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LATEST PANTECHNIK'S ECR ION SOURCES PERFORMANCES

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Abstract

Electron Cyclotron Resonance Ion Sources (ECRIS) are commonly used as injectors in many accelerator laboratories and industries and therefore, pushing their limit towards very high charge state and intense ion beams for nuclear and elementary particle physics and low charge state ion beams for surface treatments and medical purposes. For these applications, several models of ECRIS are designed and developed by PANTECHNIK.
This article presents a short description of the latest ECR ion source models delivered to the clients along with their typical beam intensities.
A focus will be made on our latest Supernanogan source (14.5GHz) which has just been installed at INSP, Sorbonne Université, France. We will present improvements of highly charged ion production as a function of time and the efficiency of the new gas injection design.

INTRODUCTION

The Electron Cyclotron Resonance Ion Sources (ECRIS) [1] are among the most powerful tools capable to produce high-intensity and/or high-charge state ion beams.

Their reliability enables them to be used for research, medical therapy and surface characterization.

We present two of the latest Pantechnik sources delivered to the clients: a MICROGAN Industry® [2] and a SUPERNANOGAN® [3].

The first one is a permanent magnets source, working with 100 W RF power at 10 GHz, commonly used for monocharged ions and some low charge states production. The second one is also a permanent magnets source, working with 300W RF power at 14.5 GHz, generally used for both monocharged and multicharged ion production.

Finally, we will present the first step of our new R&D project, the design of a new gas injection. One of the most common problems in ECR sources is, in fact, the onset of plasma instabilities that may cause a reduction in the extracted current or even the extinction of the plasma. This is due to the fact that ECR sources are characterised by a vacuum environment in which we inject a gas of a few mbar with a controlled flow rate (in cm^3/min). Depending on the geometry of the mechanical parts of the source and according to the proprieties of the gas, the injection modalities are specific with induced pathways of atoms that can cause plasma disruptions. Studies show that these instabilities grow with the increase of the magnetic field and the microwave power and decrease with the increment of gas pressure [4-6].

We decided to work on a new mechanical guide within the gas injection system that would limit turbulence in critical areas of the ECR source. Like the radio frequency waves that are transported by waveguides into the plasma chamber, we made the hypothesis that a better control of the gas would limit the disturbances within the plasma.

MICROGAN INDUSTRY FOR PIMS

This source is part of a larger collaboration between Pantechnik, the Scottish Universities Environmental Research Centre (SUERC) and the National Electrostatic Corp. (NEC) in order to develop a Positive Ion Mass Spectrometer (PIMS) for carbon-14 dating [7]. In this kind of approach, unlike Accelerator Mass Spectrometry (AMS) where a sputter negative ion source is used, only positive ions generated from carbonic gas (CO_2) are energised, resulting in an increase of the overall efficiency of the machine. The generated positive carbon ion beam is then accelerated to a differentially pumped charge exchange gas cell. The interfering nitrogen and hydrocarbon molecules are removed during this process, and the exiting beam is negative. Thanks to the ECR source, the total size of the equipment is minimised.

The first test has been performed with a NANOGAN® source, revealing some critical points, such as unwanted carbon production, high-intensity carbon ion transport issues and long-term current stability concerns. We first decided to switch to another source, a MICROGAN Industry, and now, we have modified the configuration of the source (removing the DC-Bias and modifying the permanent magnetic confinement) by aiming for a lower current and an improvement of the extraction system, in order to better channel and so exploit the surplus power to obtain a C^{1+} beam of at least 850 μA. For this source, we have designed a plasma electrode with an aperture diameter of 4 mm, followed by a simple gap extracting puller, an Einzel lens, and a mass electrode, to adapt de beam at the entrance of the dipole magnet.

Measured Performances

We recently tested our last PIMS bench at Pantechnik, optimizing the electrodes positions and tensions, in order to reach the current of C^{1+} requested by the client.

Table 1 shows the running parameters and the extracted C^{1+} beam intensity. Figure 1 shows the measured spectrum obtained with the injection of CO_2 gas into the plasma chamber. We can see that the measured current is well above the client's requirements.

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Table 1: Running Parameters and Extracted Beam Intensity of MICROGAN Industry for PIMS

Frequency	10 GHz
RF Power	100 W max.
Extraction tension	35 kV max.
Total extracted current	3.25 mA
C^{1+} extracted current	925 μAe

The bench has already been sent to NEC in order to be integrated to the rest of the line and the installation at the final client's site is scheduled for May 2023.

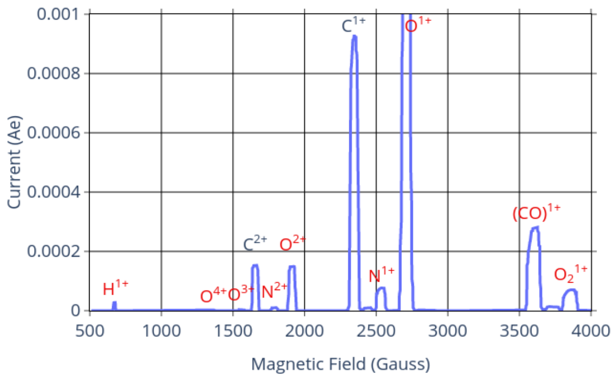

Figure 1: FAT (Factory Acceptance Test) spectrum of C^{1+}.

SUPERNANOGAN

The SUPERNANOGAN source and his extraction system have been developed in order to produce multicharged ions, up to Ar^{16+}. This bench has been connected to the "Low Energy" line at INSP (France), composed by a magnetic dipole and three quadrupoles with steerers (previously purchased from Pantechnik) for a q/m selection and a beam shaping. Along the beam line, slits, Faraday cups and a GANIL profiler allow monitoring the selected ion beam (Fig. 2).

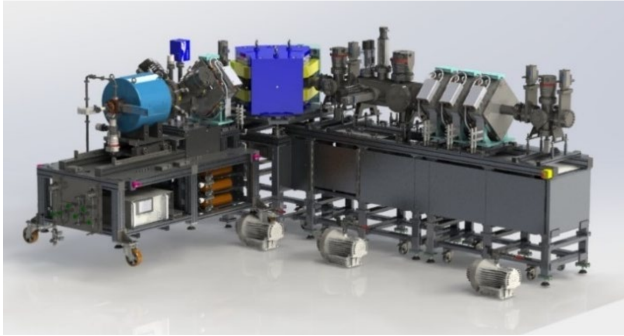

Figure 2: View of the SUPERNANOGAN ion source connected to its dedicated beam line.

We first performed several extraction simulations with IBSIMU [8] in order to obtain a suitable value for the emittance and intensity of various extracted Ar^{q+} beams (from Ar^{11+} to Ar^{16+}).

We simulated a beam composed of 30000 particles, with a beam distribution comparable to the experimental data of a previous source and an electron temperature of 10 eV passing through a plasma lens with a 6 mm aperture. The mesh for the simulation has been considered to be 0.25 mm and the calculation has been performed with 50 iterations. The resulting simulation of the extracted beam is shown in Fig. 3.

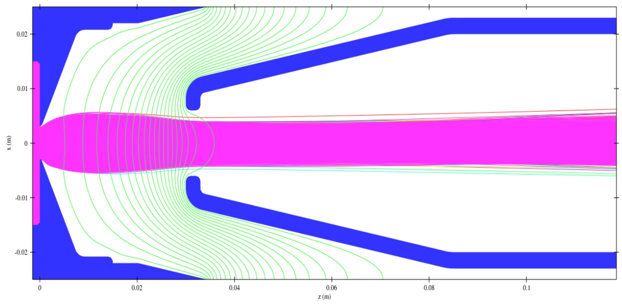

Figure 3: Extraction simulation at 15 kV of an argon beam performed with IBSIMU.

The resulting argon beam has been fed into the TraceWin transport code [9, 10], in order to simulate the line optic elements by considering several characteristics of the beam, such as space charge. Figure 4 shows the simulation of the Ar^{16+} beam obtained for an extraction tension of 15 kV passing through the electrodes, a quadrupole, the Pantechnik's magnetic dipole and a slit and reaching the Faraday cup.

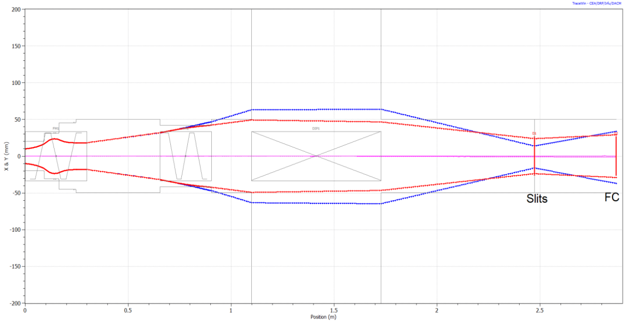

Figure 4 : Simulation of the Ar^{16+} beam passing through a quad and a dipole, for an extraction tension of 15 kV.

The simulated normalised emittance at 4 RMS is 0.27 π mm mrad, with an alpha parameter of -0.136 and a beta of 0.084 mm/mrad. This corresponds to a geometrical emittance of 77 π mm mrad.

Measured performances

We successfully performed both FAT (Factory Acceptance Test) and SAT (Site Acceptance Test) in the last months.

The first criterium of acceptance was about the vacuum levels at injection and extraction, which needed to be less than 10^{-7} mbar. The best measured values at injection and extraction were respectively 8×10^{-8} mbar and 5×10^{-8} mbar.

We next extracted a beam with a source tension of 10 kV, after optimization of the source and optic extraction parameters for different charge states. Up to now, using oxygen as support gas, the best results have been obtained optimising Ar^{13+}, for which we measured a beam current of 3.5 µA (as can be seen in Fig. 5). In the same spectrum, we can observe the presence of Ar^{16+} with an extracted current of 40 nA.

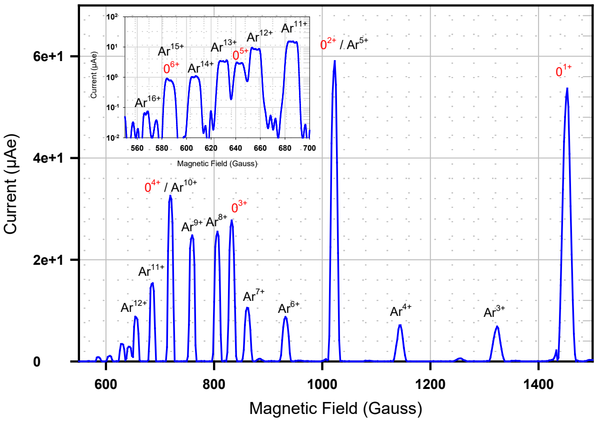

Figure 5 : Experimental spectrum optimised for Ar^{13+}.

New Gas Injection

First tests of our new gas injection prototype have been performed with the same ECR ion source at INSP.

Through a specific study on gas flow rates, we were able to show that the critical point is the gas injection, due to the fact that the usual one is situated above the vacuum turbopump, impacting the gas flow rate and therefore the stability of the plasma. We decided to design a new injection system with an axial gas outlet, and we moved the turbopump away from the gas injection point (Fig. 6).

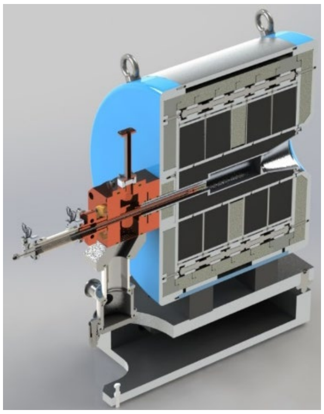

Figure 6 : Axial cut of the SUPERNANOGAN with the new injection system.

In order to estimate the validity of our prototype, we recorded two spectra, show in Fig. 7, obtained using the same set of parameters (source and extraction tensions, RF power). Due to the variation in the design, the only difference lays in the injected gas quantity. Our prototype needs less gas to work, since we inject the gas directly into the plasma chamber.

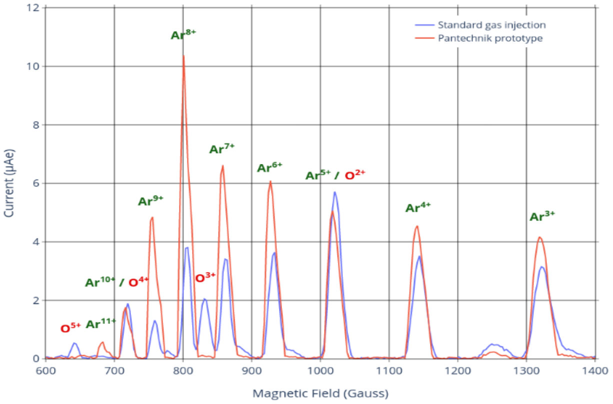

Figure 7: Experimental spectra comparison between the new gas injection prototype (red) and the standard injection (blue) obtained with the same extraction and RF power set of parameters.

As we can see, the charge state distribution is very different: the intensity of medium charge state ions currents is higher with the new prototype injection system. On the other hand, the extracted beam current for Ar^{11+} is five times lower. A possible explanation for these results may lay in the onset of turbulences into the plasma chamber, caused by the presence of effusive jets of gas from the injection. These may cause an inefficient absorption of the radio frequency wave.

CONCLUSION

Two new sources have just been delivered to the clients, both with satisficing results regarding performances. It has been demonstrated that the new system of the MICROGAN Industry for PIMS is capable to deliver more than 900 µAe of C^{1+}, and has been integrated to the NEC system in order to allow carbon-14 dating.

The SUPERNANOGAN has been successfully installed and tested at the client site with the production of highly charged argon ion beams of good intensities (a few µA for Ar^{13+} and a few tens of nA for Ar^{16+}).

Concerning the new gas injection, the tests showed that possible effusive gas jets may impact the production of high-charge state ions. In order to better understand the causes of these results, we will perform some gas flow simulations of the electrode design.

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