RECENT DEVELOPMENTS IN ECR ION SOURCES

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Abstract

There are now two main fields of the ECR ion sources development. The first one consists in going on the upgrade of the current delivered by the sources, mainly in connection with the production of secondary beams. The second one is the study of the improvement of the particle efficiency of sources for the ionization of rare radioactive species. We will make a review of the most advanced devices for production of stable gaseous and metallic ions and specially the high frequency studies dedicated to the ion sources using a 28 GHz gyrotron or higher. We will see that for cyclotrons, the main demand consists in upgrading the current of relatively low charge state ions like in GANIL or MSU. The second aspect is the use of ECR ion sources as high efficiency charge breeder for radioactive ions. This method, called "1+/n+", consists in injecting and decelerating a monocharged beam extracted from a simple radioactive source and then, in re-extracting the highest number of injected ions as multicharged ions. We will show that this method could be also suitable for the production of metallic ions by replacing the primary source by a high temperature evaporator of monocharged metallic ions.

1 INTRODUCTION

A lot of heavy ion accelerators are multi stage accelerators so in order to optimize the efficiency of acceleration they use stripping process at several steps of acceleration. In this case the charge state at the source can be a compromise between the intensity and the charge state suitable for acceleration. So generally it is a quite low charge state like Pb^{27+} at CERN, U^{25+} at GSI or Ar^{10+} at GANIL that is used for injection in the accelerator. The origin of this program comes from the request of CERN to multiply the currents of the present charge state by a factor 10 in order to achieve the suitable brightness of the beam for the future LHC heavy ion experiment.

2 CURRENT DENSITY AND PLASMA PARAMETER

The two main parameters that measure the capability of a plasma to produce multicharged ion are the electronic density n_e and the confinement time of the ions τ_i especially if we assume that the suitable electronic energy can be achieved in any case with the efficiency of the ECR heating.

The product $n_e\tau_i$ is a rough measurement of the collision rate so it is roughly proportional to the $<Z>$ of the ion in the plasma. The ratio n_e/τ_i is roughly proportional to the flux of particles arriving to the wall so the current density of a given charge state.
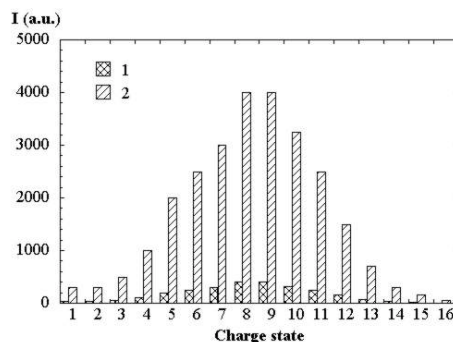

Figure 1. Low flux and high flux charge state distribution with constant $<Z>$

There are different ways of modification of this two fundamental parameters in order to expect a change of the currents that we can extract from the discharge. Presently the request of many accelerators consists in increasing the currents that we extract without modifying the charge that is used for the injection. In the case of CERN we look for a factor 10 on the currents.
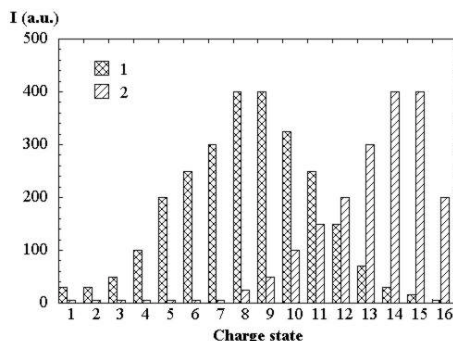

Figure 2. Low flux and high $<Z>$ charge state distribution

A first one consists in trying to multiply the density and the lifetime by a factor 3 in order to multiply the $n_e\tau_i$ by a factor roughly 10. In this case we can remark that the ratio n_e/τ_i remains roughly constant. So we will observe an increase of the $<Z>$ extracted from the source with a total

electrical current roughly constant (Figure 2). Of course we will observe a drastic increase of the current of some very high charge state but the useful current of medium charge state will decrease. In our opinion it is the situation that we observe during the so-called "frequency-magnetic field scaling" when we produce interesting currents of very high charge state of the very high charge but the electrical currents of the medium charge states remains quite low.
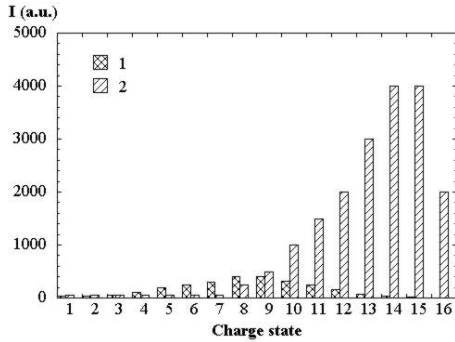

Figure 3. Low flux and high $<Z>$ / high flux charge state distribution

A second way could consist in multiplying the density by a factor 10. In this case the $n_e\tau_i$ and the ratio n_e/τ_i will be multiplied by a factor 10. So the current and the $<Z>$ will be increased (Figure 3). Of course this situation could be a dream for a lot of application but this drastic increase of the density is not very realistic and finally not really answer to the problem of the high current of medium ions.

The third way that we would like to use consists in multiplying the density by a factor 3, that seems achievable with a 28 GHz discharge and optimising the confinement time with a division by a factor 3. In this case the $n_e\tau_i$ product remains constant and only the ratio n_e/τ_i is multiplied by a factor 10. So the current is multiplied by a factor 10 and the $<Z>$ remains constant. We think that this functioning point could be achieved in a quite simple 28 GHz classical source working with a mirror ratio around 1.5.

At this point we must keep in mind that it will induce two important technological consequences concerning the UHF power and the extraction voltage. If we plan to work with high density and low confinement it means that the loss rate of the particles will be very high so that will need of a strong UHF power density in order to maintain the electronic density. The second one concerns the extraction voltage that we have to match to the current density in order to respect Child-Langmuir conditions for the extracted beam. It is the origin of the PHOENIX 28 GHz program.

3 PHOENIX 28 GHz

3.1 General Layout

The purpose of this project consists in using a very high density plasma in a quite medium confinement device in order to generate very high current density beams for the generation of high currents.

It is the reason why PHOENIX is a compact machine matched to a 10 KW 28 GHz gyrotron. The plasma chamber is a 74 mm in diameter and 300 mm in length tube with a direct and axial injection of the wave. The waveguide is a TE01 oversized for the 28 GHz frequency and it has a diameter of 32 mm (Figure 4).
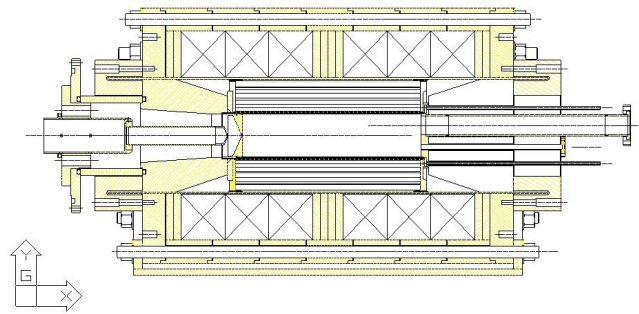

Figure 4. The source PHOENIX 28 GHz

An important point is the introduction of a thick insulator (3 mm) between the coils and the inner part of the source in order to achieve an insulation up to 60 KV for the extraction of high current density.

3.2 Magnetic structure

The axial magnetic profile is just matched to a 28 GHz ECR frequency for a mirror ratio of roughly 1.5. In this case the maximum field is 1.6 T at the injection of the wave and 1.4 T at the injection for a 1300 A current inside the coils. Final electrical consumption is roughly 200 KVA in this case. The radial field is done with a classical 80 mm in diameter FeNdB hexapole delivering 1.5 T on the pole.
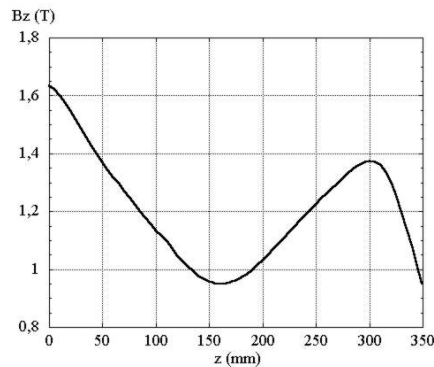

Figure 5. The axial magnetic profile of the PHOENIX 28 GHz source

3.3 Preliminary results

Only very preliminary results have been obtained with the source. In a first step we have only try to identify the possibility of production of very high current densities (above 20 mAe/cm^2). We have started the source at 25 KV and with an 8 mm hole like on any other source, but we have immediately observed a very high extracted current above 40 mAe and with a quite poor transmission. It is the reason why we have switched to a 2 mm extraction hole in order to be able to control the beam with a good transmission efficiency.

We can see (Figure 6) a first Ar spectrum obtained with an efficiency of transmission above 90% so it is a good image of the flux of ions out coming of the source. In this case we can observe that the corresponding current density is above 20 mAe/cm^2 so roughly 5 to 6 times higher that in a classical source (and with some KW of UHF power). We have also observed higher current
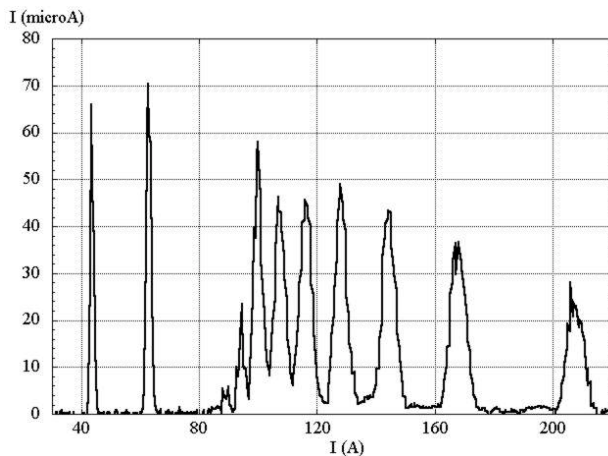

Figure 6. Preliminary Ar spectrum
obtained with PHOENIX 28 GHz.

density (up to 60 mAe/cm^2) but in this case the global transmission was smaller. We think that these results are very encouraging for the future and we now start the program of beam transmission optimization (re-opening of this extraction hole and upgrade of the extraction voltage up to 60 KV).

Another encouraging result has been the extraction and the transmission at 30 KV of 10 mAe (Ø 2 mm) of Hydrogen beam corresponding to a brightness closed to 300 mAe/cm^2.

4 SMIS 37 GHz

4.1 General Layout

In parallel with the PHOENIX experiment a second device developed at the IAP of Nizhny Novgorod, (RUSSIA) and called Simple Mirror Ion Source 37.5 GHz is used to study the production of very high current density of multicharged ions.

Here a new step in the reduction of the confinement is done. The source is reduced to a simple axial magnetic mirror placed around a simple stainless steel plasma chamber (Figure 7). There is no hexapole and the pulsed UHF power is injected on the axis of the source through a glass window. In this case the extraction hole is reduced to 1 mm only.

Due to technological limitations the magnetic field is pulsed and has a maximum value of 2.5 T during roughly 10 ms. The pulsed duration of the UHF power is limited by the high voltage power supply and has a maximum duration of 1 ms with a peak power of 130 KW.

Another specificity of this device is the use of a quasi optical coupling for the UHF injection. The power extracted from the gyrotron is a gaussian beam that is refocused by a dielectric lens before the injection under
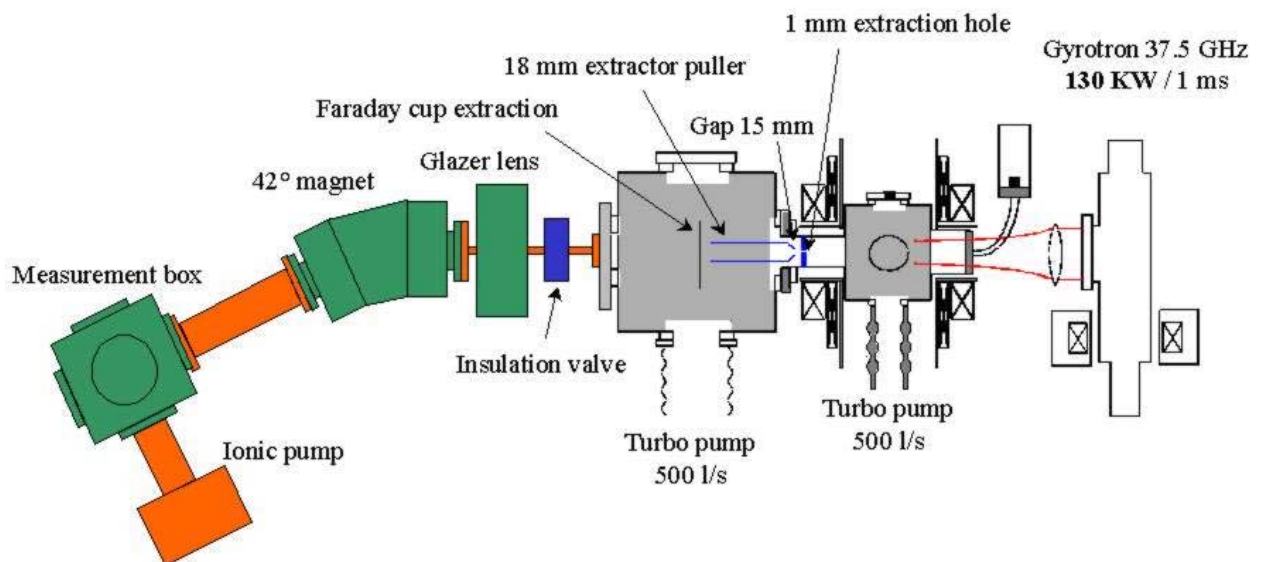

Figure 7. SMIS 37.5 GHz experimental set-up

vacuum through the glass window of the source. In this case there is no physical connexion between the transmitter and the source so no problem of insulation and power density transmission.

The source can presently only biased up to 15 KV and the analyse of the beam is done with the former charge breeding beam line of ISN/Grenoble that has been transferred to Nizhny Novgorod.

4.1 Preliminary result

We can see Figure 8 a first result obtained for Nitrogen (with C from out gassing). Here we show the spectrum during the 1 ms pulse of the UHF power and at 5 steps of 200 μs.
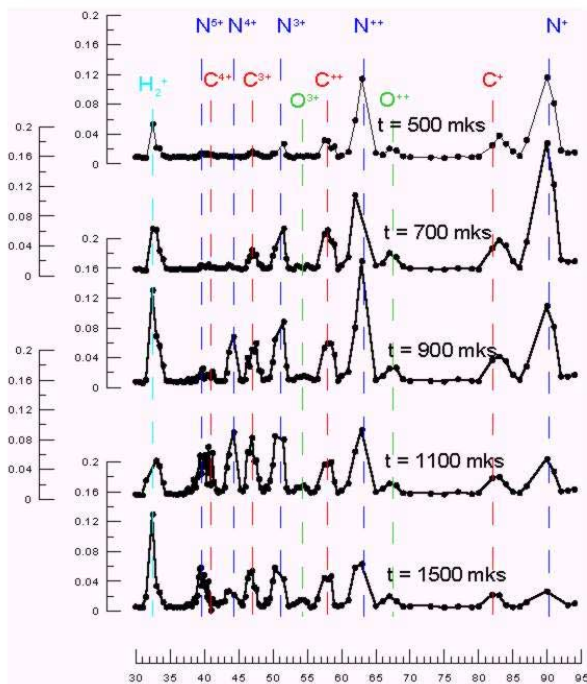

Figure 8. Charge state distribution of N obtained with SMIS and with 200 μs steps

We see that a full spectrum of multicharged ions of Nitrogen can be produced in an opened trap. Here we have a clear illustration of the compensation of the reduction of the confinement time by a very strong power density used to maintain the electronic density. The peak power is 60 KW for a 1 litre plasma chamber and the rising time of the current of N^{4+} or N^{5+} is only some hundreds of μs.

In this case the total current extracted from the source is around 5 mAe with roughly 3 mAe measured at the level of the extraction Faraday cup (Figure 7). The current density reaches more than 400 mAe/cm^2 that is roughly 10 times more than with PHOENIX and 100 times than a classical source. Of course the transmission is very poor because of the low extraction voltage and the poor acceptance of the beam line. This aspect will be upgraded in a near future but the purpose of this first experiment consists in showing the possibility to produce

multicharged ions inside an ion source without radial magnetic field.

5 CHARGE BOOSTER EXPERIMENT

5.1 Charge breeding at 14.5 GHz

The new version of the PHOENIX Booster source now working at 14.5 GHz and its application to the production of radioactive ions have been recently described [1]. We will now just shown that the charge breeding method can be extended to the production of stable metallic ions. We can see Figure 9 a spectrum of multicharged Indium ions produced with a maximum current of 20 μAe for the charge 21+ and obtained after the injection of a 39 μAe In+ beam.
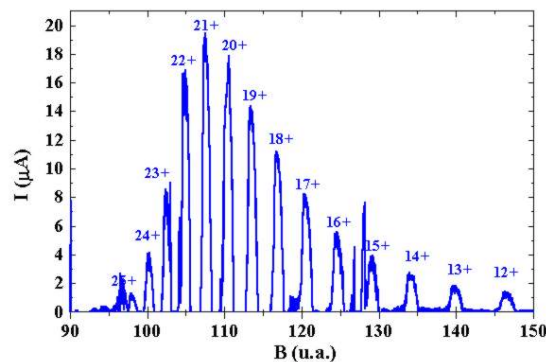

Figure 9. Medium current Indium spectrum obtained by 1+ ion injection.

It means that we can also produce beams of metallic with a level of current compatible with main request of cyclotron experiment. The interest is that with the charge breeding we can move outside the multicharged ion source the evaporator of metal. By this way the stability of the ECR source is similar to the functioning with the gaseous ions and we can choose the best suitable "1$^+$ evaporator" for a given type of ions.

6 CONCLUSION

We just start new compact devices working with high frequency and high power density and we clearly observe a drastic increase of the current density of multicharged ions. This currents densities can be produced in a minimum |B| structure with a power density in the range of 5 KW per litre or in an open magnetic trap with a power density in the range of 50 KW per litre. The next step is now the control of the beam formation in the characteristic environment of an ECR ion source for the production of multi-milliamperes multicharged ion beams.

REFERENCES

[1] T. Lamy, R. Geller, J.-L. Bouly, N. Chauvin, J.-C. Curdy, A. Lacoste, P. Sole, P. Sortais, T. Thuillier, J.-L. Vieux-Rochaz, "The Development Of The ECRIS Charge State Breeder For Generating RIB's", CAARI 2000, Denton, TX, Nov. 2000.