High Fluence Ion Beam Facility for Materials Science Research Activities

Manvendra Kumar[1, 2, a)], Vikas Baranwal[1] and Avinash C Pandey[1]

[1] *Nanotechnology Application Centre, University of Allahabad, Allahabad 211002, India*
[2]*Department of Physics, Institute of Science, Shri Vaishnav Vidyapeeth Viswavidyalaya, Indore-452002, India.*
[a)]Corresponding author: kmanav@gmail.com

Abstract. An electron cyclotron resonance (ECR) based medium energy ion beam facility, known as High Fluence Ion Beam Facility (HFIBF), is commissioned at Nanotechnology Application Centre, University of Allahabad. The facility is a user facility for ion beam driven materials synthesis, properties modification and their characterizations. The source can be operated up to maximum of 25 kV extraction and 300 kV platform potential and it includes RF plasma, oven and sputter ion sources for gases, low melting point metals and high melting points metal ions generations, respectively. The plasma is generated by a microwave generator with a tunable RF frequency of 14.5 GHz and a maximum RF power of 750 W. The main advantages of the facility are the high flux and large area scanning and the facility is suitable for ion implantation in materials science research activities.

INTRODUCTION

The High Fluence Ion Beam Facility (HFIBF) at Nanotechnology Application Centre, University of Allahabad has been commissioned and approved by Atomic Energy Regulatory Board (AERB) in November 2017. HFIBF is a low energy ion accelerator based on electron cyclotron resonance (ECR) source [1-3]. This facility has capability to fill the gap between Universities and research institutions in the accelerator grid existing in India by providing high flux/current of beam on large scanning area. The facility is a user facility running through DST (Department of Science and Technology, India) funded research project under nano-mission program to provide a platform to the Universities to offer specialized laboratories to the nation to be served as a user facility. Presently, one can perform ion beam induced synthesis or ion implantation to develop compounds in a controlled way for the fabrication of devices. This will also provide an environment to attract younger generation to sciences related with ion beam processing and will serve the nation by acting as man power development centre in different fields, such as vacuum, electronics, mechanical, radiation safety etc.

The key features of the HFIBF are (i) high flux/current, large scan area up to 30 mm x 30 mm, less switchability time between gases and metal ions and production of wide range of ions.

In the present article, we report some testing results of HFIBF during commissioning at University of Allahabad to highlight the capability and performance of the system.

INSTRUMENTAL DETAILS

The HFIBF is shown schematically in Figure 1. The source is SuperNanogan model, by Pantechnik (France) [4], based on a permanent magnet electron cyclotron resonance ion source with a compact design, i.e. a length of 388 mm and a diameter of 482 mm. The supernanogan is composed of injection system, RF system, high voltage (HV) system, water cooling and vacuum systems at 300kV. The injection system consists of gas, oven and sputtering subsystems. The gas injection system is scheduled for solenoid valves and mass flow controllers or UDV valves. The plasma is generated by a microwave generator with a tunable RF frequency of 14.5 GHz and a maximum RF power of 750 W. The rectangular wave guide, marked as 4 in Figure 1, is used to allow a microwave injection into the plasma and heat the free electrons. These ions are also trapped in the magnetic field and can be extracted with strong electric field resulting in an ion beam propagating in vacuum. Once the ions are generated, it can be extracted by extraction system (marked 2 in Figure 1). The extraction system contains a plasma aperture,a puller electrode and a focusing lens between puller and ground. The source body containing the plasma electrode is placed at a positive high potential, while a puller electrode is placed at lower potential to create potential difference resulting in extraction electric field. The maximum source potential is up to 25 kV while the puller electrode can be biased up to −6 kV. Further, the ion beam is controlled by quadrupoles/stirrers and allow to enter to dipole magnet which bent it 90° towards beam line. The dipole magnet also acts like analyzing magnet to get desired ions and its charge states. A diagnostic box, consists of beam profile monitor, slits and faraday cup (FC), is placed after dipole magnet for beam profile, current measurements. Two double slits can be used for the reduction of the beam size and measurement of the emittance. An accelerating column is placed before second diagnostic box, which connects HV platform to beam line at ground. A switching magnet is placed after diagnostic box to allow the beam transmission in 0° and ±30° direction. Presently, only one beam line is developed at 0°. A wobbler system is placed before the third diagnostic box for raster scan in x- and y- directions on the sample during ion implantation. Ten quadrupoles and steerrers are placed throughout the beam line to tune the shape, size and steer the beam. At the end of the beam line, experimental chamber is connected through a 50 cm drift tube and the centre of the chamber is the focus point of the magneto-optic system (inset of Figure 1). The HV area of the system is placed in a pit surrounded by 20 cm concrete walls from three sides, while a 6 mm thick lead shielding [5] is placed from front side for radiation and high voltage shielding. The entire facility is under high vacuum divided in five different zones separated by isolation valves. To preserve the equipment, operating personnel and users from high voltage micro-wave radiation and overheating, a safety interlocking system is implemented which contains several sub interlocks implemented through several security components: water cooling (flow meter and thermal switches), door locks, grounding components, vacuum threshold and operator validation with user access.

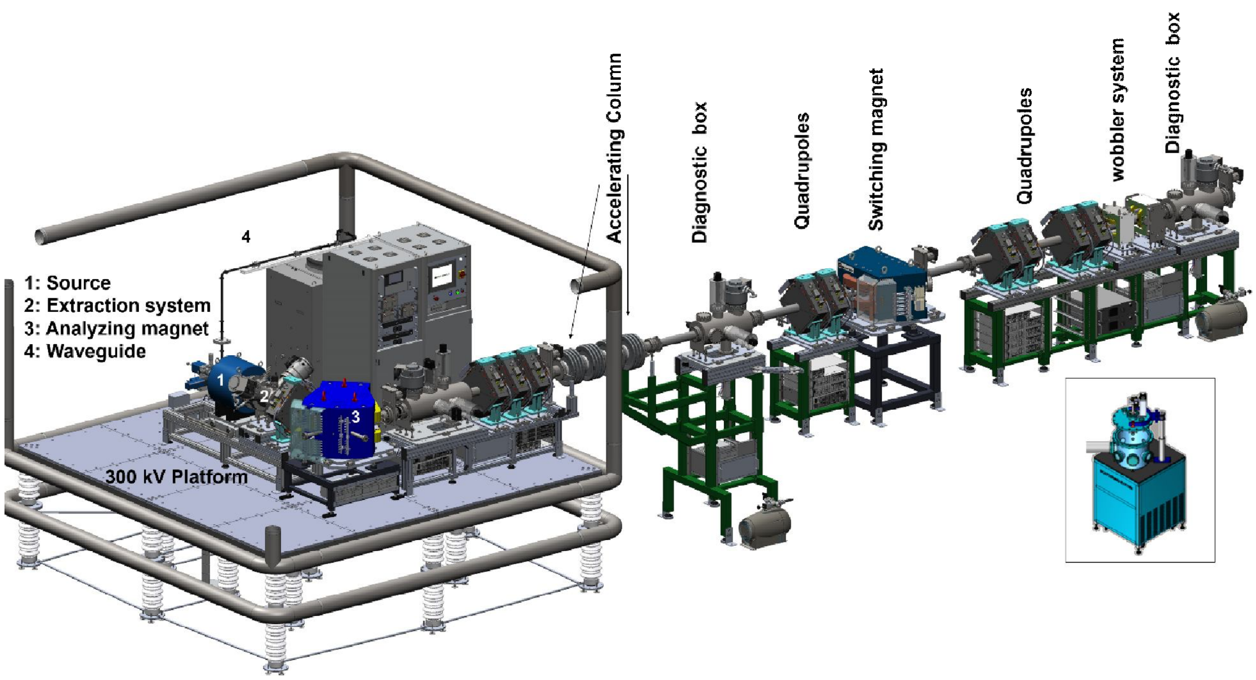

FIGURE 1. 3D view of the Supernanogan ECR with zero degree beam line installed at University of Allahabad. Experimental chamber is shown in inset in the figure.

PERFORMANCE OF THE FACILITY

The performance of the source and beam line and the quality of the beam were checked by performing several tests such as beam profile, stability, emittance, beam transport efficiency, homogeneity of the beam and emission of the X-rays. The gas source was tested for He, O, C, Ar, Xe beams, while the sputtering and oven sources were tested with Ta and Bi ions, respectively. Most of the tests were performed with Ar ions with O_2 as supporting gas. The typical beam current is 3000, 600, 160, 160, 140, 12, 10 and 3 μA for He^{1+}, He^{2+}, O^{6+}, C^{4+}, Ar^{8+}, Xe^{20+}, Ta^{20+} and Bi^{20+} ions, respectively as tabulated in Table 1. Such a huge current will reduce the time required for high fluence by several orders and will fill the gap in accelerator grid in India. For example, the typical Ar^{8+} ion beam current produced by the accelerator at Inter University Accelerator Centre, New Delhi is ~25 μA [6-7], while the current obtained from HFIBF is ~140 μA.

TABLE 1. Ions and its typical current.

Ion	Charge state	Current (FC3) in μA
He	2+	600
C	4+	160
O	6+	160
Ar	8+	140
Xe	20+	12
Ta	20+	10
Bi	20+	3

The long term, 6 hrs, stability test was performed with 2.6 MeV Ar^{8+} ions as shown in Figure 2. The beam current was stable within 10% of desired value. It was also found that the beam profiles before and after the long term stability were nearly same even after 8 hours without having any change in the beam current within allowed error. Similar behavior was also observed for horizontal and vertical emittances The emittance for Argon (Ar^{8+}) was 170 π mm mrad in the horizontal axis and 160 π mm mrad in the vertical axis.

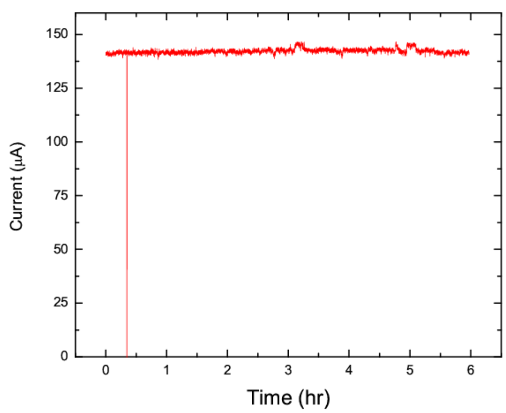

FIGURE 2. Stability test for Ar^{8+} ions up to 6 hrs.

It was observed that the current increases with increase in the gas quantity as well as RF power. The effects of the supporting gas on the beam current were studied systematically as shown in Figure 3. It is well known fact that for ECR, to increase the current for higher charge states of the element, mixing of main gas with a supporting gas is a common technique [3]. The most common supporting gases are oxygen and helium. We have used oxygen with Ar (14%) as main gas to produce Ar ions. It is clearly observed that the Ar ion current increases with increase of the oxygen gas percentage.

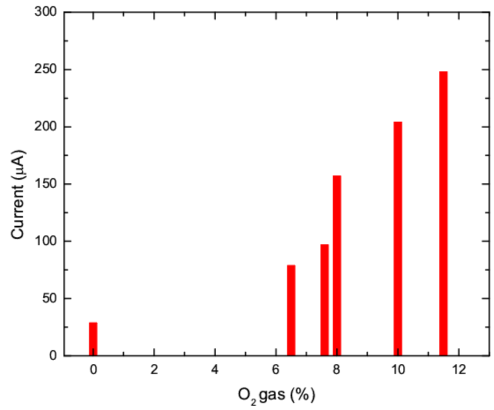

FIGURE 3. Effect of support gas (O_2) on the intensity of the current of Ar ions. The current increases with increase in the quantity of the support gas.

The current for different charge state of the ions was also measured by collecting the spectra from analyzing magnet as shown in Figure 4. Such a distribution is shown in Figure 6 for Ta (sputtering source), Bi (oven source) and Xe, O and Ar (gas sources) for different charge states. For better visualization, zoomed image of the distribution in the region of 14-25 charge states is shown in the inset of the figure. The current for high charge state (>20+) of the ions are also in the order of microampere, which is a big accomplishment for implantation on large area with high fluence.

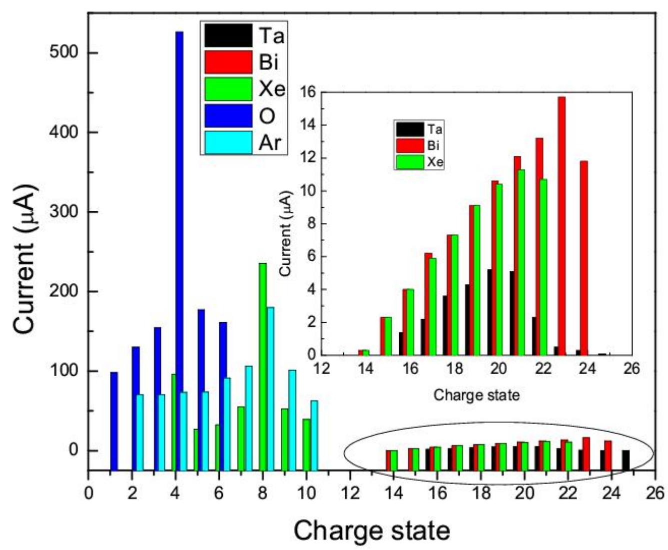

FIGURE 4. Beam intensity distribution with change states for different ions

The transmission of the beam was examined by the ratio of the beam current measured at FC3 and the current at FC1 under different platform potential. The transmission of the beam increases with increase in the platform potential and it is nearly 100% for the 250 kV potential and above as presented in Figure 5.

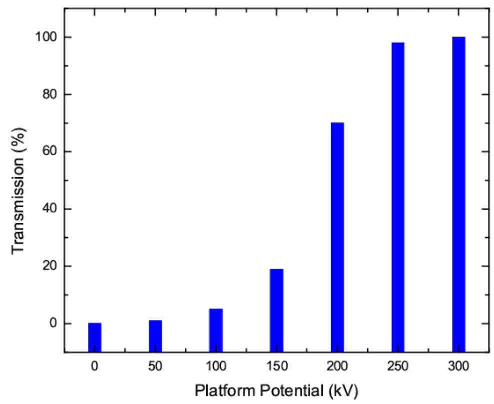

FIGURE 5. Transmission of beam intensity with platform potential.

CONCLUSION

In conclusion, a 14.5 GHz ECR source based High Fluence Ion Beam facility (HFIBF) is commissioned at University of Allahabad, India. The performance of the system and the beam quality were tested. The detailed analysis of the test results indicates that facility has good quality of the beam with high intensity highly charged ions for the cutting edge research activities.

ACKNOWLEDGMENTS

Authors are thankful to DST, India for providing funds as Nano-mission HFIBF project (IR/S2/PF/0001/2009) to install the facility. They also thank to NAC personnel for their support during the installation and testing of the HFIBF.

REFERENCES

1. V. Bechtold, N Chan-Tung, S. Dousson, R. Geller, B. Jacquot and Y. Jongen, *Nucl*. Instrum. Meth. **178**, 305-308 (1980).
2. R. Geller, *Electron cyclotron resonance ion sources and ECR plasmas*, CRC Press, 1996.
3. A. G. Drentje, A. Girard, D. Hitz and G. Melin, Rev. Sci. Instrum. **71**, 623-626 (2000).
4. PANTECHNIK, 13, Rue de la Résistance, 14 400 BAYEUX – FRANCE.
5. N. Agnihotri, A. H. Kelkar, S. Kasthurirangan, K. V. Thulasiram, C. A. Desai, W. A. Fernandez and L. C. Tribedi, Phys. Scr. T **144**, 014038-4 (2011).
6. D. Kanjilal, T. Madhu, G. O. Rodrigues, U. K. Rao,C. P. Safvan and A. Roy Indian J. Pure Appl. Phys., **39**, 25-28 (2001).
7. P. Kumar, G. Rodrigues, U. K. Rao, C. P. Safvan, D. Kanjilal and A. Roy Pramana-J. Phys., **59**, 805-809 (2002).