Chapter 6

Development of a deceleration lens for HCI

Highly charged ions carry kinetic energy by virtue of their velocity and potential energy by virtue of their charge. With ion beams of high energies, the kinetic energy of the ion plays the dominant role in ion-matter interactions. On the other hand a slow HCI offers its unshielded field of the nucleus in its interaction with matter and has its potential energy (which equals the sum of its successive ionization energies) comparable to or even higher than the ion’s kinetic energy. In terms of ion velocities, slow highly charged ion are the ones whose velocities are much less as compared to the ‘bohr’ velocity of electron in a hydrogen atom. Hence with slow highly charged ions we can study the subtle effects of the ion’s potential energy which remain suppressed by the predominant kinetic energy effects for the case of fast highly charged ions. Effects like the polarization of the target by an incoming slow HCI, the electron transfer and the post collision interactions of the outgoing slow HCI can thus be probed. In this chapter we report on the design and implementation of an electrostatic lens which would be used to decelerate and focus a beam of HCI having energy of few tens of keV/q so as to obtain a low energy (few tens of eV/q) well focused beam on the target. The deceleration lens will be coupled to the beamline of a superconducting electron cyclotron resonance ion source, the PKDELIS [1], which is installed at the Inter-University Accelerator Centre, New Delhi. The ion beam extracted from PKDELIS has a
typical energy of 30 keV/q and upon deceleration the final energy at the target is expected to be around 10 eV/q.

The various ways of obtaining slow HCI include low voltage extraction, electrostatic deceleration, using buffer gas to slow down ions, use of low energy target recoils as projectiles or by the use of a decelerating RFQ. Each of these ways have their inherent advantages and disadvantages. Our aim is to decelerate the ion beam extracted from an ECRIS and the use of electrostatic lenses is the most suitable way for our case in terms of variation of final beam energy as well as ease of implementation.

Electrostatic cylindrical lenses are widely used to control beams of charged particles [2, 3, 4]. One of the fundamental goals in the design of electrostatic lenses is to keep the lens parameters constant over a wide range of voltage ratio of final-to-initial energy and the ease of implementation of the design. In regions of varying electric fields an ion beam experiences forces in axial as well as transverse directions which result in changes in beam energy as well as divergence. The challenge in deceleration is to devise a system which doesn’t defocus the beam while it’s energy is being reduced. Regions of varying electric fields can be generated in the gaps between electrodes by keeping them at different potentials. Our design of the deceleration lens is based on an electrostatic system consisting of cylindrical electrodes arranged along a common axis.

On the basis of their divergence properties, ion beams may be classified as converging, diverging or parallel. Deceleration, transport and focusing of parallel beams is comparatively easier than that of converging or diverging beams. This is because for diverging beams extra force is required in the transverse direction to control their cross section during transport and deceleration, while controlling the cross section of converging beams is not possible along with deceleration. With parallel beams the cross section can be kept constant with gradual deceleration and subsequent focusing becomes easier. Practical ion beams are almost never parallel as they have a tendency to diver due to space charge effects. Hence it was necessary to design a system which can decelerate parallel as well as diverging beams.
CHAPTER 6. DEVELOPMENT OF A DECELERATION LENS FOR HCI  87

6.1 The simulation

The ion optics simulation program SIMION (see appendix B) was used to model the deceleration lens. The deceleration lens essentially consists of a set of five cylindrical electrodes followed by a cone shaped electrode, all arranged along a common axis. As the beam traverses successive gaps between electrodes, it encounters an increasing potential. The axial part of the electrostatic force is directed opposite to the direction of the incoming beam and has the net effect of reducing the energy of the beam. The dimensions of the electrodes as well as the spacing between them is optimized to keep the divergence of the beam at a minimum. During simulation it was observed that the cone angle of the last electrode plays a critical role in focusing and transmission of the beam. It was decided to place the lens inside a housing made from a general purpose accelerating tube.

The following points had to be taken into consideration while doing the simulations

- The gap between electrodes should be appropriate so as to avoid high voltage breakdown problems. We had a constraint of a maximum gradient of 15kV/inch.

- During simulation the first electrode has to be at ground potential so that the beam starts from a field free space as would be the actual case.

- The radius of the beam should be slowly varying while traversing the electrodes and it should be confined as near to the axis as possible.

- The applied voltages should be such that it gives a well focused low energy beam at the target with the possibility of varying the final energy of the beam. The last electrode and the experimental chamber has to be floated to get the minimum energy beam at the target.

- The geometry of the electrodes should be such that the interior of the experimental chamber is field free. This is to ensure that the detecting systems placed within the chamber are not affected by the voltages applied on the lens electrodes.
CHAPTER 6. DEVELOPMENT OF A DECELERATION LENS FOR HCI

- The possibility of the inner assembly of electrodes and the outer housing assembly for having the same potential configuration has to be explored for the ease of applying the voltages from outside without disturbing the vacuum.

Apart from the above stated points ease of fabrication and assembling of the setup was also taken into account during the simulation runs. Figure 6.1 to figure 6.4 shows the ion trajectories in the simulated design.

The salient features of the deceleration lens are as follows

- The lens can be used for parallel as well as diverging incoming beams to deliver a well focused minimum energy beam at the target.

- The lens being completely electrostatic, the potential configuration for a given charge is independent of the incoming ion.

- The energy of the ions incident on the target can be changed simply by changing the potentials on the electrodes.

- As the inner electrode’s potential configuration is same as that of the outer housing, changing the various potentials is easy without disturbing the vacuum inside the beamline.

Figure 6.5 shows the variation of energy along the length of the deceleration lens.
Figure 6.1: A parallel beam of diameter 10mm and energy 30 keV/q is focused to a spot of 4mm diameter and 5 eV/q energy at the target with 100% transmission efficiency.
Figure 6.2: Equipotential surfaces for deceleration from 30 keV/q to 5 eV/q
Figure 6.3: A parallel beam of diameter 10mm and energy 30 keV/q is focused to a spot of 2mm diameter and 500 eV/q energy at the target with 100% transmission efficiency.
Figure 6.4: A beam of 5mm radius and ~35mrad divergence having initial energy of 30 keV/q is focused with 85% of the beam within a radius of 1.5mm at the target.
6.2 Fabrication and Installation

The deceleration lens consists of a set of six cylindrically symmetric electrodes (fabricated using SS 340) connected to each other using ceramic spacers assembled inside a general purpose accelerating tube. Each gap between electrodes has four ceramic spacers for providing insulation as well as mechanical strength. (see figures 6.6 and 6.11). Since the voltage to the electrodes has to be applied from the outside using metal rings of the general purpose accelerating tube, these parts are internally connected to the various electrodes. The inner assembly consisting of the six electrodes is held in place with the help of grub screws and ceramic spacers. Grub screws from the outer side of the first electrode (which is at ground potential) to the inner side of the general purpose accelerating tube holds the electrodes from one side and ceramic spacers connecting the last electrode to the experimental chamber holds the inner assembly from the other side.

A multi-port high vacuum chamber (OD=324mm, thickness = 4mm,
Outer Assembly
(General purpose accelerating tube)

Inner Assembly
(Lens electrodes with ceramic spacers)

Figure 6.6: SOLIDWORKS: Cut out view of the mechanical design of the deceleration lens

height=427mm, material:SS 304) has been fabricated to be coupled with the deceleration lens assembly. The dimensions of the chamber are such that the focal point of the deceleration lens is at the center of the experimental chamber. It has eight ports at the beam level, five ports at the lower level and one port each at the bottom and the top. The large number of ports gives us the flexibility in connecting various detecting systems, high voltage feedthroughs, pumping systems, vacuum gauges and/or viewports. The beam entry port has an 8" NEC flange to be coupled to the general purpose accelerating column which will house the deceleration lens. All the other ports have conflat flanges (CFF). Complete metal sealing makes the chamber ideal for UHV applications. The description of the ports at the beam level are shown in figure 6.7.

The beam currents of slow HCI are expected to be low and hence a well defined interaction zone is needed for performing experiments. Taking this into consideration the top lid of the experimental chamber was designed, allowing provision for finer target alignment. Figure 6.8 shows the 3D mechanical drawing of
the designed lid. A 6" CFF port was fabricated as part of the top lid of the chamber and was designed for the purpose of holding an arrangement for target alignment. The target alignment assembly comprises of a bellow and a sliding guide rail arrangement which can be rotated in a slot made on the upper side of the top lid. The target (a gas jet or a solid sample) will be held by a rod inserted in vacuum through a wilson seal coupling. This assembly enables the $x$, $y$ and $\theta$ adjustments for better beam-target interaction.

To insulate the experimental chamber from the ground, four high voltage ceramic insulators are provided for the stand. Also since the experimental chamber has to be floated on high voltage, a perspex box is designed to either insulate or ground the experimental chamber when required. This box has two sockets, one at high voltage and the other at ground potential. A plug connected to the high voltage point of the resistance chain used for generating the potential gradient and
which fits in both of these sockets is fixed at the end of a long perspex rod. This rod can be moved inside a slot on the perspex box and is used for grounding or
CHAPTER 6. DEVELOPMENT OF A DECELERATION LENS FOR HCl

floating the chamber as and when required. The experimental chamber was tested for any possible leaks and the best vacuum attained was $2.7 \times 10^{-9}$ torr after baking.

![Schematic of the beamline of the PKDELIS ECR ion source.](image)

Figure 6.10: Schematic of the beamline of the PKDELIS ECR ion source.

The schematic of the beamline where the deceleration lens is installed is shown in figure 6.10. Beams of HCI extracted from the PKDELIS ECRIS are mass analyzed by using a $90^\circ$ bending magnet and then directed to the deceleration lens. The input current and size of the beam is controlled using suitable apertures. A linear motion feedthrough holds a stainless steel plate having a set of circular apertures of different sizes (10mm, 6mm and 3mm) which helps in regulating the current and radial size of the beam. A faraday cup with electron suppressor is placed between this aperture and the deceleration lens to measure the beam.
current just before it enters the decelerating setup. This system of apertures and faraday cup will be used for measuring the transmission efficiency of the system. The pressure in the beamline prior to the deceleration lens system is $3.0 \times 10^{-8}$ torr while the deceleration assembly along with the experimental chamber stands evacuated to a pressure of $1.4 \times 10^{-8}$ torr.

For the final deceleration the experimental chamber and it’s associated vacuum components and detecting systems have to be floated to a high potential (around 30 kVs). For this purpose an isolation transformer of rating 110 kV/2 kWatts has been installed.

![Actual photograph of the deceleration lens assembly.](image)

6.3 Testing of the deceleration lens

The deceleration lens has to be tested for the final beam energy, for its beam transmission efficiency and size of the beam spot. A voltage divider system composed of a chain of resistors connected in series (net resistance = 200 MΩ) is assembled atop a 1cm thick perspex sheet for providing the voltage gradient required for deceleration. The resistance chain assembly is mounted on top of the deceleration lens to allow easy access for connections. Connections to the deceleration lens were made using thin teflon coated wires running from appropriate points on the
resistance chain to parts of general purpose accelerating tube. The voltage gradient on the inner assembly of six electrodes is provided by internal connection from the general purpose accelerating tube to the inner electrodes. The isolation transformer is used to isolate the chamber ground from the ground of the ECR source.

To measure the final energy of the beam, a repeller plate analyser (RPA) is designed. The RPA consists of four SS plates, insulated from each other and also from the chamber, placed at a certain distance apart from each other. Schematic of the RPA is shown in figure 6.12. The first three plates have a 80 mm hole covered with meshes (30 lines/inch) to allow the beam to pass through while the last one is a beam collector to be used for measuring the beam current. The beam energy will be measured by applying retarding voltages to these meshes and the beam current will be measured as a function of the applied voltage.

To measure the transmission efficiency of the deceleration lens, the faraday cup placed just before the deceleration lens and the last plate of the RPA will be used.
CHAPTER 6. DEVELOPMENT OF A DECELERATION LENS FOR HCI 100

The size of the beam spot will be determined by scanning a wire along the x and the y direction across the focal point of the beam and measuring the beam current as a function of position of the wire. In case the beam currents are very low a channel electron multiplier will be used instead of a wire and counts as a function of position of this detector will thus give the beam size along the x and the y directions.

Figure 6.12: Repeller plate analyser
Figure 6.13: Picture of the beamline with the deceleration lens and experimental chamber