Metal Vapour Production for ECR Ion Sources

M.Cavenago, G.Binelle, M.F.Moisio, F.Scarpa, A.Zanon, L.Ziomi and A. Vassiliev*
Lab. Naz. di Legnaro INFN, via Romea n 4, I-35020 Legnaro (PD) Italy
*ITEP, Bolshaja Cheremushkinskaja n 25, 117259 Moscow, Russia

Abstract

The status of the MetAlice project, under development in our Laboratories, is presented; this project studies a very small Mevva source and high temperature induction ovens as possible injectors of metal vapour inside ion sources, in particular inside our ECR ion source Alice. Tests of the nanoMevva show that the arc is not always stroke, when it is operated below 20 A arc current and 0.001 mbar of pressure (with an aluminium cathode and a Kr atmosphere). Preliminary results for the probability of the striking the arc, as function of pressure and magnetic field are discussed. The adjustment of pulse power supply needed are presented, featuring higher voltages. The induction oven concept is briefly compared to the resistive oven one, showing the evolution of our design of both.

1 INTRODUCTION

A program to develop and test new metal vapour sources for ECR ion sources [1] is going on in our Laboratories; up to now, we built a nanoMevva with its dedicated test vacuum chamber and its power supply and performed first experiment with this system; moreover, the comparative design of induction oven and resistive oven is well advanced.

The nanoMevva consists in a small Mevva (MEtal Vapour Vacuum Arc [2]), located on the ECR axis few centimeters from ECR plasma (see Fig. 3 in ref. [3]) and operated for short pulse length τ_o (12 μs) with high repetition rate ν (goal is $10-20$ Hz) at low arc current I_a; the metal ablated from Mevva diffuses to the ECR. Metal flow may be directly regulated by the arc current and its duty cycle. If the final device will exhibit sufficient arc stability, say within 10 % in average I_a, a feedback loop may be unnecessary.

On the contrary, in ovens the metal flow is a rapidly changing function of temperature; for that reason a feedback loop is necessary, where beam current changes are used to correct oven power; if temperature can be measured, its feedback regulation will be also advisable. Ovens are also difficult to miniaturize.

Our first goal is indeed to develop small vapour sources that stay within a 3 cm long 3 cm diam cylinder. The second is to develop sources cheaper than the obvious choice of a powerful laser ablating a sample. The third is to have a fine regulation of emitted metal flow F_X, in the range

$$F_X = 10^{13} \div 10^{14} \quad \text{atom/s} \qquad (1)$$

Indeed ECRISes give the best results for highly charged ions of element X when X concentration is few percent, as known from two-gas-mixing experiments [4],[5] (the increase in charge state is only few units on a charge of 25, but is very useful for the injected accelerator and can be cumulated with other ECR improvements). A fine regulation of F_X will help also the promising concept of mixing three elements [5].

From eq. 1, extrapolating known values of Mevva and requesting a $\nu \geq 10$ Hz as proved elsewhere [3], we find:

$$I_a\, \tau_o \leq 70\, \mu\text{C} \qquad (2)$$

Thus the arc current must be low, so that we can not rely on the cathodic hot spot mechanism only (see hot spot currents for most cathode material in Table 4.1 in Ref. [6]); on the contrary several plasma process become relevant, as sputtering or Townsend discharges.

First test of Mevva led us to improve its pulse power supply; still we found that arc is not always started on each new pulse below 20 A and 0.001 mbar Kr pressure.

We gave the measured frequence of striking the arc; they are very small in several cases and only clear identification of new supporting mechanism for the arc may will allow to reach a repeatability ≥ 0.9 that is desired.

2 INSTALLATION OF NANOMEVVA

The nanoMevva was installed in test vacuum chamber, precisely in the vertical arm of the vacuum chamber (Fig. 1), which offers an exact replica of the Alice source and its removable plasma chamber. Two water cooled pancake coils are necked on this arm and connected to a current supply. Primary diagnostic of nanoMevva operation is, of course, the arc current measurement. Other arms allow mounting of different metal sources, and the future insertion of several diagnostics, among which a film deposition meter. Three viewports are provided.

A 250 l/s Varian Macrotorr turbopump, baked by a Fomblin-oiled mechanical pump, allows us to reach a satisfying 3×10^{-8} mbar base pressure (also thanks to cleaning action of the glow discharges in Mevva). Gas enters through a dosing valve, connected to a Kr bottle via some pressure reducers and a nylon tube, filled at 1.5 Atm (absolute).

We aim at having a 90 % or better pure Kr atmosphere in our experiments. Regulating the flow of Kr, a pressure p_{Kr} up to 0.0001 mbar may read on the Penning gauge; since the Penning and the dosing valve are midway between the Mevva arm and the pump, we can assume that p_{Kr} is the pressure in the nanoMevva when at rest. To reach higher pressures, we must close the gate valve on the pump; in static condition pressure uniformity is guar-

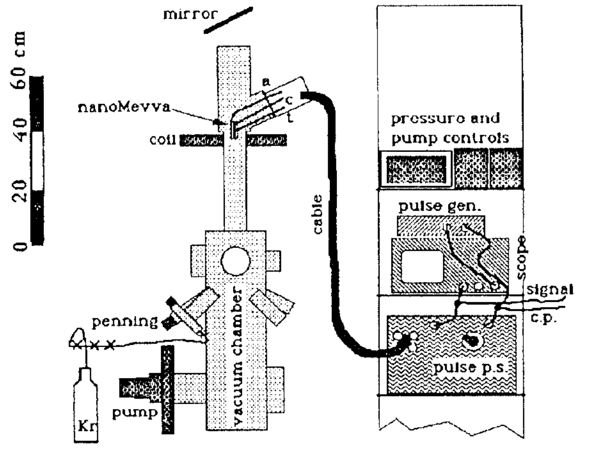

Figure 1: The nanomevva installation and nearby rack.

anteed, but degasing may be significant up to 0.001 mbar. We plan to reduce pumping speed to 10 l/s in the future, to allow uniform pressure regulation in the range $10^{-6}-0.003$ mbar.

The nanoMevva construction followed the design described elsewhere [3]. The two needles (connecting to Mevva electrodes) are supported from a CF100 flange, and may be easily inserted and extracted with the whole flange; a 44 mm inner diam tube will enclose these needles, and being connected to the anode, will allow pulse return with minimized inductance; noise generation will be reduced.

We built a small spark gap in air (a steel needle pressing an alumina bead against a copper cathode; another wire end separated by $1-2$ mm of air serves as the anode), by which we can verify the status of power supply.

2.1 The power supply

The secondary of a transformer allows to match an arc gap very simply: at start no current flows, so that voltage is maximum; when gap closes the arc current I_a is limited by

$$I_a < I_1/n \tag{3}$$

because of the transformer voltage ratio $n = 1 - 2.0$. In our circuit I_1 is about fixed 400 A and voltage on primary V_1 rises up to $500-550$ V. Our power supply adds a stronger regulation [7] of I_a by requiring the arc current to pass through a large air inductance (0.00358 H) coupled through a diode to the arc circuit (see fig. 5 in ref [3] or fig. 3 in ref [7]); if no current is stored in the inductance, I_a must start from zero. If a current I_L is previously stored, I_a cannot exceed this value. On the contrary, if the arc delays or fails, the full voltage $V_a = nV_1$ will stay applied, while I_a stays zero.

We built a prototype of the pulse power supply, designed to give a current I_a regulated between 0 and $I_{\max} = 28$ A for a fixed time about $\tau_o \cong 12\mu$s up to 10 Hz rep rate; this unit had also a trigger circuit giving high starting voltage (15 kV) and low current ($I_t = 100$ mA), magnetically coupled to the main arc circuit [3], so that main arc was fired when trigger arc ended. While this was properly working with the air spark gap, it was not guaranteeing a pulse start when applied to nanoMevva.

On the working hypothesis that trigger pulse was too short to reliably heat the cathode, we changed power supply design by adding a separate transformer for the trigger circuit. The trigger voltage is now applied at the same time as the cathode-anode voltage V_a. We also increased the transformer ratio n from 2 to 4 (which does not decrease the current I_a), that required the substitution of the ferrite core with an iron yoke, giving a more compact but more lossy transformer. The bigger voltage V_a improved the repeatability of the arc in several regions, even if not always.

The whole device is packed inside a 6U rack unit. Regulation of I_L is manual. Timing is derived by a single optoisolated TTL input pulse, here named control pulse (c.p.): on front edge, voltage is applied to main inductance to build up I_L; on trailing edge (say at t=0), the trigger and main arc SCR are enabled to close.

As main monitor signal, the device gives the voltage, induced by the cathode current into a winding of N turns on a cut ferrite core, shunted by a resistor R ; for safety reasons, we have $N = 45$ and $R = 1.8$ ohm. For high frequency signals ($f > 5$ kHz) this voltage is

$$V(t) = \tilde{I}_a(t)R/N \tag{4}$$

3 EXPERIMENTS

The signal generator which sends the control pulse to the power supply also triggers the scope sweep (a Lecroy 150 MHz digital scope). A short cable connects the signal $V(t)$ to a 50 ohm channel of the scope. Among several mathematical operation, the scope can average pulses.

From some $V(t)$ tracks, we observe that I_a has sharp peak starting at $t = 3-5\ \mu$s and $3-4\ \mu$s wide, followed by a plateau ending at $t = 18-20\mu$s, as predetermined by the power supply; after we observe a decaying tail of V with sign reversed, as expected qualitatively from current transformer bass filtering; this signal is consistent with $I_a = 0$ within errors. The plateau height is proportional to $R_g = I_L/I_{\max}$; this shows that the regulation works. The peak, that is much bigger than the one due to the trigger only, is probably due (in part) to parasitic capacitance (of the cable, of the coupling diode, etc.). Some other V tracks are similar, but a large noise is superimposed especially near the peak. These tracks qualify clearly as good shots (gs).

In some tracks, the plateau are missing (and the peaks may be also missing). This are failed shots. In some cases, the plateau exists, but is shorter and/or lower than expected. We may consider them acceptable shots if integral of plateau is 70 % of a good shot.

The signal can also be sent to an unit that cuts a window ($8\mu s < t < 20\mu s$) of it, integrates it, and if integral exceed a value, counts it. In principle, this unit can be set to select the arc pulse according to previous definition; in practice, the noise from the pulse alters the window timing and can screw the results. Several noise filtering methods were tried, with erratic results.

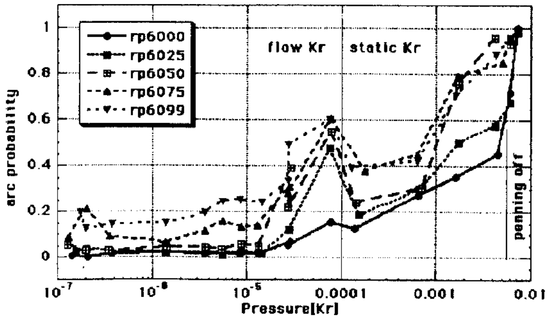

Figure 2: Preliminary results for the repeatability R_p of pulses versus pressure. The line rp4099 means for example R_p when $R_g = 0.40$ and $B_z/B_z^{\max} = 0.99$. Errors, not shown, are as large as usual for pressure, and within $\pm\sqrt{R_p(1-R_p)/N}$ with N=30 for R_p .

In alternative, considering that an average will decrease the noise, and most of all, will not reject good pulses which are perturbed by a spike, we define the repeatability as :

$$R_p = \frac{< V(15\mu s\ ) - V(21\mu s\ ) >}{(V(15\mu s\ ) - V(21\mu s\ ))|_{gs}} \qquad (5)$$

where $< >$ is the average on all events, rejecting none, and $|_{gs}$ is the restriction to one or few particular good shots. This ratio is evidently equivalent to count good and failed shots; the acceptable shots may be weighted also, if long enough. All data processing needed can be done by the scope. Moreover $< V(t) >$ can be displayed, and its edge shows some information on the distribution of plateau duration.

Results for R_p as function of pressure, for $R_g = 0.6$ and for several magnetic fields B_z, are summarized in fig. 2. We express B_z as a percentage of the maximum magnetic field at cathode face, which is about $B_z^{\max} = 1370$ G from simulation; this simulation is consistent with measured values outside the vacuum chamber. Note that when R_p is low, adding a magnetic field may improve the repeatability; still this improvement is not enough, and there are some indications that it saturates at 75 % ($B_z = 1$ kG), which by chance, is about the stray field that Alice will produce on the inserted nanoMevva.

A peak shows up just on the border between flow Kr and static Kr experiments, but we have no reason to assume it is an artifact due to displaced abscissa values; to verify it we are going to change flow conditions as explained in section 2. Note that some arcs may be obtained at very low pressure, provided that a $B_z = B_z^{\max}$ is applied.

We can manually count good shots when they are unprobable, and similarly failed shots, sampling one out of two or three pulses (with triggering of scope) , obtaining ratio c of good shot to total shots. This method generally agrees with R_p results. For example we find $c = 0.9$ for $R_g = 1$ and $p_{\mathrm{Kr}} = 9 \times 10^{-5}$ mbar, which shows that arcs can be stable in fairly good vacuum, provided we allow a little more arc current.

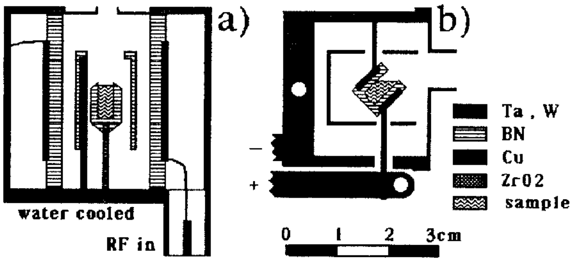

Figure 3: Induction oven a) and resistive oven b)

Decreasing repetition rate, we can observe pulse to pulse correlation, which deserves future investigation, since good shots (or failed shots) come typically in sequences of three to ten shots.

4 OVENS

Both the induction (Fig 3a) and the resistive oven (Fig 3b) feature an outer case cooled by water, an intermediate radiation shield and a small melting pot, so that radiated power

$$P \cong \sigma\,\epsilon\,A\,T^4 \qquad (6)$$

where A is the area of the melting pot surface, ϵ is its emissivity and σ is the Stefan constant, can be limited to $100 - 150$ W (for $A = 2 - 3$ cm^2, $T \cong 2000^0$K, $\epsilon = 0.5$). Induction ovens offer the perspective advantages of a quicker response time, and of an increased lifetime of the heating element, which stays near the outer case and can be kept cool. But they require a longer development, including the matching of the rf generator (about 10 MHz).

From simple numerical simulation of thermal conduction in the induction oven, we find that for heating power of 100 W, the melting pot temperature (respectively the shield temperature, the coil temperature) is about 2180^0 K (respectively 1300^0 K, 450^0 K) and response time is 15 s to recover within 40^0 K after 10 s stop of heating power.

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