

## OPERATION OF THE ORNL ECR SOURCE

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### Abstract

The ORNL ECR multicharged ion source, dedicated for studying the atomic physics interactions of multicharged ions with atoms, ions, electrons, and surfaces has been in operation since 1984. High charge state ion beams ranging from fully stripped light ions (up to Ne) to up to 40% stripped heavy ions ( $A \sim 200$ ) have been produced. Ion beams of the metallic elements developed to date include Cr, Fe, Ni, Ta, and Au, and are obtained by the use of a solid feed technique.

### Introduction

In order to be able to extend ongoing studies of the atomic physics of multicharged ion collisions, an Electron Cyclotron Resonance (ECR) ion source has been in operation at ORNL since 1984. The initial operation of the ORNL ECR source has been previously described.<sup>1</sup> While far from optimized in its first year of operation, the ion source was nevertheless already able to provide fully stripped ion beams of C, N, O, F, and Ne of sufficient stability and intensity to permit electron capture cross section measurements using an atomic hydrogen target.<sup>2</sup> Optimization of the source, particularly of the first stage, occurred intermittently over the period of a year starting late 1984 and resulted in improved ion beam intensity and stability, facilitating the first crossed beams<sup>3</sup> and merged beams<sup>4</sup> experiments carried out using the source. In 1985 iron ion beams were developed and used for a comprehensive crossed beams study of electron impact ionization along the Fe isonuclear sequence from charge 5+ to 15+. In the meantime, the repertoire of experiments carried out with the ORNL ECR source has steadily expanded, and includes now high resolution spectroscopic measurements of Auger electrons emitted during multicharged ion-atom collisions, and investigations of multicharged ion-surface interactions at low energies. This paper describes the present configuration of the ORNL ECR source, as well as current source performance and operating experience to date. In addition, metal ion production using the ECR source will be discussed.

### The ECR Source

The salient features of the ORNL ECR source are shown in Fig. 1 (present source parameters are summarized elsewhere<sup>5</sup>). The source operates at a microwave frequency of 10.6 GHz and consists of two stages, quite similar in size to MINIMAFIOS.<sup>6</sup> The first stage, essentially a preionizer, consists of a 2.5 cm diameter circular waveguide, and generates singly charged ions (and electrons) in an ECR discharge, which then drift into the second or main stage of the ion source. The second stage is separated from the (high pressure) first stage by two stages of differential pumping, which is sufficient to maintain low  $10^{-6}$  Torr operating pressure in the second stage. The second stage serves to confine energetic electrons that are heated by resonant microwave absorption. By collisions with these "hot" electrons, the singly charged ions are stripped to the high charge states that are then extracted from the source. Figure 2 shows the axial magnetic field profile characterizing the ion source. The first stage ECR plasma electrons are weakly confined in an axial

magnetic mirror. An iron plate in back of the first stage provides a region of high magnetic field where the first stage microwave vacuum window is located. The second stage ECR plasma electrons are confined in a "minimum B" configuration produced by a superposition of the axial magnetic mirror field shown in Fig. 2 and a radial magnetic hexapole field. The hexapolar field is produced by a compact assembly of  $\text{SmCo}_5$  permanent magnets positioned around the cylindrical vacuum wall of the second stage. The hexapolar

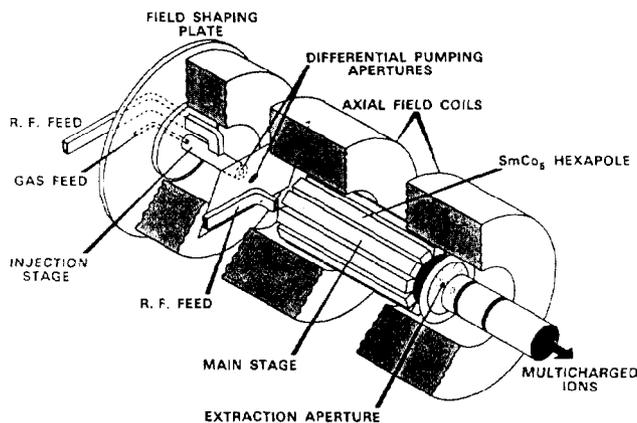
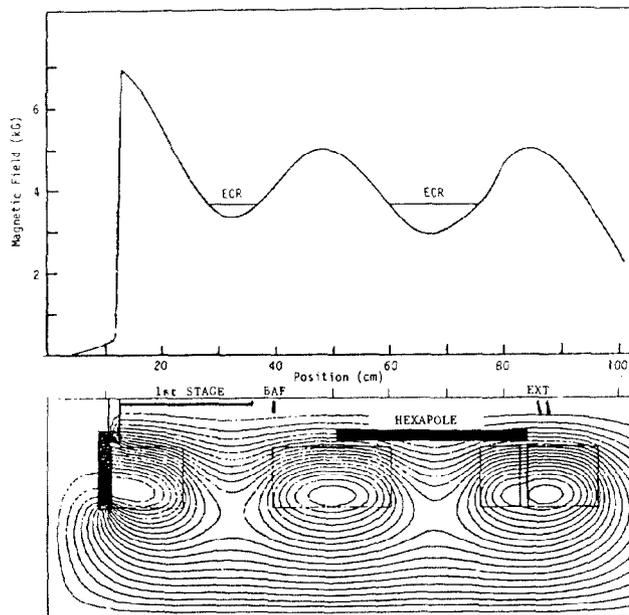


Fig. 1. Cutaway drawing of the ORNL ECR source.



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Fig. 2. Solenoidal magnetic field profile of ORNL ECR source (top) calculated using PANDIRA; PANDIRA solenoidal magnetic field lines output (bottom) showing location of first stage, differential pumping baffle (BAF), plasma and puller electrodes (EXT), coils and iron field shaping plate.

magnetic field strength at the vacuum wall is about 4 kG. Figure 3 shows a cross sectional view of the 12-piece hexapole magnet assembly.

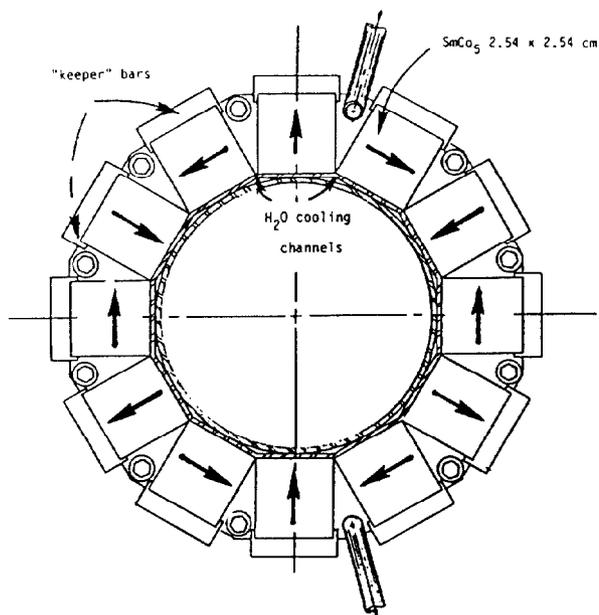


Fig. 3. Cross sectional view of SmCo<sub>5</sub> permanent magnet hexapole assembly; arrows indicate magnetization directions.

The multicharged ions escaping through the 0.8 cm aperture in the plasma electrode at the end of the main stage are formed into an ion beam using a "Pierce-like" extraction geometry. The ions are accelerated across a 2.6 cm gap to a "puller" electrode with 1.0 cm aperture. For optimum beam currents, the puller electrode requires negative biasing of at least a few hundred volts. An Einzel lens<sup>7</sup> located 50 cm downstream focuses the extracted beam onto the entrance aperture of a stigmatic 90° magnetic charge analyzer having a 40 cm radius of curvature.

The ECR source was designed for a maximum source potential of 20 kV. Ion beams of energy  $17 \times q$  keV are produced routinely. Beam divergences have been measured using a rotating wire beam scanner located about 1 m after the exit slits of the 90° charge analyzer. For 50 keV O<sup>5+</sup> beams, the divergence half angles of the central 2 × 2 mm portion of the ion beam were measured to be 12 and 8 mr in the horizontal and vertical planes, respectively. The full analyzed beam intensity is usually obtained when the analyzer slits are opened to 10 × 10 mm. Low energy ion beams have been extracted at source potentials as low as 400 V. At energies below about  $5 \times q$  keV, the magnetic fringe field of the ECR source contributes significantly to the focusing of beams having low magnetic rigidity.<sup>7</sup> Under some conditions, this fringe field, acting as half of a "Glaser" lens, is sufficient to focus the extracted beam onto the entrance slits of the charge analyzer without the assistance of the Einzel lens.

Until early 1987, beams from the ECR source could be delivered to only one "user port," located about 1.5 m after the exit slit of the charge analyzer. A half scale version of the main 90° charge analyzer is being installed and will be used to switch the beam between the original straight-through beamline and one oriented at 90° to it. A rotatable spherical sector electrostatic 90° deflector will be installed in the

new beamline to provide two additional user ports later this year. The resulting total of four beamlines have all been designed for maximum beam transmission, and will greatly increase the flexibility and accessibility of the ECR source facility.

#### Source Performance

Table I summarizes typical beam currents obtained using the ORNL ECR source for a few representative elements. Ions of elements existing as permanent gases are straightforward to produce. Gas mixing was used to obtain maximum beam currents in the high charge state tail of the charge state distribution. He or H<sub>2</sub> was found to be effective for the lighter elements ( $A < 20$ ). N<sub>2</sub> or O<sub>2</sub> were used with the heavier elements. Ions of the metallic elements were produced using a solid feed technique similar to that described by Delaunay et al.<sup>8</sup> The technique entails inserting a small metallic sample into the ECR plasma, thereby heating the sample by electron impact and raising the vapor pressure of the sample sufficiently to yield usable ion beam currents. Most of the metallic samples used were in the form of thin foils (0.025–0.25 mm thick), to minimize the thermal time constant that determines the rate of sample heating, and also to minimize thermal conduction away from the foil edge in contact with the plasma, while maximizing the surface area from which vaporization occurs. The rate of vaporization is determined by the local electron power density seen by the sample, and can thus be varied by changing the foil position, tuning the source magnetic field, or adjusting the microwave power.

In the case of the Fe and Ni beams, nonmagnetic samples of stainless steel and Inconel were used to avoid mechanical stresses due to the magnetic fields confining the main stage ECR plasma. Inconel could

Table 1. Representative ORNL ECR source beam currents (electrical  $\mu$ A); 10–12 kV source voltage.

	<sup>16</sup> O	<sup>40</sup> Ar	<sup>56</sup> Fe	<sup>58</sup> Ni	<sup>84</sup> Kr	<sup>127</sup> I	<sup>129</sup> Xe <sup>a</sup>	<sup>181</sup> Ta	<sup>197</sup> Au
+1	400	110	10						
+2	300	120	*						
+3	170	90	20						
+4	100	75	*						
+5	83	*	23	3	20				
+6	50	65	25	5	25				
+7	2.5	73	*	7	26				
+8	0.1	105	*	12	27				
+9		45	20	20	33		5.0		
+10		*	10	17	31	8	4.5	12	25
+11			3.0	5	33	10	3.5	*	27
+12		0.7	*	5	40	14	3.5	12	21
+13			2	3	23	18	3.2	12	18
+14			*	1	21	20	2.5	12	*
+15			1.5	0.5	15	18	1.5	12	18
+16				0.15	5	*	1.2	12	15
+17				0.03	1	10	1.0	11	12
+18				*	*	*	0.6	8	10
+19					0.25	3	0.6	5	7
+20						2	0.5	3.5	5
+21						*	0.25	2	5
+22						0.5	0.12	1.8	4
+23								*	3
+24								1.5	2.5
+25							0.08	1.0	*
+26							0.05	*	0.9
+27								0.4	0.4
+28								0.1	*
+29								0.05	0.1
+30									0.015 <sup>b</sup>
+31									0.005 <sup>b</sup>

\*Indicates m/q degeneracy with contaminant beam.

<sup>a</sup>5 × 5 mm slits.

<sup>b</sup>2 × 2 mm slits.

also be used to produce copious beams of Cr. "Mix" gases of nitrogen or oxygen were used to sustain the main stage plasma in the absence of metal vapor, and to optimize the high charge states as mentioned above. When using the Inconel foil sample for Ni beams, the use of O<sub>2</sub> was found to result in significant oxide formation on the foil, which inhibited sample vaporization and resulted in erratic and unstable ion beams. The situation was significantly improved after switching to N<sub>2</sub>. A similar effect was not observed when using O<sub>2</sub> with stainless steel foils. A typical consumption rate measured for the stainless steel foil samples was 3.5 mg/hr. In the case of both the Fe and Ni beam generation, significant gettering action by the metal vapors was observed, as evidenced by a lowering of the second stage pressure as the metal vapor pressure increased.

Ta ions could be produced either from a 0.025 mm thick foil or from the Ta liner protecting the vacuum wall of the second stage. The latter method required lowering the solenoidal magnetic field in the second stage, thereby expanding the ECR plasma toward the Ta liner until sufficient interaction took place for wall material "recycling." The Au sample used consisted of 0.5 mm wire wound around a matrix of two 0.8 mm W rods, the free ends of which were then clamped to the foil positioning mechanism. In the case of the Au ions, a large variation in sample position was required in order to optimize different charge states, low charge states requiring the sample to be inserted significantly farther into the plasma to generate sufficient Au vapor density than the highest charge states. Figure 4 shows sample charge state distributions obtained for gold ions under different source conditions.

#### Operating Experience

The day to day reliability of the ORNL ECR source has been extremely good. Cleaning of the source is required only after many weeks of metal ion production. Source opening is required to change solid feed materials, but this is accomplished conveniently and quickly. Typical cycle times required by two people to change samples are about half an hour.

During the three years of operation to date, only three major source related failures have occurred. The first was a vacuum leak that developed in the 10.6 GHz Klystron after about 1300 filament hours. In less than a week that tube was replaced by a backup tube purchased with the original microwave system and stored at VARIAN. In Dec. 1985 the extraction side solenoidal field coil of the ECR source developed a water leak. Fortunately, the leak could be quickly isolated to one of the double pancakes making up the coil, which was then bypassed and taken out of the electrical and cooling circuits. The coil power supply had sufficient reserve current capability, so that the resulting loss of turns could be compensated by an increase in the coil current. Down time resulting from the coil failure was less than two days. In the fall of 1986 the turbopump providing differential pumping between first and second stages failed (after 25000 pumping hours). In the two weeks that elapsed until a replacement could be installed, the ECR source was operated without the turbopump, using a rebuilt first stage having smaller aperture. Output of intermediate charge state beams (e.g., O<sup>5+</sup>) was comparable to that obtained during normal operation.

#### Conclusion

Since start of operation in early 1984, the ORNL ECR source has reliably produced ion beams over a broad range of charge states and energies. The source has proven to be convenient and straightforward to

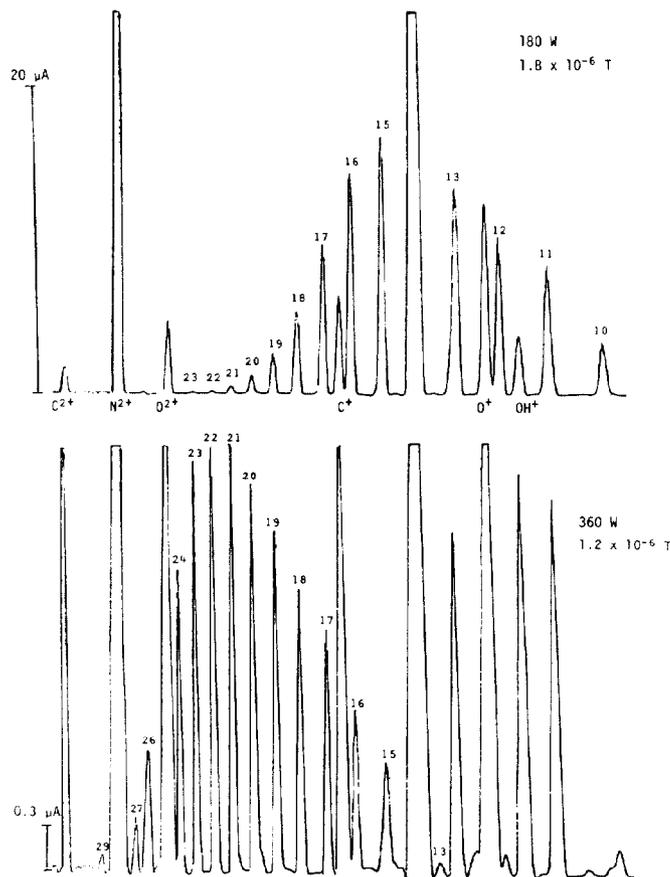


Fig. 4. Charge state distributions of Au ions extracted from the ORNL ECR source obtained for different source conditions.

use, and extremely flexible in terms of the large variety of ion species it can provide. In the course of the many atomic physics experiments carried out to date, the ORNL ECR source has demonstrated its usefulness as a research tool in the study of the atomic collision interactions of highly charged ions.

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