Ion Beam Imaging in a Mass Spectrometer Using an MCP based Imaging Device

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Abstract. The application of ion beam imaging devices in mass spectrometers is proving to be very useful for validating the ion optical designs. An attempt has been made to image the ion beam in mass spectrometer at two different locations – the first location is before the magnetic analyzer and the second one is at the final collector positions. Experimental results of beam imaging studies under varying beam conditions and with or without einzl lenses, will be presented. Results of simulation studies of ion optics in the same mass spectrometer using commercial software will also be discussed. Experiments with a movable strip type collector at first location give to estimate the beam dimensions are also discussed.

1. Introduction
Mass spectrometers with sector field magnetic analysers are routinely used for the high precision and accurate isotope ratio measurements. The ion beam generated in the ion source, most often either an electron impact (EI) or a thermal ionization (TI) source, is accelerated to a few keV before being subjected to the magnetic field and finally detected using a faraday cup. Ideally one would expect a narrow ribbon of the ion beam to reach the collector without any physical spread. However, the transmission of ions through the ion optical elements like focusing lenses and magnetic field, is associated with many aberrations like chromatic, spherical etc. These aberrations influence the final shape of the beam and the net effect is a broader beam at the collector. Correction methods are employed to minimise the effects of these aberrations and improve the focusing to obtain the desired instrumental sensitivity, resolution and abundance sensitivity. Use of stable electrical supplies reduces chromatic aberrations caused by the energy spread of the beam, where as reduction of spherical aberration is accomplished by containing the divergence of the beam entering the magnetic analyser, to within ± 0.5°, by placing an aperture at the entrance of the magnet. But this has a deleterious effect of obstructing the peripheral ions, thereby limiting the overall transmission.

Ion optical elements in a mass spectrometer are designed using commercial software packages and SIMION [1] is the most popular among them. This package is useful to arrive at an optimum geometry for the ion optical element for efficient transport of the ion beam through this element under varying input conditions. However, these designs have to be experimentally validated before incorporating them into the mass spectrometer. Conventional methods of beam profiling are generally either indirect or time consuming. With the recent availability of commercial imaging devices, the imaging and profiling of low energy ion beams has become more realistic. Application of such devices during design and development stages of a mass spectrometer greatly reduces the product development time. This paper presents a case study conducted on an existing thermal ionization mass spectrometer.
TIMS designed and developed in VPID, BARC, using a commercially available imaging device based on micro-channel plate (MCP) – phosphor screen (PS) combination.

2. Experimental Setup

Figure (1) shows the schematic of TIMS used for these studies and the location of the imaging device. It uses a modified TI source [2] operating at 10 kV with an immersion lens and two stage einzell lens after ion source slit for focusing the ion beam both in vertical and horizontal directions. Following steps were carried out during this study:

a) Simulation of this TI source was carried out using SIMION and the effect of source parameters on the beam characteristics were studied.

b) Initial beam profiling was carried out using a small metal strip (10mm x 10mm) mounted on a linear motion feedthrough acting as total ion collector. Data was collected at an interval of 1mm across the ion beam both in vertical and horizontal directions.

c) Two sets of experiments were conducted by locating the imaging device at two locations: location 1 which is the position down stream of the ion source slit before the magnetic analyzer, and location 2 which is the position of the collector cups along the beam axis. Location 1 is fixed with respect to the source slit. A bellow arrangement is provided to vary the distance between the exit face of the magnetic analyser and the imaging device at location 2. Ion beam imaging at the first location is useful to study the effect of source potentials on the ion beam shape and intensity, whereas the imaging at collector location is useful for estimating the beam characteristics for optimally fixing the collector cups.

The imaging device has a 40mm diameter active surface area and an overall thickness of 20mm and its optical output is photographed using a suitable CCD Camera. The resulting video signal is encoded using an in house developed image grabber card and associated software.

3. Result and discussion

3.1. Simulation study

Figures (2a) and (2b) show the ion paths under two different conditions of the einzell lens. In the first condition, Figure (2a), the einzell lenses were physically present but shorted to ground. In the second condition, Figure (2b), suitable voltages were applied to einzell lenses. The focusing effect on the peripheral ions, due to the voltages applied to the einzell lenses, is evident from these two figures.
central portion of the ion beam seen in Figure (2b) is uniformly dark over a wide region compared to that seen in Figure (2a). As will be shown later, this gives an enhanced overall sensitivity.

Figure (2a). Simulated ion beam with grounded einzel lenses.

Figure (2b). Simulated ion beam with voltage on einzel lenses.

3.2. Ion beam profiling by metallic strip

The metallic strip was very useful for profiling the ion beam and the observations from the simulation studies were experimentally verified through this exercise. Figure (3) shows the ion beam profile obtained with the metal strip without and with voltages applied to the einzel lenses. The profile with einzel lenses having potential applied has less intensity in the tail portion and lower slope in the high intensity (central region of the beam) region as compared with that of grounded einzel lenses. This is because, with potential applied to einzel lenses, the peripheral ions (tail portion of the profile) get focused inward thereby increasing the overall intensity of the ion beam in the central zone. This helps in getting enhanced system sensitivity (~30% more) at the collectors.

Figure (3). Ion beam profile at the entry of the analyzing magnetic field using a metallic strip.
3.3. Imaging and profile study with MCP-PS

3.3.1. Device at location 1. Figure (4a) and (4b) show the images of the ion beam from TI source at about 300 mm from the source defining slit. It is evident from these figures that the beam is more intense and converged with voltages on einzel lenses. The corresponding profiles of the beam are shown in Figures (5a) and (5b), which give the numerical values for the beam dimensions (FWHM), and intensity. The images of the beam at various accelerating potentials were also recorded and beam dimensions were measured at this position of the imaging device. Table 1 presents this data. It is clear from the table that higher accelerating voltage (higher energy of the beam) increases the ion intensity.

![Figure (4a)](image1)  Ion beam profile at the entry of the analyzing magnetic field with grounded einzel lens

![Figure (4b)](image2)  Ion beam profile at the entry of the analyzing magnetic field with voltage on einzel lens

![Figure (5a)](image3)  Ion beam profile at position 1 (grounded einzel lens)

![Figure (5b)](image4)  Ion beam profile at position 1 (with voltage on einzel lens)

| Accelerating voltage | Grounded einzel lens | With voltage on einzel lens |
|----------------------|----------------------|-----------------------------|
|                      | Beam width in mm (At 5% FWHM) | Beam height (At 5% FWHM) | Beam intensity (arb. Units) | Beam width in mm (At 5% FWHM) | Beam height (At 5% FWHM) | Beam intensity (arb. Units) |
| 3kV                  | 7.6/4.6              | 10/6.5                      | 120                        | 6.4/2.4                      | 10/7.8                      | 145                        |
| 4kV                  | 8.6/4.1              | 10/6.5                      | 150                        | 7.3/3.7                      | 11/7.9                      | 180                        |
| 5kV                  | 9.1/4.9              | 10.1/7.3                    | 165                        | 7.0/3.8                      | 11.5/8.6                    | 195                        |
| 6kV                  | 8.5/4.9              | 11/6.3                      | 195                        | 7.7/4.1                      | 11.2/8.2                    | 215                        |
| 7kV                  | 8.2/4.9              | 12/6.8                      | 220                        | 7.2/4.1                      | 11.2/8.6                    | 235                        |
3.3.2. Device at location 2. Though einzel lenses help in improving the overall transmission, there is a chance that they introduce a marginal shift in the final focusing position of the beam at the collectors. This shift can be taken care of by making minor adjustments in the position of the collector. Table 2 shows the variations of the beam width with the position of the MCP along the ion beam. This data helps in determining the final position of the collector cup so as to detect finely focused beam. Table 3 shows the variation in the beam width with the exit angle of the analyzing magnetic field. Using this data one can decide the exact angle for the given position of the collector. Data shown in Table 4 reveals the improved transmission with increase in accelerating potential.

| S. No. | MCP position along the beam (in mm) | Beam Width (at 5% of peak intensity) (in mm) |
|-------|----------------------------------|---------------------------------------------|
| 1     | 595                              | 0.77                                        |
| 2     | 600                              | 0.75                                        |
| 3     | 605                              | 0.75                                        |
| 4     | 610                              | 0.74                                        |
| 5     | 615                              | 0.68                                        |
| 6     | 620                              | 0.6                                         |
| 7     | 625                              | 0.69                                        |
| 8     | 630                              | 0.75                                        |
| 9     | 635                              | 0.77                                        |
| 10    | 640                              | 0.8                                         |
| 11    | 645                              | 0.82                                        |
| 12    | 650                              | 0.86                                        |

| S. No. | Exit angle (degree) | Beam width (at 5% of peak intensity) (in mm) |
|-------|---------------------|---------------------------------------------|
| 1     | 26.5                | 1.02                                        |
| 2     | 26                  | 0.91                                        |
| 3     | 25.5                | 0.83                                        |
| 4     | 25                  | 0.78                                        |
| 5     | 24.5                | 0.67                                        |
| 6     | 24                  | 0.6                                         |
| 7     | 23.5                | 0.75                                        |
| 8     | 23                  | 0.78                                        |
| 9     | 22.5                | 0.87                                        |
| 10    | 22                  | 0.99                                        |
| 11    | 21.5                | 1.11                                        |

| S. No. | Accelerating Voltage (kV) | Intensity (pixel) |
|-------|---------------------------|-------------------|
| 1     | 3                         | 44.4              |
| 2     | 4                         | 53.2              |
| 3     | 5                         | 68.4              |
| 4     | 6                         | 72                |

Imaging of ion beams of seven Neodymium isotopes was also carried out and is shown in Figure 6. From this figure it can be seen that the resolution of the mass spectrometer (m/Δm) is adequate to clearly separate all the isotopes. Thus it can be concluded that capturing the images of the ion beams helps in determining the inter cup separation in the final configuration of the multi collector mass spectrometer. Presently, five faraday cups are incorporated at the locations of optimum focal point, each corresponding to the ion beam of a particular isotope.
Sources of error in the data: MCP with phosphor screen has enough electron current before the screen to produce the space charge effect which can broaden the apparent beam size. This effect has not been taken into consideration while collecting the data on beam size. Hence the actual beam size may be less than the measured one.

4. Conclusion
The imaging device (MCP-PS) has proved to be a very useful tool in determining the ion beam profile in the mass spectrometer to ascertain the various design parameters of the instrument like beam size, collector position and the exit angle of the analyzing magnetic field. The experimental results obtained indicate that there is a definite improvement in overall sensitivity when einzel lenses with appropriate voltages are incorporated in the system.

5. Acknowledgements
Authors wish to thank Dr. V. C. Sahni, Director, Physics Group and Dr. S. Kailas, Associate Director, Physics Group (N), BARC for their encouragement, keen interest, and support for this work. They also wish to thank Shri S. K. Lalwani, Electronics Division, BARC for providing the image grabber card and software for this work.

Reference
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