Introduction

The ion source with reflectron structure was invented by Boumsellek and Chutjian (1) with the main propose to ionize electronegative substances by electron attachment. The formed ions were extracted by fields applied normal to the electron beam initial direction. Already by this procedure, the ion source was condemned to a pulsed operation as the attachment happens at very low electron velocities, strongly perturbed even by low extracting fields.

Most often reflectrons are working with homogeneous electrostatic fields, also inhomogeneous electric fields being incorporated in reflectrons designed by computer simulations (2). The homogeneous fields have no other than longitudinal focusing properties, those with inhomogeneous fields having largely unknown focusing properties protected by patents.

Below we describe a double focusing source reflectron assembly. The time focusing (longitudinal ion packet focusing) is obtained simultaneously with lateral focusing by capitalizing the properties of the cylindrical electrostatic fields.

Geometry

The double focusing time of flight mass analyzer is assembled from five cylindrical electrodes with a common axis. The ion source part consists of three electrodes: an external electrode, the grid $G_3$, another, grounded, $G_1$, of radius $r_1$, and an intermediate one, $G_2$, of radius $r_2$ (fig 1). The filament is located outside the above cylinders in front of the grid $G_3$. The reflectron, itself, is composed of an entry grid $G_0$, grounded electrode of radius $r_0$, and a high voltage electrode of radius $r_4$. To keep the electric field distribution as close as possible to the ideal, auxiliary electrodes must be inserted between the above two, fed by appropriate potentials through a voltage divider.

Fig 1. Definition of main geometric parameters of the double focusing reflectron
For the experimental model the following geometric parameters were selected: \( r_1 = 10\,\text{mm} \), \( r_2 = 20\,\text{mm} \), \( r_3 = 30\,\text{mm} \), \( r_0 = 600\,\text{mm} \), \( r_4 = 1000\,\text{mm} \). The source reflectron assembly was created by installing the components on a common base plate. This assembly is slid inside the flight tube pumped by a turbomolecular pump. The sample is admitted to the ion source by a capillary tube.

**Basic principle**

The double focusing ion source-reflectron assembly is intended mainly to handle ions formed from electronegative substances. The ions are created between the grids \( G_3 \) and \( G_2 \). The electrons are accelerated from the filament \( F \) towards the grid \( G_1 \) and retarded between \( G_1 \) and \( G_2 \). The potential of \( G_2 \), during the ionization time lapse, must be so selected that electrons be stopped at some distance from \( G_2 \). The negative ions are produced by electron attachment on the electron trajectory part of almost vanishing velocity. The negative ions are extracted from the region of their formation next, by lowering suddenly, during some nanoseconds, the potential applied to \( G_3 \).

During the time lapse of the negative ion production, the ions formed earlier migrate towards \( G_3 \) and are widening the extraction region. By lowering the \( G_3 \) potential the electron emission from \( F \) is suppressed.

The potentials of \( G_1 \) and \( G_2 \) must be applied according to the double focusing conditions i.e. the extracted ions must be focused longitudinally on the axis of cylinders while they are coming there from different points of the cylindrical extraction region, the electric forces acting on them being all directed radially towards the common axis.

From the axis the ions are flying to the reflectron grid. They are returned by the decelerating field created between \( G_0 \) and \( G_4 \). The potential on \( G_4 \) is selected again to ensure double focusing for the ions returned to the system’s common axis. Detection is to be achieved by multichannel plates slightly shifted with respect to the common system axis and by a small incidence angle at the ion packet arrival to the reflectron grid. The effect of the oblique incidence on resolution was reported in ref 3. The detection could be performed also on a collar type detector, probably with considerable loss of sensitivity as the ion packet closely concentrates around the packet axis.

The time of flight mass analyzer assembly can be operated also for positive ion double focusing. Besides the obvious electrode polarity inversion, the ionization process happens by electron bombardment. The ionization efficiency curve starts from a minimal electron energy, attains a maximum depending on the involved sample substance, then declines. The electron accelerating potentials should be so selected on \( G_2 \) and \( G_3 \) to create a so thin region as possible where the ion formation efficiency is high. For positive ions, the extraction region is also extended by the drift of the earlier formed ions, but their motion sense is directed now towards \( G_2 \).
DOUBLE FOCUSING REFLECTRON

Conditions of double focusing

The ions are formed inside the space between the cylindrical surface of \( r_m + d \) and \( r_m \) radii, \( r_m \) being a cylinder located between \( r_1 \) and \( r_2 \). To obtain an ion packet of high density at the system common axis, the formed ions must be focused both longitudinally (in time) and laterally (normally to their direction of motion). The flight time (space focusing) condition for two cylindrical field ion sources were derived. The motion equation for the radial direction was obtained from the Lagrangean. Integrated twice this gave the flight time between \( G_3 \) and \( G_2 \), \( G_2 \) and \( G_1 \). The flight time over the field free space of \( r_1 \) length (till the system axis) was added to obtain the total flight time from the ion formation to the source focusing point. Space focusing in time is obtained by developing the total flight time in series with respect to \( d \), and cancelling the first term of the development. This gives the double focusing condition as the lateral focusing condition is implicitly satisfied by the source geometry. So the double focusing condition for the ion source is:

\[
2p^3 \exp(p^2) p^{1/2} \int_0^p \exp(-x^2) dx + q^2 \exp(-q^2) + p^{1/2} \left\{ 2q^3 \exp[q^2(p - 1)] \right\}
\]

Here the following symbols were used:

\( p = V_m/V_2 \), \( p_2 = \ln(r_m/r_2) \), \( q_2 = \ln(r_2/r_3) \), \( V_m \) and \( V_2 \) being the respective potentials.

The ions leaving the source focus must be refocused in the same point (with the detector shift already discussed). They fly freely the distance \( r_0 \) before the reflectron and from \( r_0 \) to the return point at \( r_{mr} \). This flight time must be doubled as the total flight time is double that on the decelerating portion. A similar treatment as for the source but simpler, as only one nonvanishing potential is involved give for \( r_{mr} = 1.339r_0 \).

Resolution

The time mass resolution of the double focusing assembly is roughly given by the ratio of the total flight time from the ion source focus, back to this point and twice the ion packet length at its arrival to the detector. This flight time \( T_f \) is given by:

\[
T_f = r_0 \frac{2k \exp(k^2)}{\int_0^k \exp(-x^2) dx + 1/2} \nu, \text{ with } k = \ln(r_{mr}/r_0), \text{ and } \nu, \text{ the reference ion velocity}
\]

The packet length results from the extraction region depth inside the source and the turn around time \( t_v \) of the ions boon with some initial velocity originating in the molecular motion.
Thus the resolution, $R$, is given by the formula:

$$R = \frac{T_{\beta}}{\left[2\left(A_{\beta} \delta^2 + t_{ar}\right)\right]}$$

with $A_{\beta}$ the aberration coefficient, $\delta$ the initial energy spread.

For the double focusing condition satisfied the above quantities become:

$$T_{fr}=3.424r/v_r, \quad A\delta=0.75r/v_r$$

Resolutions of the order of hundred should be obtained at high sensitivity levels.

**Experimental model and preliminary results**

The ion source is shown on fig 2. The cylindrical reflectron and the electronic units are presented in fig 3 and 4 respectively. A view of the flight tube and vacuum system can be seen on fig 5. The ion source testing on residual gas at 1.2×10⁻⁵ torr, for $V_{G3}=1500\,\text{V}$, 100µA electron emission, produced in continuous regime 2.6nA of positive ions. With the ion source pulsed at 500Hz, with 9µs pulses the ion current on the final detector, ion packets returned by the reflectron, was of 4×10⁻¹⁴A.
Conclusions and expected developments

The double focusing time of flight mass analyzer assembly is a well souhaited mass spectrometer especially for electronegative substances.

Its potentially very high sensitivity results from the lateral focusing action on the formed ion packets and the concentration of the ions in each packet from a large arc of the formation region. Next the tests of the assembly working in pulsed regime will follow to demonstrate entirely the theoretically predicted properties.

References