PRAMANA
— journal of
physics

Vol. 59, No. 5
November 2002
pp. 805–809

ECR ion source based low energy ion beam facility

P KUMAR, G RODRIGUES, U K RAO, C P SAFVAN, D KANJILAL and A ROY
Nuclear Science Centre, Aruna Asaf Ali Marg, New Delhi 110 067, India

Abstract. Mass analyzed highly charged ion beams of energy ranging from a few keV to a few MeV plays an important role in various aspects of research in modern physics. In this paper a unique low energy ion beam facility (LEIBF) set up at Nuclear Science Centre (NSC) for providing low and medium energy multiply charged ion beams ranging from a few keV to a few MeV for research in materials sciences, atomic and molecular physics is described. One of the important features of this facility is the availability of relatively large currents of multiply charged positive ions from an electron cyclotron resonance (ECR) source placed entirely on a high voltage platform. All the electronic and vacuum systems related to the ECR source including 10 GHz ultra high frequency (UHF) transmitter, high voltage power supplies for extractor and Einzel lens are placed on a high voltage platform. All the equipments are controlled using a personal computer at ground potential through optical fibers for high voltage isolation. Some of the experimental facilities available are also described.

Keywords. Electron cyclotron resonance; ion source; plasma; ion beam; ion implantation.

PACS No. 07.77.K

1. Introduction

The advent of electron cyclotron resonance (ECR) ion sources [1,2] has created a tremendous impact on the production of high intensity beams of multiply charged positive ions. A low energy ion beam facility based on an ECR ion source was set up at Nuclear Science Centre to provide research facilities in the field of materials sciences, atomic and molecular physics. A nanogan type of ECR source based on a fully permanent magnet design was chosen for this purpose [3]. The ECR ion source along with all its peripheral electronics and vacuum components placed on a 200 kV high voltage platform provides multiply charged positive ions in a widely varying energy range from a few keV to a few MeV where energy $E = q(V_s + V_p)$ keV, q is the charge state of the ion, V_s and V_p are the potentials (kV) of the source and HV platform respectively. To increase the energy up to 30 keV, V_s is varied. V_p is varied to increase the energy by tens of keV up to a maximum of 200 keV. For increasing the energy of the beam by hundreds of keV up to a few MeV, appropriate charge state is selected and ion source parameters are optimized. The successful commissioning and regular operation of this facility provided us experience and expertise to start development of a high temperature superconducting ECR ion source on a high voltage platform for the high current injector of the super-conducting linear accelerator (LINAC) at NSC.

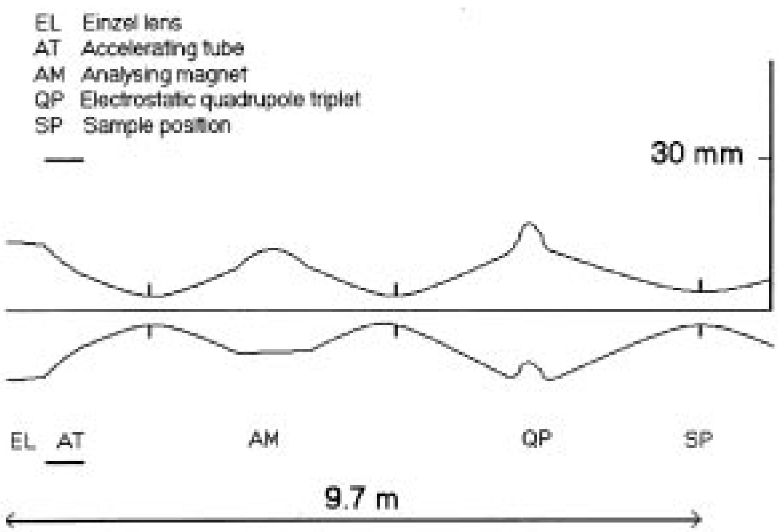

Figure 1. Profile of a typical 75 keV oxygen ion beam from ECR ion source to the sample.

2. Description of the facility

2.1 *Facility layout*

A typical beam profile from ECR source to the sample location for 75 keV oxygen beam ($^{16}O^{+}$) is given in figure 1. All related components like vacuum pumps, high voltage power supplies and electronic modules placed on high voltage platform are powered by a custom made 300 kV isolation transformer having a maximum power rating of 10 kVA. The source is coupled to a pumping tank which houses an Einzel lens. A general purpose accelerating tube together with the Einzel lens focuses the beam at the object plane of the analyzing magnet as shown in figure 1. The beam after 90° deflection and mass analysis is finally transported to the experimental chambers by an electrostatic quadrupole triplet for having strong focusing properties at the targets placed at various locations along the beam line. An electrostatic beam scanner capable of scanning at 1 kHz frequency can cover a scanning area of 50 mm $\times$ 50 mm on the sample. All the beam line components like electrostatic steerers, Faraday cups, pneumatic straight through valves, all-metal double slits, electrostatic quadrupole triplets etc., have been fabricated in-house. The beam-line vacuum is maintained by using turbo-molecular pumps at various locations along the beam line for distributed pumping. The 90° analyzing magnet has an additional 15° port for another beam line dedicated to atomic, molecular and cluster physics experiments.

2.2 *The ECR source and the analyzing system*

The source is based on fully permanent magnet (NdFeB) based design procured from Pantechnik S.A., France. The resonance field, B_{ecr} $(= m\omega/e)$, for the electrons at the operational frequency of 10 GHz is 3571 G. In order to confine the plasma in all possible directions, a 'magnetic bucket' structure comprising of a permanent magnet solenoid and a Halbach type multipole is built into the source where the field increases outwards in all directions. Because of this magnetic configuration, a closed egg-shaped ECR surface is formed where the electrons gain or lose energy corresponding to their phase with respect to the UHF. The electrons in turn ionise the ions, atoms and molecules of the particular species of interest to finally form a stable plasma. The extraction of the positive ions from the plasma is done by polarizing the source at a positive potential with respect to ground and pulling out the ions with properly shaped electric field configurations to form a parallel beam. In addition to using gaseous species, the source has built-in provisions for using a micro-oven and a sputtering system for producing beams from solid materials. The analyzing system consists of a 90° degree high resolution magnet having a mass resolution of 1 in 300 for a 4 mm slit width. The bending radius of the magnet is 600 mm with a maximum field of 1.4 T. The analyzed beams are transported and collected in a Faraday cup placed close to the image slit of the magnet for interruption of the beam and measurement of beam currents.

2.3 *Experimental facilities*

The experimental systems have two high vacuum chambers, one for the materials science and another for atomic physics experiments. The materials science experimental chamber consists of a residual gas analyzer mounted on one of its ports for identification of the sputtered and desorbed particles from the target during implantation. A target ladder holder has facilities for mounting multiple samples as well as heater and temperature sensors. A constant temperature up to 500°C can be maintained using a temperature controller during implantation. View ports have been provided at different locations for monitoring and conducting optical studies. Experiments on ion beam mixing, preparation of silicon-on-insulator (SOI), modification of the behavior of spin tunnel junctions and ion implantation are carried out. The atomic and molecular physics experimental chamber consists of a gas jet interacting with the highly charged ion beam. The recoil ions and electrons are detected using a time-of-flight (TOF) spectrometer. The ions are collected using position and time-sensitive micro channel plate detectors. A decelerating section for soft landing of multiply charged ions at sub-keV energies is being developed for studies of hollow atom formation and potential sputtering.

2.4 *Control software*

All source related parameters on the high voltage platform are monitored and controlled from a dedicated computer at ground potential. The communications are carried out using two fiber optic cables connected to the RS232 port of the computer. The analyzing magnet, electrostatic quadrupoles, Faraday cups etc. are controlled via the serial ports. Field point modules are used for AD and DA conversions. The software is written in LabView for easy monitoring and control of various components.

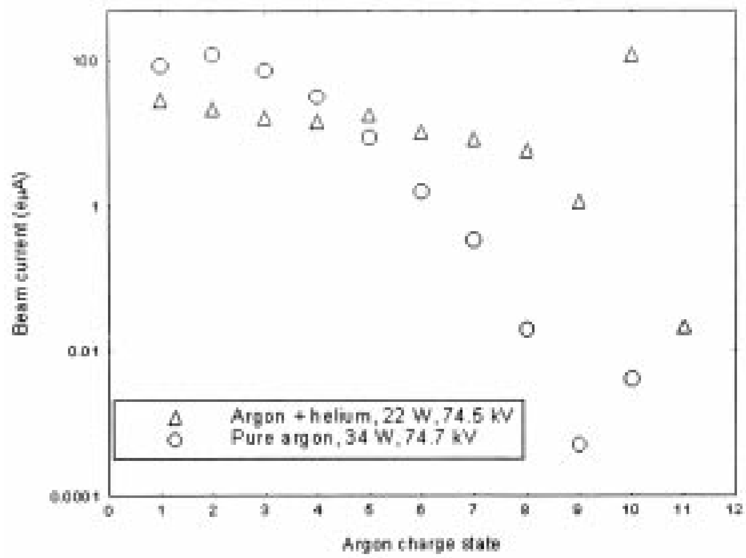

Figure 2. Typical argon charge state distribution with and without helium gas mixing.

3. Source performance and results

The ECR source has been performing satisfactorily so far. Experiments have been performed using various beams. Since our analyzing magnet was earlier designed for sputtered negative ion source having lower emittance compared to ECR ion sources, there is a loss in intensity of the beam from the ECR source while passing through the magnet due to its lower acceptance. In order to improve the beam transmission, we reduced the aperture of the plasma electrode of the ECR source from 7 mm to 3 mm. This improved the transmission through the magnet and minimized loading of the Einzel lens.

In order to produce relatively higher beam currents of the highly charged ions , the ‘gas mixing’ technique [4] has been used successfully. Figure 2 shows a typical charge state distribution for pure argon gas with and without helium gas mixing. It is clearly seen that the intensities of higher charge states of argon beam are enhanced by using helium as the mixing gas. The sudden increase in beam current of argon for a charge state of 10 is due to the fact that superposition of trajectory of $^{12}C^{3+}$ background and $^{4}He^{+}$ from mixing gas having the same mass to charge ratio of 4 on the argon beam at the same magnetic field. Table 1 gives a list of analyzed beam currents of ^{16}O from natural oxygen gas. The beam current for charge state 4+ is not mentioned in the table because it has contributions from $^{12}C^{3+}$ and He^{+} background. Further studies are going on to improve the source output and to improve the transmission to the experimental stations by performing simulations using the IGUN code [5].

4. Conclusion

The LEIBF facility developed at NSC is unique in the sense that the complete ECR system including all associated electronics, vacuum system, gas control system, UHF transmitter

Table 1. Typical analyzed beam currents of ^{16}O from natural oxygen gas.

Charge state	Input UHF power (W)	Beam current (euA)
1+	13	350
2+	14	300
3+	15	180
5+	17	11
6+	20	5
7+	20	0.13

and cooling facilities are installed on a high voltage platform powered by a 300 kV isolation transformer for providing a large variety of charged particles in a wide energy range of a few keV to a few MeV. All components are controlled through fiber-optics communications from a personal computer placed at ground potential. The facility is being used regularly for conducting various planned experiments in materials sciences, atomic and molecular physics by various research groups.

References

[1] R Geller, B Jacquot and M Pontonnier, *Rev. Sci. Instrum.* **56**, 1505 (1985)
[2] T A Antaya and S Gammino, *Rev. Sci. Instrum.* **65**, 1723 (1994)
[3] D Kanjilal *et al*, *Indian J. Pure Appl. Phys.* **39**, 25 (2001)
[4] A G Drentje, A Girard, D Hitz and G Melin, *Rev. Sci. Intrum.* **67**, 953 (1996)
[5] R Becker, *Rev. Sci. Instrum.* **63**, 2756 (1992)