TESTS OF A NEW AXIAL SPUTTERING TECHNIQUE IN AN ECRIS*

R. Scott#, R. Pardo, R. Vondrasek, Argonne National Laboratory, Argonne, IL 60439, U.S.A.

Abstract

Axial and radial sputtering techniques have been used over the years to create beams from an ECRIS at multiple accelerator facilities. Operational experience has shown greater beam production when using the radial sputtering method versus axial sputtering. At Argonne National Laboratory, previous work with radial sputtering has demonstrated that the position of the sputter sample relative to the plasma chamber wall influences sample drain current, beam production and charge state distribution. The possibility of the chamber wall acting as a ground plane which influences the sputtering of material has been considered, and an attempt has been made to mimic this possible ground plane effect with a coaxial sample introduced from the injection end. Results of these tests will be shown as well as comparisons of outputs using the two methods.

INTRODUCTION

There are two Electron Cyclotron Resonance Ion Sources (ECRIS) in operation at the ATLAS facility at Argonne National Laboratory. The ECR charge breeder (ECRCB) has been dedicated primarily for charge breeding development and production as the Californium Rare Ion Beam Upgrade CARIBU comes online. ECR2 has become the primary stable beam producer at ATLAS using a variety of techniques including gas injection, oven, and sputtering. Sputtering was developed at Argonne [1] and has been used often on both sources. ECR2 is an evolved version of an AECR-U [2] type ECRIS. While radial sputtering has been heavily used, axial sputtering has not been characterized on this specific source. A new co-axial sputtering technique has been tested and compared with radial and axial methods in hopes of better understanding this form of metal ion production. The characterizations obtained could also be useful for final development of the Actinide Accelerator Mass Spectroscopy project [3].

SPUTTERING TECHNIQUES

Three sputtering methods were used during the course of this evaluation. Efforts were made to provide consistency of measurements. The same negative bias power supply was used for all tests for repeatable voltage and current measurements. Single frequency (~14GHz) RF inputs at prescribed power levels as well as similar source bake out conditions were maintained. Oxygen was used for support with no additional gas mixing. The injection side bias disk was grounded to eliminate another variable. Standard radial, standard "bare" axial, and axial with grounded sleeve techniques are described next.

*Work supported by the U.S. Department of Energy Office of Nuclear Physics, under contract No. DE-AC02-06-CH11357
#rscott@phy.anl.gov

Standard Radial

This method is the preferred for sputtering at ATLAS. ECR2 has a generous radial port to allow up to a 5mm diameter sample to be inserted. The sample is inserted through an air-lock/insulator assembly toward the plasma into a pumping port that exists in a gap between the hexapole bars (see Fig. 1 below).

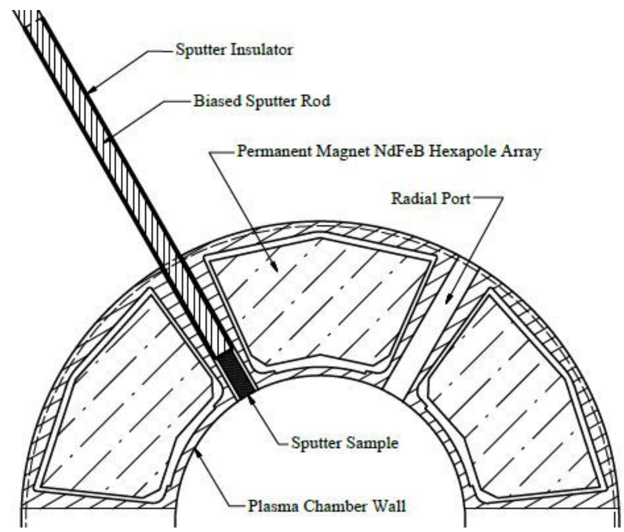

Figure 1: Section view of standard radial sputtering.

Typical gaps between the port wall and the sample are between 0.25 mm and 1.25 mm. Through previous experimentation with ECR2 the ideal location for sputtering has been found where the face of the sample is even with the plasma chamber wall. This location was chosen for our tests. Beam current and consumption rate measurements as well as radial sputtering parameters were used as a comparison to the 2 axial methods.

Standard Axial

Although radial sputtering is preferred, it cannot always be used. The use of radial ports spreads the magnet bars apart increasing the plasma chamber bore and weakening the hexapole magnetic confinement. Many groups omit this gap (and port) for this reason. Also, fundamental design constraints for all-permanent magnet ECRIS and 3rd and 4th generation superconducting ECRIS do not allow for radial ports. In these cases sputtering is only allowable axially.

Typically a sample is attached to a biased rod and inserted into the plasma chamber injection end (see Fig. 2). A location with an existing hole in the shaping plug was chosen. It is offset 2.2 cm from the centerline of the plasma chamber and in between the magnetic loss lines, evidenced by the plasma star on the biased disk, which

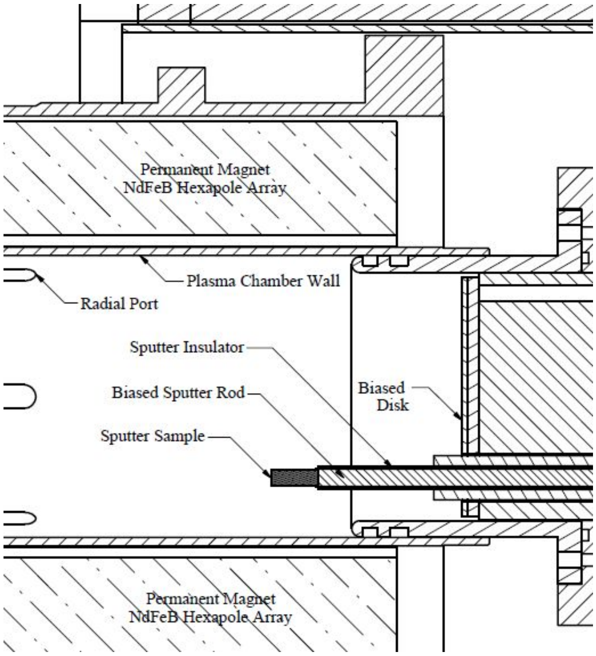

Figure 2: Standard axial sputtering.

helps minimize the effect of plasma heating on the sample.

The rod was attached to an available 5 cm travel linear motion feed-thru (LMFT) as the ideal location for sputtering was unknown. In this case the full sputter sample is exposed in the plasma chamber as well as the floating AlO_2 insulator. Others have used no insulator, leaving the biased rod of material other than that of interest exposed in the plasma chamber.

Axial with Grounded Sleeve

This modified axial method uses the same technique described above with biased rod, sputter insulator and attached sample. The assembly was placed co-axially inside a sleeve (grounded to the plasma chamber) which travelled with the sample. The face of the sample is even with the face of the ground sleeve (see Fig. 3). The assembly was inserted with the LMFT. In these tests the same axial insertion point was used as well as distances travelled into the plasma chamber by the assembly. The gap between the sputter sample and the ground sleeve was equal to that of the radial sample to port wall gap for each material used. Two sleeves were fabricated of 6061 Al, which is the same material as the plasma chamber wall. One is oval shaped at the tip to more closely replicate conditions at the radial port where only two points are closest to the sample. This sleeve was used with a large diameter Ag sample. The 2nd sleeve has a round opening at the tip and was used with the smaller diameter Ti sample. For all instances using this method, $^{27}Al^{7+}$ production (possibly attributable to the sleeve) never exceeded 50% more than the corresponding bare axial case.

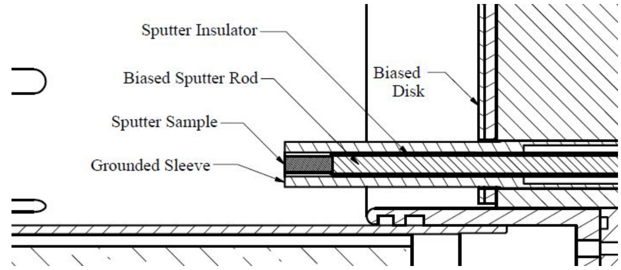

Figure 3: Axial sputtering with ground sleeve.

BEAM TESTS

Ideal Axial Position

It has been shown that beam current with axial sputtering varies with position relative to the plasma and with solenoid current [4]. Position vs. beam current was first plotted for $^{107}Ag^{21+}$. Initial position chosen was flush with the bias disk for both standard axial and axial with ground sleeve. The step size used was 1.2 mm when farther from the plasma and 0.3 mm when closer to the plasma. At each position the source was tuned using gas, solenoids and RF power. Both standard and sleeve cases measured maximum beam current at the farthest travel of 5.2 cm from the bias disk. This suggests the optimal location is likely closer to the plasma than the LMFT was able to travel. For Ti, adjustments were made within the limitation of the already fabricated ground sleeve to start travel at 1 cm past the bias disk and end 6.2 cm past the disk. Using the same sequence, optimal position for $^{48}Ti^{13+}$ was found to be at full travel suggesting that the true ideal location is closer to the plasma than could be measured. Sputter bias was removed at optimal locations resulting in immediate beam current drops of up to 50% with gradual declines thereafter as wall recycling tapered. This was done to insure that the major component of the beam output was due to sputtering and not plasma heating. All further data was taken at the closest location allowed by the existing apparatus.

Sputtering with Silver

Silver was chosen for its refractory properties, ease of sputtering and low number of stable isotopes creating a simple charge state distribution. In all cases the ECRIS was tuned for the intermediate charge state of 21+. Axial w/sleeve and standard axial were tested successively. Maximum outputs after a few days of conditioning were 18.1 µA for axial w/sleeve and 18.8 µA for standard axial. Maxima were achieved at the same RF power and in this case solenoid settings. Sputter voltage was then decreased to achieve 18.1 µA for standard axial for comparison. The sputter bias power was ~3X higher and the sputter drain current was ~4X higher for the bare sample vs. the sample with the grounded sleeve (see Table 1). The charge state distribution (C.S.D) was shifted slightly higher for the ground sleeve case. Maximum measured output for radial was 27 µA. The sputter voltage was not pushed further for fear of melting the

Table 1: Summary of Silver Production

Technique	use rate (mg/hr)	107/21+ (µA)	sputter V (kV)	sputter I (mA)	sp pwr P (W)	14 GHz (W)	ext I (mA)	sol. 1 I (A)	sol. 2 I (A)	V1(Torr)
Radial	1.7	18.3	0.58	0.43	0.25	280	1.91	528	519	1.80E-07
Axial w/sleeve	---	18.1	3.7	0.1	0.37	245	1.45	495	490	2.10E-07
Axial bare	4.2	18.1	2.7	0.46	1.24	249	1.5	494	490	1.90E-07

Table 2: Summary of Titanium Production

Technique	use rate (mg/hr)	48/13+ (µA)	sputter V (kV)	sputter I (mA)	sp pwr P (W)	14 GHz (W)	ext I (mA)	sol. 1 I (A)	sol. 2 I (A)	V1(Torr)
Radial	0.03	2.2	0.51	0.46	0.23	350	2	501	514	2.70E-07
Axial w/sleeve	.22	2.2	6.5	0.55	3.58	352	2.5	455	476	2.30E-07
Axial bare	0.81	2.2	3.1	1.1	3.41	350	1.8	522	483	2.20E-07

sample. Radial sputtering gave a much lower C.S.D. and required more RF power to achieve 18.3 µA compared to the two axial methods above.

Sputtering with Titanium

Titanium was chosen as a contrast to silver. It is more difficult to produce at high beam currents. It's C.S.D. slightly overlaps that of silver which was tested beforehand, so the most abundant isotope at lowest charge state without conflict $^{48}Ti^{13+}$ was chosen for these tests. Axial w/sleeve, standard axial and radial methods were tested successively. Maximum outputs after a few days of conditioning were 2.2 µA for axial w/sleeve, 5 µA for standard axial and 16 µA for radial. At an averaged 1 µA output for all methods, consumption rate was highest for standard axial, followed by ~4 times less for axial w/sleeve. Radial sputtering consumed another ~ 7 times less than axial with sleeve. Sputter current and power vs. consumption rate did not trend perfectly but there is believed to be some relation between the three (Table 2). Preliminary emittance measurements show a more divergent beam for standard axial vs radial. This could be from the exposed biased sample and insulator disrupting the plasma. Normalized (x,y) in mm mrad were (.094,.149) for axial vs. (.057,.090) for radial. Scheduling conflicts prohibited emittance measurement of axial with ground sleeve. It is hoped that all of these measurements can be done in more depth in the future.

REMARKS

The ground plane effect proposed cannot significantly be proven from these efforts. There is a definite difference between some of the operating parameters of the standard sputter and the sputter with grounded sleeve techniques. Consumption rates and drain currents are significantly different for the two methods. It may be that the radial technique helps to shield the majority of the sample and the ungrounded "floating" insulator from the plasma allowing sputtering from a finite surface. Use of a grounded co-axial sleeve may help to replicate this aspect of radial sputtering.

Maximum silver output was similar between standard axial and axial w/sleeve. For titanium, maximum output was double for standard axial compared to axial w/sleeve. Either the sample material or the type of sleeve (oval tip for silver and round tip for titanium) could have influenced these results.

Higher sputter voltages are observed for all axial vs. all radial results. This may be due to the further location from the plasma of the axial samples. It was observed that as the LMFT was retracted, beam current could be restored by increasing sputter voltage.

If allowable, future plans are to bring samples closer to the ECR resonance zone and to water cool the ground sleeve.

REFERENCES

[1] Harkewicz R, Billquist P, Greene J, Nolen J, Pardo R, Rev Sci Instrum., 1995, **66**: 2883

[2] Vondrasek R, Scott R, Pardo R, "Magnetic Field Upgrade of Argonne National Laboratory 14 GHz ECR Ion Source", Proceedings of the 10th International Conference on Ion Sources, Rev. Sci. Instrum., 2004, **75**: 1532

[3] Pardo R, Vondrasek R, Scott R, Kondev F, Palchan T, Kondrashev S, Paul M, Collon P, Youinou G, Salvatores M, Palmotti G, Mcgrath C, Imel G, "Plans for Laser Ablation of Actinides into an ECRIS for Accelerator Mass Spectroscopy", These Proceedings.

[4] Gaelens M, Loiselet M, Ryckewaert G, Proceedings of the 9th International Conference on Ion Sources, Rev. Sci. Instrum., 2002 **73 (2):** 714