PERFORMANCE INVESTIGATION OF THE NSCL 18 GHZ SUPERCONDUCTING ECR ION SOURCE SUSI

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Abstract

SUSI the SUperconducting Source for Ions at NSCL/MSU is under commissioning and will be moved into operation for the coupled cyclotron facility (CCF) in the coming months. Very good results have been obtained for the production of medium charge states for various gas and metallic elements. Beam extraction studies are presented, for a ^{84}Kr beam. In particular it is observed that the initial beam formation can results for medium and lower charge states in hollow or shallow beam distribution when the ion source is tuned for maximum intensity.

INTRODUCTION

Two ECR ion sources are used for stable beam production for the CCF at Michigan State University. These sources need to be able to produce a wide variety of gas and metallic beam ranging from ^{16}Oxygen to ^{238}Uranium in order to respond to the needs of the nuclear experimental program. In addition, source reliability and stability are essential requirements in a user facility such as the CCF. The best performances for the facility are currently obtained using ARTEMIS [1] a descendant of the AECR-U [2]. ARTEMIS operates up to 25kV and uses a 14GHz Klystron generator to sustain the ECR plasma. The SC-ECR, on the other hand, has been in operation since 1991 and was the first fully Superconducting ECR built and used to inject highly charged ions into an accelerator [3]. SC-ECR will be replaced during the summer with SUSI a Superconducting ECR ion source that operates at 18 GHz. The development of SUSI had two main objectives. First, to replace the SC-ECR and provide higher intensity of heavy ion beams of medium charge state to the CCF Second, the intent was also to provide NSCL with the experience for both the design and the fabrication of a high performance ECR ion source for the driver linac of the future Facility for Rare Isotope Beams (FRIB) [4].

SUSI FEATURES

For injection into the K500 cyclotron, the ECR ion sources are optimized to produce medium charge states ion beams. In addition, the transverse acceptance of the K500 cyclotron is limited and the transport through the injection beamline must be optimized to provide as much beam within the cyclotron acceptance, (an upper limit of 75pi.mm.mrad is generally accepted [5]). Another constraint is also to minimize beam losses at the K500 extraction. To date, large gains in performances have been achieved by improving various optical elements in the K500 injection beamline and by collimating the ion beam [6]. However further improvement will likely come from an ion source and beam line where it is possible to optimize the beam brightness (i.e to optimize the current within a given emittance). With a diameter of 100mm, the aluminum plasma chamber of SUSI is somewhat smaller than other comparable ion sources such as VENUS, SECRAL or SERSE therefore making SUSI more suitable to produce medium charge state ions. The axial magnetic field profile of SUSI can be adjusted by using 6 independent solenoids. Therefore both the gradient around the minimum B and the position of the maxima at the extraction (with respect to the fixed plasma electrode) can be optimized to favor the production of the desired charge state for different beams. Besides the intensity, the initial beam formation is greatly influenced by the intensity and profile of the magnetic field in the extraction region and the flexible field configuration featured by SUSI can provide a tool to better match the extraction conditions. SUSI operates at 18Ghz. Up to two kilowatt of microwave power are available with the klystron generator. The nominal magnetic field on axis reaches 2.4T at the injection and 1.3T at the extraction while the radial field at the plasma chamber wall reaches also about 1.3 T. The injection hardware is mounted on a movable baffle that provides the possibility to change the position of the injection flange over 10cm. Therefore the length of the plasma chamber can be changed from 40 to 50 cm giving a plasma volume between 3.1 and 3.9 liters. The injection flange includes a bias disk, an oven and 2 waveguides for dual injection of 14GHz and 18GHz microwave power. Finally, the bias disk position can be changed relatively to the injection flange by 2 inches.

EXPERIENCE AT 18GHZ

The SUSI coil system has been working reliably for almost two years. Initial quenches problems have imposed to ramp together the solenoids and the hexapole and additional stability was obtained by adjusting the support links and by changing the hexapole polarity [7]. During a dedicated test, the coil assembly was ramped successfully to even higher currents to demonstrate the capability of

SUSI to run with a 24 GHz frequency generator. SUSI was commissioned for various gas and metallic beams. Table 1 summarizes the performances achieved so far for various elements.

Table 1:Performances obtained from SUSI for various beams

	Intensity (eμA)
^{84}Kr	
14+	400
17+	250
25+	45
27+	16
^{129}Xe	
20+	330
26+	250
27+	170
30+	56
^{209}Bi	
28+	150
31+	90
33+	66
36+	15

Most of the beam intensities shown in Table 1 were obtained with the 18GHz microwave power close to its 2kW limit (~1.8kW). In addition it is estimated that up to 30% of the microwave power is lost through the long waveguide section going from the generator to the ion source. For Xenon no saturation of the beam current is observed with the microwave power and better performance would be most certainly obtained if more power was available at 18GHz. Injecting additional power with a 14GHz generator was not found to be very significant for medium charge but was more important, when tuning for higher charge states as shown in Figure 1 where the charge state distribution was optimized on Kr^{25+}. In this case a total of 2.5 kW of Microwave power was injected into the plasma by using both generators. Moving the injection baffle often helped significantly to keep the plasma very stable even at high power. More systematic work needs to be done to quantify the impact of the B-min on the beam intensity extracted.

Tests have been done also for the production of metallic elements. In particular Bismuth was produced using a resistive oven. More than 60 euA of Bi^{33+} was obtained as shown in Figure 2. On the other hand preliminary tests with our inductively heated oven which work very well for ARTEMIS has not deliver the beam intensities expected for ^{58}Ni or ^{76}Ge. Some modifications to the design are being pursued to better couple the power from the power supply to the coil by limiting the inductance of the current leads. Presently, only about 15eua of $^{58}Ni^{17+}$ were obtained in this case.

EXTRACTION STUDIES

Past experience at NSCL has shown that using a solenoid to provide the initial focusing of a beam extracted from an ECR ion source can lead to significant emittance degradation [8].

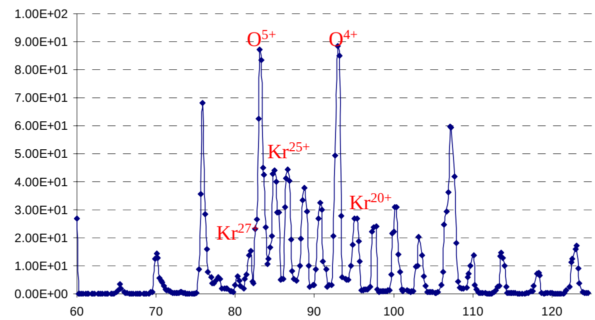

Figure 1: ^{84}Krypton distribution optimized on Kr^{25+}

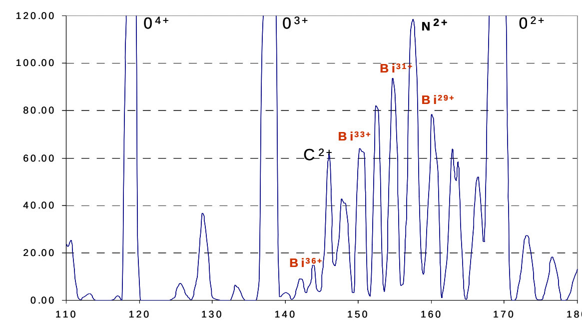

Figure 2: Bismuth distribution optimized on Bi^{31+}

To mitigate space charge problem with the beam before charge selection it was decided to connect the ion source directly to the 90-degree selecting magnet. The 90-degree selecting magnet provides double focusing by using pole faces presenting an angle of 27.3 degree. It has a large 18 cm gap and actively corrects for higher order aberrations. In order to limit the angular divergence of the ion beam, and mitigate the potential degradation of the beam quality due to the space charge forces, it was decided to bias the beam line from the ion source extraction to the analysis faraday cup located after the bending magnet. However, it was found that in this situation large amount of secondary electrons were emitted in this section and accelerated toward both the faraday cup and the ion source. In addition long conditioning was needed before the voltage on the beam line could be increased reliably. Finally, this configuration was not pursued as corona currents were developing in the extraction region that was causing the beam to be increasingly unstable. Nonetheless even without biasing the beam line it should be noted that this configuration does provide very good transmission from 80 to 90 % for relatively low extracted current (1 to 2mA) to about 70 to 75% for a 4mA current.

Diagnostics after the bending magnet include a faraday cup a beam viewer and an Allison type emittance scanner. A four-jaw slits system is also mounted just in front of the faraday cup. A current-scan diagnostics using the 4-jaw collimator and the faraday cup has been developed to provide a direct comparison to images obtained from the potassium bromide viewer. An additional image processing analysis was also developed with MATLAB.

The initial beam formation was observed to be very sensitive to the source conditions and the position of the puller. When the ion source is tuned to optimize the intensity of Kr^{13+} current-scans reveals that medium and low charge states appear to have relatively hollow intensity distribution in real space and distorted phase spaces as shown on figure 3 (Top). On the other hand when the ion source is optimized at a lower total extracted current, the real space distributions are more homogeneous and the corresponding emittances less distorted (figure 3 - Bottom).

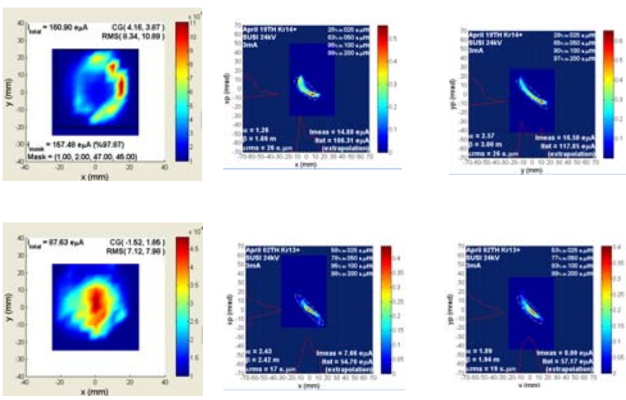

Figure 3: Kr^{13+} beam imaging using the current-scan technique (left) and transverse emittances (center and right). The top row corresponds to the ECR tune for maximum intensity. The bottom row corresponds to measurements done to a tune optimized for lower drain current but more homogenous distribution.

Simulations with the code IGun confirm the experimental results. Figure 4 illustrates the results of the simulation. The top picture show the potential profile and beam envelope obtained with a 3mA beam extracted at 24kV. The bottom left picture obtained with a 2mA beam show that a higher plasma density results in a concave plasma boundary. In this situation the beam distribution tend to be hollow as observed experimentally for middle charge states. At a lower drain current corresponding to a lower plasma density, the plasma boundary is more flat and the beam distribution homogenous. The simulation also show that higher charge states such as Kr^{17+} are less affected than lower charge states by the shape of the plasma boundary as illustrated above and experimental profile did confirm in this case a more homogenous distribution.

CONCLUSION

The commissioning of SUSI is ongoing. The source has been working reliably for almost two years. Beam extraction studies show that the plasma boundary (density) has a very important impact on the formation of the beam especially for medium charge states. Optimum brightness cannot be solely obtained by tuning the ion source for maximum intensity but by carefully optimizing both the puller gap and the source parameters. SUSI will be moved and connected to the superconducting cyclotron in July 2009. It is expected that the whole operation will take up to 10 weeks to complete. Prior to the move, further tests regarding the beam formation and extraction will be done by adding an einzel lens right after the puller. A dedicated collimation channel to clean up the beam emittance will also be installed and tested. The acceptance of this channel is flexible and the system could be helpful to tune the ion source for optimum beam brightness.

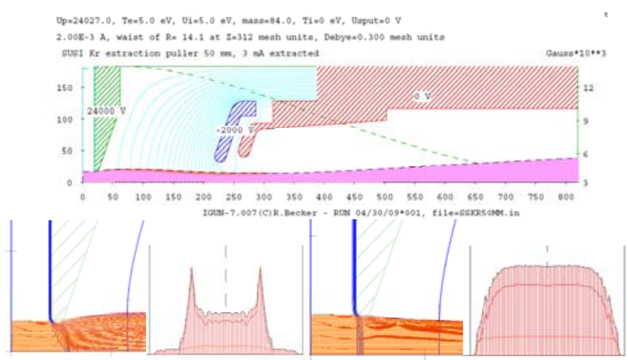

Figure 4: I-Gun calculations done for a Krypton beam. Top: potential profile for a 24kV beam and a puller gap of 50mm Bottom: (Left) Kr^{13+} and Kr^{17+} distributions for 2mA drain current. (Right) Kr^{13+} and Kr^{17+} distributions for 1mA drain current. Distributions are shown at the end position of the simulation.

ACKNOWLEDGMENTS

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