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# THE PRODUCTION OF BEAMS FROM SOLID MATERIALS AT THE LBL ECR SOURCE*

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Abstract - Two ovens are described for the feed of vapor from solid materials in the LBL ECR source. A low temperature oven, operating up to 700 deg. C, has been used for Li, Mg, P, K, Ca, Ti and Bi. A high temperature oven operating up to 2000 deg. C, has been used for Sc, Fe, Ni, Cu, Ag, La and Tb. At the 1 eμA level the charge states from the oven beams are very close to those from gases.

## 1 - INTRODUCTION

For the production of beams of elements which are gases at room temperature, we can use standard leak valves to obtain a stable and sensitive control of the gas supply. For elements which are not available in gaseous form a method must be found for vaporizing them in the source. Two methods have been used at the ECR sources at various laboratories.

In the first method the material is placed at the plasma boundary where it is heated by the plasma to produce sufficient vapor /1/. The material is supported either by the vacuum chamber or by a movable mechanical actuator which can be adjusted to optimize the vaporization rate and perhaps to maintain the rate constant in time. This plasma heating method is simple but it makes optimizing the source difficult, since tuning the magnetic field or rf changes the plasma and thus the heating and vapor flow of the material.

An externally heated oven makes a more flexible feed system. Here the material is contained in a crucible, which is electrically heated either by conduction from a heater section, or by direct heating from electric current or electron bombardment. The feed rate is not affected by plasma conditions, and is thus similar to gas feed. This external heating system is used in the ovens described in this paper.

At LBL we initially used plasma heating of rods inserted into the plasma. We then built an externally heated "low temperature oven" which operates up to 700 deg. C. It provides most of the present beams requiring solid material feed and has been described previously /2/. Later an externally heated "high temperature oven" was built to feed elements which needed temperatures up to 2000 deg. C. This paper describes the design of both ovens and their performance with the ECR source.

## 2 - THE LOW TEMPERATURE OVEN

The low temperature oven is mounted radially on the side of the second stage of the ECR source, as shown in Fig. 1. The oven assembly is shown in Fig. 2. The oven is mounted on a faceplate on the vacuum chamber. Using it in the second stage rather than the first minimizes the usage of material, an important consideration for expensive isotopes such as $^{48}Ca$. This location also avoids contamination of the first stage. The material is contained in a tantalum crucible in a copper or inconel oven, conduction heated by a resistance heated copper base. The oven nozzle is pointed toward the center of the plasma through the space between the sextupole bars. The vapor pressure in the oven is about $10^{-3}$ torr during operation. A commercial controller regulates the oven temperature using a thermocouple attached to the oven to monitor the temperature. The maximum temperature available is about 700 deg. C, limited by the construction material (copper). The time constant for temperature control is a few minutes but outgassing of the charge material may take a few hours in some cases. The oven can be cooled down for changing in a few minutes.

The operation of this oven has been very satisfactory. It produces stable beams for runs lasting several days. The beam output from this oven is shown in Tables 1 and 2 in the columns labeled **L**. The charge distributions shown are those of a single source tuning for each element, rather than the sum of the maximums for several tunings. In each case the distribution with the highest average charge state was chosen. In most cases higher intensities could have been obtained for the lower charge states at other tunings. The beams listed were run with pure element feeds, except for $TiF_4$ for titanium feed, and KCl + Ca for potassium feed. Support gas is normally oxygen, except that helium is used when running lithium. Material usage is about 1 mg/hr. Several elements gave unusual operation. The lithium needed a temperature of about 500 deg. C, higher than expected and corresponding to $10^{-2}$ torr. The phosphorus (red) needed an inconel rather than a copper body on the oven for proper flow, and a high temperature of 350 deg. C, rather than the expected 165 deg. C. For the loading of new material in the oven the source is vented to dry nitrogen. The following

pump-down takes several hours for good performance.

## 3 - THE HIGH TEMPERATURE OVEN

For high temperatures of up to 2000 deg. C we needed a compact design where the heating is uniform enough to prevent condensation of the charge at the exit aperture. The choices of heating were resistance heating or electron bombardment. The complicated field shapes in the source and the possibility of discharges, made the electron bombardment heating method look difficult, so the resistance heating method was chosen.

The oven is a resistance heated tantalum crucible, supported by watercooled copper clamps, as shown in Fig. 3. The crucible is cylindrical in cross-section. It is similar to a design used in the production of atomic beams /3/. The crucible region is shown in Fig. 4. Tantalum was chosen because it is one of the highest melting point materials that is easy to fabricate in the shop. This makes the oven suitable for vaporizing elements in a large part of the periodic table.

Heating is supplied by an AC current which is passed directly through the crucible, as indicated in Fig. 3. At the 2000 deg. C level the power required is 340 amps at 2.2 volts. The power is fed through a 20 kV isolation transformer to the oven, which is at the source bias voltage of about10 kV. The power is controlled by a course and fine variac at ground potential which are fed by a regulated ac voltage. We plan to use solid state control to replace the variac.

The water cooling of the end blocks minimizes the volume of material at high temperature, thus giving a short time constant of about 30 seconds for temperature control. The volume available for charge is .4 $cm^3$. The top of the crucible is opened to load the charge and to inspect it. Stainless steel set screws clamp the copper end blocks to the crucible stems. The exit hole for vapor is 3 mm diameter, and points toward the plasma center line. The crucible can be removed from the copper mount for exchange or maintenance without breaking the water cooling circuit, since the clamp blocks are conduction cooled from the water cooled blocks.

The design includes a water-cooled copper housing surrounding the crucible. Its purpose is to intercept the material that does not reach the plasma region and to prevent heat loading of the sextupole structure. It also contains a heat shield between the crucible and room temperature. In tests it was found that the heat shield didn't change the temperature of the crucible much, for a given heat input, so it is not used in operation.

A vacuum test stand was used to do initial development and testing of the oven. This was very useful since the ECR source is heavily scheduled for cyclotron and atomic physics use. The temperature of various parts of the crucible was measured as a function of the heating current, with an optical pyrometer. Also the vapor flow could be seen by deposits on glass slides. Typically the pressure had to be $10^{-2}$ torr for a deposit to appear on the glass in a few minutes - about 10 times higher operating pressure than when the oven was used in the ECR source. The oven was weighed before and after a run to measure flow rate.

Test runs have been made on the ECR source to measure the charge state distributions of a number of beams. These are shown in Tables 1 and 2 in the columns labeled **H**. These beams were tuned for the highest charge states, to evaluate the energy available from the cyclotron with intensities of about 1 eμA from the ECR source. Pure elements were used and the support gas was normally oxygen. The best runs are reported here. The performance of the ECR can be degraded after running ions such as carbon and chlorine giving lower average charge states. Higher intensities of lower charge states were available by increasing the oven temperature and support gas flow. For example the $Fe^{9+}$ current could be increased from 9 μA to 23 μA in this way. The usage of material is typically a few mg/hr, but for a high intensity low charge state iron beam 30 mg/hr was seen. Long term stability was observed on a 3 day run of $Cu^{19+}$, $Cu^{17+}$ and $Cu^{15+}$. During this run no change in heating power was made, but the support gas was adjusted several times to bring the source back to its original value. Beam intensities stayed about the same. A small removable tantalum cup is used in the crucible to remove most of the feed material when changing material. In addition the oven is normally baked out in the test stand at about 400 deg. C higher than the temperature needed for the next run, as a cleaning procedure. When running elements like iron and nickel, alloys form with tantalum causing a slow disintegration of the crucible or its small insert cup. To prevent this, insert cups of alumina are used. A complete insert or coating of alumina on the inside of the crucible would be even better. This alloying also occurs with the rare earth elements.

## 4 - HIGH CHARGE STATE COMPARISON WITH GASES

It is interesting to compare the high charge state currents produced by these ovens with those of gas feed cases where optimization is easier and faster. Following the paper of Jacquot /4/ we plot the charge at the 1 eμA level as a function of Z for gases and for the two ovens described here. Fig. 5 shows this plot. Intensities of each isotope of an element were added, to determine the 1 eμA level. The plot shows that

the ovens provide beams of approximately the same charge states as the beams from gas feeds. This means that the vapor feeds from the ovens can be as well optimized for high charge states as in gas feed operation. This result is somewhat different than that of Jacquot /4/, where the solid material feed cases dropped below the gases, in a periodic way. For the low temperature oven the tuning was not always for the highest charge state, so a few of those points fall lower.

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Table 1. Currents for Beams from Ovens: Lithium to Titanium

| Q | $^{7}$Li L | $^{24}$Mg L | $^{31}$P L | $^{39}$K L | $^{44}$Ca L | $^{45}$Sc H | $^{48}$Ti L |
|---|---|---|---|---|---|---|---|
| 1 | 5 | | | | | | |
| 2 | 7 | | | | | | |
| 3 | .5 | | | 4 | | | |
| 4 | | | | 5 | | | |
| 5 | | 5 | | * | | | |
| 6 | | 8 | 6 | 8 | | | |
| 7 | | * | 8 | 11 | | 6 | |
| 8 | | 8 | 12 | 18 | 14 | 7 | |
| 9 | | 6 | * | 37 | 22 | 13 | 12 |
| 10 | | 2 | 4 | * | 44 | * | 10 |
| 11 | | .1 | | 12 | * | * | 8 |
| 12 | | | | | 14 | 27 | * |
| 13 | | | | | 5 | 14 | 1 |
| 14 | | | | | * | * | |
| 15 | | | | | .2 | * | |

All currents in eμA at 10 kV beam energy.

* indicates not measured because of overlap with other ions.

Natural isotopic abundance source feeds were used, except for $^{44}$Ca.

**L** indicates low temperature oven. **H** indicates high temperature oven.

**Q** is charge state.

Table 2. Currents for Beams from Ovens: Iron to Bismuth

| Q | $^{56}Fe$ H | $^{58}Ni$ H | $^{63}Cu$ H | $^{107}Ag$ H | $^{139}La$ H | $^{159}Tb$ H | $^{209}Bi$ L |
|---|---|---|---|---|---|---|---|
| 10 | 8 | 3 | 5 | | | | |
| 11 | 9 | * | 8 | | | | |
| 12 | * | 5 | * | | | | |
| 13 | 8 | 6 | 10 | | | | |
| 14 | * | 5 | 9 | | | | |
| 15 | 5 | 3 | 7 | 2 | 1 | | |
| 16 | * | 3 | * | 3 | 1.4 | | |
| 17 | .5 | 2 | 3 | 4 | * | | |
| 18 | | | | * | 2 | | |
| 19 | | | | 6 | 3 | 3 | |
| 20 | | | | * | * | * | |
| 21 | | | | 3 | 5 | 5 | 2.2 |
| 22 | | | | 1.4 | 5 | 5 | 2.6 |
| 23 | | | | | * | * | 3.1 |
| 24 | | | | | 4 | 5 | 3.7 |
| 25 | | | | | * | 4 | 3.6 |
| 26 | | | | | * | * | * |
| 27 | | | | | 2 | * | 3.0 |
| 28 | | | | | * | 1.2 | 2.5 |
| 29 | | | | | .4 | .6 | 1.6 |
| 30 | | | | | | * | * |
| 31 | | | | | | .1 | .6 |
| 32 | | | | | | | .3 |
| 33 | | | | | | | .2 |

All currents in eμA at 10 kV beam energy.

* indicates not measured because of overlap with other ions.

Natural isotopic abundance source feeds were used.

**L** indicates low temperature oven. **H** indicates high temperature oven.

**Q** is charge state.

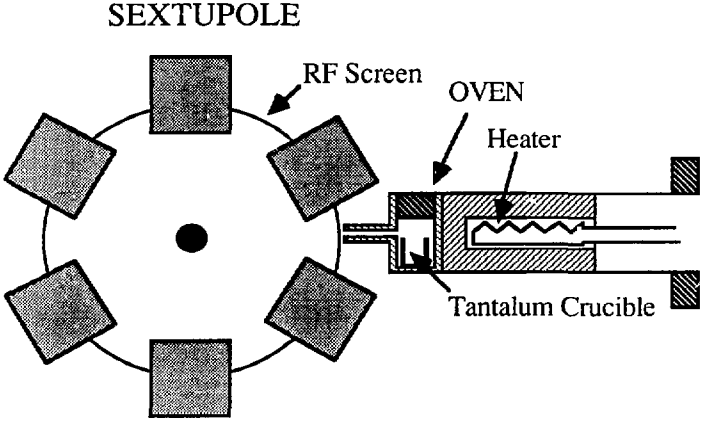


Fig. 1 - Cross-section of second stage of LBL ECR source and low temperature oven.

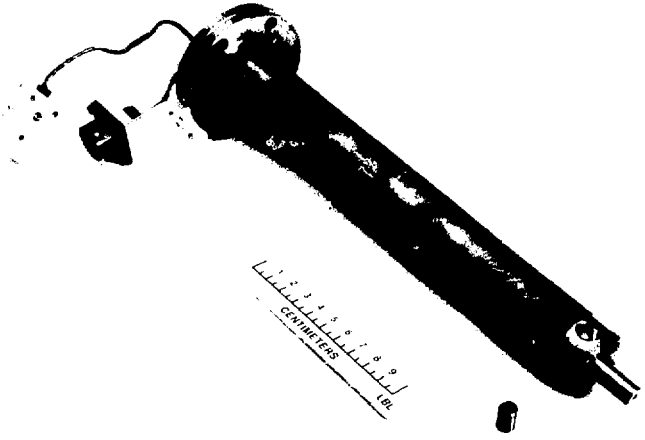


Fig. 2 - Photograph of low temperature oven assembly. CBB 888-7570.

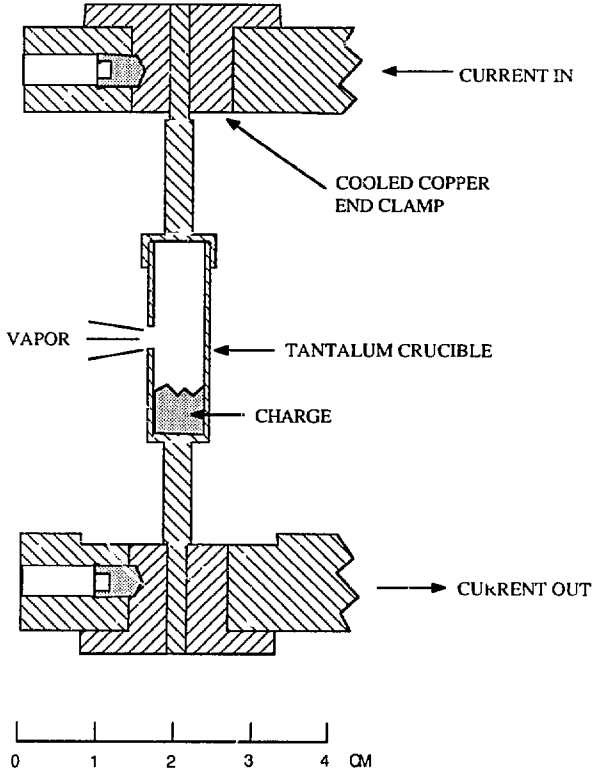


Fig. 3 - Schematic drawing of high temperature oven.

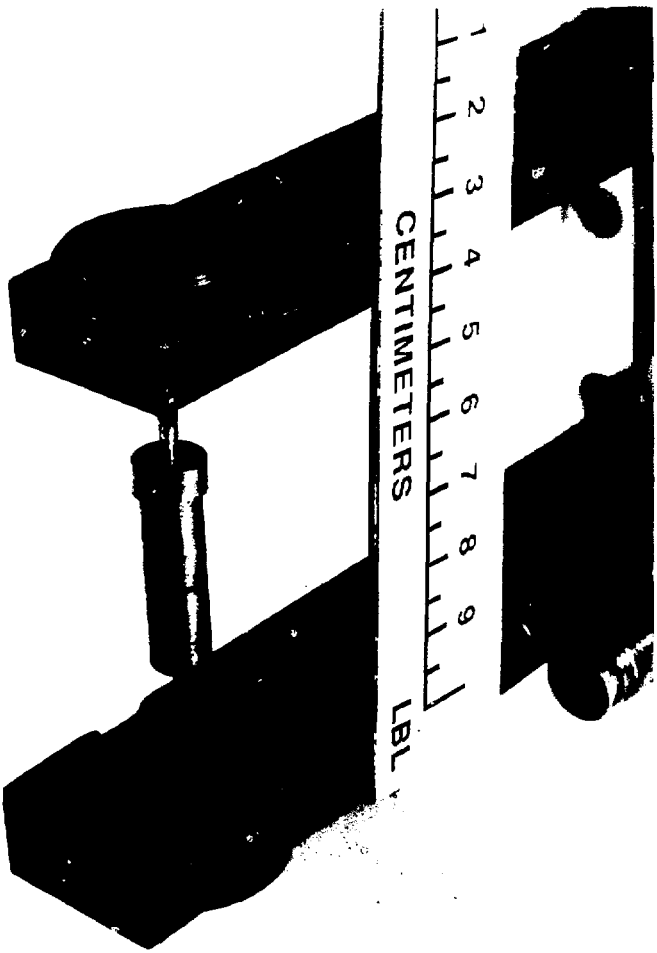


Fig. 4 - Photograph of high temperature oven showing assembled crucible and end clamp assembly. CBB [illegible]-7574.

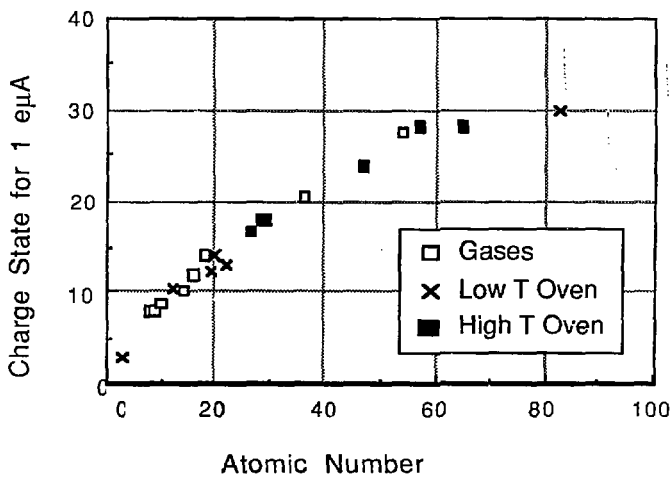


Fig. 5 - Charge states for the 1 eμA level for elements run from gas feed and from the low and high temperature ovens.