Metallic Beam Development with an ECR ion source at Michigan State University (MSU)

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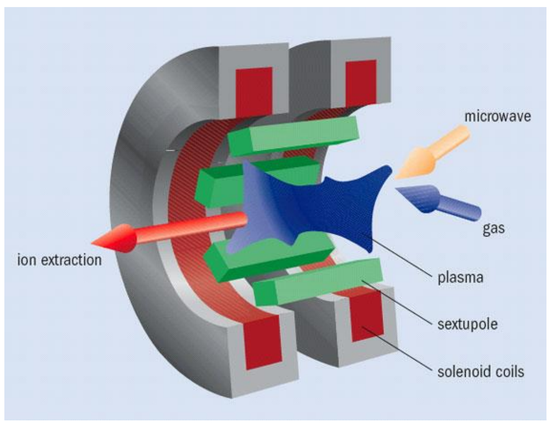
Abstract

Session II, Poster # 29

Electron Cyclotron Resonance (ECR) ion sources have been used at MSU to provide metal ion beams to the coupled cyclotron facility (CCF), and in the future, for The Facility for Rare Isotope Beams (FRIB). The challenges of metallic beam production with ECR are in production, efficiency, stability and contamination. Future facilities such as FRIB will add the challenge of intensity. We report development of two rare earth metals and the conversion from the oxidized state into metal. The enriched isotopes of ^{144}Sm, and ^{176}Yb are commonly available in the sesquioxide form which is unsuitable for use in our standard ovens. We report here results from the off-line chemical reduction of samarium, and ytterbium oxides into metal. We were able to demonstrate efficiencies of up to 90 % throughout the conversion process. The samples were then run on our ECR ion sources to confirm the products of the reduction. In addition we report the development of cadmium metal by passing vapor though over 3/4 m of heated stainless steel tubing and observed 4.3 eμA of Cd^{20+} with an average consumption of 1 mg/hr.

Electron Cyclotron Resonance (ECR) Ion Sources



Above: *Schematic of an ECR Ion Source showing the ECR plasma in relation to the solenoid and hexapole magnets [1].*

What is an ECR Ion Source?

+ Workhorse plasma ion source for accelerator facilities such as NSCL/FRIB (USA), GANIL (France), RIKEN (Japan), CERN (Switzerland), ATLAS (USA), and many more.

+ ECR sources may ionize the periodic table with elements ranging from helium to uranium.

+ Electrons rotating at cyclotron frequency in a magnetic field are heated by co-circulating electric fields →Circularly polarized light!

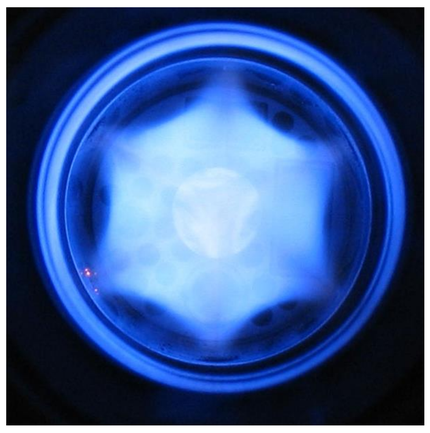
$$f = 2\pi\frac{qB}{m} \cong 28\frac{GHz}{T} * B \text{ (For } e^-\text{)}$$

+ Magnetic field satisfies cyclotron resonance condition and allows confinement of ions.

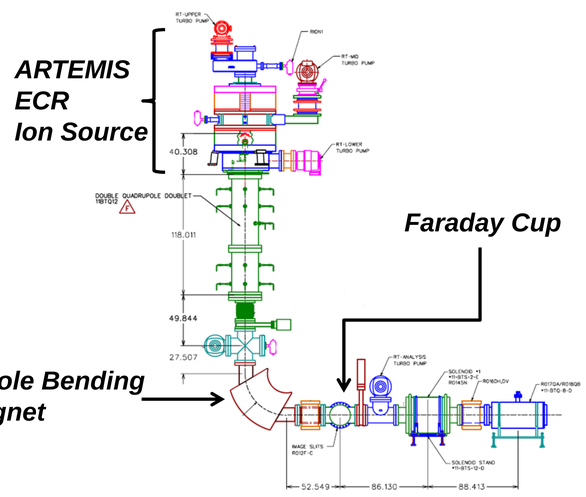
→ Minimum B field configuration.

+ Plasma is extracted from a series of electrodes.

+ Ion species may be selected with a dipole bending magnet, and beam intensity measured on a faraday cup.



Above: *Argon plasma sustained with 14.3 GHz microwave radiation as imaged in the visible band [2].*



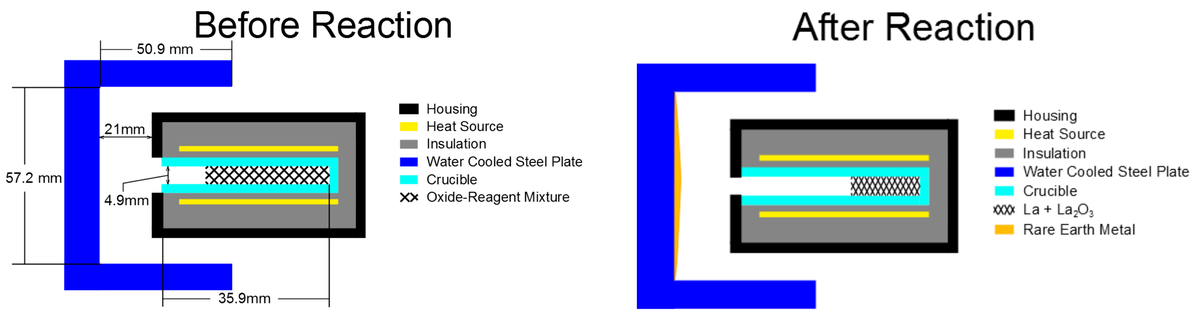
On Right: *Schematic of ARTEMIS ECR beam line at MSU NSCL. Key components are highlighted.*

Chemical Reduction of Rare Earth Oxides

Primary beams of ^{144}Sm and ^{176}Yb are among the top 5 most requested primary beams for the new heavy ion user facility FRIB. However, chemical reduction of the natural oxide form is required to produce a beam.

$$R_2O_3 + 2B \leftrightarrow B_2O_3 + 2R$$

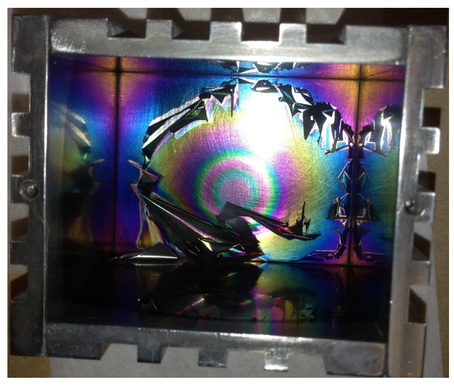
Wherein **R** is a rare earth metal and **B** is the chemical reagent. Reaction occurs at 1200° C and 1350° C [3] for ytterbium and samarium respectively.

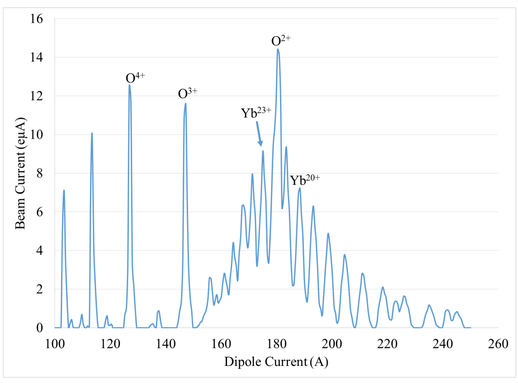


On Left: *Metal vapor oven and deposition plates prior to heating.*
On Right: Post heating (12-24 hrs), a rare earth metal sample is deposited.

Element	R2O3 (mg)	R (mg)	Temperature°C	Efficiency (%)
Yb	353	208	1200	66
Yb	251	196	1300	87
Sm	214	167	1500	90
Sm	203	68	1340	39

Above: *Table of chemical reduction sample size and efficiency (by weight).*

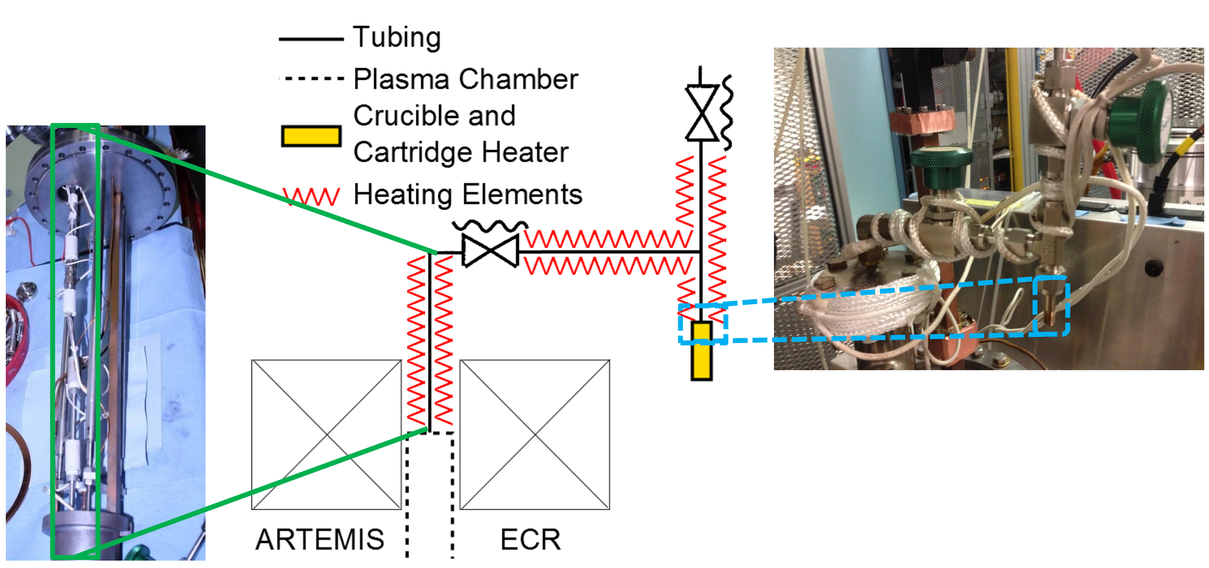




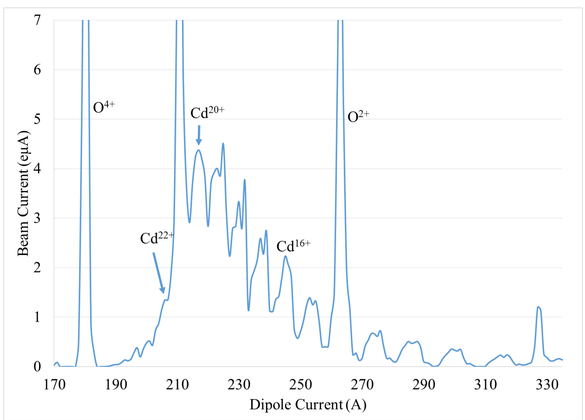
On Left: *Ytterbium metal deposited into the stainless steel box as photographed upon venting vacuum chamber.*
On Right: Charge state distribution of the ARTEMIS plasma exhibiting natural ytterbium peaks. The sample was converted to metal with the presented technique.

Cadmium Development on ARTEMIS

^{106}Cd is one of FRIB's top 10 most requested primary beams by the nuclear science community. Cadmium vapor is injected into an oxygen plasma to ionize the metal. We developed a technique to vaporize cadmium that may allow for precision valve regulation. Valve regulated metal vapor would increase the stability of the ion source.



*Transfer line (**On left**), schematic of exterior oven (**Center**), and image of sample reservoir (**On right**). Key components have been highlighted for ease of identification. The sample cartridge heater (not shown), but would screw onto the bottom of the threaded crucible (**On right**)*



On Left: *Cadmium was developed for 13 hrs with an average consumption of 1 mg/hr. The charge state distribution was obtained with a transfer line thermocouple reading of 140° C and a sample temperature of 260° C at a power consumption of 336 watts across all heating elements, with 65% drawn by the heater tapes, 19% by the transfer line, and 16% by the sample cartridge heater.*

Conclusion

We demonstrated the efficient chemical conversion of ytterbium and samarium from the sesquioxide into elemental form with efficiencies up to 90% without modification to our standard resistive oven. We were able to positively identify Yb and Sm samples by vaporizing these metals into our ECR ion source ARTEMIS. In addition we exhibited an exterior oven design that is applicable to a metal such as cadmium that requires heating to sublimate. The exterior oven may be useful for the production of extremely stable cadmium and selenium beams in the future by precision valve regulation.

REFERENCES:

[1] D. Leitner, CERN Courier, May 2005
[2] ATOMKI ECR Ion Source Group, WWW Document, http://www.atomki.hu/Accelerators/ECR/plasmaph.htm (2009)
[3] E. H. Kobisk and W. B. Grisham, *Mat. Res. Bull.* 4, 651 (1969)

ACKNOWLEDGEMENTS:

This work was supported by Michigan State University and the National Science Foundation: NSF Award Number PHY-1102511

The NSCL is funded in part by Michigan State University and the National Science Foundation.