High current, high frequency ECRIS development program for LHC havy ion beam application

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High Current, High frequency ECRIS development program for LHC heavy ion beam application

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Abstract

A research program with the aim of producing pulsed currents with hitherto unequalled intensity of Pb^{27+}*, with length and repetition rate compatible with those desired by CERN (1 mAe / 400 μs / 10 Hz in the context of future heavy ion collisions at LHC) is organised in a collaboration between CERN/GSI/CEA-Grenoble and IN2P3-ISN-Grenoble. Two main experimental programs will be carried out : (i) tests with the LNS-Catania team on the SERSE superconducting source with a 28 GHz gyrotron, (ii) tests on a non-superconducting source (new source at Grenoble) with a 28 GHz gyrotron. For this purpose CEA/DRFMC has borrowed from CEA a 28 GHz - 10 kW gyrotron transmitter. The project includes also the construction of a source body, by ISNG, with conventional coils and permanent magnets for working at the frequency of about 28 GHz and biased up to 60 kV. This source called PHOENIX will run on a test bench at ISN. PHOENIX is an improvement of the present ECR4-14.5 GHz/CERN source, having a mirror ratio R=2 at 14.5 GHz, and R=1.7 at 28 GHz (possibly reaching 2.1 T on the axis of the source), and with a plasma volume up to 2.5 larger. Experiments at 28 GHz will be performed on the SERSE source in Catania at INFN/LNS where both the axial and the hexapolar fields will be varied so that the mirror ratio is continuously varied up to R=1.6 ; the SERSE source will be also operated at lower magnetic fields such as those which can be produced by conventional magnets (less than 2 T axial field at injection - far from the 28 GHz High-B mode).*

1 Introduction : Requirement for a performant ECRIS

In order to produce intense beam of medium charge states, an efficient ECRIS needs energetic electrons, a high density plasma, a good ionic confinement and a performant extraction system as well. For example, Pb^{27+} ions, many electrons should have energies above 800 eV. Creating these hot electrons in a minimum-B structure is not a problem (however, it is necessary to have a close resonance surface[1]).

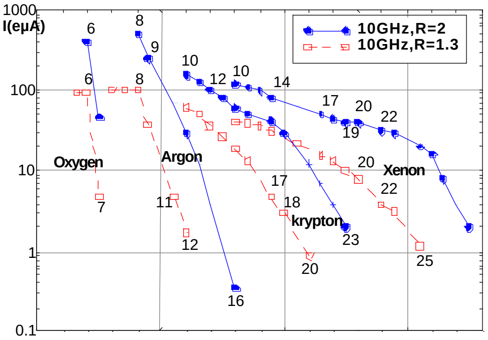

Figure1: influence of the confinement on the performances of Caprice 10GHz. solid lines:R=2, dashed lines:R=1.3

The main problem is to create such hot electrons in a large amount, to achieved a high density plasma. This requires an efficient confinement and a high frequency. However, increasing the density then leads to a high current, which requires a well designed extraction system. After a review of the role of some main parameters of an ECRIS, we will described the experiment to be carried out on the SERSE source. Then, a new room temperature source under construction will be presented. Finally a presentation of the coupling of the 28 GHz frequency will be done.

2 Main parameters of an ECRIS

2.1 Electron confinement

It has been shown [2,3] that the efficiency of the electron confinement can be characterized by the ratio :

$$R = B_{max} / B_{res}$$

Where B_{max} is the value of the maximum magnetic fields (axial and radial) inside the plasma chamber and B_{res} is the value of the resonance field.

Figure 1 shows the effect of the confinement on the performances for the Caprice source at 10 GHz. Two types of curves are shown : one with a low value hexapole and low axial magnetic field corresponding to a mirror ratio R = 1.3, the other one being the extracted beam with R=2. This figure clearly shows that a higher mirror ratio gives better performances.

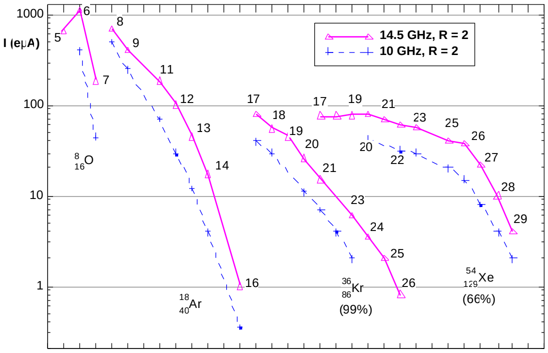

Figure 2 : effect of the frequency on the performances of Caprice with R = 2
solid lines : 14.5 GHz, dashed lines : 10 GHz

2.2 Frequency

The density in the source for highly charged ions is directly related to the square of the frequency [4]. Therefore increasing the frequency enables to achieved a higher density for the same energy of the electrons. This phenomenon is shown in **Figure 2** where are plotted some results of Caprice 10 GHz [5] and 14.5 GHz [6]. This effect was also clearly demonstrated by Gammino *et al.* in MSU [7], and by the most recent experiments performed on SERSE in Catania [8].

2.3 Ionic confinement

The ionic confinement is directly related to the size of the source : in a large source the ions can stay for a long time in the plasma, so that the ionic confinement time is increased. Spectroscopic measurements performed on two different sources have been performed (**Figure 3**) [9]. The volume of the Quadrumafios source is ten times greater than that of Caprice, consequently the confinement time of a multiply charged ion (like O^{6+}) is much larger in Quadrumafios than Caprice. The volume effect is also shown in the 6.4 GHz MSU and Texas A&M ion sources, where the large ion confinement compensate for their low frequency [10, 11].

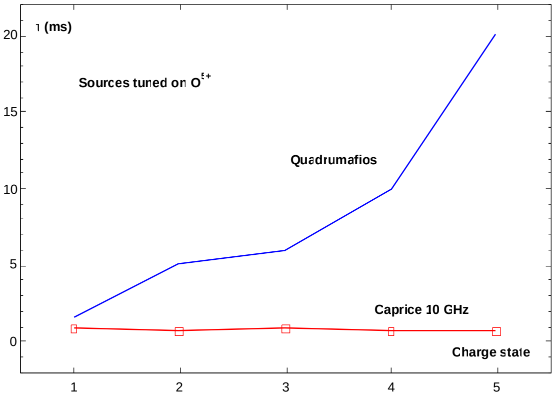

Figure 3 : Confinement time of oxygen ions for two ion sources having different plasma volume

3 Experiments in Catania

The goal of our project being to produce very intense beams of medium charge states, typically 1 emA of Pb^{27+}, different tests have to be performed before the construction of the suitable ECR ion source. To enhance the electronic density, one has to increase the heating frequency up to 28 GHz. In the case of SERSE, the maximum radial mirror ratio available would be R=1.6, which is less than the optimum value (about 2) [8]. However, the electronic density could be increased by a factor of 2.4 compared to the 18 GHz operation.

Since it is the first time that such a frequency is going to be launched into a minimum B structure with a closed resonance surface, a special emphasis has to be done on the way the microwaves are coupled to the plasma.

In addition, thanks to the possibility of varying both radial and axial magnetic profiles, the effect of the mirror ratios (i.e. the ionic confinement) on the extracted currents will be studied.

The afterglow mode operation will also be studied at 18 GHz and 28 GHz.
Finally, 1mA of Pb^{27+} requires a high current flowing out of the source, therefore, extraction becomes a tricky problem, and the variation of the extracted beam with the high voltage will also be studied.

4 Design and operation of PHOENIX 28 GHz at GRENOBLE

PHOENIX is an improvement of the present ECR4/14.5GHz/CERN source, from R=2 at 14.5 GHz to R=1.7 at 28 GHz (possibly up to 2.1 T on the axis of the source) and with a plasma volume up to 2.5 higher than ECR4.

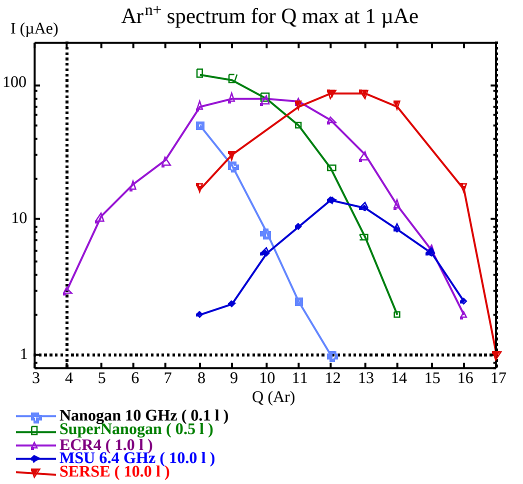

Figure 4 : Ar spectrum for various ECRIS when they are tuned for 1 µAe on the maximum charge

The purpose of PHOENIX consists in exploring functionning point of the source specially optimized for the production of medium charge state corresponding to the average <Z> observed on "medium performance" 10 GHz sources like Minimafios or CAPRICE 10 GHz, typically Ar^{8+} or Ar^{9+} or Pb^{25+}.

But here the level of current must be roughly 10 times higher. The sources like Nanogan, SuperNanogan, ECR4 or MSU 6.4 GHz work with radial and axial magnetic field of 0.7 to 1.1 T, but with different plasma chamber volumes from 0.1 to 10 L. Figure 4 shows the extracted spectrum of Ar when the source is tuned for the maximum <Z>, assuming that it is the tuning for the highest charge state at the level of 1 µAe.

We can see figure 4 than the volume clearly "tuned" the maximum <Z> of the sources and that for a plasma chamber just above 1 L is enough to reach the <Z> that we look for.

On the other hand with a fixed volume of 10 L and with the coralated increasing of the magnetic field and the frequency we observe a general increase of the the current extracted from the source similary to the effect observed between Minimafios 10 and 16 GHz [12].

So with PHOENIX, we would like to take part of the frequency effect that increasing the density and of the "optimisation" of the confinement time that controls the flux of particules outgoing from the source. The charge state is proportional to the confinement time and the density ($n_e\tau_i$) but the current is proportional to the flux (n_e/τ_i).

So if we assume an increase of the factor 4 of the density ($(28/14)^2$) and a decreasing of the lifetime of a factor 2 or 3, an increase of a factor 10 for the current, by respect to a source like ECR4, seems achievable if we can maintain the average energy of the electrons.

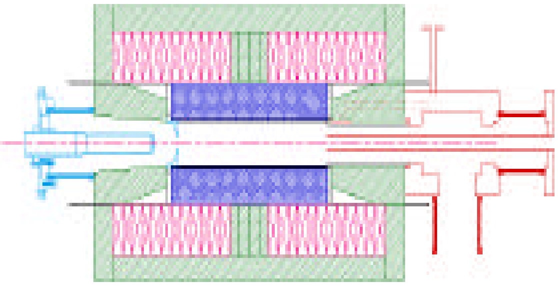

Figure 5 : PHOENIX 28 GHz ECR ion source

The construction of a source body is done with conventional coils and permanent magnets for working at the frequency of about 28 GHz and biased up to 60 kV in order to be able to compensate space charge effect in case of very high total current (Figure 5).

The hexapole will be done with FeNdB magnet with an optimised Pauthened/Halbach geometry, in order to reach 1.55 T at 1 mm from the pole. With the axial field (Figure 6) it will be possible to close magnetic lines up to R=1.7.

The source will be installed on the former SARA test bench at ISN, that includes the required electrical power, the cooling and shielding systems, the analyzing magnet, the pumping, necessary for studies of UHF power coupling at high frequency, and of the extraction of the desired lead currents

5 28 GHz frequency transmitter and line

Because of the very high cost of a new 28 GHz transmitter, we have borrowed, from CEA / Saclay,

a Varian VGA 8028 type gyrotron, formerly used for isotopic separation. It is a brand new tube whose power supply (30 kV – 1A) has to be refurbished. The tube is able to deliver 10 kW DC, however it will also be pulsed to study the afterglow mode.
One disadvantage of this high frequency remains in the protection system: the only way to prevent the tube from discharge is to use arc detectors. In addition one has to measure the reverse power with a directional coupler to prevent from a too high reflected power.

We plan to get the transmitter ready by July 1999, then tests on a water load will be performed without and with the transmission line. Finally the complete system is planned to be installed in Catania next fall.
Regarding the transmission line from the tube to the source, the output mode of the gyrotron is the cylindrical waveguide mode TE_{02} (circular polarization) . It is a mode difficult to propagate, specially with bends. Because of our schedule, we avoid an optical propagation and therefore use the cylindrical TE_{01} mode. This leads to the study of a new type of coupling to the plasma. A HE_{11} launching with a linear polarization in a cylindrical waveguide is also under study.

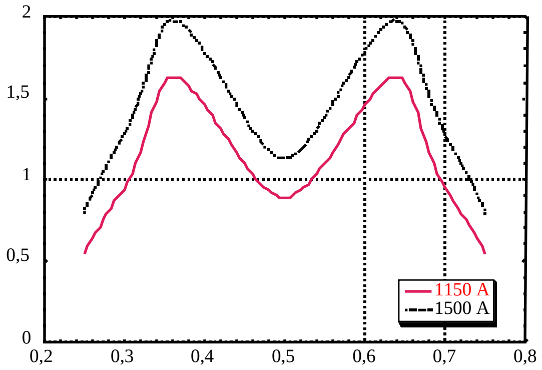

Figure 6 : PHOENIX axial magnetic profils at 1150 A and 1500 A

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