MULTIGAN®: A NEW MULTICHARGED ION SOURCE BASED ON AXISYMETRIC MAGNETIC STRUCTURE

L. Maunoury#, J.Y Pacquet. M. Dubois, P. Delahaye, P. Jardin, P. Lehérissier and M. Michel
GANIL, Caen, France
C. Pierret, CIMAP, Caen, France
X. Donzel, G. Gaubert, R. Leroy* and A.C.C. Villari, PANTECHNIK, Bayeux, France
S. Biri, ATOMKI, Debrecen, Hungary

Abstract

The regular ECR ion sources, allowing the production of multicharged ions, have openings only at their two ends. Based on the MONO1000 ECRIS [1] concept and experience, a new multicharged ECR ion source has been designed with a large opened space in the middle of the source enabling a direct contact with the ECR plasma. This source will combine the advantages of the axisymetric magnetic structures made only of permanent magnets with a high operating frequency.

The magnetic structure calculations as the mechanical design and stress will be described in details. An estimation of the electronic energy distribution has been calculated using the TrapCad code [2] and thus the performances of the source have been deduced. A rough calculation of the beam extraction and formation has also been calculated taking into account of the several fields (magnetic and electric) surrounding the extraction system.

The ion source presented in this paper is a prototype which shall validate the magnetic concept and which shall confirm the expected performances. The next step will be the design of an optimized ECRIS according to its future applications.

INTRODUCTION

In the framework of the SPIRAL1 facility upgrade, the design of a new ECR ion source ionizing radioactive metallic species in multicharged states is an alternate way in the actual NANOGANIII TIS system. It should contain open sides in order to have a close connection between the hot target and the plasma. Obviously the ECRIS should ionize the radioactive atoms with a high efficiency that requests to operate the ECRIS with a high value for the RF frequency. Based on an existing Mono1000 magnetic system, the prototype is under construction to demonstrate the ability of such an ECRIS to produce multicharged ions with an intermediate expected average charge state <Q> ≥ 2. This development is realized in collaboration with the Pantechnik company which has applications for this type of ECRIS.

MAGNETIC AND MECHANICAL DESIGN

The magnetic structure (principle has been used in two other ECRIS's [3,4]) takes back the two Mono1000 rings made of permanent magnets (NdFeB Vacodym 655HR) coupling with iron (ARMCO) which concentrates and transports the magnetic flux lines in the centre of the source. The magnetizations of the rings are similar and are aligned on the axis of the source. In our case, the trick is to shape the iron as to bring the maximum magnetic flux for creating a closed B iso-magnetic surface having a high value (here the last closed B iso-module reaches 4800 Gauss) far from the saturation of the iron (saturation value is 1.8T).

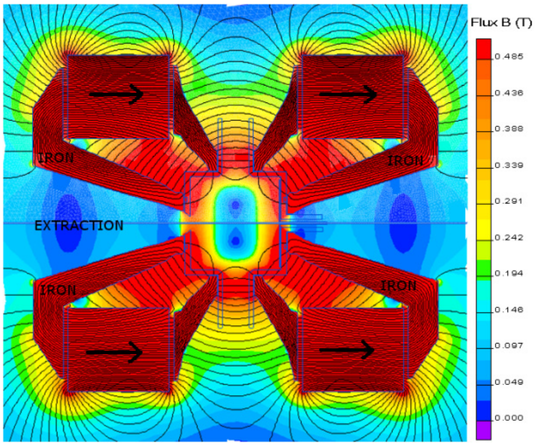

Figure 1: calculated magnetic structure with QuickField software

Figure 1 displays the output calculation made with the QuickField software: value of the total magnetic field at each point of the source. The magnetic field values decrease from the ECRIS wall down to almost 0 in the middle of the source. The magnetic field is lowered voluntarily in the extraction region in order to make a type of "ion funnel". Using a RF frequency of 7 GHz, corresponding to a resonant magnetic field of 2500 Gauss, the mirror ratio is 1.92.

After the iron design and the permanent magnet ring used, a mechanical design of the source has been realized. Figure 2 shows a sketch of the source. The ion source is relatively compact: length is 252 mm with a total diameter of 280 mm. The dimensions of the plasma chamber (grey) have been chosen such an RF wave with a frequency higher than 5.5 GHz can propagate inside the cavity. A movable disk is set on the back of the source, it has double objectives: RF tuning and plasma bias (negative voltage). Hence the RF is injected directly inside the cavity with a direct connection between the RF guide and the plasma chamber.

#maunoury@ganil.fr
* also at GANIL

Mechanical calculations have been performed about the stress applied on different parts of the source. Reinforcements (blue) on the iron pieces had to be added due to the magnetic strengths applied on the plasma chamber. The maximum displacement is 0.04 mm. Thermal calculations have been also carried out.

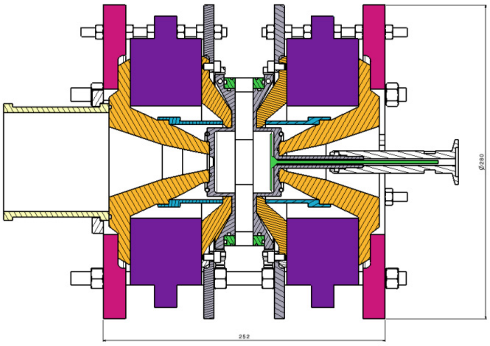

Figure 2: Mechanical design of the source

The maximum temperature elevation is around 70°C using 500W RF power and a water cooling down system. This will be still improved to get 50°C maximum.

TRAPCAD CALCULATIONS

The TrapCad code, developed by the Atomki ECR team, is a PC simulation tool which can be used to predict the general behavior of a source and, in a certain way, the performances of an ECRIS [5, 2]. TrapCad is only used to study the electron population and the ability of the source to heat up these electrons. It is why the calculation time is always below 50µs. In these conditions the particle collisions can be neglected (in the case of Multigan $1/\nu_{ee} \sim 200\mu s$ [6]). The typical fixed parameters for the TrapCad calculations were: 20000 initial electrons, energy range from 0.1 to 1 eV, electrons are randomly distributed on the ECR resonance surface. The variable parameters were the time, RF frequency and RF power. In the following, the electronic density in an ECR ion source, which varies with the square of the RF frequency, is taken into account. The electronic density reference is the Multigan ECRIS operating at 7 GHz.

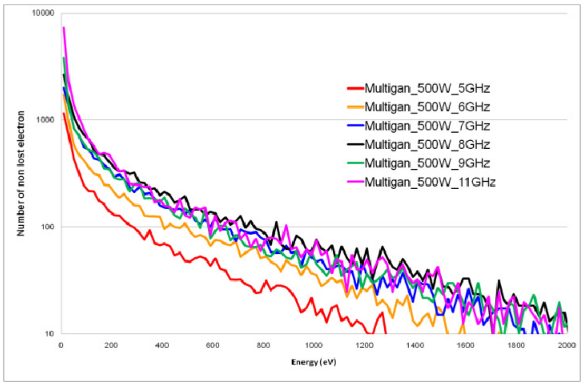

Figure 3: Evolution of the non lost electron distributions with the RF frequency of the injected wave

Figure 3 shows the evolution of the non lost (plasma) electron population with the RF frequency of the injected wave. The power and time were set to 500W and 1µs respectively. For RF frequencies below 7 GHz the non lost electrons are less energetic. From 7 GHz up to 11 GHz the distributions are really close but the 8 GHz is a little above. Another calculation at 7 GHz and 500 W of RF power gives an average energy of the non lost electrons of 380 eV. This energy is obtained in 5 µs.

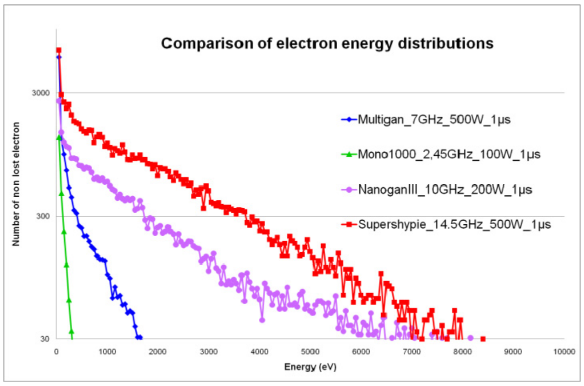

Figure 4: Non lost electron population for four ECRIS's

Let's consider now the case of phosphorus ions. Considering that the maximum single ionization cross section energy corresponds to energy of $\sim 10E_{ionization}$ for one charge state [7], it should be possible to ionize phosphorus atoms up to 5+ ($E_{ionization}$ = 67.9 eV). Regarding the reference [8], multicharged phosphorus ions have been already produced up to 2+ charge state with Mono1000 ECRIS at 100W of RF power. Figure 4 shows that, in the energy range of 1 – 700 eV (charge state range 1+ – 5+) the ratio of the non lost electrons population for Multigan 7GHz and Mono1000 2.45 GHz varies from 2.5 up to 100. These arguments reinforce the potential of multicharged ion production of this ECRIS. The Multigan non lost electron population is located between that of NanoganIII and Mono1000 as expected. These sources having an average charge state of 2.8 and 1 respectively [2], it is reasonable to expect for Multigan a value around 2.

EXTRACTION CALCULATIONS

A rough calculation of the extraction has been also carried out. Due to the high magnetic field gradient in the extraction region ~39 T/m, the ions extracted should be highly perturbated (it is roughly twice the SUPERSHyPIE ECRIS value). The extraction calculations are based on the methods described in [9]. In that paper, the space charge was neglected. The goal was to compute at first order the characteristics of the extracted beam. Figure 5 shows the extraction geometry which gives the best results. Another difficulty comes from the fact that the shape of the iron imposes a limitation of the possible shape of the first electrode. The plasma electrode is directly designed in the plasma chamber. Its aperture diameter is fixed at 7 mm. An intermediate electrode

(U_{inter}), biased positively, should have been added (figure 5) in order to get a small beam with an emittance value as small as possible.

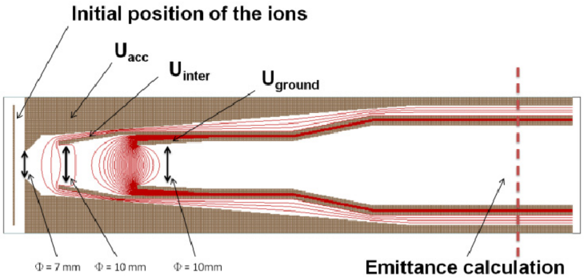

Figure 5: Sketch of the Multigan extraction geometry

As it is shown in figure 5, there are two regions: one between the plasma electrode and the intermediate electrode which is located inside the higher magnetic field gradient and the second region separating the intermediate electrode and the grounded electrode. The initial ions are made of phosphorus ions (mass = 31 u.m.a.) distributed either randomly or concentrated [9] on a disk of 10 mm diameter. They are located a few millimeter backward the electrode plasma biased at the plasma potential of 10V. Their initial energy is 0.5 eV and both the azimuthal and elevation angles vary from -90° to +90°. The charge states were fixed from 1 to 6 with a homogeneous number of ions: 2000 per charge.

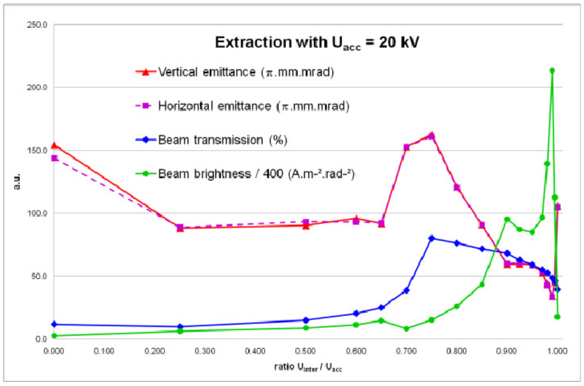

Figure 6: Evolution of the emittances, ion transmission and brightness of a phosphorous beam

The figure 6 displays the evolution of the emittances, ion transmission and brightness with the ratio $R = U_{inter} / U_{acc}$. The emittances present a plateau from R = 0.25 to 0.6 then a maximum for R = 0.75 and a diminution. The ion transmission which corresponds to the ratio of the ion number at the emittance calculation over the initial ion number follows roughly the same behaviour. The brightness which is more or less the ratio of this transmission over the emittances product increases slowly up to R = 0.8 and arises suddenly for reaching a maximum at R ~ 0.9 before dropping down. This can mean for R > 0.8 that the first extraction region acts smoothly on the ion angles for preparing them before to be focused by the second region which makes the main acceleration (90%).

CONCLUSION

A development of a new ECR prototype using the magnetic structure of the Mono1000 ECRIS has been undertaken by collaboration between GANIL laboratory and Pantechnik company. The objective is to get an ECRIS with large opened space in the middle of the source able to ionize atoms in multiply charged states with $<Q> \geq 2$. It has been shown this new ECRIS is mechanically stable and the effective cooling of the plasma chamber allows injecting high RF power. The magnetic structure and the plasma chamber dimensions have been designed for RF waves with frequencies from 5.5 to 13 GHz. A movable electrode will serve for RF tuning and to bias negatively the plasma. The TrapCad code gave results for the expected performance of the source: the optimal RF frequency should be around 8 GHz. The distribution of the non lost electron population calculated is between those of the Mono1000 and NanoganIII ECRIS that reinforces our confidence in the potential of this source to produce multicharged ions. The preliminary extraction geometry calculations show that, despite the high magnetic gradient in the extraction region, it is possible to get a beam with reasonable emittance values. Pantechnik company built up a test bench where this prototype will be experimentally tested at the beginning of 2011. Depending on the results a new ECRISs will be specifically developed towards the objectives of each partner.

REFERENCES

[1] P. Jardin et al., "Mono1000: A simple and efficient 2.45 GHz electron cyclotron ion source using a new magnetic concept", RSI, 73, 789 (2002)

[2] L. Maunoury et al., "Studies of the ECR plasma using the TrapCad code", PSST, 18, 015019 (2009)

[3] C. Huet-Equilbec et al., "MONOBOB: A radiation-hard and efficient 2.45 GHz ECRIS dedicated to radioactive ion production", NIMB, 240, 752 (2005)

[4] F. Labrecque et al., "MISTIC: Radiation hard ECRIS", NIMB, 266, 4407 (2008)

[5] S. Biri, A. Derzsi, E. Kekete and I. Ivan., "Upgraded TrapCad code", High Energy Physics and nuclear Physics, 31 165 (2007)

[6] J.L. Delcroix and A. Bers, "Physique des plasmas", Savoirs Actuels / CNRS Editions (1994)

[7] S. Matt et al., "Experimental and theoretical determination of electron ionization cross sections for atoms, molecules and molecules ions relevant to fusion edge plasmas", Czechoslovak Journal of Physics, vol 48 (1998), Suppl 52

[8] L. Maunoury et al., "Production of charged (singly and multiply) phosphorous beams with electron cyclotron resonance ion source", RSI, 77, 03A324 (2006)

[9] L. Maunoury et al., "Extraction from ECR ion sources: a new way to increase beam brightness", proceedings of the International Workshop on ECRIS, Chicago, IL, USA, 224 (2008)