP codes show the beam quality improvement at the end of the LEBT. © *2012 American Institute of Physics*. [doi:10.1063/1.3660820]

I. INTRODUCTION

During the last 2 decades, CEA at Saclay has developed high current mono-charged ECR ion sources for different projects, with specific extraction system designs. The SILHI (Ref. 1) source is running at Saclay since 1996 and regularly produces more than 100 mA of H^+ at 95 keV, with high reliability and reproducibility. A dedicated test bench BETSI (Ref. 2) is now used to test new sources either with permanent magnets or coils with several mA of beam extracted at 40 kV. The SPIRAL2 (Ref. 3) H^+/D^+ source has been designed and built, and the injector is now running for commissioning at Saclay. The very high intensity D^+ ECR ion source, 175 mA CW total beam with 145 mA of D^+ and its dedicated low energy beam transport (LEBT) developed for IFMIF (Ref. 4) injector is also currently under commissioning at Saclay.

As we increase the extracted current, the beam space charge is increasing, even if we can slightly play on the extraction aperture diameter, resulting in an increase of the divergence. To avoid too large beam diameter and divergence, there is only 2 ways: a faster acceleration in the first mm of extraction like in IFMIF source, or placing the first LEBT solenoid, as close as possible to the extraction using the new concept of ALISES (this source developed at Saclay is under patent number FR1060578 and this patent is pending).

II. MONOCHARGED ION ECR TYPE EXTRACTION STANDARD GEOMETRY

The ECR type light ion sources for H^+ or D^+ production are usually composed 3 major components (Fig. 1):

(1) A plasma chamber (1) localized at RF waveguide extremity (2), which feeds the chamber with a $f = \omega/2\pi$ frequency wave.
(2) A set of coils or permanent magnets producing the magnetic field (3) to obtain the ECR resonance at $\omega = eB/m_e$ (e = electron charge and m_e = electron mass, respectively).
(3) A multi-electrode extraction system (4) allowing beam extraction at a fixed energy E.

The plasma chamber and the RF chain, as well as the magnetic elements generating the magnetic field are usually at high voltage (HV) on a ground-insulated platform. The beam is extracted through the extraction system from the high voltage to the laboratory ground in a vacuum chamber (5). The beam is transported and magnetically or electrostatically guided in a low energy beam transport line, to be used or studied.

To electrically insulate the beam line from the source, we generally use an accelerator column (A), which is a cylindrical insulating structure composed of ceramics (6) and potential adjusting annular metallic pieces (7) from HV to laboratory ground. They are assembled by mean of 2 metallic flanges (8 and 9). This structure is then connected on one side, at laboratory ground, to the vacuum chamber downstream the extraction aperture (5), and on the other side to the support flange of the source at HV (10). The different electrodes

a)Contributed paper, published as part of the Proceedings of the 14th International Conference on Ion Sources, Giardini Naxos, Italy, September 2011.
b)Electronic mail: olivier.delferriere@cea.fr.

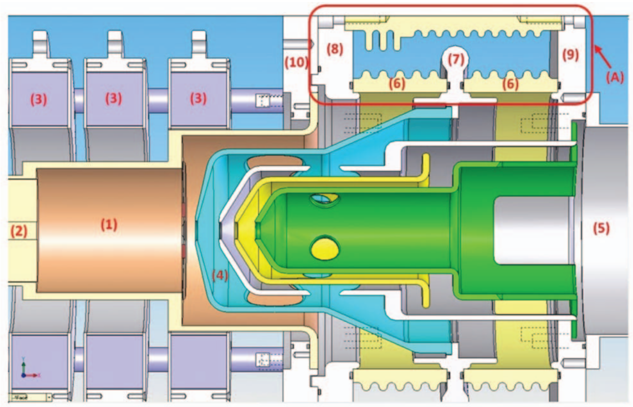

FIG. 1. (Color online) Standard ion source extraction system: (1) plasma chamber, (2) RF entrance, (3) coils or permanent magnets, (4) extraction, (5) vacuum chamber, (6) electrical insulation, (7) metallic ring, (8 and 9) metallic flanges, (10) support flange, and A: accelerator column.

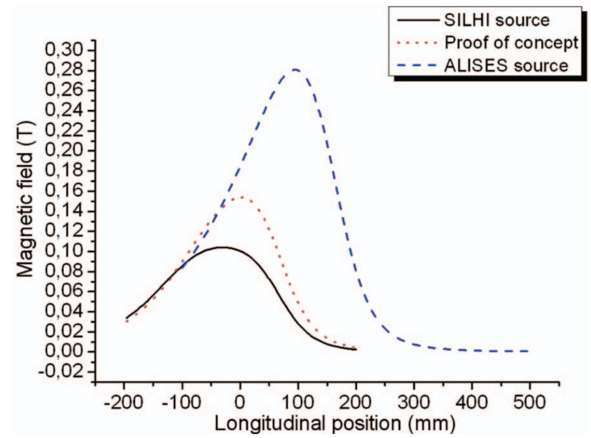

FIG. 3. (Color online) OPERA-2D (COBHAM software) magnetic field calculation on axis (extraction at $z = 0$, resonance at $z = -100$ mm). SILHI (—), ALISES (- - -), and ALISES *proof of concept* on SILHI (· · ·).

are connected to the accelerating tube or to the ground via a "Russian dolls" scheme.

III. NEW ASSEMBLY FOR SOURCE AND EXTRACTION SYSTEM DESIGN: THE ALISES CONCEPT

The main drawbacks of this geometry are the following:

(a) The complex structure of the electrodes and supports.
(b) The large diameter of the insulating structure due to the "Russian dolls" assembly principle and the necessary inter-electrode distances to avoid sparks.
(c) The significant length of this tube (in order of 300 mm for a typical 100 keV extracted beam).
(d) The coils at HV on the platform.
(e) The lack of vacuum system before the extremity flange (7) to assure a sufficient vacuum level in the extraction system, that could induce sparks between electrodes.
(f) A beam focalization by the first LEBT solenoid far from the extraction aperture, leading to beam brilliance decrease.

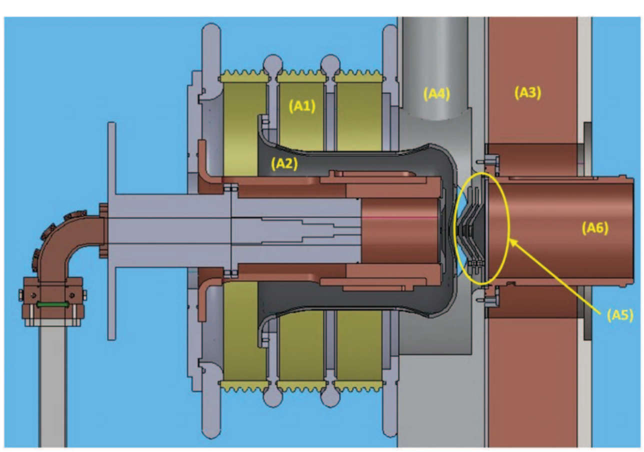

FIG. 2. (Color online) ALISES scheme: A1: electrical insulation, A2: intermediate electrode, A3: coil, A4: pumping, A5: extraction, and A6: vacuum chamber.

The main goal of ALISES is to reduce the extraction system length to a few 50 mm length for a 100 kV extraction system usually of 300 mm (c), by positioning the insulating structure (A1) behind the plasma chamber (Figs. 2 and 4). To avoid forward electrode connections, only the intermediate polarized electrode between HV and ground potential has to be linked to the insulating structure on one of the metallic annular pieces (A2). It is now the more complex electrode geometry ((a) and (b)).

The space gain in front of the extraction system allows now to put a solenoidal coil at laboratory ground (A3) in the vicinity of the plasma chamber to allow ECR resonance by its fringe field. There is no coil at HV (d).

The vicinity of the LEBT solenoid, leads to a divergence reduction of the beam at extraction.

For pumping inside the extraction system (e), a vacuum chamber (A4) is introduced between the insulating structure and the solenoid.

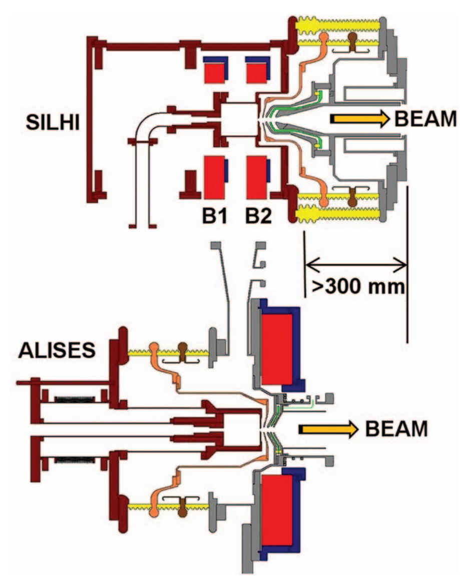

FIG. 4. (Color online) Source assembly comparison (SILHI and ALISES).

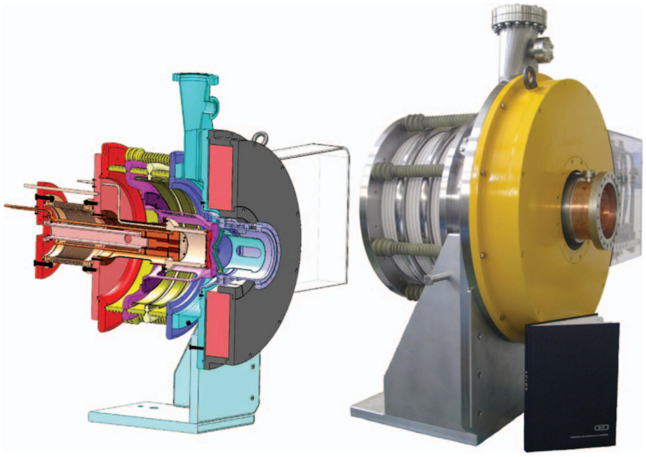

FIG. 5. (Color online) ALISES mechanical model and source.

The distance between the insulating structure and the extraction system is not a critical distance any more: it just defines the intermediate electrode length (A2). The vacuum chamber can be adjusted in length.

The electrode geometry downstream the intermediate electrode (A2) is largely simplified. The negatively polarized electron repeller electrode is here inserted between 2 annular shaped electrodes, assembled and insulated by mean of ceramics. This simple 3-electrode assembly (A5) is directly fixed on the LEBT vacuum chamber at laboratory ground. An insulated connection is needed for the link to the HV power supply.

A first "proof of concept" has been tested on SILHI source, consisting on pushing the 2 coils as close as possible to the extraction and adjusting the 2-coil currents to realize an increasing magnetic field from the resonance location to the extraction. With current value of I_1 = 70 A and I_2 = 120 A for B1 and B2 coils, respectively, we have easily extracted 70 mA of H^+ at 80 keV with the axial magnetic field profile shown on Fig. 3 in black.

IV. ALISES STATUS

The source has still a large diameter due to the accelerator column which has not been redesign, using a spare part

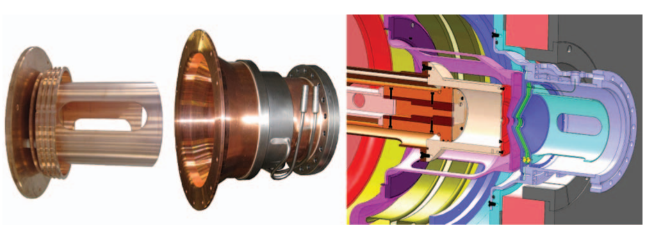

FIG. 6. (Color online) Extraction system electrodes.

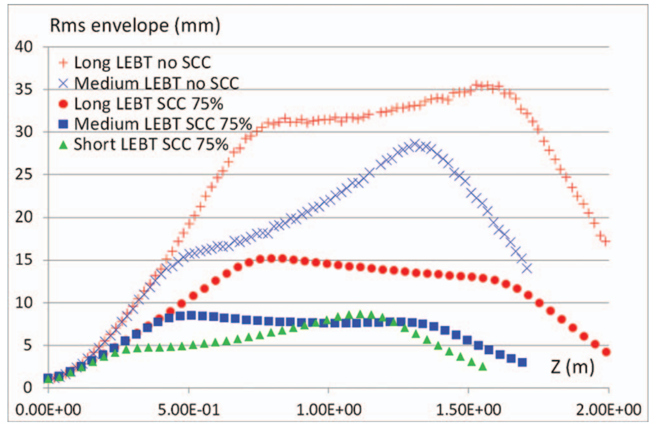

FIG. 7. (Color online) LEBT comparison with AXCEL and SOLMAXP.

of 95 keV SILHI source (Figs. 4 and 5). All the ALISES components have been manufactured and delivered except the plasma chamber which is expected at the end of August. This is a length-adjustable plasma chamber for plasma and beam extraction studies. The source is currently under assembly (Figs. 5 and 6) and will be installed and tested on BETSI test bench at the end of September.

Beam dynamic simulations are being performed in order to compare previous situations and new ECR component arrangement. First, the effect of the ALISES solenoid is negligible. But, the space gain in front of ALISES solenoid allows installing one 300 mm long IFMIF-type solenoid[4] at 100 mm from the extraction compared to 600 mm in the IFMIF LEBT. An intermediate position is on the BETSI LEBT where the distance is 300 mm. First simulation results without and with 75% space charge compensation have shown a large reduction of both beam diameter and beam divergence (Fig. 7).

V. CONCLUSION

The ALISES concept which consists to reverse insulating structure and magnetic field generation material, coils, or permanent magnets, gives the maximum space in front of the extraction to allow the best possible beam transport on the LEBT. It is also available at any extraction energy, by simply extending backward the insulating structure. This is an important step for high current beam generation with high space charge level, where the focalization is usually too far away from extraction leading to emittance growth.

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