

DOUBLE FOCUSING REFLECTRON

D.Ioanoviciu, C.Cuna, V.Cosma, N.Lupsa, V.Mirel, I.Albert,
E.Szilagyi

National Institute for R & D of Isotopic and Molecular
Technologies 71-103 Donath Str., P.O.Box 700 RO-
400293 Cluj-Napoca 5 ROMANIA

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

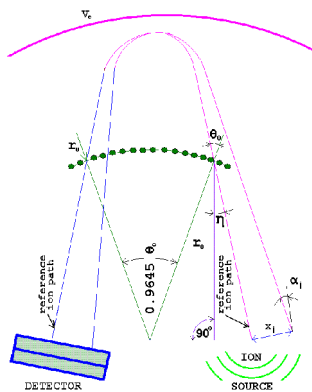


Fig. 1

Fig 1. Definition of main geometric parameters of the double focusing reflectron

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 of radius r_3 , another, grounded, G_1 , of radius r_1 , and an intermediate one, G_2 , of r_2 radius (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.

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_3 and retarded between G_3 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_3 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 .

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_3 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 source 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 :

$$2\rho[2p^3 \exp(p^2)\rho^{1/2}/(\rho-1)^{3/2} \int_0^p \exp(-x^2)dx + q^2 \exp(-q^2) + \rho^{1/2} \{2q^3 \exp[q^2(\rho-1)] \int_{q(\rho-1)^{1/2}}^{q\rho^{1/2}} \exp(-x^2)dx + p^2/(\rho-1)^{3/2} - q^2/(\rho-1)^{1/2}\}] = 1$$

Here the following symbols were used:

$\rho = V_m/V_2$, $p_2 = \ln(r_m/r_2)$, $q_2 = \ln(r_2/r_3)$, 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_{ft} is given by:

$$T_{ft} = r_0 [2k \exp(k^2) \int_0^k \exp(-x^2)dx + 1/2] / v_r \text{ with } k_2 = \ln(r_{mr}/r_0), \text{ and } v_r \text{ the}$$

reference ion velocity

The packet length results from the extraction region depth inside the source and the turn around time t_{ar} of the ions boon with some initial velocity originating in the molecular motion.

Thus the resolution, R, is given by the formula:

$$R = T_{ft} / [2(A_{\delta_2} \delta^2 + t_{ar})]$$

with A_{δ} the aberration coefficient, δ the initial energy spread.

For the double focusing condition satisfied the above quantities become:

$$T_{ft} = 3.424 r_0 / v_r \quad A_{\delta} = 0.75 r_0 / v_r$$

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 $V_{G3} = 1500V$, $100 \mu A$ electron emission, produced in continuous regime $2.6 nA$ of positive ions. With the ion source pulsed at $500 Hz$, with $9 \mu s$ pulses the ion current on the final detector, ion packets returned by the reflectron, was of $4 \times 10^{-14} A$.

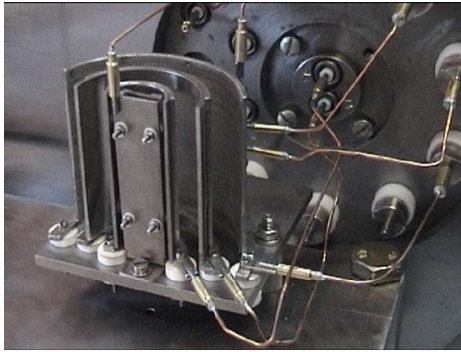


Fig 2. Ion source of the experimental model

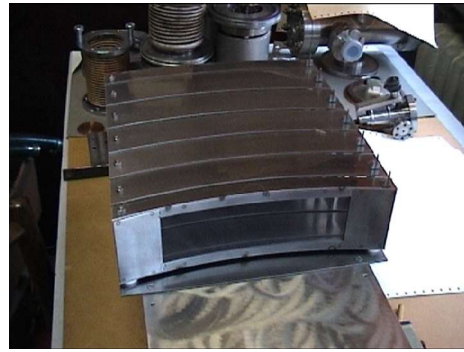


Fig 3. The cylindrical reflectron of the experimental model



Fig 4. Electronic units of the experimental model



Fig 5. General view of the flight tube and vacuum system

Conclusions and expected developments

The double focusing time of flight mass analyzer assembly is a well souhated 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

1. S. Boumsellek, A. Chutjian, Rev.Sci.Instrum.64,1135(1993)
2. R. I. Cotter Ch II in Time of Flight Mass Spectrometry American Chemical Society, Washington DC 1994
3. D. Ioanoviciu et al J. Mass Spectrom. In press