DEVELOPMENT OF A NOVEL VARIABLE DISPERSION ZOOM OPTICS FOR MAGNETIC SECTOR MASS SPECTROMETER

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Introduction

Magnetic Sector mass spectrometers are used in the precise isotopic ratio measurement of the inorganic samples in gaseous or solid form. TPD, BARC has been developing these instruments *[1]* for various applications in DAE. The instruments developed so far are based on conventional design of collector system whereby each collector is mounted on a mechanical motion feed-through *[2]*. This set-up suffers from the following limitations: a) In case of higher number of faraday cups (5 or more) mechanical assembly is very bulky and unwieldy, b) limited peak flatness (500 – 600 ppm) due to limited aperture size (~ 1 mm), c) difficulty in angular adjustment of the collector cups affecting the peak shape, d) the physical dimensions of the collector viz., 2.5 mm, restricting the placement of collectors at desired locations which limits the mass range for multi-collection ratio measurement to around 250 amu, e) prominent surface bulging effects during the fabrication of collector f) microphonic pick-ups in the collector mounting mechanism leading to higher noise in the amplifier and thus the internal precision.

To circumvent these problems, a new collector set up with variable dispersion zoom optics is developed. The main advantages of this set-up are elimination of mechanical motion feed-throughs and improved peak flatness leading to better precision and accuracy. This paper discusses the design aspects, experimental study and evaluation using Strontium standard for isotopic ratio measurement.

Design Details

The setup consists of DC quadrupole *[3]*, deflection optics and five fixed collectors with wider input apertures. DC quadrupole adjusts the dispersion of ion beams by suitably varying the potentials such that these are well aligned with the respective apertures on the

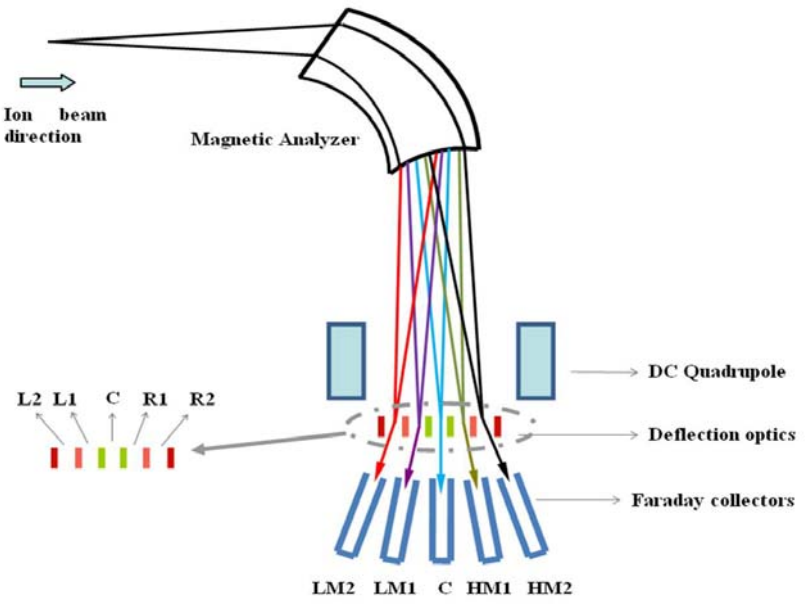

Fig. 1: Schematic of Variable dispersion zoom optics; five masses dispersed by magnetic analyzer adjusted for optimized dispersion by VDZO and collected by respective faraday collectors.

deflection optics. The deflection optics consists of thin metallic plates stacked together but electrically insulted from each other and hence forming different apertures for the passage of ion beams. It deflects the ion beam passing through respective apertures in such a way that the distance between the beams increases when they reach the respective collectors as shown in Fig. 1. The increased distance allows using collectors with wider apertures which leads to more peak flatness. For the collection of ion beam, five faraday collectors with 3 mm aperture are used. These are mounted on a single stainless steel plate enabling simpler and sturdier mechanical assembly.

Computer Simulation

The entire geometry was simulated using SIMION 7.0 software *[4]* and a study was carried out for the optimum set of potentials for all the ion optical elements that will give the maximum transmission for the isotopes of a given element. Two different potential arrays-one with geometry of DCQ, deflection optics and faraday cups and the other consisting of the 30 cm, 90° deflection stigmatic magnet geometry, were coupled together in the work bench. The ion flight paths through above optics were generated using ion groups having an energy of 7 keV, originating from a source slit of 0.3 mm (placed at 600 mm from the magnet boundary) with a divergence of ±0.5°. The masses of interest for these simulations correspond to the isotopes of Sr, Nd and U. The ions were allowed to pass through the given geometry of VDZO to be collected on the faraday cups after the dispersion by the magnet. A comparison study was conducted for a variety of design features of each component and the final design was worked out for maximum transmission of the ion beam for all required elements. Simulated optimum potentials for different elements are summarized in Table 1. The effect of DCQ potentials on the beam width as well beam height was also studied and the dimensions of the Faraday cup were accordingly fixed.

Experimental

A working model based on the outcome of the simulation studies was fabricated for experimentation. The experiments were carried out in three different parts. In the first part a micro-channel plate phosphor screen (MCP-SP) imaging device was used to capture the images of the ion beams to study the effect of variation in voltages on DCQs and deflection optics on dispersion of ion beams. The second part involves placement of final collectors and obtaining flat top peaks by optimizing deflection optics potentials. Third part consists of carrying out isotopic ratio measurements on these collectors for desired elements by optimizing DCQ potentials and small adjustment of deflection optics potentials.

To check the effect of VDZO on performance of the instrument, DCQ potentials were optimized and isotopic ratio measurement for strontium was carried out. The Strontium standard sample (SRM 0978) was used for the measurement of isotopic ratio $^{87}Sr/^{86}Sr$ using multi-dynamic mode. The sample was deposited on the rhenium side filaments of triple filament assembly. The data was collected in 10 blocks of 10 ratios each, for the same assembly to estimate the internal precision (calculated as the relative standard error over all 100 ratios). The same sample was analyzed on ten separate filament assemblies on a turret/sample magazine for external precision measurement (relative standard deviation).

Table 1: Optimized values of potentials on VDZO for collecting various ion beams on faraday cups

Element	Potentials on Deflection optics and DCQ in volts L2 / L1 / C / R1 / R2 (-ve in volts) ; DCQ(+/- in volts)	
	Simulations	Experimental
Sr	1000 / 0 / 0 / 0/ 1000 ; 140	1030 / 0 / 0 / 0 / 1100; 120
Nd	1100 / 100/ 0 / 100 / 1100 ; 30	1200 / 150 / 0 / 70 / 1150; 20
U	1000 / 0 / 0 / 0/ 1000 ; 40	1030 / 0 / 0 / 0 / 0 / 1100; 20

Results and Discussion

From the imaging studies involving MCP-PS, it was observed that the dispersions for all the elements were closely matching with the simulated values. For example the dispersions obtained for Sr isotopes before and after the application of DCQ potentials of ±120 volts (Fig. 2) are almost same as the simulated values of 6.9 mm and 8 mm respectively. Similarly the VDZO parameters were verified for Nd taking their images on MCP-PS.

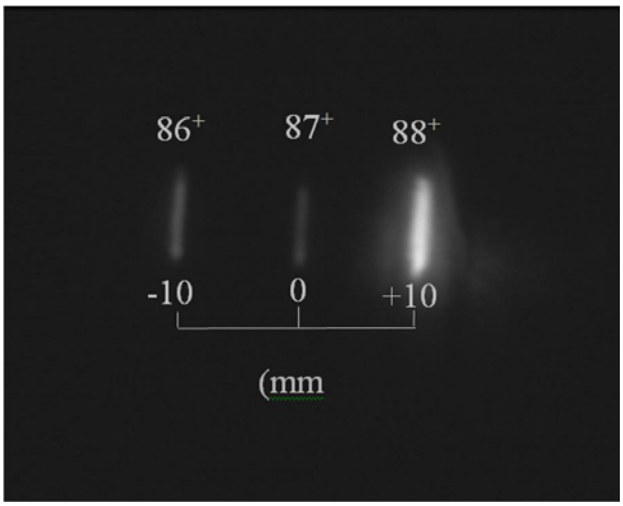

Fig. 2: Images of Sr isotopes on MCP

The peak shapes (for ^{88}Sr isotope) without DCQ potentials (but using deflection optics) were sequentially studied on all the collectors by suitably varying magnetic field. A peak flatness of ~3000 ppm of mass and a beam width of 0.8 mm was observed on each of the collectors. The isotopic ratio measurement of Sr, corresponding to masses 86, 87 and 88, on collectors LM2, C and HM2, were carried out at a DCQ potential of ± 120 V. This resulted in an increase in beam width to 1 mm and a decrease in peak flatness to 2500 ppm which is in full agreement with computer simulations. Fig. 3 shows the simultaneous peaks of strontium isotopes on LM2, C and HM2 collectors indicating ability of VDZO in matching the peaks. Similarly, the peak matching for Nd and U isotopes was also carried out.

The results for isotopic ratio measurement of Sr on conventional and the VDZO setup are tabulated in Table 2. It is seen that internal precision is nearly same in both the systems (conventional and VDZO) but the external precision (8 ppm) is much better with VDZO as compared to that obtained with conventional setup (22 ppm). The accuracies in case of conventional and VDZO systems were found to be 50 ppm and 10 ppm respectively for a true value of 0.710244.

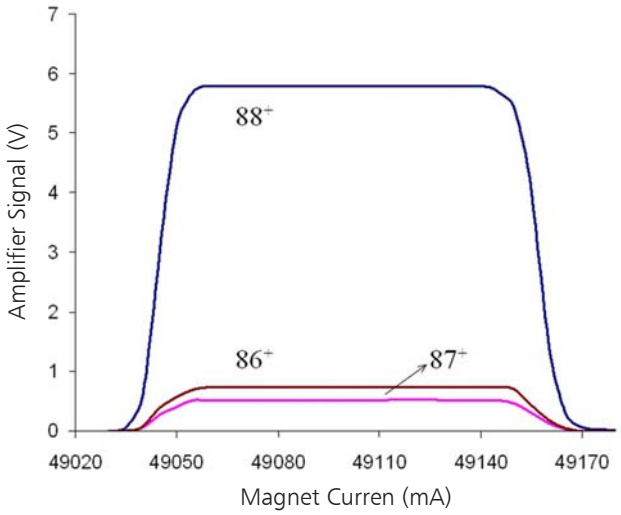

Fig. 3: Peak shape for Sr isotopes (86, 87, 88)

Table 2: Comparison of zoom optics with conventional collector setup for isotopic ratio measurement of standard Sr sample (SRM 987). Average 87/86 ratio with relative standard error (internal precision; in parentheses)# has been given for each sample.

Sample Number	Ratio ($^{87}Sr/^{86}Sr$)	
	On conventional setup (without zoom optics)	On setup with zoom optics
1.	0.710194 (6)	0.710246 (4)
2.	0.710210 (4)	0.710241 (8)
3.	0.710219 (4)	0.710239 (6)
4.	0.710199 (4)	0.710230 (7)
5.	0.710198 (4)	0.710242 (7)
6.	0.710239 (4)	0.710231 (8)
7.	0.710190 (5)	0.710234 (5)
8.	0.710222 (4)	0.710241 (8)
9.	0.710190 (4)	0.710230 (6)
10.	0.710220 (5)	0.710233 (5)
Average Ratio	**0.710208**	**0.710237**
RSD (external precision)	**23 ppm**	**8 ppm**

(# the value in parenthesis is the variation in last significant digit of the ratio value)

Conclusions

A new Faraday collector system (with five cups) for thermal ionization mass spectrometer has been developed based on variable dispersion zoom optics. The system enables fixed collector cups with wider apertures that facilitate analysis of different elements with a simple adjustment of suitable potentials to deflection optics rather than the mechanical movement of collectors. Further, wider collectors help in improvement of peak flatness from 500 ppm to 3000 ppm for Sr^{88}. The system design was optimized for analysis of U, Sr and Nd isotopic ratio analysis by simulation. The system enables improvement in both precision and accuracy of analysis. This has been demonstrated by analysis of $^{87}Sr/^{86}Sr$ ratio where precision and accuracy have been improved from 22 ppm to 8 ppm and 25 ppm to 10 ppm respectively.

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