THE SUPER GAS MIXING TECHNIQUE FOR HIGHLY CHARGED URANIUM IONS

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ABSTRACT

Producing uranium ions in an ECR ion source is problematic. Uranium hexafluoride is highly corrosive and hard to handle. It also poisons the ion source. Metallic uranium has a low vapor pressure versus temperature profile— with direct insertion into the plasma, it melts before adequate vapor is produced. Uranium oxide is more refractory, aiding direct insertion vaporization, but the position sensitivity is sharp—either too much or too little uranium is produced. We have found a new technique that is based on the insertion of uranium metal powder into a high pressure oxygen plasma. The uranium concentration is low, hence the moniker 'super gas mixing', but the uranium charge state distribution is peaked around 30+ in a 6.4 GHz ECR source. The uranium consumption rate is a low 100–250 $\mu gms/hr$, and no source poisoning is observed. This technique has general applicability—we have tried it for magnesium, vanadium, nickel and molybdenum with equal success. Since small quantities of powdered metal are consumed, enriched isotopes, most generally available in powdered form, require no special handling.

1. Super Gas Mixing Technique

The origin of this technique was not actually the production of a uranium beam but rather a request to make an intense $^{92}Mo^{25+}$ beam for an isotope search experiment at the K1200 cyclotron[1]. The natural abundance of ^{92}Mo is 15%. Our starting point therefore was 100% enriched ^{92}Mo metal powder. We tried various techniques to turn this powder into a metallic fluke for direct plasma inser-

tion, but had trouble either with material consumption (too high), or the charge state distribution (too low). We did find that powder would stick to the end of a small diameter (4mm) alumina rod. This alumina rod could be directly inserted into the oxygen plasma in the RTECR main stage with very good results, if the oxygen plasma is set up in the following manner:

1. The RTECR is initially tuned on Xe + O_2 to optimize the high charge state Xenon ions (27-31+).

2. The Xenon gas feed is shut off

3. The oxygen feed is raised above that of the $O_2 + Xe$ mixture, until the pressure has risen approximately $\frac{1}{2}$ order of magnitude above the optimum value for the high charge state Xenon tune.

4. The microwave power is approximately doubled, but the magnetic field of the ion source is held constant.

5. An alumina rod is coated with approximately 10mg of ^{92}Mo powder, then inserted radially into the RTECR, just until molybdenum ions are observed in the plasma.

With this technique, one has a relatively uncritical oxygen plasma. The details of the sample radial insertion scheme are shown in Figure 1. The resulting charge state RTECR distribution is shown in Figure 1. (In this case, the mixing gas is 90% enriched ^{18}O). As the upper spectrum shows, on the
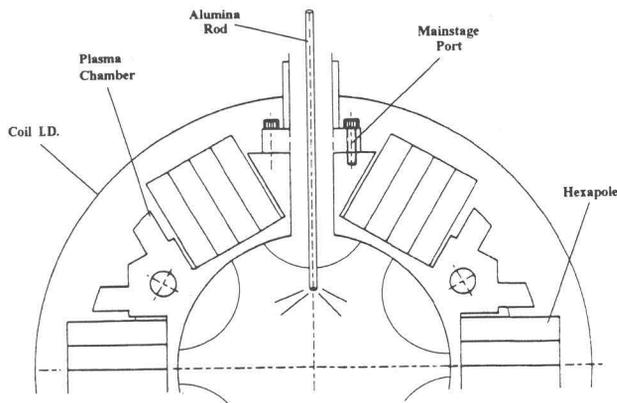
Figure 1. The metal powder doped alumina feed rod is inserted radially into the main stage plasma.

Figure 2. An $^{18}O + ^{92}Mo$ spectrum for a 'super gas mixing' tune of the RTECR is shown, normal scale and expanded to show the molybdenum charge state distribution.

intensity scale of the oxygen ions, the molybdenum ion peaks appear as impurities. But with the scale expanded, in the lower spectrum, highly charged molybdenum ions are observed. One sees also that the oxygen charge distribution is rather poor.

We have now used this technique for V, Ni, Mo, and U ion production. When applied to ^{238}U ion production, we obtain the spectrum shown in Figure 3. To see the significance of this technique, the U ion performance of the 18 Hz ECRIS in Grenoble is also shown in Fig. 3 [2]. One can see that the RTECR actually exceeds the 18 GHz source performance for the highest charges.

Enriched isotope materials are used in powdered form with no special handling. Material consumption is low, with an upper limit of about $2\mu gm/min$ for uranium and other materials have rates of $2-5\mu gm/min$. With such small material consumption rates, source poisoning is not an issue, and metallic species chemistry hardly plays a role in the behavior of the plasma. The plasma appears to be an uncritical, high pressure oxygen plasma with a poor oxygen charge state distribution. However, the charge state distribution of the heavier metallic species comes automatically peaked at highly charged ions with very little tuning. The sample is not generally moved after initial contact with the plasma, and only the tip of the alumina rod is observed to be running hot.
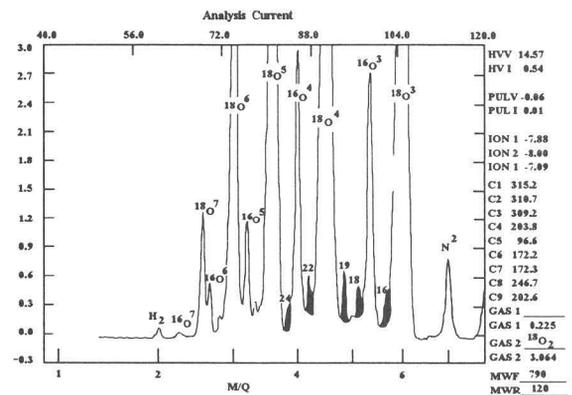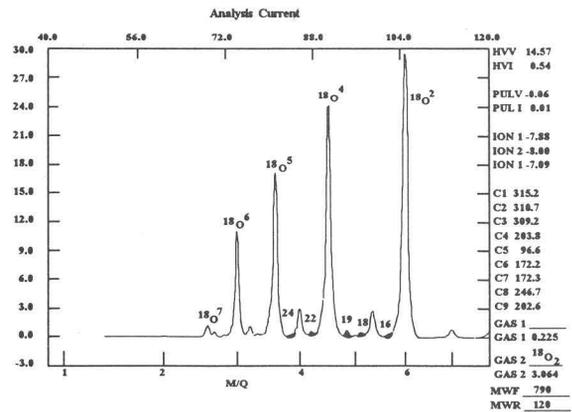
2. RTECR Overall Performance

The other curious feature of this tune is that the metallic ion performance for highly charged ions is the same as nearby gaseous feed species, including the noble gases. Further, as Figure 4 illustrates, the $1e\mu A$ output level of the RTECR is regular and smooth from Nitrogen to Uranium, and appears to be predictable on the basis of the ionization potential, which for all of these ions is approximately $1keV$.

3. Ionization Difficulty

The smooth performance of the RTECR has lead to a model for the ionization difficulty in the plasma. The mechanism for the production of

highly charged ions is Successive Impact Ionization

$$X^{i+} + e \rightarrow X^{(i+1)+} + 2e \qquad (1)$$
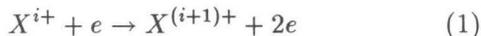
The ionization rate $\nu_{i,i+1}$ for a single step is

$$\nu_{i,i+1} \;=\; n_e(E_e)\sigma_{i,i+1}(E_e)v_e \;\; (\text{sec}^{-1}) \qquad (2)$$

therefore, the step ionization time $\tau_{i,i+1}$ is

$$\tau_{i,i+1} \;=\; \frac{1}{\nu_{i,i+1}} = (n_e\sigma_{i,i+1}v_e)^{-1} \;\; (\text{sec}) \qquad (3)$$

If we take

$$\xi_{i,i+1} = \; < \sigma_{i,i+1}(E_e)v_e >_{T_e} \qquad (4)$$

Then the ionization step time averaged over the electron distribution would be

$$\overline{\tau}_{i,i+1} = \frac{1}{n_e\xi_{i,i+1}} \qquad (5)$$

Suppose $\overline{\tau}$ is the average ion lifetime in the plasma. We then make the assertion that, for the step $i \rightarrow i+1$ to be feasible, we should have

$$\overline{\tau} > \overline{\tau}_{i,i+1} \qquad (6)$$

Then we have finally

$$n_e\overline{\tau}_{i,i+1} \geq \xi_{i,i+1}^{-1} \qquad (7)$$

If we choose optimum conditions for a particular ion, Eq.(7) can be solved for the optimum charged state of other species that would be produced under equivalent conditions. Table 1 shows such a calculation for the noble gas charge states that would be produced when conditions are optimum for N^{7+} or Ne^{10+}. Table 1 also includes the actual performance achieved with the RTECR (in $p\mu A$). Hence on the basis of purely ionization rate considerations, the N^{7+} performance is a good predictor of the RTECR performance for other species, as was shown in Fig. 4. As Table 1 shows, this scaling breaks down somewhat as a predictor of heavy ion species having ionization difficulty equal to that of Ne^{10+}. However, at present this model only includes ion production, and the inclusion of ion loss mechanisms in this calculation, particularly charge transfer processes, will correct the inherent over estimation of very highly charged ions as shown for Ne^{10+}.

Table 1. RTECR Performance vs. Theory

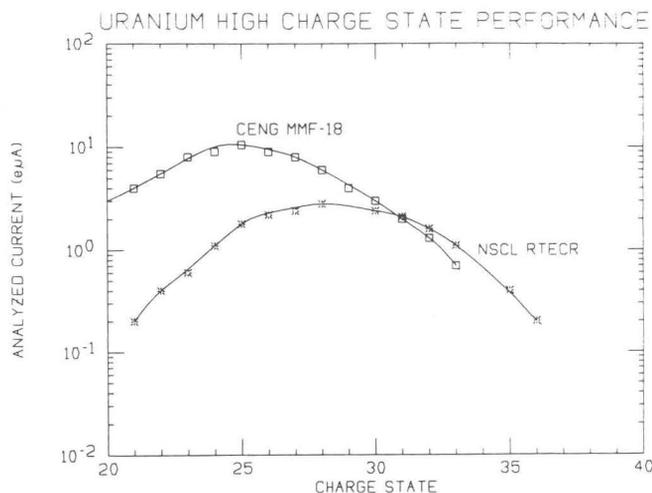| Opt. Ion	Te^{opt}	Ne	Ar	Kr	Xe	U
N^{7+}	3.8 keV	9	14	20	28	34
RTECR	$0.1p\mu A$	9	14	19	26	28
Ne^{10+}	7 keV		16	26	35	47
RTECR	$0.01p\mu A$		16	22	29	35

Figure 3. A comparison of uranium charge state distributions for the 18 GHz minimafios ECRIS in Grenoble [2], and the RTECR tuned via the super gas mixing technique.

4. 14.5 GHz Metallic Ion ECRIS

For the super gas mixing technique, the ion source mode is simple—a high power, high pressure oxygen plasma with little or no magnetic field tuning. Since tuning is so simple, the source design can be simplified as well. This design simplicity would then allow more operational flexibility. A projection of this technique to 14.5 GHz is shown in Figure 5. The estimated cost of hardware (sans transmitter) is 100k$. The main difference in this design is that the metallic sample is fed into the main stage through a microwave coax. Why 14.5 GHz? A further improvement in intensity and ionization efficiency would be expected on the basis of improved confinement at the higher operating frequency, at least for intermediate charge ions.
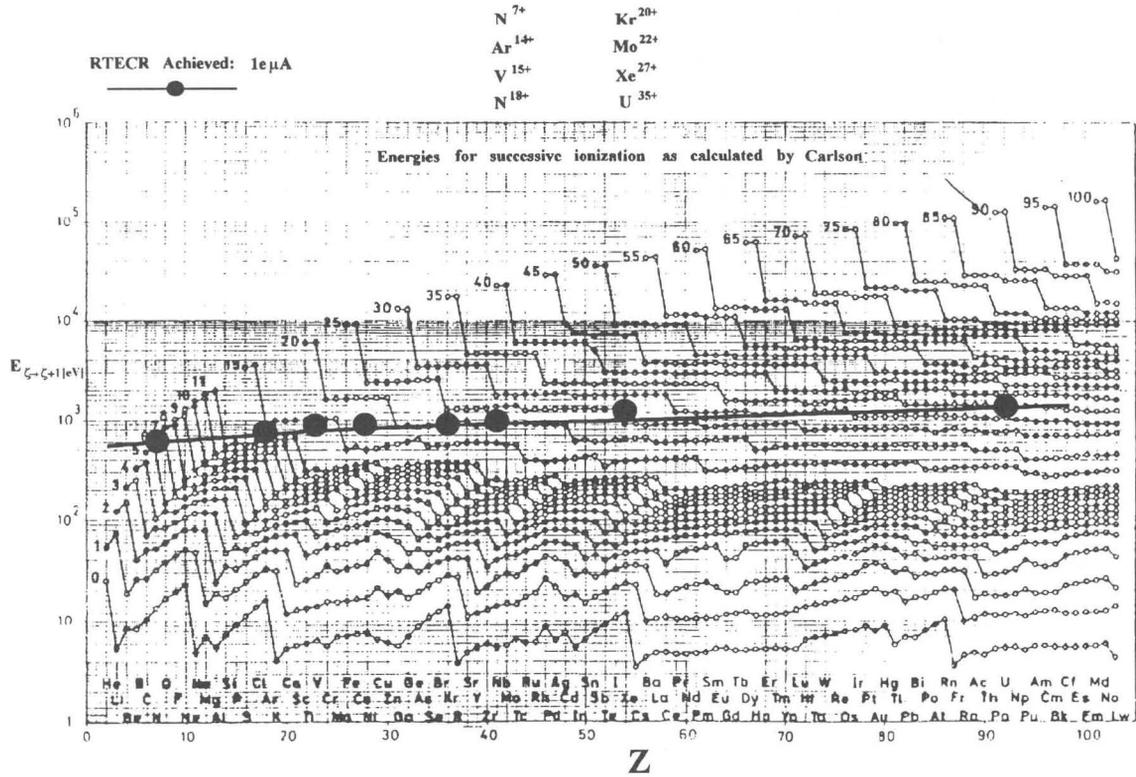
Figure 4. The $1e\mu A$ extracted charge state of various ions extracted from the RTECR are marked on this familiar plot of step ionization potential versus z from ref [3].

5.   REFERENCES

1) Yennello, et.al., Phy.Rev.C, to be published, (1992).
2) Melin, G., private communication, (1991).
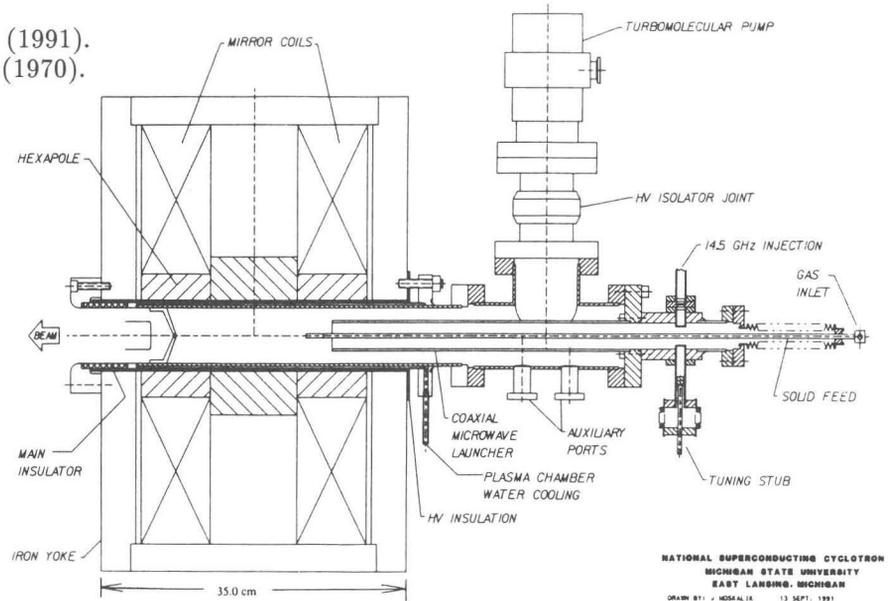3) Carlson, T.A., et.al., ORNL-4562, (1970).

Figure 5. A 14.5 GHz RTECR source design based on the super gas mixing technique.