HIGH CHARGE STATES ION BEAMS FROM SOLID MATERIALS WITH THE SUPERCONDUCTING ECR ION SOURCE SERSE

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Abstract

The superconducting electron cyclotron resonance (ECR) ion source SERSE, developed by INFN/LNS of Catania and CEA/DRFMC of Grenoble, is operational since 1997 and it has produced the highest currents for highly charged ion beams of gaseous elements. In 1999-2000 the production of highly charged ion beams from solid materials have been the most relevant task, because the source is now coupled to the K-800 Superconducting Cyclotron and there was a large request of heavy elements from users. The paper will report the most relevant results in terms of high charge state production and stability. Preliminary results of tests in afterglow mode will be also discussed.

1 INTRODUCTION

The superconducting Electron Cyclotron Resonance (ECR) ion source SERSE [1,2,3] was designed on the basis of the concept of High B mode [1,4] (i.e. the radial magnetic field must exceed the value of $2 \cdot B_{ECR}$, where B_{ECR} is the resonance magnetic field, corresponding to 0.52 T for the frequency of 14.5 GHz and 0.64 T for the frequency of 18 GHz). The source construction has been completed in 1997 at the Grenoble testbench and the source is operating at LNS since June 1998. The main features of the source are described in tab. 1 and other details may be found in [1,2].

Table 1. The main features of SERSE				
Frequency	18 GHz + 14.5 GHz			
Available power	2 kW + 2 kW			
Type of launching	WR62, off-axis			
Axial maxima distance	about 490 mm			
B _{max} (injection side)	2.7 T			
\mathbf{B}_{\min}	0.3 to 0.6 T			
B _{max} (extraction side)	1.6 T			
Resonance zone length	< 100 mm			
Hexapole length	700 mm			
B _{rad} (at chamber wall)	1.55 T maximum			
LHe consumption	4 l/h			
	8 mm			
φ puller	12 mm			
Extraction voltage	20 kV			
Vacuum	2*10 ⁻⁸ mbar			

Table 1: The main features of SERSE

2 THE HIGH TEMPERATURE OVEN

The high temperature oven is available since 1997 [5] but it was not extensively used until 1999, when the axial injection line for the Superconducting Cyclotron became operational and the injection by means of ECRIS sources replaced the radial injection by means of a 15 MV Tandem. The beams to be developed for nuclear physics experiments were mainly heavy ion beams, available from solid materials, by means of the high temperature oven. The oven optimization faced many mechanical constraints: the cryostat did not permit a radial positioning of the oven and the insertion along the axis or parallel to it was also limited by the microwave and gas injection system, leaving the room for a 35 mm tube, to be used for oven and biased disk. Thus the first version of the oven (fig. 1), which has been used up to now, did not use a bias voltage, limiting in such a way the achievable currents. Another limitation of this oven was the unavailability of a vacuum valve to substitute the crucible without breaking the vacuum. Moreover, the presence of long current leads (900 mm) to feed the oven, which orifice is located 50 mm inside the plasma chamber, was the major concern in terms of reliability, reproducibility and stability of the source.



Figure 1: The oven with its current leads, before the insertion into the source.

Experience gained during one year let us conclude that the presence of this oven does not change the overall performances of the source and that also the large power (up to 400 W) which is needed to reach the maximum temperature (above 2000°C) does not reflect negatively on the ECR source behavior.

Typical times for outgassing and conditioning were in the order of 10 to 30 hours. Reproducibility of each parameter is excellent (within 2-3%).

The reliability and stability of the oven has been excellent and a typical curve vs. time is shown in fig. 2 for a beam of Sn^{27+} during ten hours. Long run have been carried out for gold (more than 200 hours), nickel (about 100 hours) and tin (more than 600 hours), featuring a very low sample consumption (being the source was tuned for high charge states). For Sn, the average charge states was 27^+ or 28^+ , and the total consumption was lower than 0.04 mg/hr (an overall efficiency of 50% has been estimated).



Figure 2: Beam current measurement during ten hours.



Figure 3: The new oven design.

Some modification are now under way so that the new version of the oven (fig. 3) may operate with high reliability at the highest temperature, allowing to add the bias voltage and to replace the sample without breaking the vacuum.

Its new features consist of boron nitride crucible in place of the alumina one, of the insulation of the filament with respect to the chamber, so that it can operate as a biased probe, and of the insertion of a valve with a separate chamber, to allow replacement of the crucible.

3 ION PRODUCTION FROM METALS

In fig. 4 a typical Au charge state distribution is shown, optimized for 36^+ . In order to separate the Au peaks from contaminants, the slits were closed to ± 4 mm, instead of ± 10 mm, so that only one part of the beam was measured by the Faraday cup .When the slits were opened the current for 30^+ reached 30 eµA and for 38^+ about 3.5 eµA.



Figure 4: Gold charge states distribution.



Figure 5: Nickel charge states distribution.

Nickel beams were also produced for experiments and a typical charge states distribution is reproduced in fig. 5, featuring about 5 μ A of Ni¹⁷⁺. and about 1 μ A of Ni¹⁹⁺.

Fig. 6 shows a charge states distribution optimized for Sn^{32+} . Especially in this case our goal was not the production of very high current of such beams, but the long term stability of beam; the source was tuned to produce 2 to 10 eµA of the charge state to be injected into the superconducting cyclotron, by using a quite high rf power (above 1500 W) and low gas pressure (about 1*10⁻⁷ mbar).

Tab. 2 reports typical results for solid material, compared with typical results for gaseous elements. It must be underlined that for the former elements the current was not optimized by increasing the evaporation rate, which was kept low. In addition, the unavailability of a biased probe limited the source performance up to now.



Figure 6: Tin charge states distribution.

Table 2: Best reproducible currents (in $e\mu A$) from SERSE for highly charged ions from gaseous and metallic elements (for metallic elements, no biased disk was used and the evaporation rate was kept low, then they cannot be considered as maximum performances).

O ⁶⁺	540	K r ²²⁺	66	Ni ¹⁷⁺	6
O ⁷⁺	208	Kr ²⁵⁺	35	Ni ¹⁹⁺	1
O ⁸⁺	55	Kr ²⁷⁺	7.8	Sn ²⁷⁺	12
Ar ¹²⁺	200	K r ²⁹⁺	1.4	Sn ³⁰⁺	5
Ar ¹⁴⁺	84	Kr ³¹⁺	0.2	Sn ³²⁺	1.5
Ar ¹⁶⁺	21	Xe ²⁰⁺	105	Sn ³³⁺	0.6
Ar ¹⁷⁺	2.6	Xe ²⁷⁺	78	Au ³⁰⁺	30
Ar ¹⁸⁺	0.4	Xe ³⁰⁺	38.5	Au ³³⁺	12
Kr ¹⁷⁺	160	Xe ³³⁺	9.1	Au ³⁵⁺	5.5
Kr ¹⁸⁺	137	Xe ³⁴⁺	5.2	Au ³⁸⁺	3.5
Kr ¹⁹⁺	107	Xe ³⁶⁺	2	Au^{40+}	0.5
Kr^{20+}	74	Xe ³⁸⁺	0.9	Au ⁴¹⁺	0.35

4 ION PRODUCTION IN PULSED MODE

The outstanding results and the availability of a larger magnetic field than the one currently used, have suggested to use SERSE as the test-bench of the "gyroSERSE" source, which will be a scaled version of SERSE, able to operate in High B mode (HBM) at a higher frequency, between 28 and 37 GHz [3], to produce very high currents for intermediate charge states (20^+ to 30^+), whose production is required by the LHC heavy ion injector (e.g. 1 emA of Pb²⁷⁺ within a 1 ms, with a 10 Hz repetition rate [6]).

The test have just begun at LNS and SERSE (set to the highest magnetic field which can be safely achieved) has been successfully coupled to a 28 GHz, 10 kW gyrotron oscillator, to be used in dc or in afterglow mode.

In order to add a new reference frame for the future tests in afterglow mode at 28 GHz, preliminary tests at 18 GHz were performed for Kr and Au beams (fig. 7).

It was observed that the source gives current of the same order of the dc ones, unless very high charge states are to be obtained or very high power is used. Afterglow peaks for $Au^{2^{9+}}$ were obtained by reducing the source pressure from $2*10^{-7}$ mbar to $1.5*10^{-7}$ mbar and increasing the rf power at the same time (1650 W). We also observed that the optimization of the peak was possible just by incrasing the magnetic field at the extraction side (about 1.8 T). The duty cycle was 50 to 60% and the peak value was above 37 eµA, with a FWHM above 1 ms.



Figure 7: A typical afterglow peak for Kr^{22+} (peak height is twice the dc current).

Anyway the gain for $Au^{2^{9+}}$ was not so relevant as it was for the optimization of 38^+ and 41^+ (gain between two and four). The explanation of the smaller effect for larger extracted currents is found in space charge effects which increase the divergence of the beam and then a large part of the beam is lost on the puller. In fact, after the preliminary tests in dc mode with the 28 GHz gyrotron, the plasma chamber was removed and we found that the puller was largely sputtered by the ions (the extractor was optimized for high charge states, relatively low current beams). For this reason, we have recently modified the extractor , decreasing the gap, so that the losses on the puller for intense medium charge states beam could be limited.

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