A LOW POWER SURVEY OF RADIAL-OFFSET AXIAL SPUTTERING AND HIGH INTENSITY URANIUM PRODUCTION FROM AXIAL SPUTTERING IN SUSI*

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Abstract

Results of a low power survey of axial sputtering, to test sputtering efficiency at incremental radial offsets from on axis position, is reported. Also, prototype axial sputtering hardware has been tested in the SuSI ion source and the uranium ion production results is discussed.

INTRODUCTION

The National Superconducting Cyclotron Laboratory (NSCL) depends on each of its ECR ion sources for production of all required primary beams found on the Coupled Cyclotron Facility user beam list. A schedule of beam development for the SuSI ECRIS [1], supporting the NSCL experimental program since Fall 2009, is ongoing. Parallel efforts toward development of Uranium beams from SuSI are being pursued at this time. The process of producing uranium beams from axial sputtering has been investigated and is being developed.

The SuSI plasma chamber injection baffle is 100mm in diameter and therefore has limited area for installation of RF waveguides, gas port, biased disk, and RF inductive oven or resistive oven assemblies. The need to install a sputter target, for possible uranium beam development, on an already congested surface led to the question of where a sputter target must be located. Intuitively, the sputter surface would seem to be best on the plasma chamber axis, but the possibility of sputtering at positions radially offset from the axis and the relative sputter efficiency at such positions was unknown.

In December of 2009 a simple survey of relative sputter efficiency of radially off-axis sputter target positions and at increasing axial insertion toward the plasma was done. Based on the results, a prototype on axis sputter assembly was built, tested and is presented in this paper.

LOW POWER SURVEY OF SPUTTER TARGET POSITION

In December of 2009 a survey of radial offset sputtering was performed, The survey was done at very low RF power (500W) due to the sample not being cooled and the risk of X-ray damage to the plasma chamber insulation, which had not at that time been upgraded to tantalum shielding and PEEK insulation [2]. Considering the uranium target geometry, sputtering on the side of a cylindrical surface, was expected to be very inefficient. The sputter target was swept through an arc into the radial loss line and finally to the on axis position (see Fig. 1).

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Measurements of uranium production intensities were made at radial positions of 0mm, 9mm, 18mm, 27.5mm and completely away from plasma interaction. The injection baffle was generally located on the injection field maximum. At each radial offset position the sample sputter surface was initially 10mm from the injection baffle surface and then moved longitudinally toward the plasma by increments of 5mm. The sputter target was biased over a limited range of 0 to -2kV.

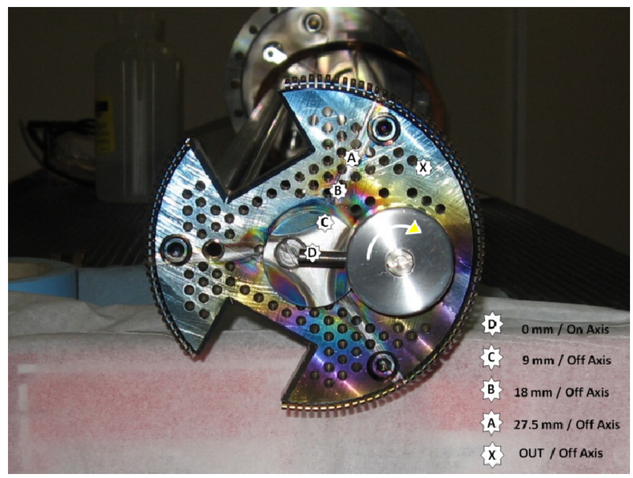

Figure 1: Low Power Radial-Offset Sputter Survey Hardware.

In addition to the survey, a small uranium sample with a diameter of 5 mm was mounted on axis and inline with the plasma chamber axis. It was positioned longitudinally 25mm above the injection baffle surface (toward the plasma). The baffle was located at the injection field maximum. A low power survey of sputter efficiency was done moving the sample into the plasma chamber in 5mm increments. Additionally, an assortment of support gases was tried.

Results of Survey

Results of the survey are shown in figure 2. It was clear that the Uranium sputter production yield is highest on the axis of the plasma loss cone, (0 mm radial offset). Sputter production does occur along the radial loss line with a sputter efficiency that is remarkably uniform from 9mm to 27.5 mm radius. In general the sputter yield increased with axial insertion of the sample from 0 – 15 mm and with target bias voltage from -1 kV to -2kV.

Sputter yield increased with heavier mass support gases, with oxygen and neon being reasonable choices for middle to high uranium charge states. Argon sputters very efficiently, but being a poor mixing gas drives the charge state distribution toward lower charge states with robust sputtering.

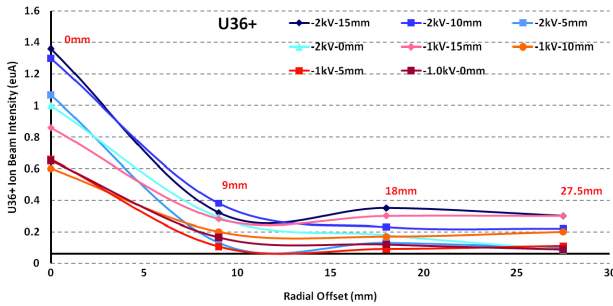

Figure 2: Uranium Sputter Yield Using ^{16}O Support Gas with Radial and Axial offset at -1kV and -2kV bias.

Based on this survey, a prototype sputter assembly was built utilizing a larger diameter and water cooled uranium target. The target was mounted on axis with a longitudinal adjustment of 50mm and bias voltage range of 0 to -5kV. An assortment of support gases and mixtures of support gases would be evaluated.

SuSI URANIUM BEAM PRODUCTION FROM ON AXIS SPUTTERING

In June 2010 the first attempt was made to sputter uranium axially and at higher power in the SuSI ECRIS to meet the Coupled Cyclotron Facility primary beam list requirements at NSCL. The prototype sputter hardware consisted of a water cooled 10 mm diameter and 15 mm long depleted uranium target mounted inline with the plasma chamber axis (see Fig. 3). The injection baffle is adjustable through a range of +/- 50mm around the injection field maximum; generally the baffle was left very near the injection field maximum. The sputter target surface was located 2 mm above the injection baffle surface toward the plasma. The sputter target could be inserted up to 50mm further toward the plasma relative to the baffle position.

Because the on axis location of the sputter target displaced the biased disk, the bias disk was replaced with a biased ring with internal diameter of 19 mm allowing the sputter target to travel through the ring (see photo). The uranium sputter target could be biased from 0 to -5kV and the biased ring could be biased from 0 to -2kV. It should be noted that the biased ring worked well, however the bias voltage required for the ring to perform as well as the original disk was about a factor of ten higher or -700 to -1000 V. Additionally, the biased ring ceased having an effect on beam intensity when the sputter target bias reached about -4kV.

The sputter production was evaluated changing target axial position, bias voltage, and support gases while tuning the source field and RF power to optimize performance and stability. Performance was measured primarily by the intensity of U^{33+} at the end of the SuSI collimation channel. During the uranium development, the transport efficiency of beam produced by SuSI through the collimation channel using 10mm - 12mm slits was about 50% due to efforts to obtain best resolution of charge states. Beams were developed using various support gases alone and in combination.

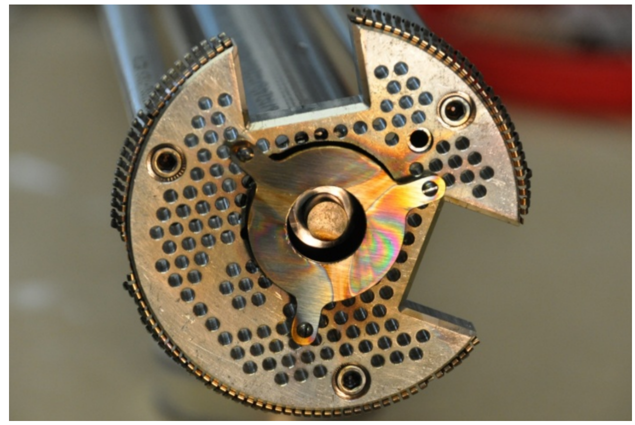

Figure 3: High Power Axial Sputter Hardware.

Results of Initial High Power Test

Low intensity uranium ion production, on the order of 20euA of U^{33+}, began immediately without the target being biased. This can be explained by considering that there is enough target interaction with the normal flow of ions leaving the plasma on axis through the loss cone to initiate sputtering. Beam intensity increased greatly with increased target bias voltage. While generally, sputter yield increases with insertion of the target toward the plasma, the sputtering was so robust at higher power and voltage that the best axial position was the starting position of 2 mm above the injection baffle and toward the plasma. Biased ring and biased target voltages were adjusted together producing increasing intensity until the target bias reached -4kV and the ring bias, no longer helping, was reduced to less than -100V.

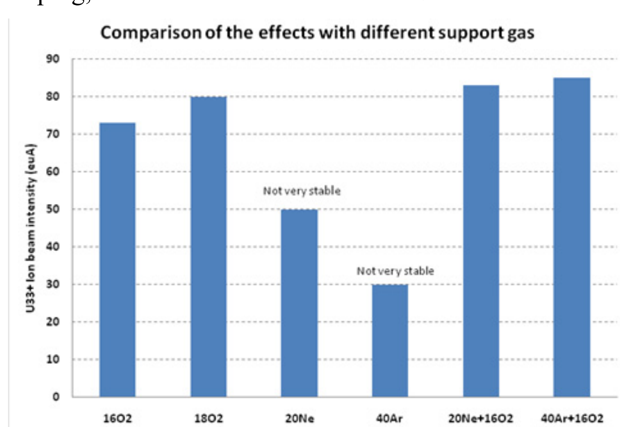

Figure 4: Uranium Sputter Yield Using Various Support Gases and Combinations.

Beam production increased with RF power and was ultimately limited by maximum power available at the time of 2.5 kW with a maximum drain current of about 5mA. Gas mixing advantage was gained using oxygen but best sputter efficiency required gases with higher mass, as illustrated in Fig. 4, for the production of U33+. It appears that the best performance for higher charge state uranium production used a combination of ^{16}O and ^{20}Ne (see Fig. 5), while best performance for lower charge states ,< 34+, was achieved with a combination of ^{16}O and ^{40}Ar.

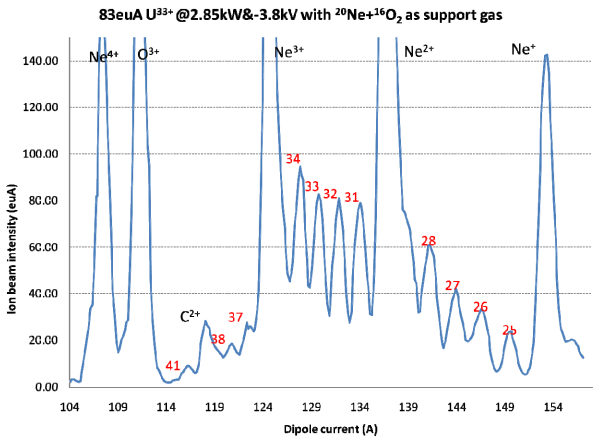

Figure 5: Higher Uranium Charge State Distribution Sputtering With Neon and Oxygen.

The sputter pattern on the surface of the sputter target shows that the effective interaction area is greater than the 10 mm diameter of the target. Also, the sample was misaligned 1 mm radially resulting in significant loss of sputtered material available to the plasma. Uranium production averaged 30 euA over 105 hours and consumed 211 mg or 2mg / hr.

Further development, scheduled Fall 2010, will include a redesign of the sputter equipment to allow the target to be withdrawn at least 25mm behind the injection baffle, increase the target size to 25mm diameter, and increase RF power capability beyond 3kW.

REFERENCES

[1] P. A. Zavodszky et al, Proc. 17th Int. Workshop on ECR Ion Sources and Their Applications (2006, Lanszhou, China)

[2] L. T. Sun et al, Proc. 21st Int. Workshop on ECR Ion Sources and Their Applications (2010, Grenoble, France)