UDK 537.533.34

ELECTROSTATIC ENERGY ANALYZER OF CHARGED PARTICLES ON THE BASIS OF A QUADRUPOLE-CYLINDRICAL FIELD IN THE "RING-AXIS" FOCUSING REGIME

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A study of corpuscular-optical parameters of the electrostatic energy analyzer scheme based on the quadrupole-cylindrical field which proposed earlier was conducted. The operation regime of the energy analyzer, in which the charged particles source locates on an inner cylinder and a detector locates on the symmetry axis ("ring-axis" focusing regime), was considered. Focusing properties of a quadrupole-cylindrical mirror were calculated. Instrumental function was received. Relative energy resolution and luminosity of the device were estimated.

Keywords: energy analyzer, electrostatic field, quadrupole-cylindrical mirror, corpuscular-optical parameters, angular focusing.

Introduction

Currently, there are many methods of electron spectroscopy for analyzing the solid surface. To satisfy the technological needs, new methods and devices are constantly being created. For the purpose of energy analysis of charged particle flows, electrostatic devices with the geometry of the following fields and their super positions were most often used: a spherical field, a cylindrical field, a hyperbolic field, a uniform field, etc. An important part of the experimental scheme is the energy analyzer - a device that allows to determine a current density of charged particles with energies in the selected range from E to $E+\Delta E$.

A cylindrical mirror became the most widespread, becoming the basic element in most electron spectrometers. A cylindrical mirror has several advantages, such as high energy resolution, simplicity of design, etc. Operation of a cylindrical mirror is based on the focusing and dispersing action of the field in the space between two coaxial cylindrical electrodes on a charged particles beam. The theory and the possibility of practical application of a cylindrical mirror were studied in detail by a scientists group under the guidance of prof. V. Zashkvara [1].

One of ways to improve the operation of energy analysis tools is a modification the deflecting field by changing the shape of an outer electrode of a cylindrical mirror. A design of a quadrupole-cylindrical mirror, which has higher corpuscular-particle parameters compared with a classical cylindrical mirror, was proposed in [2].

The work [3] is devoted to a study of electrostatic quadrupole-cylindrical fields. Results of the calculation of the structure of electrostatic quadrupole-cylindrical fields were given. Equipotential portraits of quadrupole-cylindrical fields of various types were presented. The options for their use in corpuscular optics were discussed. The "ring-ring" focusing regime was previously investigated [4], when a ring source of charged particles and a ring detector are located near an inner cylindrical electrode. It was shown that the scheme mirror with A =- 0.01 has the best quality of focusing, the outer electrode of which has an increasing exponential profile with a small angle of inclination relative to a symmetry axis of a mirror.

In the present work, a study of corpuscular-optical parameters of the quadrupole-cylindrical mirror in the “ring-axis” focusing regime was carried out.

1. Numerical modeling of a quadrupole-cylindrical mirror

A quadrupole-cylindrical field is constructed on the basis of a superposition of a cylindrical field $\mu \ln r$ and an axially symmetrical cylindrical quadrupole:

$$U_q(r,\mathrm{z}) = U_0\left(\mu + z\right)\ln r \tag{1}$$

where μ is a coefficient specifying the weight contribution of a cylindrical field.

A quadrupole-cylindrical field (1) at the value $\mu = 1$ coincides with the well-known Wannberg field [5]. Wannberg proposed an electrostatic energy analyzer with a field close to a cylindrical one; the case of angular focusing of beams of various energies near the surface of an inner cylindrical electrode was considered. The focal surface in such an analyzer for the case of focusing on an inner cylindrical electrode has a shape that is close to cylindrical shape.

The potential of the Wannberg field in the coordinate system *r, z* is described by the following expression

$$U = \frac{V}{\ln \dfrac{r_1}{r_o}}\left(1 + Az\right)\ln \frac{r}{r_o} \tag{2}$$

where A is a small dimensionless parameter.
The presence of a small dimensionless parameter A gives an additional degree of freedom in choosing the desired distribution of an electrostatic field and expands ability to search for the most optimal analyzer scheme based on a quadrupole-cylindrical field.

A quadrupole-cylindrical mirror consists of two axially symmetrical coaxial electrodes. Inner cylindrical electrode with radius r_0 is grounded. Outer electrode under potential U creates field heterogeneity and has a curvilinear profile $r = r_o \exp\left[\dfrac{\ln\left(r_1/r_o\right)}{(1+Az)}\right]$. The difference from the classical cylindrical mirror is that the profile of an outer deflecting electrode is well approximated by a cone, a generator of which has a small angle of inclination relative to a symmetry axis of a mirror, equal to ~ 1.75 degrees.

In fig.1 shows the scheme of the energy analyzer at A = –0.01 and trajectories in it for case when a source of charged particles is the ring slit on an inner cylinder and a detector is located on a symmetry axis. According to the scheme, charged particles emitted from a real source input to the field through the entrance ring slit on an inner electrode, and under the action of the potential on the outer electrode are deflected back, and after they are recorded by a detector.

Numerical modeling of the energy analyzer was carried out by using the “Focus” program for modeling of corpuscular optics systems [6].

The relative energy of particles is E/U =1.3 E [eV] / U [V]=0.9. Initial entrance angles are $30° - 45°$. Position of a ring source (entrance ring slit) is x = 1.5 and y = 1.0. The distance of the ring source from its point image is equal to d = 6.31. The radius of an inner cylindrical electrode r_0 = 1. All sizes are expressed in arbitrary units. The scheme provides a “ring-axis” type second-order angular focusing regime.

Fig.2 shows differences of trajectories in a classical cylindrical mirror (a) and a quadrupole-cylindrical mirror (b). It can be seen that focusing quality of charged particles in a quadrupole-cylindrical mirror is better than in a cylindrical mirror.

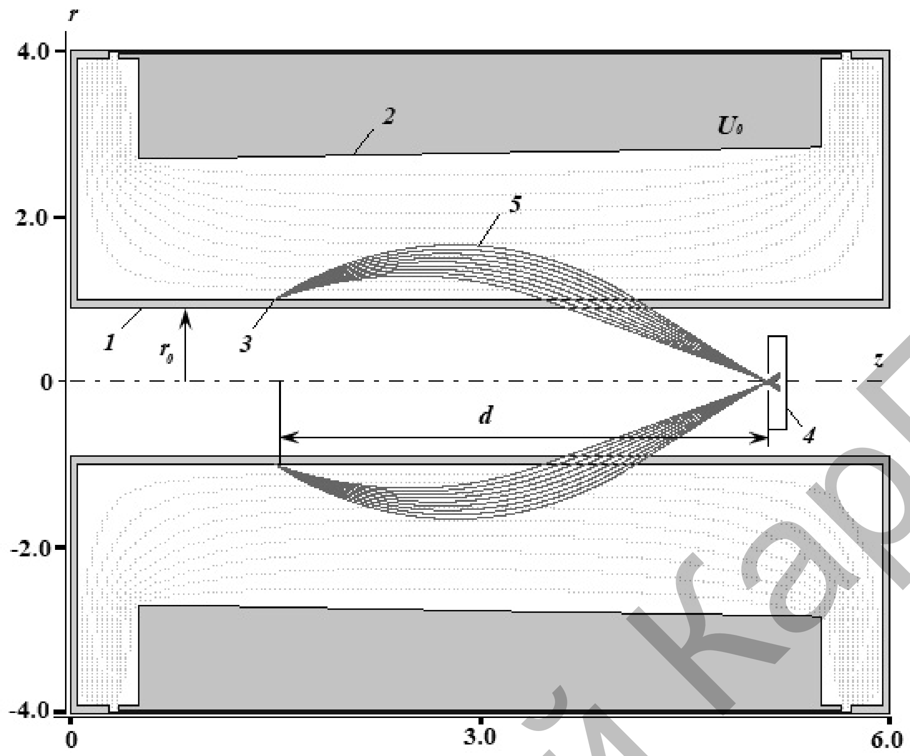

Fig.1. Trajectories of charged particles in the quadrupole-cylindrical mirror: 1 –an inner grounded cylindrical electrode, 2 – an outer deflecting electrode, 3 – a source of charged particles, 4 - a detector, 5 - trajectories of charged particles.

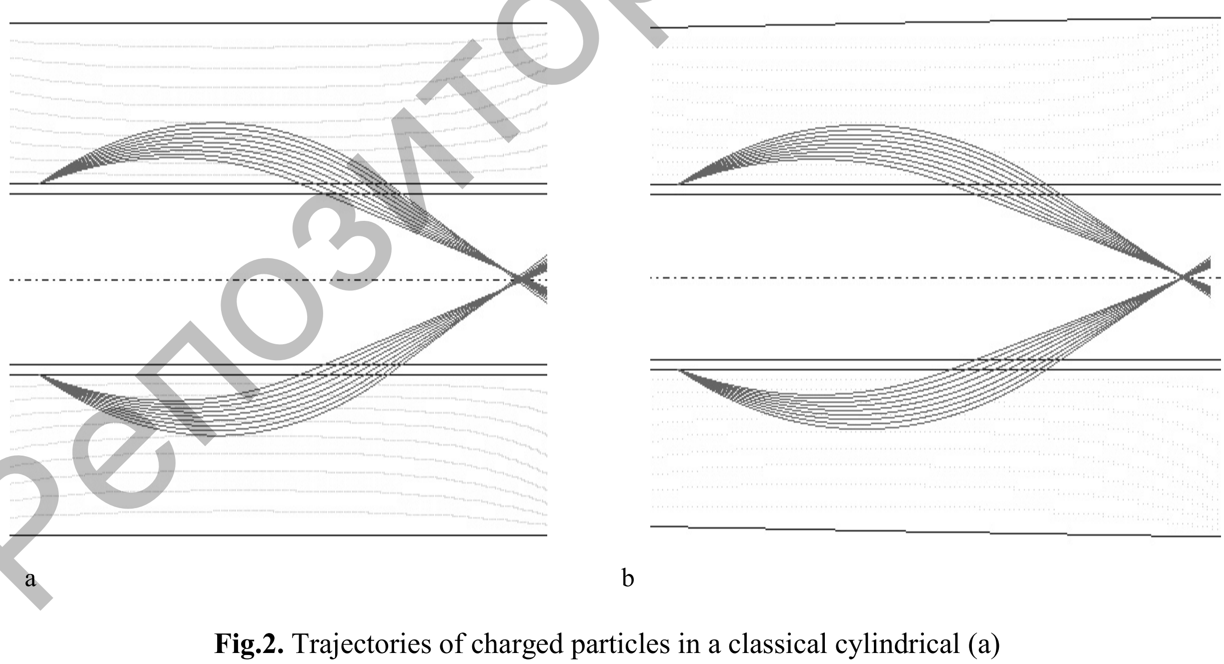

Fig.2. Trajectories of charged particles in a classical cylindrical (a) and a quadrupole-cylindrical mirror (b)

Fig.3 allows to compare the focusing qualities in a cylindrical field and a quadrupole-cylindrical field. It shows the dependence of a intersection point coordinate of a trajectory with symmetry axis z at exit from the analyzer on entrance angle α_0 of particles into the analyzer for second-order angular focusing regime.

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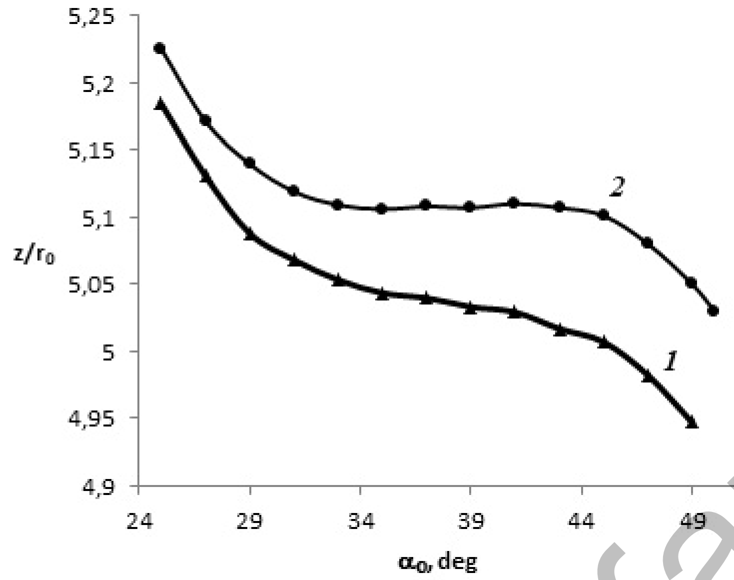

Fig.3. Intersection point coordinate of a charged particles trajectory with symmetry axis z depending on a entrance angle α_0 .

From Fig.3 it is seen that intersection point coordinate of a trajectory with symmetry axis z in the quadrupole-cylindrical mirror in entrance angles range $30° - 45°$ is more constant than in a cylindrical mirror. Thus, a optimal range of entrance angles of particles in a quadrupole-cylindrical field is an initial angles interval $30° - 45°$, which ensures a maximum luminosity Ω= 16% and the best focusing of the charged particles beams.

The Table 1 presents calculation results of the corpuscular-optical parameters of the energy analyzer on the basis of the quadrupole-cylindrical field at A = -0.01 in the "ring-axis" focusing regime.

Table 1. Corpuscular – optical parameters of the energy analyzer on the basis of the quadrupole-cylindrical field at A = -0.01

Focusing type	«ring-axis»
Focusing order	2
Center focusing angle	36.5^0
X coordinate of focusing	5.12
Y coordinate of focusing	0
Total length of the electron-optical scheme, $l = L/r_0$	6
Reflection parameter, P	1

Thus, trajectory analysis showed that the design of an energy analyzer based on a quadrupole-cylindrical field has a "ring-axis" type second-order angular focusing of near a central entrance angle of charged particles $36.5°$.

To calculate the instrumental function of the quadrupole-cylindrical energy analyzer, particles are launched from a ring source in an initial angles range $30° - 45°$ and initial energies range 0.888-0.912. Fig.4 shows the instrumental function of the energy analyzer based on a quadrupole-cylindrical field at A = -0.01 for the "ring-axis" type angular focusing regime.

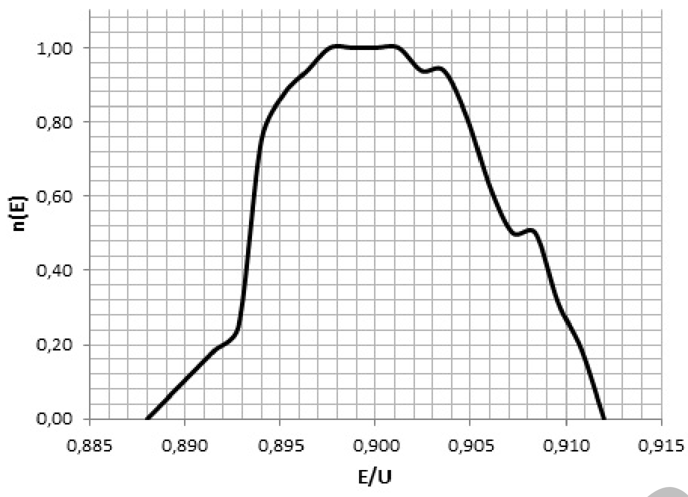

Fig.4. The instrumental function of a quadrupole-cylindrical energy analyzer in the "ring-axis" focusing regime

Relative energy resolution at the half-height of the instrument function of the energy analyzer with an output diaphragm radius of $0.04\, r_0$ is 1.5%.

Conclusion

A study of corpuscular-optical parameters of a quadrupole-cylindrical mirror was conducted. Second-order focusing conditions in a quadrupole-cylindrical field were found, when a ring source is imaged at a point on a symmetry axis ("ring-axis" focusing regime). It is shown that the quadrupole-cylindrical mirror provides a higher quality of focusing than a classical cylindrical mirror. The instrumental function of the energy analyzer is calculated. To ensure maximum luminosity, the entrance angles range of particles should be $30°$ to $45°$ (wherein luminosity Ω= 16%).

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Article accepted for publication 19.11.2018

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