BEAMS FROM RF OVENS AND ECR ION SOURCES

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Abstract

The Electron Cyclotron Resonance Ion Source (ECRIS) can be conveniently considered as a charge breeder for any vapor source; this approach allows to compare the injection of metals from ovens with the injection of single charged RIB (radioactive ion beams) or the simple injection of heavy gases. Experiments extracting beams of copper (charge up to 13+), silver (charge up to 19+) or xenon (charge up 20+), tin and praseodymium with the same ECRIS conditions are described, and the advantage of rf oven over gas injection are discussed. In particular the oven crucible can be easily voltage biased up to -1.2 kV, to modify ECRIS plasma shape. A higher temperature oven, heating the tantalum crucibles over 2250 K (average temperature) in bench tests, requires careful a axial alignment to avoid the formation of hot spots; platinum vapor were produced.

INTRODUCTION

Heavy ion beams are strongly requested for atomic and nuclear physics experiments, especially from rare isotope of metallic elements [1]. ECRIS (Electron Cyclotron Resonance Ion Sources [2]) may be conveniently used to convert a small particle flow F_T of vapor or singly charged ions into highly charged ions T^{i+}, where T is the isotope to be ionized and $I_i(T)$ the current produced at the charge i, selected for use. Progress in the theorical modelling of this process named charge breeding [3] were described elsewhere [4]. Several particle flow generators were coupled to ECRIS, including gas feeding when possible (T is a gas or has gaseous compounds), or sputter probes, ohmic ovens and injection of beam. We develop an oven were the sample is heated by radiofrequency and may be held at a large potential V_b respect to the source plasma cavity, with a simple insulation. Good performances with Ag were described elsewhere [5]. Here we report on the characterization of this oven with other elements, like Sn and Pr, up to average sample temperature $T_s \cong 1600$ K. Also bench tests of higher temperature version ($T_s \cong 2250$ K) are described, with some result for Pt, and discussing the possibility of hotter crucible region (hot spots).

Finally, it should be noted that the emittance and charge state distribution (CSD) of the extracted beam are determined by the parameters of the ECRIS used. In particular our choice of the extraction hole $r_h = 3$ mm (relatively small) and extraction current ($I_s \cong 0.6$ mA) gives a low emittance and a good resolution of natural isotope mixtures, making a good transport possible.

A good figure of merit of an oven system (or, in general, a feeding system) is the ratio R between the currents $I_i(T)$ and the currents obtained, when, at the same ECRIS conditions, we replace T with a gas T' with approximately the same atomic mass number A. In particular, ECRISes use also a lighter element B as a buffer gas, so current $I_i(B)$ are also monitored, to keep flow F_B roughly equal. While ovens are typically more complex than a rod inserted into a plasma or compound gas feedings, it is expected that they perturb less the ECR plasma, so they achieve a larger R, typically $R \cong 1$. In our case, tunability of V_b gives possibility of further improvement of R, at least for some element (Silver).

EXPERIMENTAL SET-UP

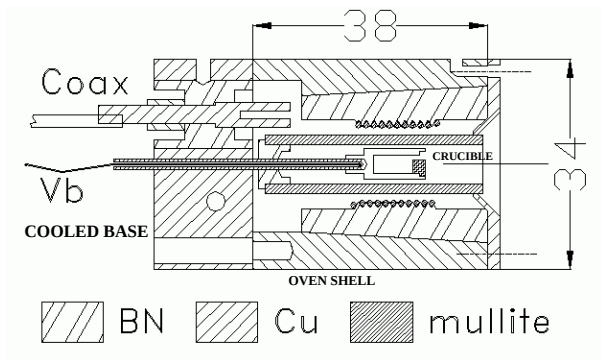

Figure 1: Miniaturized rf oven, with copper coil and a mullite heat shield. The crucible is cantilevered on isolator tube, where a tungsten wire passes (bias connection V_b).

Miniaturization of rf oven to fit inside our ion source and some first results with copper and silver beam were described elsewhere [5]. In this concept a coil induces eddy currents into a crucible-sample assembly; only the oven shell is cooled by water, which simplifies construction, and only a small sample is heated to an high temperature T_s, while the coil assumes an intermediate temperature (see Fig. 1). By careful design, temperature $T_s > 1600$ K can be reached, without melting the copper coil. A limited rf power $P_o \cong 90$ W is used.

An ECRIS consists of a plasma cavity (see Fig. 2) where an external magnetic field is applied and microwaves (14 GHz) are injected. Since this cavity is at a potential $V_s \cong 10$ kV respect to ground, a radiofrequency $f = 1$ MHz is fed to the oven by an insulation transformer, which gives a voltage V_o and current I_o. Details of matching were discussed elsewhere. Oven is controlled by f and the amplifier

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input amplitude U_g; since pickup of I_o and V_o are easily obtained, oven power $P_o = \Re(I_o^* V_o)$ is monitored.

The beam emitted from the source contains many charge states of T^i and B^j; an analyzing dipole with a regulable field $B_{\rm dip}$ allows to obtain ion spectra, separated according to the mass ratio $M = A/i$. In our case, the ion source and the analyzing dipole are enclosed into an high voltage platform, connected with a transport line to further accelerators.

Coupling to ECR plasma

The optimal distance between oven and plasma was previously found to be between $L_{oe} = 70$ and 107 mm. Similarly, the microwave power was chosen, for the used ion source, $P_k = 85$ W: enough for good ionization and not too large for quiet stable source operation (after oven conditioning).

The interaction between oven and plasma can be tested by measuring the current I_b flowing from the sample to the plasma. The plasma itself is generally believed to have a potential V_p from $+10$ to $+20$ V with respect to the ECRIS cavity.

Fig. 2 also shows a concept of the plasma density pattern induced by oven. An oven vapor neutral travels into a straight line, until it is ionized for the first time, and thus becomes part of the plasma. Let L_X the average penetration depth of neutral vapor, evidenced by wall deposits (our source has cold walls, which limit recycling very much, so part of the oven emitted vapor is lost). The trapping of a non-neutral particle into the plasma is more difficult, since unless it has the same potential V_p, or it is repelled away, or it travels too fast inside plasma. Since the oven emits also water vapor, and is bombarded by energetic electrons from the ECRIS plasma, a denser plasma is there generated and diffuses following the field lines to the ECRIS. The voltage V_b helps to maintain this plasma, that we call 'plasma channel'. A denser plasma improves neutral trapping.

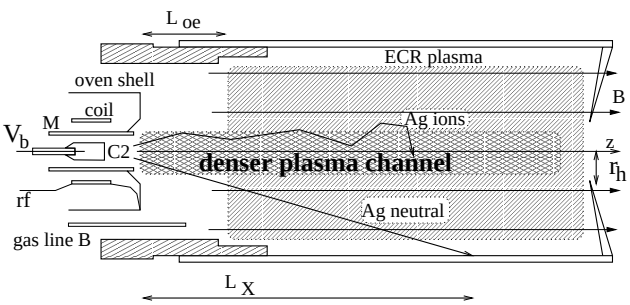

Figure 2: Model (not to scale) of oven placement, with the z axis horizontal, and ECR plasma, assuming parallel field lines for simplicity; consistently ECR plasma region is represented by a cylinder, not by an egg. A denser plasma diffuses from the oven following field lines. Note oven to plasma distance L_{oe}, mullite tube M, crucible C2, coil, gas lines B and bias connection V_b .

High temperature oven

Another oven prototype design reached $T_s = 2250$ K in bench tests with $P_o = 240$ W. The molybdenum coil is glued to a BN support for better thermal conduction. Use of this oven inside ECRIS to produce beam of platinum and hopefully zirconium is foreseen after completion of tests of previous oven.

Inside the test bench, the oven axis is vertical; oven shell and crucible support stem are slightly different. Stems in alumina, zirconia or hafnium oxide were used or considered. Temperature is directly measured with a pyrometer and vapor deposition with a resonating quartz balance.

In the case of platinum, melting was achieved, and evaporation terminated because the Ta crucible was damaged, so that platinum could spill out. This was related with a crucible misalignment: some crucible parts were nearer to the coil. This gives a larger local heating, which increases resistivity and thus heating; a 3D simulation of these effects is very difficult and radiative losses anyway strongly oppose to a positive feedback. Chemical corrosion seems possible. In case of zirconium, a careful alignment of crucible allowed more stable operation, but evaporation was difficult to detect. In conclusion, high temperature ovens ($T_s > 2200$ K) face challenging problems of materials and of uniformity of temperature.

BEAM PRODUCTION

Some beams suitable for further acceleration are listed in Table 1, with the comparison of an usual xenon beam (in that case, charge 18+ was covered by nitrogen), while a Sn current spectra is shown in Fig. 3. Note the typical three digit shape of tin same charge peaks, due to abundance of isotopes in natural material, separated since the spectrometer resolving power is $R_m = \Delta M/M \cong 1.5\rho_0/2r_h \cong 125$, where $\rho_0 = 0.5$ m is the magnet bending radius.

In comparison with $^{118}Sn^{18+}$ (with $M = 6.56$), the $^{124}Sn^{19+}$ position ($M = 6.53$) represents the typical phenomena of charge crossing of a highly spread isotope mixture and is noteworthy, since run with enriched sample of this isotope are foreseen. Direct separation is not possible, since $R_m \cong 224$ would imply a separator equipment too large to fit over the source platform. Still the analyz-

Table 1: Typical extracted beam for some charge state i and major preparation conditions: T_1 needed temperature for 1 Pa vapor pressure (an upper operation limit), buffer gas used B in these runs

Isotope	i	I_i **[nA]**	T_1 **[K]**	**buffer B**
^{63}Cu	11	980	1510	O,N
^{107}Ag	18	680	1290	N
^{120}Sn	18	340	1500	O
^{129}Xe	17	514	n.a.	N
^{141}Pr	19	240	1680	O

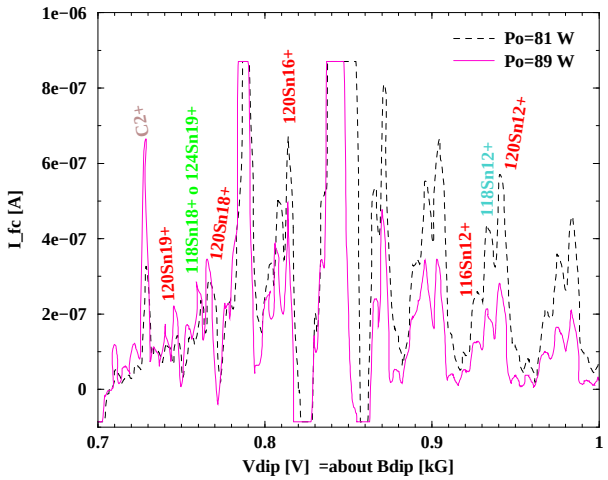

Figure 3: Ion spectra, evidencing tin peaks, for different oven power P_o

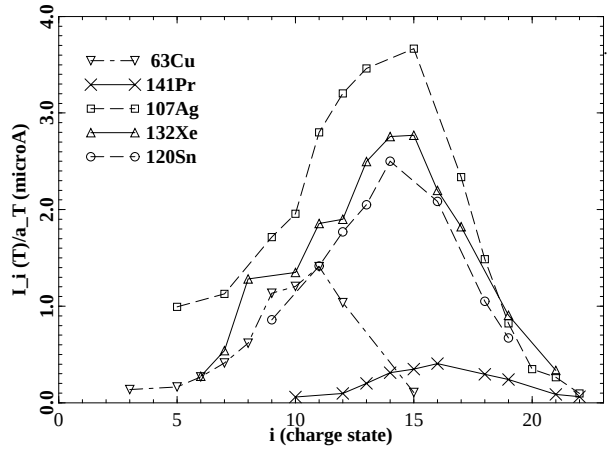

Figure 4: Currents I_i obtained for several leading isotopes T vs charge state i (scaled by isotopic abundance a_T)

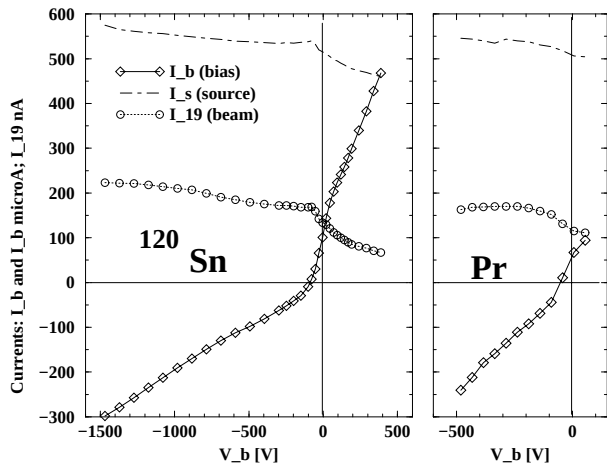

Figure 5: Correlation between bias current and ion output in case of tin and Praseodymium. In latter case, $V_b < -500$ V is not plotted because gives excessive bias current and thus plasma instabilities.

ing dipole produces an appreciable peak separation after the beam is extracted from the platform, so beam can be further purified. By combining this and mixture enrichment, reducing contamination of ^{124}Sn below 1 % seems well feasible, as it was proved in similar cases for xenon.

A comparison of currents obtained for several metal and xenon is shown in Fig. 4. Only the leading isotope are shown; the current of other isotopes are proportional to their respective natural abundance a_T.

Comparing silver and xenon current, we see that silver current are generally equal or greater, even after correction for a_T. Other elements show lower currents, that may be due to accidental facts in their development. Copper was the first element tested two years ago, so other copper runs are in program.

In the case of tin, any overheating easily makes the material to flow out from the crucible. Also some care should be taken to cool slowly the oven when tin solidifies (it expands 2 %). Result for praseodymium are preliminary, and in any case, limited in power for a change of amplificator. Anyway a current of about 240 nA of 19+ was maintained for days, which is encouraging.

Praseodymium is an active electron emitter, as seen from bias current in Fig. 5, which are greater than tin, at equal V_b. We observed a I_b up to 0.5 mA (at $V_b = -0.5$ kV) when increasing power, so we kept V_b moderate. In the tin case, source performance increase with $-V_b$ up to 1.2 kV. The relation between bias voltage and source performance for this oven is similar to the well known, even if not completely explained [6], behaviour of biased disks: making V_b more negative increases not only $|I_b|$, but also I_s; therefore, I_i increases. Good results for tin also depend from a good conditioning.

For Pr, we had a maximum of I_i at some $V_b = V_b^o \cong 0.2$ kV, which is well explained by the too large value of I_b for larger $|V_b|$; consistently, maximum position V_b^o moved with source conditioning.

Acknowledgements

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