RECENT ACTIVITIES AT THE ORNL MULTICHARGED ION RESEARCH FACILITY (MIRF)*

F.W. Meyer#, M.E. Bannister, J.W. Hale, C.C. Havener, H.F. Krause$, C.R. Vane, S. Deng, I.N. Draganić, P.R. Harris, Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6372 USA

Abstract

Recent activities at the ORNL Multicharged Ion Research Facility (MIRF) are summarized. A brief summary of the MIRF high voltage (HV) platform and floating beam line upgrade is provided. An expansion of our research program to the use of molecular ion beams in heavy-particle and electron collisions, as well as in ion-surface interactions is described, and a brief description is provided of the most recently added **I**on **C**ooling and **C**haracterization **E**nd-station (ICCE) trap. With the expansion to include molecular ion beams, the acronym MIRF for the facility, however, remains unchanged: “M” can now refer to either “Multicharged” or “Molecular.”

THE MIRF UPGRADE PROJECT AND RECENT FACILITY ACTIVITIES

In order to enhance the capabilities of on-line experiments of the MIRF [1], a facility upgrade project was undertaken to add an all permanent magnet ECR source on a new 250 kV HV platform, and to modify the existing CAPRICE ECR source to inject a new floating beam line, from which beams could be decelerated into grounded end stations with final energies as low as a few eVxq, where q is the charge state of the analyzed beam [2][3][4]. An electrostatic trap end station was also added to the facility, for multi-second confinement of metastable-multicharged or hot-molecular ions to reduce their degree of internal excitation either for lifetime or subsequent cold collision studies [5].

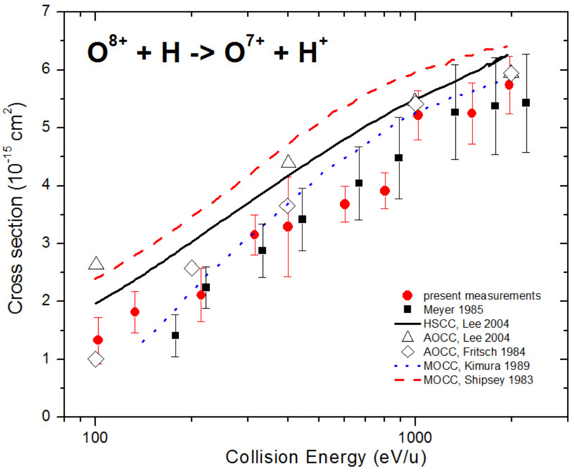

Figure 1: Results for O^{+8} – H electron capture [7].

Table 1: Performances of the MIRF ECR sources [6]

Ion		CAPRICE 10 GHz	Platform ECR source
Xe	+20	35 µA	52 µA
	+26	9	24
	+29	--	3
Ar	+8	500	510
	+11	70	90
O	+6	400	650
	+7	50	90

The new permanent magnet ECR source was designed and built at CEN-Grenoble, and has been previously described [6]. Table 1 summarizes typical multicharged ion performances for the CAPRICE and the new permanent magnet ECR sources injecting the low-energy and high-energy MIRF beam lines, respectively.

To illustrate the increased experimental capabilities made possible by the facility upgrade, Figure 1 shows recent results for electron capture by fully stripped oxygen ions from atomic hydrogen obtained with the upgraded ion-atom merged beams experiment. For these measurements, a well-collimated, small-cross section O^{8+} beam was merged with a fast ground-state atomic hydrogen beam produced by photodetachment, and the protons resulting from charge exchange collisions between the two fast beams monitored.

The present MIRF layout is shown in Figure 2. The facility is comprised of 5 on-line experiments fed by the new HV platform ECR source, and 3 on-line experiments injected from the new low-energy floating beam line.

---

*Work supported by the Office of Fusion Energy Sciences, and the Office of Basic Energy Sciences of the U.S. Department of Energy, under Contract No. DE-AC05- 00OR22725 with UT-Battelle, LLC. SD, ID, and PRH were appointed through the ORNL Postdoctoral Research Associates Program administered jointly by Oak Ridge Institute of Science and Education and Oak Ridge National Laboratory

#meyerfw@ornl.gov

$retired

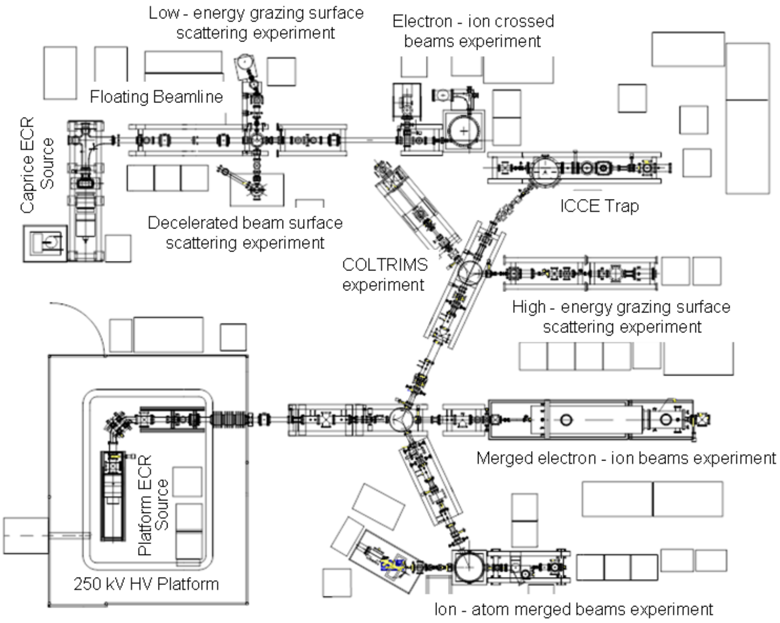

Figure 2: Present configuration of the ORNL Multicharged Ion Resarch Facility. A total of eight on-line experiments studying electron- and heavy-particle collisions, and ion-surface interactions utilize ion beams from either the new permanent magnet ECR ion source on the 250 kV HV platform or from the existing CAPRICE ECR ion source injecting the new floating beam line (see above).

Molecular ion beams

In addition to their well documented capability of highly charged ion production, both ECR sources in the MIRF have recently found increasing use for production of molecular ion beams as well, due to the increased programmatic focus of our research activities on the atomic collision and surface interactions occurring in the cool edge of magnetic fusion devices, and on electronic driven process in systems of increasing chemical complexity. Figure 3 illustrates synthesis of B and F mono- and di-hydride molecular ion beams in the CAPRICE ECR source plasma using a mixture of BF_3 and D_2 source gases that can be optimized by a combination of high source pressure and low rf power. These beams were required for exploration of electron impact dissociation of such molecular ions along iso-electronic sequences. Figure 4 illustrates synthesis of D_3^+ ions, again in the CAPRICE ECR source, from D_2 source gas at very high source pressures and low rf powers. Such beams, decelerated to a few eV, are used in our studies of low-energy chemical sputtering of C materials. Intense beams of molecular ions have been obtained using the all-permanent magnet HV platform ECR source as well [8]. However, extraction region discharges due to the poorer extraction region pumping of the permanent magnet source limit its high-source-pressure operation. The D_3^+ beams from the platform ECR source are typically lower

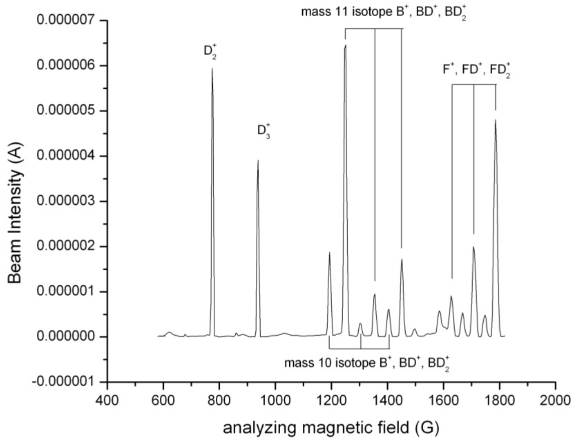

Figure 3: B and F mono- and di-hydride beam production by CAPRICE ECR gas mixing of BF3 and D2 at a total source pressure of 1x10-4 Torr and 4 W forward rf power.

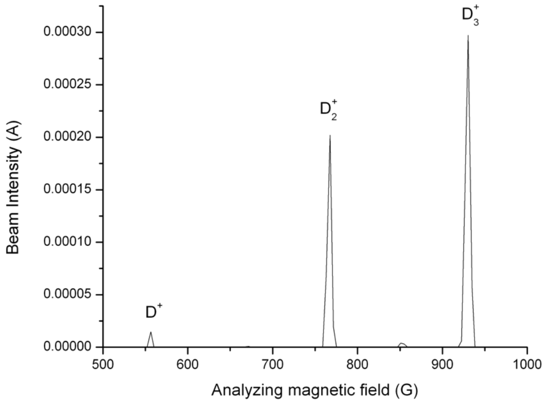

Figure 4: CAPRICE ECR D beams for a source pressure of 5x10-5 Torr and 10 W forward rf power.

in intensity than those produced with the CAPRICE, and, unlike Figure 4, can't be tuned to exceed the D_2^+ current.

ICCE Trap

The final element of the MIRF upgrade project was the development and installation of the **I**on **C**ooling and **C**haracterization **E**nd-station (ICCE) trap. This electrostatic trap is side-injected by a combination of 32° and 13° pulsed parallel plate deflectors, simplifying HV switching and permitting DC operation of the two electrostatic end mirrors [5]. A neutral fragment imaging detector located outside one of the end mirrors is implemented to permit analysis of kinetic energy release during electron- or heavy-particle-induced dissociation of the trapped molecular ions. Figure 5 shows a schematic of the ICCE trap. Recently multi-second trapping of CO^+ ions has been achieved. In-situ electron and gas jet targets are being used to study electron and heavy-particle collisions of molecular ions as function of trapping times, i.e., as function of the degree of internal cooling of the trapped ions.

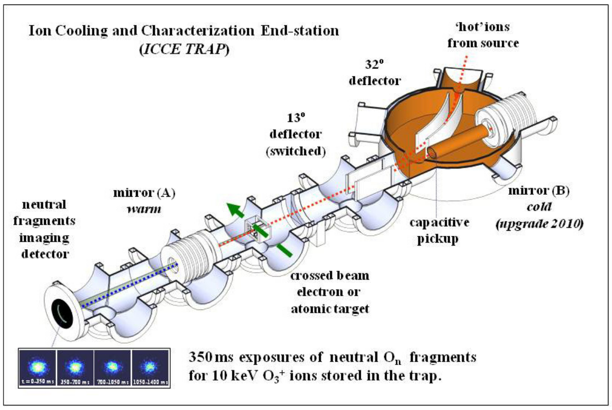

Figure 5: Schematic diagram of the ICCE trap [5].

Plasma potential measurements

An issue of continuing interest is the determination of the ECR source plasma potential and the energy spread of extracted ions. These parameters impact the magnitude and uncertainties of impact energies of decelerated beams used in our low energy ion surface interaction studies [9] and thus must be known. In addition, knowledge of these parameters may improve fundamental insights into the ECR plasma dependences on pressure, microwave power, confinement magnetic fields, and elucidate the basis of the gas mixing effect. In-situ Langmuir probe measurements of MIRF CAPRICE plasma potentials have been reported in [10]. More recently, complementary measurements of plasma potentials based on retardation analysis of extracted ion beams [11] have been carried out, which are generally consistent with the in-situ probe measurements. A typical plasma potential and ion energy spread result from analysis of external beam deceleration is shown in Figure 6.

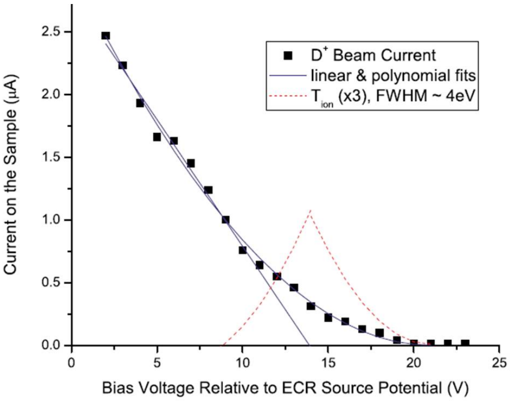

Figure 6: CAPRICE ECR plasma potential (~13.8 eV) and ion energy spread (~4 eV) deduced from retardation analysis of a D^+ ion beam extracted at a source pressure of $2x10^{-6}$ Torr and 6 W forward rf power [11].

REFERENCES

[1] F.W. Meyer in: J. D. Gillaspy (Ed.) "Trapping Highly Charged Ions: Fundamentals and Applications" (Nova Sciences Pub., New York, 2001) p. 117-165.

[2] F.W. Meyer et al., "The ORNL Multicharged Ion Research Facility Upgrade project," Nucl. Instrum. Methods Phys. Res. **B 242**, 71 (2006).

[3] F.W. Meyer, M.R. Fogle, and J.W. Hale, "The New ORNL MIRF Floating Beamline," Proceedings, 22nd Particle Accelerator Conference (PAC'07), Albuquerque, NM, June 25-29, 2007; IEEE Cat. No. 07CH37866, ISBN: 1-4244-0917-9, p. 3139.

[4] M.E. Bannister et al., "Control System for the ORNL MIRF High Voltage Platform", 2005 Particle Accelerator Conference, Knoxville, TN, May 16 – 20, 2005, published on CD, IEEE Cat. No. 05CH37623C, Piscataway, NJ, (2005).

[5] S. Deng et al., J. Phys. Conf. Ser. **194**, 142010 (2009), ICPEAC 2009, Kalamazoo, Mich., 22-28 July.

[6] D. Hitz, et al., "An All-Permanent Magnet ECR Ion Source for the ORNL MIRF Upgrade Project", AIP Conference Proceedings **749**, 123 (2005).

[7] C.C. Havener, I.N. Draganić, and D. Seely, in preparation for submission to Phys. Rev. A.

[8] I.N. Draganić et al., "Production of Molecular Ion Beams using an ECR Ion Source," submitted to Journal of Appl. Phys., Aug. 2010.

[9] e.g., H. Zhang and F.W. Meyer, J. Nucl. Mat. **390-91**, 127 (2009).

[10] H.J. You, F.W. Meyer, and K.S. Chung, "The Cold and Hot Electron Populations, Temperatures, and Their Transports in the Edge Plasma of the ORNL CAPRICE ECR Ion Source," Plasma Sources Sci. Technol. 18, 015004 (2009).

[11] P.R. Harris and F.W. Meyer, "Plasma Potential and Energy Spread Determination using Ion Beams Extracted from an Electron Cyclotron Resonance (ECR) Source," Rev. Sci. Inst. **81**, 02A310 (2009).