

ECRIS DEVELOPMENT FOR THE SPIRAL II PROJECT

P. Sortais, J.-C. Curdy, A. Lachaize, T. Lamy, A. Ponton, P. Sole, J.-L. Vieux-Rochaz, T. Thuillier, D. Voulot, LPSC, Grenoble, France

Abstract

The SSI/LPSC laboratory is involved in the development of high intensity sources for the SPIRAL II driver accelerator and in the improvements of a charge breeding system for its operation inside an highly radioactive environment. The results obtained for the qualification of a 5 mAe/40 KV beam of Deuteron ions dedicated to the feeding of the driver will be presented. Concerning the heavy ions, the source PHOENIX 18/28 GHz has been chosen as injector of the driver. The first SPIRAL II beam requirement is the reliable production of 1mAe / O^{6+} and 0.3 mAe of Ar^{12+} at 60 KV. These beams developments are presently realized with the room temperature version of PHOENIX (including a new version of the source's hexapole). In parallel, an upgraded version of PHOENIX, using HTS coils, is under construction and is dedicated to the production of very high intensities of argon ions (up to 1 mAe of Ar^{12+}). A charge breeding system is also under qualification. The PHOENIX Booster source confirms that efficiency for mass around hundred can reach up to 3%. Now the efforts consist in defining precisely the 1+ beam matching for charge breeding (emittance measurements).

MICROPHOENIX 10-18 GHZ

The Micro-PHOENIX ECRIS (see Figure 1) [1] is based on a permanent magnet (Nd-Fe-B) structure allowing the use of frequencies from 10 to 18 GHz. Initially the source has been designed as an universal injector for the charge breeding test bench up to 60 KV. It is the reason why the source is built around a large mono or multi electrode extraction system. A specific permanent magnet ring with conical shape has been used at the extraction gap in order to save room for pumping and insulation gap size.

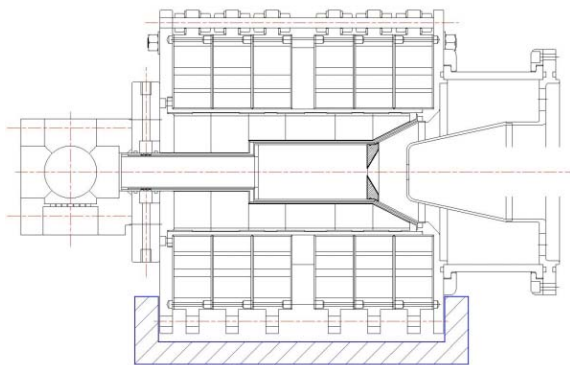


Figure 1: Micro-PHOENIX 10-18 GHz with high voltage extraction system

The source has been also used for the production of high intensities beams for the Deuteron beam of SPIRAL II.

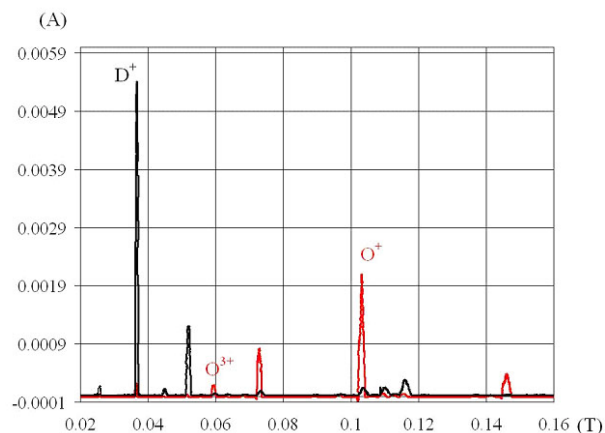


Figure 2: High voltage (40 KV) and low power (100 W) different tunings : from high current of Deuterium (5 mA) to medium current of Oxygen ions (3 mA).

Up to 12 mAe of total current beams, corresponding to 8 mAe of H^+ (38 KV, extraction hole: 5 mm), has been obtained. Without any modification the source can be used for medium current production of heavier gas or metallic ions for charge breeding tests.

The results show that a same ECR source can be used equally for the production of high currents of light ions or low currents of multicharged ions.

PHOENIX 28 GHZ / 60 KV

The PHOENIX source [2] is now working with a 28 GHz / 10 KW gyrotron transmitter delivered by the GYCOM company (Russia). The source is now mainly dedicated to the high current Q/A 1/3 development for the main SPIRAL II injector.

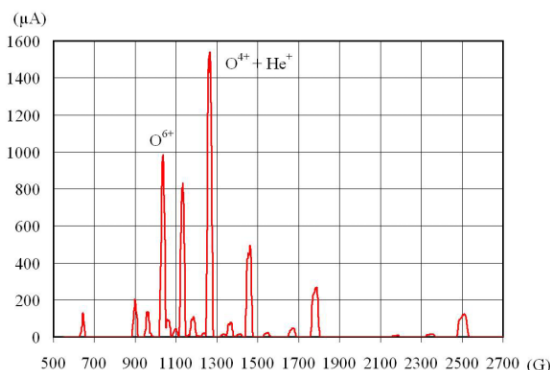


Figure 3 : Typical spectrum of O^{6+} at 60 KV with PHOENIX 28 GHZ (SPIRAL II nominal beam)

Beam and emittance measurement

The source works in pulsed or CW regime up to 1.8 KW of average UHF power. The nominal spectrum (figure 3) has been obtained at 60 KV for a total extracted current of 6 mAe with a global transmission higher than 90 % in order to minimize the losses that could induce heating of the extraction area.

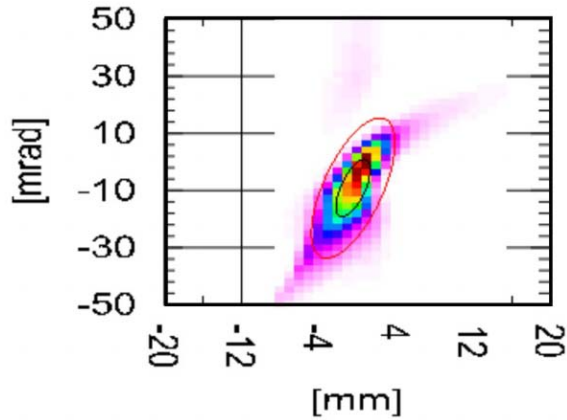


Figure 4 : 1 mAe of O⁶⁺ horizontal emittance beam at 60 KV (0.22 π .mm.mrad at 1 σ normalized)

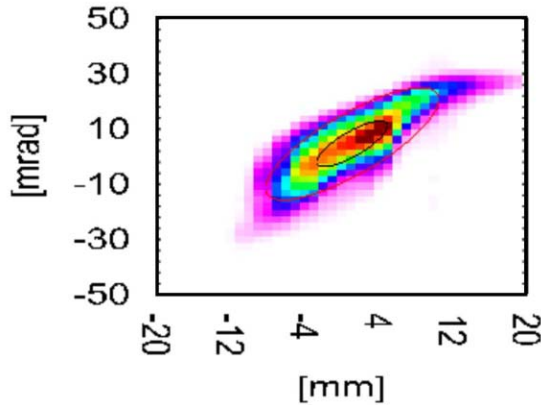


Figure 5 : 1 mAe of O⁶⁺ beam vertical emittance at 60 KV (0.22 π .mm.mrad at 1 σ normalized)

The measurement of the nominal beam is done after the magnetic mass spectrometer. The figures 4 and 5 show the nominal 1 mAe beam emittance at 60 KV (with a 10 mm extraction hole and a 45 mm monogap extractor). The 1 σ RMS normalized emittance is roughly 0.22 π .mm.mrad which easily fits the 0.4 π .mm.mrad request of the project.

A campaign

Thanks to the 90% beam transmission through our test bench, the emittance measured after the spectrometer is a clear picture of the plasma source parameters only convoluted with the beam line optic effects.. In this case it is relevant to measure H and V emittances for every Q/A produced by the source (see Table 1). We can observe that the 1 σ normalized emittance is roughly constant for the different charge states of Oxygen and independent of the current level per charge state. We can also observe

than the light ions He²⁺ from support gas and H⁺ from outgassing are produced with a higher emittance. These facts show that the different Q/A or masses can have different intrinsic characteristics inside the source. This topic is under study and will be published

Ion	Normalized emittance		I [μA]	$\beta\gamma$ Lorentz
O1+	0.2	X	120	2.74*10 ⁻³
O1+	0.14	Y	120	2.74*10 ⁻³
O2+	0.27	X	300	3.87*10 ⁻³
O2+	0.22	Y	300	3.87*10 ⁻³
O3+	0.3	X	450	4.74*10 ⁻³
O3+	0.26	Y	450	4.74*10 ⁻³
O4+/He+	0.30	X	1600	5.48*10 ⁻³
O4+/He+	0.32	Y	1600	5.48*10 ⁻³
O5+	0.21	X	800	6.12*10 ⁻³
O5+	0.27	Y	800	6.12*10 ⁻³
O6+	0.22	X	920	6.71*10 ⁻³
O6+	0.22	Y	920	6.71*10 ⁻³
O7+	0.15	X	135	7.24*10 ⁻³
O7+	0.27	Y	135	7.24*10 ⁻³
O8+/He2+	0.33	X	225	7.74*10 ⁻³
O8+/He2+	0.44	Y	225	7.74*10 ⁻³
H+	0.72	X	245	1.1*10 ⁻²
H+	0.60	Y	245	1.1*10 ⁻²

Table 1 : Systematic emittance measurements after the bending magnet (X & Y at 1 σ) for all Q/A produced by the source with a global transmission higher than 90 %.

Beam and emittance simulation

These measurements can be used to describe the initial conditions of the beam formation at the extraction gap of the source. In principle, the beam dynamics during transport can be described by 3D calculations. In this case it is possible to “rewind” the beam up to the exit of the extraction gap. At this point we can test the common initial conditions applied to the different charge states that can fit all the set of measurements. This task has been performed the “home made” EXTRACT program which is a 3D , multi charge state and ECR magnetic parameter simulation. The input of the program are the main ECR parameters ($T_{i\perp}, T_{i\parallel}, T_{e\perp}, T_{e\parallel}$, plasma potential, spatial distribution, initial space neutralisation, fringe field, etc...). The output is the set of emittance for every Q/A. It is relatively easy to fit one beam produced by the source. But to obtain the simultaneous matching of every Q/A beam emittance it is necessary to find a common set of initial parameters suitable for all the Q/A. This global fit was applied to the O⁶⁺ beam (figure 6). In this case an acceptable solution is obtained by assuming that the different Q/A are not uniformly distributed on the extraction hole. This study confirms that high charge states seem to be concentrated near the axis while the light ions are more uniformly distributed on the 10 mm extraction hole.

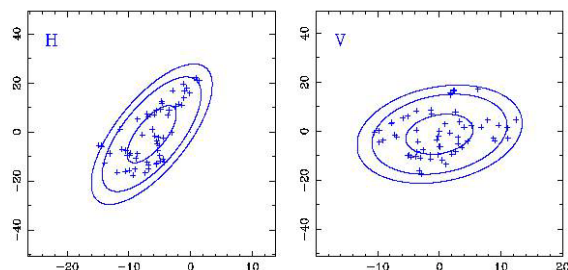


Figure 6: Simulated emittance for O^{6+} beam corresponding to the conditions of the figures 5 & 6 measurements

A-PHOENIX : UPGRADE OF THE PHOENIX SOURCE WITH HTS COILS

A new version of PHOENIX 28 GHz called A-PHOENIX is now under construction [3]. The source will use two HTS coils for the axial magnetic field and permanent magnets for the radial one. This technology will reduce the power consumption from 200 KW down to 15 KW.

The purpose of the project consists in producing up to 1 mAe of Ar^{12+} , inside a compact ECRIS insulated at 60 KV.

PHOENIX “BOOSTER” : OFF LINE AND ON LINE OPERATION

Two ECR charge breeders are now under operation. The new LPSC test bench system for off line operation is now ready for an upgrade at 18 GHz, while at ISOLDE, the CRLC Daresbury PHOENIX booster is at IS397* collaboration disposal. A third one is under commissioning at TRIUMF.

Off line at Grenoble

The new test bench has been installed inside a new laboratory [4]. In order to define the future injection requirements of the SPIRAL II radioactive beams, 1+ emittancemeters in the X and Y directions will be setup. A vertical emittancemeter is already available.

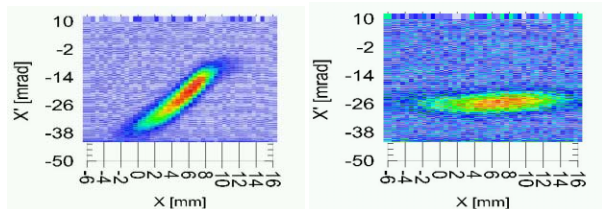


Figure 7 : Faraday cup and charge breeding beam matching of the In^{+} beam on the LPSC test bench

We have started systematic measurements of the injected test beams when the source is tuned for the charge breeding operation. The charge breeding efficiency is the ratio $I_{n+}/(n \cdot I_{1+})$, where I_{1+} is the current

measured before the final focus in the source (less than 1 m before the plasma chamber) and I_{n+} is the current of the $n+$ charge state analysed. We observe (Figure 7) that the faraday cup optimized beam and the injection optimum are quite different. For charge breeding the beam is defocused at the level of the emittancemeter. It explains why the efficiency measurement is not easy because in such a situation the current read on the Faraday cup can be minimized.

On line at Isolde

A very preliminary on line charge breeding test has been done at ISOLDE. First radioactive beams of $^{94}Rb^{+}$ and $^{96}Sr^{+}$ coming from the surface ionisation source have been injected inside the ECR charge breeder, and easily re-extracted with the charge state 15^{+} and an efficiency higher than 1%.

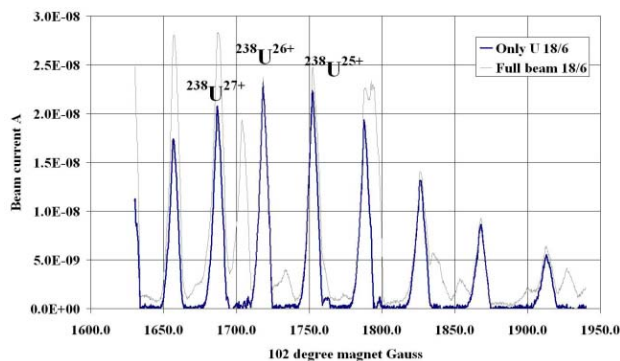


Figure 8 : ^{238}U multicharged ion spectrum obtained after injection of 30 nAe of U^{+} coming from the target and on line source (surface ionisation) at ISOLDE

The breeding tuning has been performed with a 30 nAe, ^{238}U “pilot” beam. The $n+$ spectrum obtained is reported Figure 8. Then, the switch to the radioactive ions has been easily obtained by the change of the ISOLDE and PHOENIX Booster analysing magnet values.

REFERENCES

- [1] T. Lamy, J.-C. Curdy, P. Sole, P. Sortais, T. Thuillier, J.-L. Vieux-Rochaz, and D. Voulot, “Micro-PHOENIX: Intense deuteron beams production for SPIRAL II”, Rev. Sci. Instrum. 75, 1485 (2004).
- [2] T. Thuillier, J.-L. Bouly, J.-C. Curdy, E. Froidefond, T. Lamy, C. Peaucelle, P. Sole, P. Sortais, J.-L. Vieux-Rochaz, D. Voulot, “High Intensity Ion Beams Prospects for Accelerators with PHOENIX 28 GHz” EPAC’02, Paris, June 2002, p. 1744 (2002).
- [3] T. Thuillier, J.-C. Curdy, T. Lamy, P. Sole, P. Sortais, J.-L. Vieux-Rochaz, and D. Voulot, “Advanced magnetic calculations for high magnetic field compact ion source”, Rev. Sci. Instrum. 75, 1526 (2004).
- [4] T. Lamy, J.-L. Bouly, J.-C. Curdy, P. Sole, P. Sortais, T. Thuillier, J.-L. Vieux-Rochaz, and D. Voulot, “ECRIS charge breeding: High resolution spectra and emittance”, Rev. Sci. Instrum. 75, 1624 (2004).

*DARESURY, MUNCHEN, LPSC, GANIL, ISOLDE