STUDIES OF METALLIC ION BEAMS USING ECRIS

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Abstract

Low energy (from a few keV to a few MeV) metallic ion beams have wide applications in various research fields especially in materials science, atomic and molecular physics. Several metallic ion beams have been developed successfully using all permanent magnet 10 GHz electron cyclotron resonance (ECR) ion source based low energy ion beam facility (LEIBF) at Inter University Accelerator Centre (IUAC), New Delhi. For the development of these metallic ion beams, different methods e.g. oven, sputtering, insertion and metal ions using volatile compounds (MIVOC) have been utilized. The charge state distribution (CSD) studies of two metallic ion beams are presented.

INTRODUCTION

To get the operational experience of ECR ion source [1] on high voltage platform and to provide the low energy ion beams from gaseous and solid species, the LEIBF [2] has been set up at IUAC. The most important feature of the facility (LEIBF) is that the ECR ion source and all its peripheral components including electronics (power supplies and RF power amplifier) and vacuum systems are on a high voltage (300 kV) platform. The various parameters of the source are controlled through fiber optics communications at 300 kV isolation. The regular operation of this facility provided us experience and expertise to design and build the world's first High Temperature Super-conducting ECR Ion Source (PKDELIS) [3] for use on a high voltage (400 kV) platform. The ion source has been tuned to get optimum intensities of metallic ion beams which are being used for research in emerging fields like nano science and spintronics. The high intensities of low energy metallic ion beams are suitable to engineer the optical, electrical and structural properties of materials via ion implantation and ion irradiation.

METALLIC ECR PLASMA PRODUCTION

The ions, inside the source, are produced by the impact of resonant electrons and are confined axially and radially by using permanent magnets (NdFeB). The desired vapors of materials are introduced into the source for ionization using micro-oven, sputtering system and MIVOC [4] method. A micro-oven, compact in size, is used for the heating of metallic elements in a temperature range of 100^0 - 1200^0 C. The heating is done using a 36 V, 4 A power supply. For micro-oven, a typical voltage of 14 volt is required in order to achieve a oven temperature of about 1000^0 C. A small cylindrical crucible (ceramic) filled with a few mg quantity of desired metallic element in powder or rod form is placed into the micro-oven. The micro-oven along with crucible, placed on a mounting system is injected into the plasma chamber from the injection side of the source. In order to have a continuous operation of the source to complete the experiments, the operational temperature is kept well below the melting point of the materials.

In the process of plasma sputtering, the sputtering target (high melting point > 1000^0C) in the form of a disc, wire or pellet is exposed to a background plasma. In regular operation of the source, the background plasma is developed using noble or inert gases. The ions lost from the plasma strike the sputtering target and the vapors of desired metallic species are released for the process of ionization. In MIVOC method, the vapors of volatile compounds are allowed to diffuse into the plasma chamber using a pressure control valve. The metal atoms in the structure of volatile compounds are released in the plasma. The ionization of these metal atoms then takes place by the impact of resonant electron.

ION EXTRACTION AND ANALYSIS

The extraction system consists of an extraction aperture (at high voltage (30 kV max.)) of 3 mm in diameter, puller electrode El1 in conical shape (at ground potential), a focus electrode El2 (at high voltage (15 kV max.)) and another electrode El3 at ground potential. The puller electrode, focus electrode and the last grounded electrode form two gaps (decelerating and accelerating gap) for the extraction and strong focusing of the ion beams. A rough sketch of the structure (plasma chamber and extraction) is shown in figure 1.

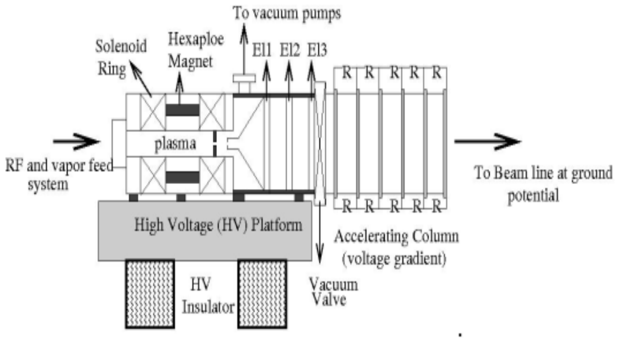

Figure 1: Schematic of source and extraction system

The ions extracted from the source can have maximum energy of 30 x q (charge state of ion extracted from source) keV with respect to high voltage platform voltage. A accelerating column placed between platform (at high voltage, max. 300 kV) and beam line (at ground potential) results in a further energy gain of 300 q keV (maximum). The beam coming out of Einzel lens is focused by voltage gradient along the accelerating column. The ions are analyzed in mass and energy using a high resolution dipole magnet having two bending ports ($90^0$and 15^0). The maximum beam rigidity (ME/q^2) of the dipole magnet for the 90^0 bend is 34 MeV amu. The analyzed beam currents/intensities are measured using a high power Faraday cup.

SOURCE OPERATION WITH METALLIC IONS AND RESULTS

Using LEIBF, various metallic ion beams e.g. Au, Ni, Fe, Sn, Eu, Zn and Cu of different energies suitable for experiments have been extracted and developed.

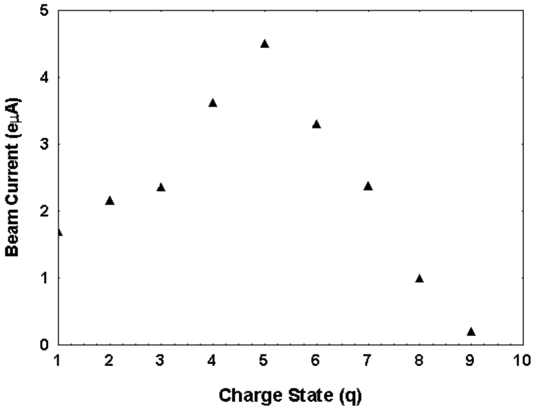

Figure 2: CSD of Ni optimized on +2 charge state

$^{58}Ni^{+2}$ and $^{56}Fe^{+}$ ions for total potential difference (E/q) of 100 kV and $^{63}Cu^{+8}$ for E/q = 160 kV, were produced using their volatile compounds (($(C_5H_5)_2Ni$, $(C_5H_5)_2Fe$ and $(C_5H_5)_2CuP(C_2H_5)_3$) respectively. The operating source pressure, in the case of Ni and Fe, was ~ 5x 10^{-6} mbar. Input microwave power of about 20 W was set to stabilize and populate the ECR plasma with low charge state ions. For $^{63}Cu^{+8}$ beam, the source was operated at $3x10^{-7}$ mbar. The ECR plasma has been produced using ~ 80 W of power. A typical CSD of Ni is shown in figure 2. The highest ion current/intensity of 4.7 µA was observed for q = 5.

^{120}Sn and ^{66}Zn ion beams were developed using the micro-oven. High purity Sn powder and Zn foil were kept in micro-oven to get the desired metallic vapors for the production of ECR plasma. In the case of Sn, the input microwave power was 47 W. The source was operated at a pressure of 6.5 x 10^{-7} mbar. The total potential difference (E/q), for the acceleration, was set at 100 kV. The oven temperature was kept ~ 2000C. The melting point of Sn powder is 231^0C. The CSD of Sn is optimized for m/q =9.23 (+13 charge state) and is shown in figure 3.

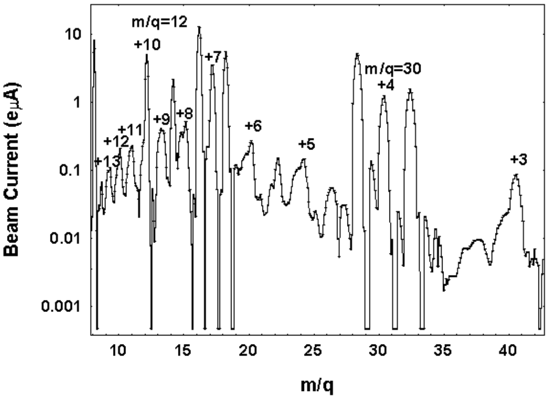

Figure 3: CSD of Sn optimized for m/q = 9.23

Although ^{64}Zn has the highest natural abundance, $^{66}Zn^{+2}$ ion beam was chosen to avoid the contamination with oxygen as $^{64}Zn^{+2}$ and molecular oxygen (O_2^+) have same m/q. The beams having same m/q can not be resolved using dipole magnet.

The sputtering process has been utilized to develop ion beams of ^{151}Eu and ^{153}Eu ion beams. In order to start the sputtering process, the argon gas has been used to generate the background plasma. ^{151}Eu and ^{153}Eu have natural abundance of 47.18% and 52.19% respectively. The E/q = 93.79 was set in this case and ions having charge states +4 are extracted to deliver 375 keV ion beam for experiment. With operating source pressure of $7x10^{-7}$ mbar and microwave power of 88 W, the source was tuned to extract the ion beam. The highest intensity/current of 8 µA was observed for q = 5 (mass 153). The optimized distance between sputtered target and background plasma was 7 mm.

DISCUSSION

The energy of ion beams can be increased by populating the ECR plasma with ions in high charge states. Lower pressure and the higher microwave power are essential to tune the source for such requirements. In fact with increasing q (beyond the most populated charge state), the intensity of ion beam decreases. For implantation, high intensity ion beams are needed. These beams are delivered by operating the source at high pressure and lower power levels of microwave. Using sputtering and micro-oven, ion beams of higher energy (higher q) are available at moderate intensities. The source tuning for better intensities over the full range of q can be achieved by using MIVOC system. The stability and intensity are two major issues which make metallic ion beams difficult to develop and optimize.

CONCLUSION

Various metallic ion beams are developed for experiments especially for implantation using LEIBF. The ECR ion source operated on high voltage platform is a unique feature of LEIBF and provides a choice of selection of energy in a wide range. The source performance is excellent for gaseous ion species. The ion beams from gases e.g. Ar, O_2, N_2, He, Ne, Xe, SO_2, CO_2, Kr, H_2 are regularly delivered for experiments. From last few years, various stable metallic ion beams have been developed for scheduled experiments by a large number of researchers.

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