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Improved Faraday collector for magnetic sector mass spectrometers

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ABSTRACT

Faraday collectors are used in isotopic ratio mass spectrometers for measurement of ion beam intensities. Ions striking the collector surface result in secondary electron emission that constitutes an error current. Typical collectors use electrical suppressors for minimizing current due to secondary electrons. However, due to mechanical errors in the placement of electrical suppressors, collection efficiency may vary for different collectors. In present study, different techniques for reducing secondary electron contribution have been investigated. These are: (a) use of magnetic field (instead of electric field) for secondary electron suppression, (b) graphite coating to reduce secondary electron emission and (c) inclination of collector to 45° with respect to ion beam. Studies have resulted in a mechanically simpler design and improved performance that has been demonstrated by measurement of $^{87}Sr/^{86}Sr$ isotopic ratio.

1. Introduction

We have earlier reported thermal ionization mass spectrometers [1] with variable dispersion zoom optics and five fixed Faraday collectors. Fig. 1 shows schematic of a Faraday collector with electrical secondary electron suppressor (SES) that has been used by us. In the present study, we have investigated some alternate approaches for suppression of secondary electrons. These are: (a) use of magnetic field in place of electric field, (b) graphite coating of collector that has lower secondary electron yield and (c) inclination of end face of collector to 45° with respect to ion beam direction. As a result of these studies, collectors with reduced secondary electron emission and escape have been developed. These have additional advantage of mechanical simplicity as there is no need to precisely place miniature stainless steel frame used as electric field based secondary electron suppressor. Use of magnetic field also suppresses secondary ions (both positive and negative) emitted due to primary ion beam striking the main collector. This is in contrast to electrical SES (having negative potential) that enhances positive secondary ion contribution. Improved Faraday collectors have been characterized by measurement of $^{87}Sr/^{86}Sr$ isotopic ratio.

Many studies on improvement of Faraday collectors have been reported in the literature [2–20]. To reduce the effect of positive secondary ions, collectors with an additional suppressor at positive potential have been used [2]. However, it results in increased complexity of the collector cup assembly. For measurement of ion current in accelerators, weak magnetic field (10 gauss) has been used to suppress secondary electrons from Faraday collectors [8]. The field was generated using combination of curved permanent magnets placed alternately in terms of their magnetic polarity so that the field is normal to the incident ion beam. In this case size of the collector is not critical. However, due to large number of collectors, placed at small distances, this configuration is not viable in case of magnetic sector mass spectrometers. Therefore, we have used magnetic field in horizontal direction (along x axis), orthogonal to the direction of analyte ions (along y axis) by placing set of magnets on either sides of the multiple collector system as shown in Fig. 2.

Graphite is known to have lower secondary electron yield [4,5] compared to stainless steel used in conventional collectors. Therefore, solid carbon materials in tubular form [2] and solid graphite walls [3] have been used to reduce secondary emission. We show that a simple approach of coating the inner walls of the metal collector with graphite results in similar reduction of secondary electron emission. As secondary electrons are preferentially emitted normal to the surface, a surface inclined to ion beam should also reduce escape of secondary electrons, and the same has been investigated.

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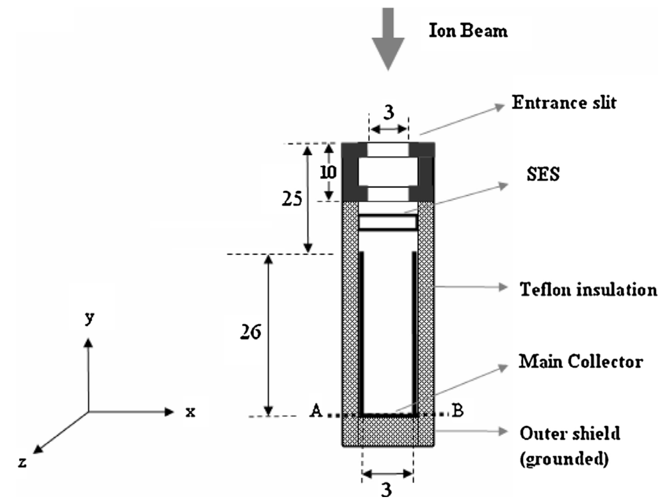

Fig. 1. Schematic diagram of the Faraday collectors (all dimensions are in mm, depth in *z* direction is 15 mm).

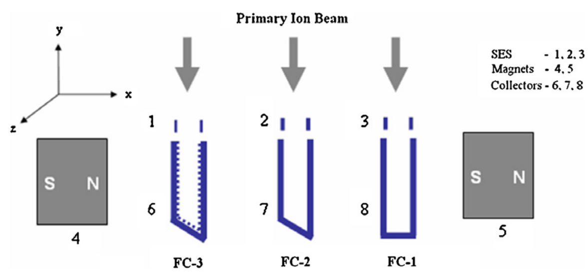

Fig. 2. Schematic diagram showing the experimental set up with collectors and magnets.

2. Theory and design aspects

Conventional Faraday collector consists of a stainless steel main collector, a secondary electron suppressor (SES) frame and a grounded entry aperture [1] as shown in Fig. 1. The primary ions, after entry through the aperture (3 mm × 15 mm), collide with the end surface (A-B in Fig. 1) of the main collector and transfer their charge that is measured by an electrometer amplifier. Energetic primary ions, on collision with the surface of collector, yield secondary electrons as well as smaller number of secondary and reflected ions. Three approaches to reduce escape of emitted secondary electrons and improve collector as mentioned in the introduction, are discussed in the following.

2.1. Coating with carbon

Secondary electron emission may be reduced by coating of inside surface of the Faraday cup by materials having low secondary electron emission. One of the important materials having low secondary electron emission is graphite [2–5] and in some of the earlier reports solid graphite has been used to make Faraday cups [3]. However, this makes the cup size large, as thicker walls of graphite need be used compared to that of stainless steel. Therefore, we have coated thin layer of graphite on stainless steel cups. The coating of graphite was carried out by dipping main collector in graphite slurry (20% by weight in alcohol medium) for a few seconds and drying it at room temperature in clean atmosphere. The graphite material used was 'ROCOL METAFLO 20' make, with particle size less than 10 μm and specific gravity 0.9 g/cc.

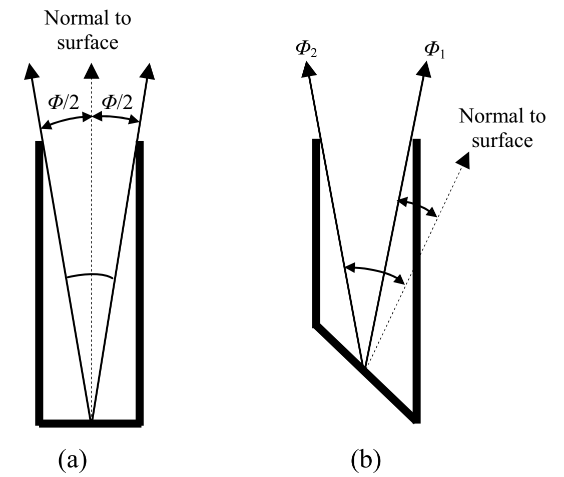

Fig. 3. Schematic showing the escape of electrons from Faraday collector with: a) normal surface and b) surface inclined at 45°.

2.2. Orientation of the end face of collector

Secondary electrons from a surface are preferentially emitted normal to the surface and emission probability at angle Φ (with normal to surface) varies as cos Φ [21]. Therefore, if end surface (A-B in Fig. 1) of the Faraday collector is inclined (instead of being normal to incident ions), most of the secondary electrons will strike wall of the collector and the probability of electron escape will be reduced. A very large inclination will also increase length of the collector and therefore, we have investigated possible reduction in secondary emission by using a collector with end surface inclined at 45° to the incident ion.

To estimate the effect of inclined surface on the escape of secondary electrons, calculations were carried out assuming cosine distribution [21] for the emission of electrons from the collector surface. The fraction (*f*) of secondary electrons escaping from the collector was calculated in both the cases i.e. normal surface and the inclined surface (at 45°). In case of normal surface, the electrons within angle $\pm\Phi/2$ with respect to normal to the surface were calculated (see Fig. 3). Here $\Phi = 6.9°$ is obtained using ratio of aperture width (*w*) to collector depth (*d*). In case of inclined surface, the ions within $\Phi_1 = 41.5°$ to $\Phi_2 = 47.5°$ as shown in Fig. 3 may escape. Using cos Φ distribution, ratio of probability of escape of electrons for normal and inclined incidence is 1.43.

2.3. Suppression of secondary electrons by magnetic field

The magnetic field applied in direction normal to the charged particles results in a circular path with radius dependent on mass of the particle. Secondary electrons have kinetic energy in 0.1–100 eV range and a small magnetic field of 100 gauss is seen to be sufficient to trap the electrons [20]. The trapped electrons also generate a negative space charge in the vicinity of the collector surface which further inhibits emission of secondary electrons. Use of magnetic field for suppression of secondary electrons also has advantage of reducing escape probability of both positive and negative secondary ions. It may be noted that, the weak magnetic field does not have significant effect on the path of the analyte ions having much higher energies (5–10 keV) and higher masses (masses Li to U) as compared to electrons.

Computer simulations were carried out using Simion 7.0 software [22] to determine effect of magnetic field on secondary electrons emitted from conventional collector as well as collector with end surface inclined at 45°. Initially, to see the effect of electric potential on escape of secondary electrons, a group of