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ALISES II SOURCE IS STILL ALIVE AT CEA SACLAY

O. Delferrière[1,*], A. Dubois[1], Y. Gauthier[1], F. Mezei[2],
Y. Sauce[1], J. Schwindling[1], O. Tuske[1], D. Uriot[1]

[1] IRFU, CEA, Université Paris-Saclay, F91191 Gif-sur-Yvette France
[2] MIRROTRON, Konkoly-Thege Miklós út 29-33; H-1121 Budapest, Hungary

Abstract

Developments of ECR intense light ion sources is an important research axis of the Laboratory for Accelerator Study and Development at CEA-Saclay. Starting in the 90's from the SILHI proton source for the IPHI accelerator [1], several high intensity proton or deuteron SILHI-type sources were provided to international facilities like IFMIF, FAIR or SPIRAL2. From 2011, CEA started a new R&D program on high intensity ECR compact ion sources with the ALISES source family. The results obtained with the first ALISES source prototype [2,3] gave us the main goals for the design of the ALISES II source that ran several months on 50 kV BETSI [4] test bench and was dismounted at the end of 2016 to upgrade the test bench to 100kV. However, this source was never reinstalled and has been replaced by the ALISES III source [5] that runs on BETSI up to now. Recently, the ALISES II source and its equipment has been reassembled to be restarted on BETSI for beam characterization before sending it to the MIRROTRON company in Hungary as the proton source for a neutron beam facility. This paper describes the setup on BETSI and proton beam characteristics obtained by emittance measurements and spatial species proportion analysis. A Low Energy Beam Transport line is proposed to match the beam to the already constructed RFQ.

INTRODUCTION

ALISE II ion source was the first compact ECR light ion source at Saclay for proton beam extraction. The source installed on the BETSI test bench in February 2015 allowed a first extracted beam current of 35 mA hydrogen ion beam (H^+ and molecular ions) at 42kV, regularly extracted through a 6 mm diameter plasma electrode with a record of extracted intensity of 38.5mA at 42kV. The source operated up to 50 kV in pulsed or continuous mode. Several experiments were carried out with this source on BETSI up to 2016 like irradiation of scintillators for a 4D emittance meter or beam stop finger bombardment (Fig. 1) for S3 separator of SPIRAL2 project in Caen (France).

The beam emittance was measured with the Allison scanner designed and manufactured by IPHC in Strasbourg (France) for the FAIR project in Darmstadt (Germany). ALISES II ion source was then dismounted while upgrading BETSI test bench to 100kV.

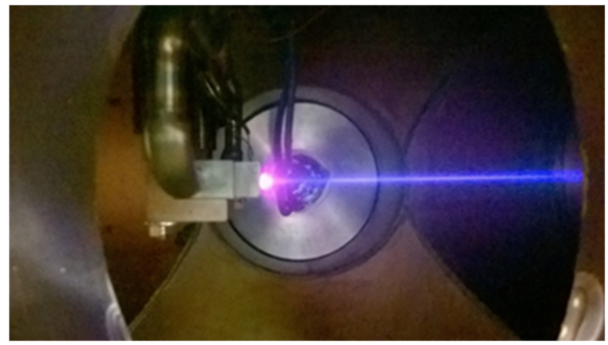

Figure 1: Finger bombardment for S3 separator of SPIRAL2 project.

ORIGINAL SOURCE SETUP AND EVOLUTION

ALISES II Ion source is a compact system originally designed to achieve the same performances as SILHI, around 100 mA of 95keV protons. A three steps ridges transition is implemented to concentrate the 2.45GHz High Frequency (*HF*) microwave onto the 90mm diameter plasma chamber axis. A copper cylinder has been machined to form the plasma chamber and the RF entrance ridged guide in one piece. A smooth ceramic cylinder built in two concentric parts realizes the insulating structure, and is in contact of the copper body. To connect the puller electrode to high voltage, 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 up to the puller connector. Both the ceramic and the source body are screwed on a copper flange and connected to the RF guide. A tunable magnetic field creates the electron resonance at the cavity's entrance when the magnetic field reaches 87.5mT to give energy to the electrons to ionize the hydrogen gas inside the plasma chamber. To extract the proton beam and also the molecular ion H_2^+ and H_3^+ present in smaller proportion, a five electrodes extraction system is used which comprises the plasma electrode (95kV), the puller electrode (70kV), two ground electrode and the electron repeller (-3kV) placed in between the later. The electron repeller prevents the electrons from the LEBT produced by ionization of the residual gas to go upstream and being accelerated toward the plasma chamber with possible damage of the boron nitride disk at the bottom of the plasma chamber, but also to avoid high power deposition on the 90° RF bend wave-guide. The plasma electrode is fixed on the copper cylinder extremity to close the plasma chamber with an appropriate

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extraction hole. The puller electrode is fixed to the source body by the mean of an intermediate ring shaped ceramic part. Both plasma chamber, ground electrode, RF bent and hollow conductor double pancake coil are cooled. The Fig. 2 shows a cut of the ALISES II source assembly.

In spite ALISES II reach 95KeV without beam extraction, we never obtain stable beam without sparks beyond 75kV. For that reason, next versions of ALISES [6,7] are developed to obtain suitable results at higher energy. One important issue of this source is the HV connection to the puller electrode, very close to the coil witch is at ground. To avoid sparks, 4-electrode extraction system without the puller electrode is used. To optimize the gap distance between plasma electrode and first ground electrode, a specific metallic cylinder is installed between the plasma chamber and the plasma electrode.

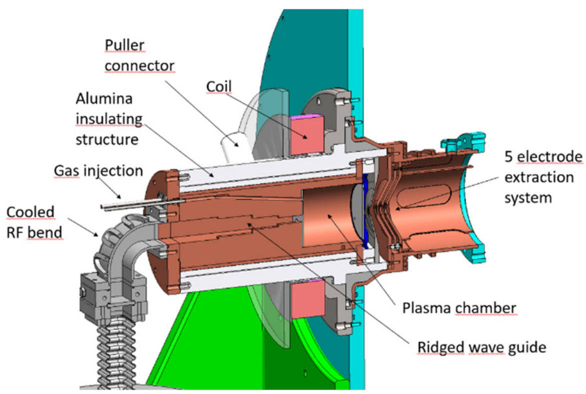

Figure 2: ALISES II source assembly.

MIRROTRON REQUIREMENTS

In the context of compact neutron source, Irfu proposed to MIRROTRON Company to loan ALISES II ion source as injector for a new facility in Hungary to produce neutrons from proton beam impacting high neutron yield target. The beam requirements from MIRROTRON are listed in the Table 1. The Twiss parameters of the RFQ input beam provided by MIRROTRON are as follows, considering 6 times the RMS, assuming waterbag distribution for the LEBT simulations.

Table 1: MIRROTRON Beam Requirements

Energy (keV)	35
Beam current (mA)	30
Duty cycle (Hz)	40
Pulse length (ms)	1.25
Vacuum (mbar) at RFQ input	10^{-6}
RFQ Input Twiss parameter	
α	3.73
β (mm/mrad)	0.34
εs π.mm.mrad (normalized emittance from source)	0.744
εu (π.mm.mrad) (normalized RFQ acceptance	2.108

INSTALLATION ON BETSI

The ion source is connected to the LEBT by the mean of a special frame at ground wich support all the RF chain. Only the back of the source up to the RF window is at high voltage. A simple polyvinyl chloride-Kapton DC-break is used to isolate the magnetron from high voltage. The coil which surround the insulating structure is at ground. The coil can slide along the axis and both longitudinal position and current setting allow optimizing the resonance for beam intensity and stability.


Figure 2: ALISES II on BETSI test bench.

EXPERIMENTAL RESULTS

The 30mA/35keV beam produced in MIRROTRON conditions at 40Hz is very stable. Long runs have been performed such as this of 100 hours recorded and visible on Fig 3. We can observe the 30mA extracted current and high voltage from the power supply and the around 20mA beam current collected at the end of the BETSI 2 solenoids beam line. Producing 1.25ms of proton beam directly from the plasma extraction is not possible due to the time of plasma ignition. Thus, it is necessary to cut in time the beam produced at least with 4ms duration as we can see on Fig 4. This can be done by a chopper or by the RFQ itself with losses on the very first vane part.

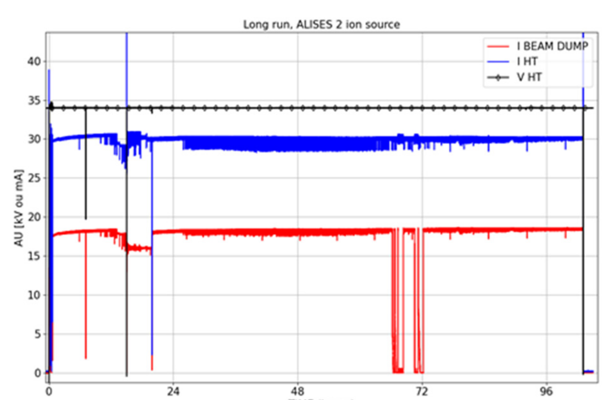

Figure 3: Long run of 100 h.

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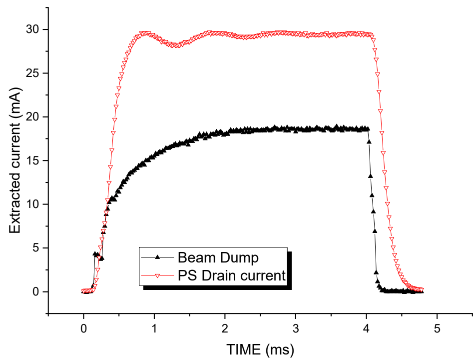

Figure 4: 4ms pulse length on BETSI beam dump.

Emittance measurements are produced with an insertable ESS type Alison scanner [8] positioned between the two solenoids. The measured proton beam rms emittance is of 1.385485 π.mm.mrad.norm. We can observe others species like H_2^+, H_3^+. Heavy elements are present suggesting a not perfect tightness of the source to the vacuum (Fig. 5).

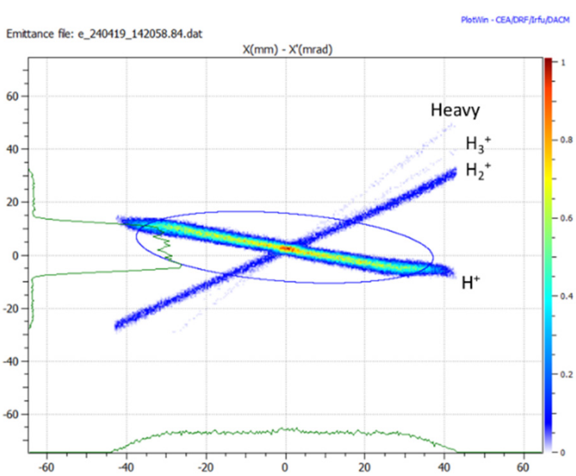

Figure 5: ALISES II emittance measurement.

The beam is also analyzed at the same position with a Wien filter [9] developed at Irfu and with first solenoid off for source characterization. This diagnostic is composed of permanent magnets providing 195 mT fixed magnetic field, and 2 plates biased from 0.V to 4.5 kV. It is motorized and scan the beam radially to determine the species proportion at each radial step from a beamlet defined by a 200µm hole diameter at beam stop diagnostic entrance. On Fig. 6, we can see the results obtained on beam axis. For this analysis, the beam is pulsed at 10Hz with a pulse length of 11ms. The FDW wire signal is sampled on 11ms with sampling frequency at 100kHz, that is to say, the pulse is defined with 110 points. The main species present in the beam are H^+, H_2^+, H_3^+, in proportion of respectively 65%, 17% and 3%. But we can observe first group of N^+, NH^+, O^+, OH^+, H_2O^+, and another one of N_2^+, NO^+, both of 15%.

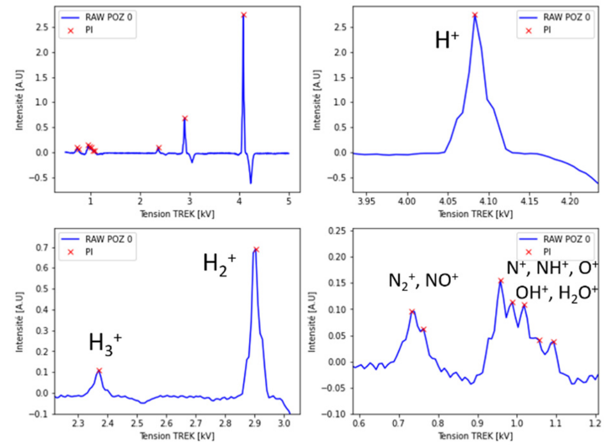

Figure 6: Analysis of ALISES II extracted proton beam.

LEBT PROPOSAL FOR RFQ INJECTION

MIRROTRON Company ask Irfu to propose a Low Energy Beam Transport line to match the ALISES II proton beam with RFQ acceptance. The design consider the first solenoid as closed to the source as possible because of solenoid non-linearity and strong beam divergence. The distance between solenoid is defined by vacuum port size. The space-charge compensation profile along the line is set similar to other lines design at Saclay, like IPHI, IFMIF. The solenoids used are similar to those used for ESS installation. To keep the LEBT as short as possible, horizontal and vertical magnetic dipole correctors are inserted inside each solenoid. The line should be as short as possible to be less than the 3 meters (Fig. 7). The parameters of the line are optimized using Tracewin code [10] with the objective of reaching the adapted Twiss parameters for the injection into the RFQ and keeping the emittance growth as low as possible (Fig. 8).

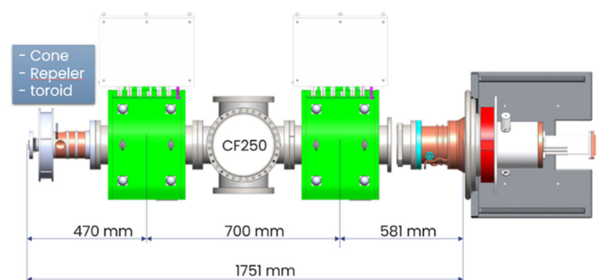

Figure 7: Proposed LEBT for MIRROTRON.

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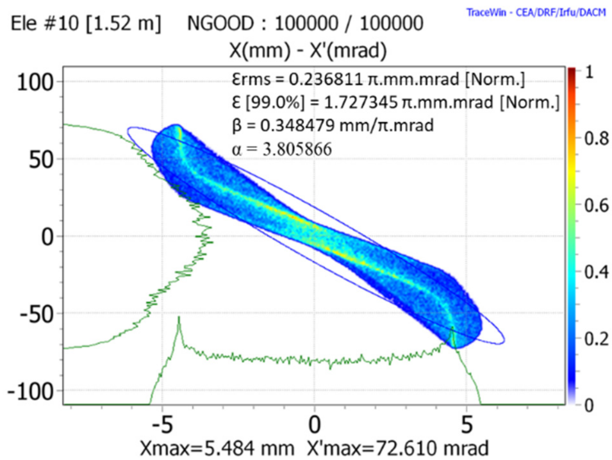

Figure 8: Beam parameters optimized at RFQ entrance.

CONCLUSION

The ALISES II source restarts in stable and reliable conditions for MIRROTRON experiment. The extracted beam purity has been qualified using the Wien filter recently developed at Irfu, allowing radial scanning to determine H^+ proportion evolution from beam center to maximum radius. From emittance measurement, beam simulations have been performed to propose a 2-solenoid LEBT for MIRROTRON installation optimized for RFQ injection. ALISES II source is expected to be delivered at MIRROTRON by the end of 2024.

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