A VAPOUR SOURCE FOR ECR ION SOURCES

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Abstract

An rf oven system was inserted and tested in the ECR ion source Alice. The test bench performance of this oven were similar to a previously described one, but it has space for a larger copper sample and can be mounted at a large angle with the vertical or horizontal. Crucibles made in stainless steel, with a partial zirconia covering and with a connection to an external generator of voltage V_b, proved to work reliably. Even if the oven is placed at some distance from actual ECR plasma, oven outgassing requires conditioning to be tolerable for ECR operation. A copper beam was extracted from the ion source with charge i up to $14+$; present conditions typically give $I_{11} = 350$ nA at $i = 11$ and $A = 63$; similarly, $I_{14} = 100$ nA. Results for I_i as a function of source condition, oven power and V_b and electronic improvements are discussed.

1 INTRODUCTION

This paper reports the first experiments testing the operation of a radiofrequency (rf) oven [1] inside an ECR (Electron Cyclotron Resonance) ion source (ECRIS) [2]. Our design of rf oven is innovative in many respects (indirect cooling, CF40 size, thermal contacts) and the operation of an rf oven inside an ECRIS is new; here discussion of experimental results will thus concentrate on simple models and ideas of the oven-source coupling and of their validation and optimisation; descriptions of the oven design and theory [1] and of the ion source used and its beam diagnostic [3] are given elsewhere.

ECRIS [2] requires a limited and well dosed flow of atoms for producing high charge states. Rf oven can concentrate an amount P_ℓ of heat on a small sample, therefore reducing total oven power P_o and in perspective reducing consumption rates, improving stability of evaporation rate and of sample temperature T_s. We obtained up to $P_o = 125$ W and up to $\eta_s = P_\ell/P_o \cong 0.6$ on bench tests [1].

The rf oven (or induction oven) has to be built in a small scale, which requires a special design: water cooling is limited to the oven base; coil is wound from a simple wire, copper or tungsten; strong compression between base, shell and cover guarantees electrical and thermal contact.

Distance of oven from plasma L_{oe} is a primary subject of experimental investigation (see fig. 1 for dimension definitions). The disadvantage of a short distance is that ECR plasma may directly heat the sample, which prevents control. Large L_{oe} distance have the disadvantage of reduction in vapour current; obstacles to vapour injection into ECR are obstructions and in-flight ionization, since the ECR plasma has a self-generated potential V_p, estimated in the order of $+10$ V [4]. The oven sample is therefore kept at a regulable potential V_b with respect to the source and thus is also a sputter probe. In-flight ionization is due both to electron impact, electron attachment and charge exchange, and thus increase with peripheral plasma pressure p_o, p_p and microwave field E_1.

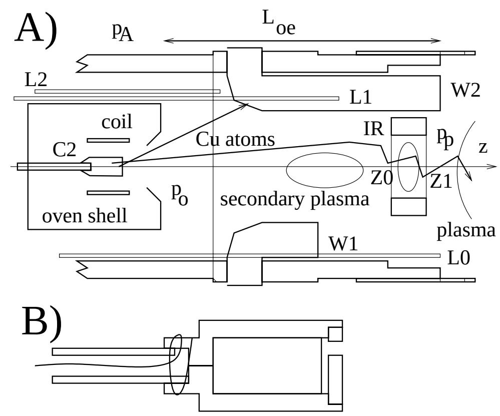

Figure 1: A) Injection of microwaves, support gas and copper into ion source Alice; B) detail of crucible C2

In section II the major particularities of the apparatus are discussed, reviewing only briefly parts described elsewhere [1, 3]. Electronics is discussed, since oven impedance matching is difficult.

In section III, experimental results for a beam of copper are presented. Discussion on future experiments and ideas is in section IV; we note also the high ionization efficiency of the charge state distribution (CSD) of copper ions.

2 APPARATUS

ECR ion sources are typically formed by two solenoids (and an hexapole), making a double maximum profile $B_z(z)$ on their common axis z; let z_1, z_2 be the maximum points; main ECR plasma stays between z_1 and z_2, while devices for injection of microwave (waveguide W1 and main waveguide W2) and gases (lines L0, L1 and L2) stay in $z < z_1$, as shown in fig 1. Note also the iron ring IR, which pertubes locally B_z on the axis z, so that maximum point z_1 split into two points, called z_0 and z_1; pressure is measured near point A, while p_o and p_p are the pressure in front of the oven and of the plasma. All these elements may affect the oven operation. The gas line position affects the ratio p_o/p_p and gas in front of the oven may scatter copper atoms; moreover microwaves may ionise this gas making a secondary plasma, which in turns ionises copper atoms and make their trajectories difficult to guess. The iron ring improves ECR operation, creating another secondary plasma, with similar effects on copper motion.

Microwave coming from a TWT amplifier (P_k be its output power readout) divides between W1 and W2 lines with the ratio 1 to 10 ; transmission losses are about 20 % for W2 and higher for W1. W1 line may be disconnected easily from the TWT (when it is off, of course). Each gas line has a dosing valve and a shutoff valve.

The crucible (diameter 5 mm, length 13 mm) can be loaded with a 3 mm diameter, 7 mm copper sample; to allow horizontal operation, first a small drop of a zirconia glue was placed in the front. This has worked reliably for one week, until partial melting of this crucible C1. In crucible C2, a stainless steel cover is placed and/or glued in the front; crucible surface was partially covered with a zirconia layer. Let z_{co} the axial displacement from the oven centre to crucible centre. Initial design called for $z_{co} = 0$ as in C1; in last experiment with C2 $z_{co} \cong -3$ mm. Crucible is cantilevered by a ceramic tube (through which a 0.127 mm diameter tungsten wire connects it to an external voltage generator).

An overview of the oven electronics is given in fig. 2; the amplifier is at fixed gain, and oven heating is controlled by the voltage V_g and frequency f by the function generator FGE; they are not at source voltage V_s. Oven inductance L is 647 nH (and 744 nH without sample) when measured at room temperature and $f_t = 100$ kHz; an LCR circuit is necessary to obtain a (mainly) resistive load Z_o. Resonating frequency f_r is determined by capacitance C, now made of five 6.8 nF polyester capacitor in parallel; $C = 31$ nF at room temperature and $f_t = 100$ kHz; capacitance are forced flow air cooled. Toroidal transformer T1 (now 14+1:10 turns) provides: a rough over-matching of the oven impedance Z_o (let Z_a be the impedance seen by the amplifier); insulation of source voltage V_s; an isolated readout V_v of the voltage V_o applied to the oven LCR circuit. An isolated readout V_i of the current I_o flowing to the oven LCR is provided by T2 (now 1:6 turns, loaded with 3 ferrite rings, ID 20 mm, OD 32 mm, thickness 8 mm each); primary is made by copper tubes. The transducer constant $K_v = V_o/V_v$ and $K_i = I_o/V_i$ are now $|K_v| = 122 \pm 3$ and $|K_i| = 0.84 \ \Omega^{-1}$ at $f = 1.1$ MHz. The oven LCR impedance Z_o change during operation due to heating and sample consumption: for last samples, from $Z_o = 70 \ \Omega$ at $V_g = 100$ mVpp to $Z_o = 40 \ \Omega$ at $V_g = 920$ mVpp. It may be argued that the ratio 14:10 in transformer T2 is not necessary; but it was experimentally observed that amplifier have problems (a severe distortion and an erratic 67 MHz resonance, leading to output power fluctuation) if and only if $Z_a < 50 \ \Omega$, while it operates without visible distortion if $Z_a > 50 \ \Omega$: here the limit of power output saturation $P_a < (10^4 V)/Z_a$ is not reached at any heating stage. Therefore turn ratios like 12:10 or 14:10 give a large safety margin against oven derive and for different crucibles.

The bias voltage power supply is at source potential V_s (as well the pressure gauge, the shut-off valve). Oven electronics proved to work even in the ECR source environment, that is, both power and pickup transformers stand the 11 kV dc source voltage (and some Paschen discharges).

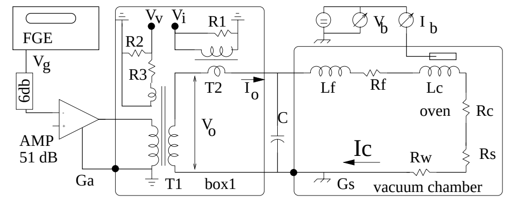

Figure 2: overview of the oven electronic set-up

3 EXPERIMENTS

3.1 Conditioning and calibration

We installed oven at $L_{oe} = 18$ cm. The optimal level of oven heating to get copper beam (depending in principle from geometry, ECR plasma conditions, outgassing, ECRIS heating the oven) was the first subject of investigation; we often report the amplitude setting of the generator V_g with the oven power P_o. A first calibration point of sample temperature with P_o is that steel crucible C1 partially melted ($T_s = 1800$ K) with $P_o = 102$ W and $P_k = 89$ W.

After replacing the crucible, oven was again progressively heated, with the ion source on, to analyse the vapour output from the oven; scan of the extracted ion were performed at regular intervals; measuring range was $10 \div 900$ nA without compander and $0.01 \div 100 \ \mu$Awith compander. Since impurities contents of the plasma may originate peak (in the scan data) of 50 nA and above, input gas lines were periodically purged (to avoid nitrogen accumulation); for simplicity oxygen was used in all the three lines and only one line was open.

The ion source tuning (depending on solenoid currents I_1 and I_2 and TWT output power P_k) was periodically scanned; let $R_1 = I_1/I_m$ where $I_m = 640$ A is the maximum current and similarly $R_2 = I_1/I_m$; typical values are $R_1 = 0.9 - 0.98$, $R_2 = 0.73$ and $P_k = 90$ W.

First clear evidence of copper from oven was found when $V_g = 815$ mVpp (oven power $P_o = 49$ W and $f_r = 1074$ kHz) with $I_{11} \ \cong \ 200$ nA after 24 hours of source and oven operation (distributed on more days). A further increases of V_g lead to a temporary decrease of I_{11} and to a large increase of the $(H_2 0)^+$ current, called here I_w, to 20 μA (typically $I_w = 5 \div 10 \ \mu$A and the total current extracted from the source is $I_s \cong 500 \ \mu$A).

The more convenient gas line resulted to be line L0. Iron ring IR was found to be necessary for ECRIS operation.

3.2 Results

After some more outgassing (total source operation: 40 h, oven operation 48 h), systematic test of the source output changing P_k or P_o or V_b were possible. Best results were obtained with $p_A = 110 \ \mu$Pa, even if a more precise indication of correct plasma condition was the current $I_s = 510 \ \mu$A. Best result were also correlated with a low nitrogen content, say $I_{N3+} \leq 200$ nA. In fig 3 results for $P_o = 51$ W are given; increasing P_k over 100 W gave

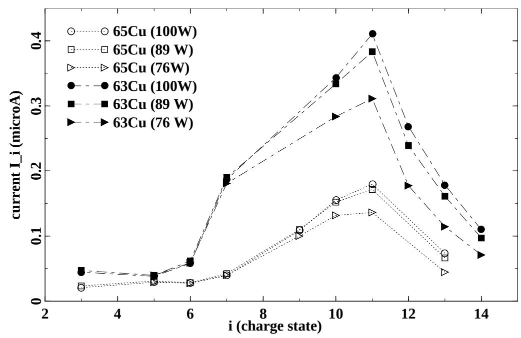

Figure 3: Ion source output vs i, at several level of total microwave power P_k; typical current error 10 nA, except for 63Cu^{7+}; solenoid regulation was $R_1 = 0.97$ and $R_2 = 0.71$, $V_g = 835$ mVpp, $P_o = 51$ W and $V_b = -160$ V; both waveguide W1 and W2 connected

no appreciable improvement. Note that copper isotopes $A = 63$ and $A = 65$ follows the known abundances of the natural element. The only evident exception is the peak at $A/i = 9$, which includes the ^{63}Cu^{7+} contribution and possibly charge exchange peaks C^{3+} to C^{2+}.

About microwave input power, waveguide W1 was terminated onto a load [see curves (a) and (b) in fig 4], adjusting the ion source tunings R_1 and R_2; curve (c) [as all curves in fig 3] was obtained with W1 connected again. We noted that closing W1 made the ion source tuning more simpler and stable: in particular small pressure drift (5 %) were tolerated.

Preliminary experiments with V_b regulable in the range ± 50 V indicate that both copper output I_{11} and the total source current I_s was slightly improved by $V_b = -50$ V.

Results obtained in the Fig 3 condition and installing a second bias voltage supply (fixed polarity, maximum limited to 200 V) are shown in Fig 5.

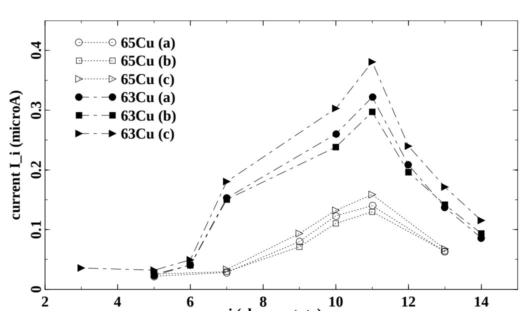

Figure 4: Ion source output vs i in several cases: (a) W1 closed, $P_k = 89$ W, $V_g = 830$ mVpp, $R_1 = 0.9799$ and $R_2 = 0.71$; (b) W1 closed, $P_k = 100$ W, $V_g = 840$ mVpp, $R_1 = 0.9661$ and $R_2 = 0.6986$; (c) W1 connected, $P_k = 89$ W, $V_g = 840$ mVpp, $R_1 = 0.98$ and $R_2 = 0.7025$.

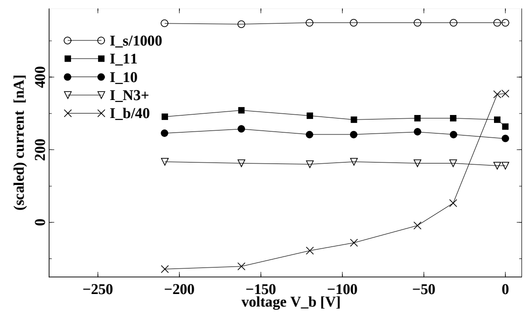

Figure 5: Some extracted ion currents vs V_b; I_{10}, I_{11} are for ^{63}Cu, I_{N3+} for N. Total source current I_s and bias current I_b are scaled as indicated in legend.

4 DISCUSSION

It must be noted that copper CSD is sharply peaked, which implies a fast ionization, and which is a property desired for charge breeder application[5]; fitting fig. 3 data with $I_i = c\, i\, \eta_i(a, b)$ where the ionization efficiency η is given in formula (12) of Ref. [6], we find $a = 5.08 \pm 0.42$, $b = 0.44 \pm 0.046$, $c = 248 \pm 22$ nA for ^{63}Cu of fig. 3, 100 W curve. It may also be speculated that a fraction of the copper ions is not trapped by the ion source, but rapidly extracted. This consideration relates rf oven with another beam-plasma injection systems (nanoMEVVA).

The limited amount of copper injected suggest to reduce the distance L_{oe} in future experiments; only the oven base need to be rebuilt for $L_{oe} = 7$ cm. To reduce the outgassing during oven operation, we plan to heat the oven coil and its boron nitride support by a direct current. The capability of baking the oven without evaporating the sample is implied by the rf oven concept and was demonstrated previously in bench test.

The proven operation up to 1800 K makes this oven suited to many elements.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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