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Calculations of the Stability of an Ion Current in an Ion Source with an Effusion Molecular Beam Crossed by an Electron Beam

Ocena stabilności prądu jonowego w źródle jonów z efuzyjną wiązką molekularną przecinaną wiązką elektronową

INTRODUCTION

Molecular beams play a significant role in many fields of physics, particularly in ion sources where ionization is produced by an electron or photon beams [1–16]. The molecular beam is usually collimated by a slot located at certain distance from the effusion hole. Such a system of forming the molecular beam ensures a well defined cross-section and homogeneity but, on the other hand, reduces significantly its intensity [11]. The other method consists of ionizing the molecular beam just at the effusion hole. It is necessary to remember, however, that cross-section outline of such a beam is difficult to determine and that a large gradient of the density is involved in it, both in longitudinal and transverse directions. Moreover, if the electron beam cross-section is comparable with the case cross-section of the molecular beam, the inevitable heterogeneity in the area of the electron beam will become significant.

The authors applied a molecular beam crossed by an electron beam for investigation of ionization processes in gases and sometimes observed not a very good stability of the intensity of the ion current while the other parameters described of the work of the ion source and parameters of a gas inlet, a vacuum, an analysing and ion detection systems of mass spectrometer, were of a very good stability.

As is well known, the number N_i, of ions produced by an electron impact in a gas unit volume, during a unit time is

$$N_i = \sigma_i n_e v_e n \tag{1}$$

where σ_i is an ionization cross-section, n_e is a density of electrons in an electron beam, v_e is a velocity of electrons, n is a number of molecules in unit volume. The intensity, I_i, of the ion current is

$$I_i = \sigma_i n I_e L \tag{2}$$

where I_e is the intensity of the electron current and L is the length of an electron beam.

As it seems from Eqns. 1 and 2 for established values of the electron energy, E_e, ($v_e = (2E_e/m_e)^{1/2}$), m_e is the mass of the electron), the intensity, I_e, of the electron current, the concentration, n, of molecules (established gas flow by an effusion capillary) and the length, L, of the electron beam (L is determined by a construction of an ion source), the intensity, I_i, of the ion current should have an established value, too. For ion sources with a homogeneous gas concentration n in the whole area of an ionization chamber and for an established value of the density, n_e, of electrons the distribution of this density across and along an electron beam

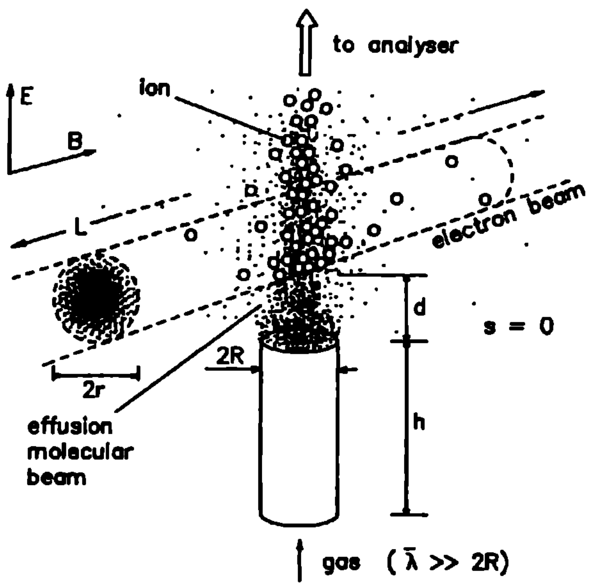

Fig. 1. Intersection of non-homogeneous effusion molecular and electron beams in the open ion source of a cycloidal mass spectrometer
Ryc. 1. Skrzyżowanie niejednorodnej efuzyjnej wiązki molekularnej z wiązką elektronową w otwartym źródle jonów cykloidalnego spektrometru mas

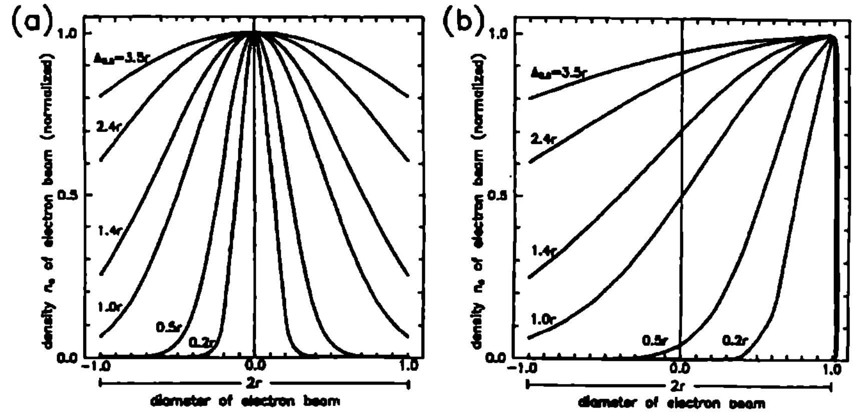

Fig. 2. The Gaussian density distribution (n_e) of electrons in the electron beam. The half-width value, $\Delta_{0.5}$, of the density distribution is: 0.2r, 0.5r, 1r, 1.4r, 2.4r and 3.5r. (a) The density distributions (n_e), are symmetrical. (b) The maximum value of this density distributions is extremally shifted across an electron beam

Ryc. 2. Gaussowski rozkład gęstości (n_e) elektronów w wiązce elektronowej. Wartości szerokości połówkowej, $\Delta_{0,5}$, rozkładów gęstości wynoszą: 0,2r, 0,5r, 1r, 1,4r, 2,4r i 3,5r. (a) Rozkłady gęstości (n_e) są symetryczne. (b) Maksymalne wartości rozkładów gęstości są ekstremalnie przesunięte w poprzek wiązki elektronowej

is not important for the stabilization of the intensity of the ion current. For ion sources with a non-homogeneous effusion molecular beam crossed by an electron beam this distribution of the density (n_e), of electrons can have a very important role for the stabilization of the ion current.

Figure 1 shows the intersection of non-homogeneous effusion molecular and electron beams in the open ion source of a cycloidal mass spectrometer. The electron beam is in the central position ($s = 0$, s — displacement of the electron beam) with regard to the effusion capillary axis and the density distribution (n_e) of electrons is the same along the electron beam (eventual changes of this density, n_e, as a result of charge space effects are not considered). For reason that the intersection occurs where the molecular beam intensity is very high, it is evident that the intensity of the generated ions is greatly affected by the position of the electron beam with respect to the capillary outlet. For the established position of the electron beam (see Figs 1 and 3) the intensity of generated ions is affected by the density distribution (n_e) of electrons in the electron beam. It is clear that for the same average density (n_e) of electrons in the electron beam its distribution across this beam can be different and it can cause the changes of the intensity of the ion current. Therefore we can measure the

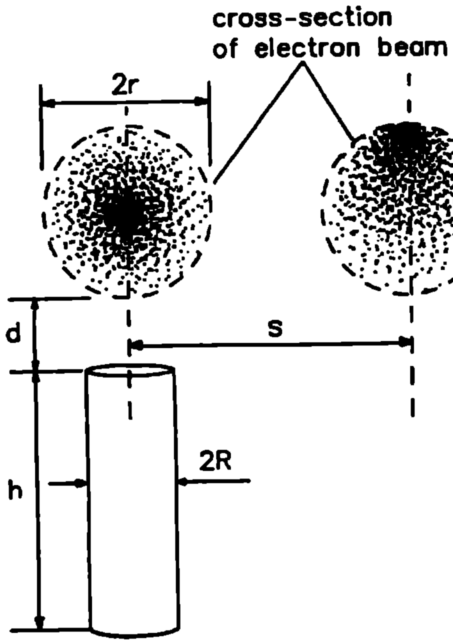

Fig. 3. The position of a non-homogeneous electron beam with regard to the effusion capillary axis

Ryc. 3. Pozycja niejednorodnej wiązki elektronowej w stosunku do osi kapilary efuzyjnej

established value of the intensity of the electron current and at the same time we can observe changes of the intensity of the ion current adequately to changes of the density distribution (n_e) of electrons in the electron beam.

We suppose that changes of the density distribution (n_e) of the electron beam can be a result of changes of the filaments position according to the forming (focusing) electrode system of this beam as well as of changes of the temperature distribution along this filament during the work of the ion source [20].

The changes of the density distribution (n_e) of electrons can have a different frequency from seconds to hours or more. In every case it can give big changes of the intensity of the ion current, which is not highly favourable in investigations of ionization processes in gases. The observation of changes of the density distribution (n_e) of electrons in the real electron beam and their influence on the stability of the ion current is very difficult. Therefore, in this work we present computer calculations of the influence of these changes of the density (n_e), on the stability of the intensity of the ion current in the ion source with the electron beam crossed by a non--homogeneous effusion molecular beam.

CALCULATION PROCEDURE AND RESULTS

In this work we have applied calculation procedure described previously [17, 20]. In this procedure we divide an electron beam on many elementary elements and then we calculate a number of molecules effusing from an effusion cylindrical capillary in each of these elements. The distribution of the number of molecules effusing from this capillary is described by an analytical formula which ensures geometrical parameters (h — lenght, R — radius) of this capillary [18, 19]. Therefore we can calculate a concentration, n, of effusing molecules in any area of an electron beam or an average concentration of molecules in a whole electron beam. Previously this procedure was successfully examined by comparison calculations and experimental results obtained in the ion source (intersection of the molecular beam with the electron beam) of the cycloidal mass spectrometer [17].

Using this calculation procedure we can examine the influence of the inhomogeneity of the electron beam on the stability of the ion current in the ion source with an effusion molecular beam as a function of geometrical parameters of the effusion capillary (h and R are the length and radius of the capillary, respectively), and radius, r, of the electron beam and the position of the electron beam with respect to this capillary (d is the distance between the capillary outlet and the electron beam, s is the displacement of the electron beam with regard to the capillary axis) (see Figs 1 and 3). The parameter, L, (length of the electron beam) has, in our calculations, an established value L = 20R, because the number of molecules effusing in the electron beam reaches its maximum at aproximately this length for different lengths h of an effusion capillary [17]. The unit of the geometrical parameters (h, r, d, s, L) of ionization system is the radius, R, of effusion capillary.

In presented calculations the inhomogeneity of an electron beam is described by the Gaussian density distribution (n_e) of electrons across this beam. Figure 2(a) shows these distributions along diameter, 2r, of an electron beam for several values of half-width ($\Delta_{0.5}$) of this distribution ($\Delta_{0.5}$ = 0.2r, 0.5r, 1r, 1.4r, 2.4r and 3.5r). Figure 2(b) shows situations when a maximum value of the density distribution (n_e) is extremally shifted across the electron beam.

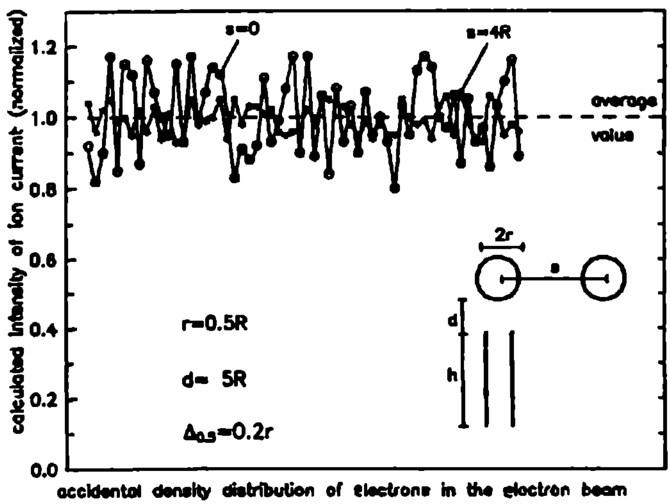

Fig. 4. The calculated intensity of the ion current (marked only the fragment of changes of the ion current intensity, i.e. 60 successive points out of 1,000 calculated points) for accidental positions (randomly determined by a computer) of the maximum value of the density distribution (n_e) of electrons in the electrons beam (see Figs 1, 2 and 3) for two displacements, s, (s = OR and s = 4R). The electron beam with the radius r = 0.5R is in the central position in the distance d = 5R from the capillary outlet. The half-width value, $\Delta_{0,5}$, of the density distribution (n_e) is 0.2r

Ryc. 4. Obliczone natężenie prądu jonowego (zaznaczono tylko fragment zmian natężenia prądu jonowego, tj. 60 kolejnych punktów z 1000 obliczonych) dla przypadkowych pozycji (losowo wybranych przez komputer) maksymalnej wartości rozkładu gęstości (n_e) elektronów w wiązce elektronowej (patrz Ryc. 1, 2 i 3) i dwu przesunięć s (s = 0R i s = 4R). Wiązka elektronowa o promieniu r = 0,5R jest położona centralnie, w odległości d = 5R od wylotu kapilary. Wartość szerokości połówkowej $\Delta_{0,5}$ rozkładu gęstości wynosi 0,2r

Figure 3 shows a non-homogeneous electron beam for displacements, s, (Fig. 3a $s = 0$ — central position; Fig. 3b $s > 0$) of this beam with regard to the capillary axis. The displacements of the maximum value of their density distribution (n_e) are different. In the presented calculations we have also examined displacements which differ from these presented in the Fig. 3. Their random values (1,000 different values in the whole cross-section of an electron beam) were determined by a computer.

For example, Figure 4 shows the calculated intensities of the ion current for accidental positions of the maximum value of the density distribution (n_e) in the whole cross-section of an electron beam (there is marked only a fragment of changes of the ion current intensity, i.e. 60 successive points out of 1,000 calculated points). In these cases the molecular beam is generated by the capillary of the length $h = 70$R and for two displacements s ($s = 0$ and $s = 4$R) with regard to the capillary axis. The electron beam with radius $r = 0.5$R is in distance $d = 5$R from the capillary outlet. The half-width value of the Gaussian density distribution (n_e), $\Delta_{0.5} = 0.3$r.

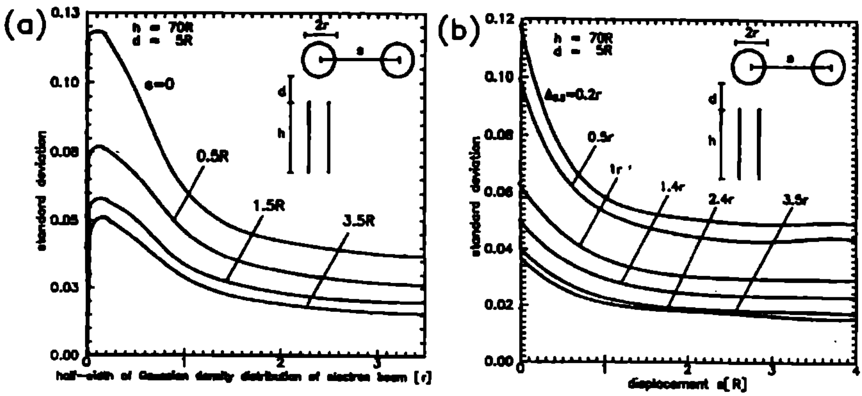

Fig. 5. (a) Stability (standard deviation) of the intensity of the ion current as a function ot the half-width value, $\Delta_{0.5}$, of the Gaussian density distribution (n_e) of an electron beam for several displacements, s, of this beam ($s = 0$, 0.5R, 1.5R and 3.5R). The electron beam is in the distance $d = 5$R and the molecular beam is generated by the capillary of the length $h = 70$R. (b) The standard deviation as a function of the displacement, s, of the electron beam. The other parameters as in the Fig. 5(a)

Ryc. 5. (a) Stabilność (odchylenie standardowe) natężenia prądu jonowego w funkcji szerokości połówkowej $\Delta_{0,5}$ Gaussowskiego rozkładu (n_e) gęstości wiązki elektronowej, dla kilku przesunięć s tej wiązki ($s = 0$, 0,5R, 1,5R i 3,5R). Wiązka elektronowa znajduje się w odległości $d = 5$R, a wiązka molekularna jest generowana przez kapilarę o długości $h = 70$R. (b) Odchylenie standardowe w funkcji przesunięcia s wiązki elektronowej. Pozostałe parametry jak na Ryc. 5(a)

For the beter comparison of the presented results the average values (each of 1,000 calculated values) of the intensity of the ion current are normalized to 1. From these results (see Fig. 4, for example) we can calculate the standard deviation of the intensity of the ion current.

Figure 5(a) shows the standard deviation of the calculated intensity of the ion current as a function of a half-width of the Gaussian density distribution (n_e) of the electron beam for several displacements, s, of this beam ($s = 0$R, 0.5R, 1.5R, 3.5R). In this case the effusion molecular beam is generated by the capillary of the length $h = 70$R and the electron beam with radius $r = 0.5$R is in the distance $d = 5$R from the capillary outlet. Fig. 5(b) shows the stability (standard deviation) of the intensity of the ion current as a function of the displacement, s, of the electron beam for several half-width value, $\Delta_{0.5}$, of the Gaussian density distribution (n_e) of an electron beam

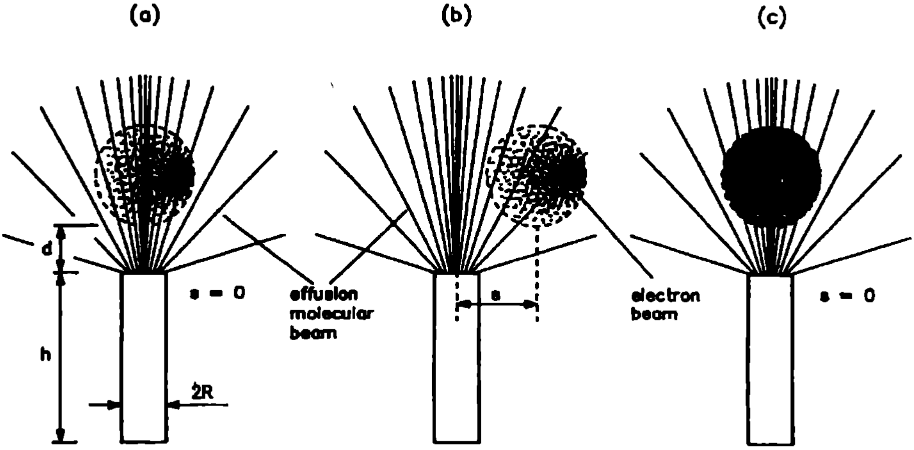

Fig. 6. The displacement, s, of an electron beam effect in the stabilization of the intensity of ion current in the ion source with an effusion molecular beam. (a) The non-homogeneous electron beam is in the central position with regard to the capillary axis ($s = 0$). (b) The non-homogeneous electron beam is shifted ($s > 0$). (c) The electron beam is homogeneous
Ryc. 6. Efekt przesunięcia s wiązki elektronowej podczas stabilizacji natężenia prądu jonowego w źródle jonów z efuzyjną wiązką molekularną. (a) niejednorodna wiązka elektronowa jest położona centralnie względem osi kapilary ($s = 0$). (b) niejednorodna wiązka elektronowa jest przesunięta ($s > 0$). (c) jednorodna wiązka elektronowa

($\Delta_{0.5}$ = 0.2r, 0.5r, 1r, 1.4r, 2.4r and 3.5r). Other parameters are the same as in Fig. 5(a). For the same displacement (s) of the electron beam the standard deviation decreases with the increasing half-width value of the Gaussian density distribution (n_e) of the electron beam (the heterogeneity of the electron beam increases). For the established value of the half-width of the density distribution (n_e) the standard deviation decreases with the increase of the displacement, s, of the electron beam and reaches its minimum at the displacement about s = 3R and remains constant. It results from this, that for bigger displacements (s) the inhomogeneity of the molecular beam is minimal. This effect is also explained in the Fig. 6.

CONCLUSION

In this work the influence of the inhomogeneity of an electron beam as well as geometrical parameters of an ionization system on the stability of an ion current in the ion source with an effusion molecular beam is presented. In the presented calculations we assume that the density distribution (n_e) of electrons in the electron beam is the same along this beam (eventual changes of this density as a result of charge space effects are not considered). For these investigations a computer method of calculating is applied. From the results presented it seems that the density distribution (n_e) of electrons in the electron beam has the significant role on the stability of an ion current in the ion source with an effusion molecular beam. The measure of this stability was the standard deviation of the calculated intensity of the ion current, for different density distributions (n_e) of electrons in the electron beam. As it seems from the presented results (Fig. 5) the stability of the ion current increases if the displacement s of the electron beam with regard to the capillary axis increases, too. Independent of the geometrical parameters of an ionization system the stability of the ion current increases for more homogeneous electron beams ($\Delta_{0.5} \to \infty$). The results presented as well as the calculation method can be applied in the construction of ion sources with the electron beam crossed by a non-homogeneous effusion molecular beam.

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STRESZCZENIE

Przedstawiono rezultaty komputerowych obliczeń wpływu niejednorodności wiązki elektronowej i niektórych geometrycznych parametrów układu jonizacyjnego na stabilność prądu jonowego w otwartym źródle jonów z niejednorodną efuzyjną wiązką molekularną cykloidalnego spektrometru mas.