

TOWARDS THE DEVELOPMENT OF RARE ISOTOPE BEAM FACILITY AT VECC KOLKATA*

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Abstract

An ISOL type Rare Isotope Beam (RIB) Facility is being developed at VECC, Kolkata around the existing $K=130$ room temperature cyclotron. In the first stage, the beam energy will be about 400 keV/u using an RFQ post-accelerator and three modules of IH-linacs. Subsequently the energy will be boosted to about 1.3 MeV/u. A separate LEBT line for material science experiments is planned. Some of the systems have already been installed and made operational. The LEBT line has been tested and stable ion beams accelerated to 29 keV/u with high efficiency in a 1.7 m RFQ. A 3.4 m RFQ and the first IH Linac tank are under installation in the post-acceleration beam line. In this contribution an overview of the present status of the facility will be presented.

INTRODUCTION

An ISOL type RIB facility is presently under construction at VECC Kolkata [1]. The $K=130$ cyclotron at VECC will act as mother accelerator for this facility. A schematic layout of the facility is shown in figure 1. The $1+$ radioactive ions will be produced inside a thick target integrated ion-source, injected into an on-line Electron Cyclotron Resonance Ion source (ECRIS) for high charge state ionization, mass separated and then post accelerated in a Radio Frequency Quadrupole (RFQ) Linac and IH-Linacs. The production target and ECR based charge-breeder system lead to two beam lines. The first one, a low energy beam transport (LEBT) line is already installed and presently delivers stable ion beams of 29 keV/u energy at the end of a 1.7m RFQ linac. The second, post-acceleration beam line will accelerate the beams to 1.3 MeV/u using a longer, 3.4 m RFQ and a series of IH linear accelerators. In the first stage, the beam energy will be about 400 keV/u using three modules of linacs.

DESCRIPTION OF RIB FACILITY

Target Ion-Source

The first component is the Integrated Ion source. Radioactive nuclei will be produced inside thick targets using proton and α -particle beams from the $K=130$ cyclotron at VECC and ionized to $1+$ charge state in the integrated surface ionization source. A possibility of using a multiple target Electron Beam Plasma ion-source is also being worked out. The low energy $1+$ ion beam from the first ion-source will be injected into the ECR ion

source for higher charge state ($n+$) production in the charge breeder.

We have undertaken a target R&D programme as we need to develop many kinds of thick targets for our facility. Since diffusion of radioactive species out of the target increases with temperature one usually selects refractory target compounds such as oxides and carbides for the target. Target materials can be deposited on Graphite matrices (RVCF fibres) that can withstand high temperature and have sufficient porosity to allow radioactive atoms to diffuse out [2].

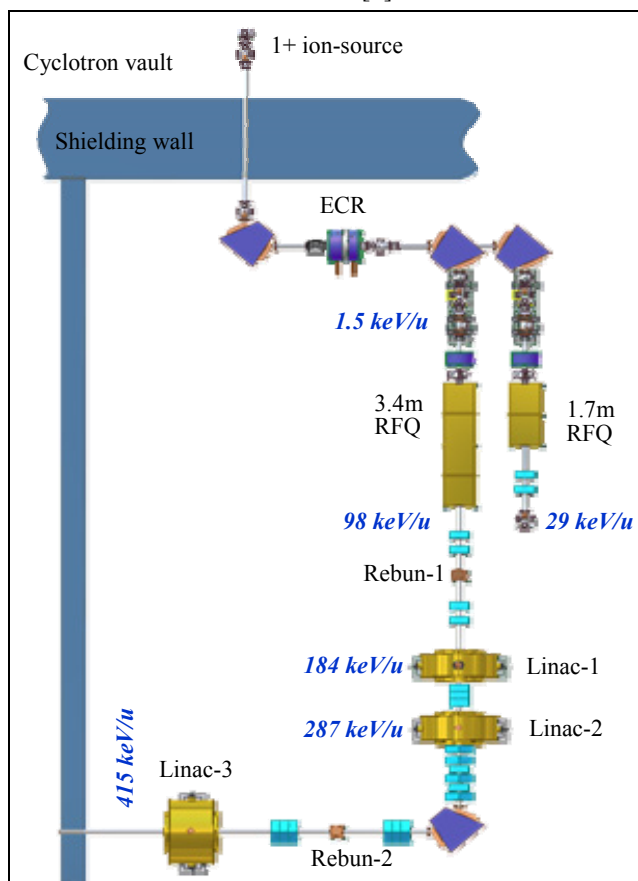


Figure 1: Layout of RIB facility.

Sintering & grain growth due to beam heating hinders the release of radioactive ions. Studies have shown that grain growth stays within limiting range if one starts with grain size of nano-metre range. Recent studies in case of ZnO have revealed that formation of a composite phase (Zinc silicate) resist the grain growth within the permissible limits even for 6 hrs heating at 1300 C[3].

*This is a VECC-DAE project

The Charge Breeder

The radioactive ions have to be ionized to higher charge state with good enough efficiency in order to accelerate a wide range of RI beams. In the “two-ion source” concept the beams are ionized to 1+ charge in the integrated target-ion source and then injected into the on-line ECRIS for further ionization to higher charge state n^+ .

The beam transport line between the integrated target surface ionization source and the ECRIS incorporates a dipole, for selection of 1^+ beam. The beam transport design ensures that the beam extent lies within the plasma region of ECR and also 1^+ beam get properly trapped in the ECR [4]. To keep the ECR volume large we have chosen a 6.4 GHz on-line ECR ion source as the charge breeder. This ion-source has been operated for both gaseous and metallic beams. A typical spectrum for ion ions produced using the MIVOC [5] technique is shown in Fig 2. Also for heavier ions, a charge breeder with ECR operating in 10+14 GHz dual frequency mode has been designed [6].

In addition to this, new R&D on efficient & fast transport and ionisation of radioactive atoms irrespective of their chemical nature has been started. The ECRIS can be exploited as a universal 1^+ ion-source. However, with an internal or close vicinity target the radiation damage to the permanent magnet drastically reduced the lifetime of the ion-source [7]. A possible alternative could be the Helium-jet coupled ECR ion-source with multiple thin target system (figure 3). This *universal charge breeder* option is highly attractive especially for the fission production route. Transport efficiencies of 50-60% can be obtained from the He-jet recoil method [8] for most of the elements. Assuming a typical skimmer efficiency of 50% and ionization efficiency of 50% for 1^+ in ECR, one can expect a total transport and ionization efficiency in the range 10 – 15 % for almost all the elements.

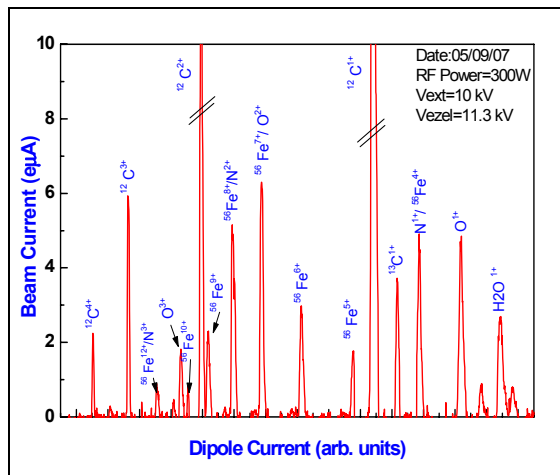


Figure 2: ECR spectrum.

The Heavy-Ion RFQ Linac

Radio Frequency Quadrupole Linac would be the first post accelerator of our RIB facility. It has been designed for $q/A=1/14$ and input energy of 1.7 keV/u. The four-rod type RFQ is 3.4m long (vane length ~ 3.2m) and operates at the resonance frequency of 37.8 MHz. The development of RFQ has been done in phases. In the first phase we have developed a 1.7 m RFQ capable of accelerating beams up to 29 keV/u. This RFQ operates at a resonance frequency of 33.7 MHz. It has already been installed and operational since the year 2005. Transmission efficiencies of about 85% were measured for Ar^{4+} and other beams like $O^{2+,3+,4+}$ and $N^{3+,4+}$ through the RFQ. The details of this RFQ and results of beam tests are reported in ref [9].

The post-acceleration RFQ is almost identical to the 1.7m RFQ but is longer to achieve higher output energy of 98 keV/u. This RFQ is also completely indigenously designed and constructed. The resonant structure including the vanes and supporting posts is made from OFHC copper and has been machined at Central Mechanical Engineering Research Institute (CMERI), Durgapur located about 200 km north of Kolkata. The top cover (cavity) has been Copper plated and built by Danfysik. A photograph of the 3.4m RFQ during installation is shown in fig. 3. In the preliminary test, beam transmission efficiency of 90% has been measured for O^{3+} in the RFQ. Further details about the RFQ system are presented in another contribution in Linac08 conference [10].



Figure 3: The 3.4m RFQ post-accelerator.

ECR to RFQ Beam-Line

The beam transport line from the ECR ion-source to the RFQ consists of an Einzel lens, a 90 degree, 0.25 Tesla dipole magnet for q/A selection, and a solenoid magnet lens downstream of the dipole magnet to ensure proper matching of the ion-beam at the entry of the RFQ. The ion optics of this low energy transport line has been designed using the computer code TRANSPORT. The separation stage is designed for a dispersion of 1.84 cm. The magnification in the dispersive plane is -0.88. The RFQ demands converging beam in both the planes. A reasonable match could be obtained using a solenoid magnet length of 30 cm and a maximum magnetic strength of 0.65 Tesla

RFQ to LINAC Beam-Line

The RFQ to LINAC-1 beam line has been designed to match the RFQ beam with the longitudinal & transverse acceptance of Linac1. A 4-gap, 37.8 MHz Re-buncher will be placed between the RFQ and Linac1 to obtain a beam of desired phase and energy width at the entry of the Linac. For transverse focusing we would be using two quadrupoles upstream and two downstream of the Re-buncher. A fortran code was written to optimize the position of Re-buncher & voltages on the drift tube. In order to recheck the results of our code we have simulated using SIMION, the time varying voltage on the drift tube of the Re-buncher and calculated the bunching property both in phase and energy, due to the applied RF voltage.

RF simulation of the Re-buncher was done using ANSYS. The height of the movable short was optimized to obtain the desired resonant frequency of 37.8 MHz. Experimentally found out value are in good agreement with calculated resonating frequency using ANSYS. The mechanical fabrication of the Re-buncher including major components such as inductive coupler, capacitive pick-up and tuner is almost complete. A photograph of the Re-buncher during assembly is shown in Fig 4.



Figure 4: The Re-buncher during assembly.

The IH-LINAC Post-Accelerators

After the initial stage of acceleration in the RFQ linac the subsequent acceleration of beams will be done in LINAC tanks [11]. For these low- β and low q/A RI beams the IH-LINAC structure is the preferred choice. In this type of structure, the LINAC cavities are excited in TE mode. Three IH-Linac cavities would accelerate the 98 keV/u beam from RFQ to about 415 keV/u. The beam energy is expected to be 184 keV/u and 287 keV/u after the first and second Linacs respectively. A photograph of the first Linac cavity is shown in Fig. 5. It is an octagonal cavity made of 25 mm thick SS304L steel clad with 5mm thick ETP Copper. The cavity has been tested at low power. The measured frequency and Q values match

reasonably well with calculated value. The axial component of the RF electric field was measured using bead perturbation technique using an insulating teflon spherical ball. The arrangement allowed us to measure frequency deviation at a step of 5 mm. The detailed design and results of Linac cavity has been presented in another contribution in Linac08 conference [12].

SUMMARY & OUTLOOK

The status of ISOL type Rare Isotope Beam facility development at VECC Kolkata has been presented. The facility is at present delivering stable heavy-ion beams of energy 29 keV/u. Experiments can be performed at two experiment stations – one at the ECR mass separator focal point and the other at the end of the 1.7m RFQ. The longer post-accelerator RFQ is also installed and very soon the beam tests will be conducted for Linac-1.

The present RIB facility has been planned around the existing K=130 cyclotron. We are also exploring the possibility for using the photo-fission route for the production of neutron rich RI beams. For this purpose we have undertaken a programme to develop a 50 MeV, 100 kW super-conducting electron Linac. In the first phase we have received funding to construct a Horizontal Test Cryostat (HTC) cavity. Recently, a memorandum of understanding was signed between VECC and TRIUMF for the joint HTC development.

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