Theoretical analysis of electro-optical characteristics of the modified three cylindrical mirror analyzer

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In this paper, theoretical electro-optical characteristics of a modified cylindrical mirror analyzer based on three coaxial cylindrical electrodes obtained with numerical calculations are presented. It was shown, for the first time, that the image of a point source of electrons located on the analyzer optical axis is in the form of a circle which does not depend on the entrance angle of electrons into the analyzer within the range of angles $\alpha = 30°-40°$. In particular, for the input angle $\alpha = 36°$ and dispersion $\Delta\alpha = \pm 3°$, the relative energy resolution is equal to 0.01% at the analyzer constant $K = 1.97$.

Keywords: cylindrical mirror analyzer, TCMA analyzer, Bashforth–Adams–Moulton method.

1. Introduction

The control of physicochemical properties of solid state surfaces in view of the various applications stimulates the dynamic development of surface analytical methods, in particular, methods of electron spectroscopy. In these methods the electron energy analyzers play the most important role. Therefore, during the development of the electron spectroscopic methods, new technical improvements of electron energy analyzer having the best analytical parameters are of great demand.

The most important parameters of the electron energy analyzers are: energy resolution, transmission coefficient, the input angle of electrons into the analyzer and the speed of spectra registration. Moreover, in some types of analyzers the acceptance angle also determines the sample–analyzer distance, which restricts a simultaneous use of different surface analytical methods to control the same surface area.

In the conventional cylindrical mirror analyzer (CMA) [1] the distance between the sample and analyzer is about 6–8 mm and remains the same also for the double pass cylindrical mirror analyzer (DPCMA), because the same conditions of the second order focusing have to be fulfilled [2, 3]. The relative energy resolution for both analyzers can be increased only at the cost of decreasing the entrance slit in the inner cylinder and transmission coefficient, at a constant sample–analyzer distance.

In order to improve the energy resolution of a conventional CMA several modifications were proposed. In paper [4], the results of theoretical analysis of a modified CMA analyzer were presented, for which the additional third cylindrical electrode with properly made slits was proposed between the external and internal cylinders of the conventional CMA analyzer. After such modification for the set transmission coefficient, the relative energy resolution (of the order of 0.1%) of the CMA was evidently better than that of the conventional one. However, the distance between the sample and the analyzer was taken in such a way that the entrance angle of electrons was about $\alpha = 40°$.

In another modification of a conventional CMA analyzer proposed by MENCHIKOV [5, 6], known as the three cylindrical mirror analyzer, three coaxial cylindrical electrodes were also used in a configuration shown in Fig. 1. In these papers, a perturbation theory analysis of the electro-optical properties of electron beam in such a system was carried out and the possibility of existence of the third order focusing conditions and relative energy resolution at the level of 0.01% was predicted.

In an earlier work [7], we presented the results of experimental investigations of the electro-optical characteristics of the electron energy analyzer (TCMA) designed and constructed on the basis of the theoretical prediction by MENCHIKOV [5, 6]. The analytical parameters obtained were very far from the theoretically predicted ones.

In this paper, we present the results of numerical calculations of electro-optical characteristics of the TCMA working under axis-ring focusing conditions.

2. Fundamentals

The TCMA consists of three coaxial metal cylinders, as shown in Fig. 1. It works in the regime of axis-ring focusing [6].

The sample and the central cylinder are grounded. The voltage applied between the outer and inner cylinders creates the electrostatic field which separates the electrons entering the analyzer.

The electrons emitted from the point source located on the analyzer axis, after having passed the four slits in the central cylinder, are focused on a circle of radius *r*

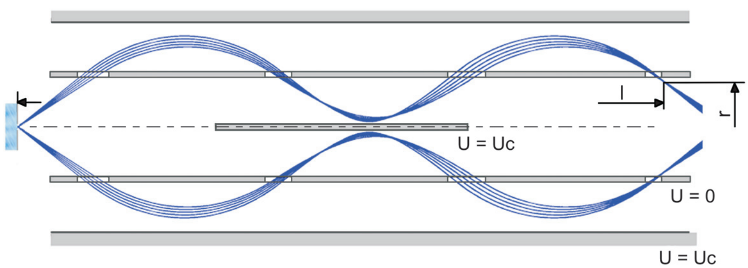

Fig. 1. A simplified diagram of the three cylindrical mirror analyzer (TCMA), working in axis-ring focusing mode, together with exemplary electron trajectories inside.

close to the central cylinder. The calculation of electron trajectories was based on the Bashforth–Adams–Moulton method implemented as *ode113* function in the MATLAB package.

Equations of the electron motion were integrated forward and backward subsequently in order to control the numerical error of the trajectory coordinates defined as the difference in coordinate r between the results of forward and backward integration. The time step of the integration was chosen to keep this error at the level better than 10^{-6} m. Our calculations were performed for the energy of electrons E and $E \pm \Delta E$, where ΔE was equal to 0.1% E or to 0.01% E, respectively. For the above mentioned energies, the trajectories of electrons were analyzed for the entrance angle α in the range 30°–40°, and the constant value $\Delta\alpha = 3°$.

3. Results and discussion

As is shown in Fig. 1, and in particular in Fig. 2, the electron beams which differ in energy by about ΔE are not only well focused, but also their focuses are well separated.

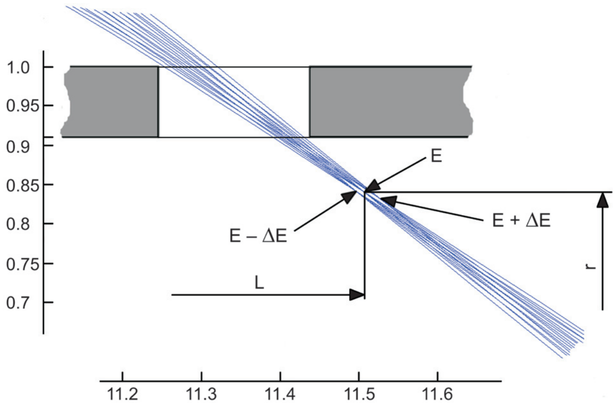

Fig. 2. An enlarged area of electron trajectories in the region of their focusing into the ring, where the input slit should be located. The focal length for $\alpha = 36°$ and $\Delta\alpha = \pm 3°$ is marked on the horizontal axis.

The well-separated electron beams confirm that the energy resolution of the analyzer is at least equal to ΔE.

A next feature of the analyzer is clearly visible in Fig. 3.

These dependences confirm that the separation of focuses is really equal to $\Delta E = 0.1\%\ E$ and $\Delta E = 0.01\%\ E$. Moreover, based on the analysis of the electron trajectories for energy varying by $\pm\Delta E$ one can conclude that, in a wide range of input angles and analyzer constant K, the energy resolution is at the level 0.1%. For the chosen values of K, one can obtain this value at the level 0.01% or even better owing to the input angle in the range 30°–40°.

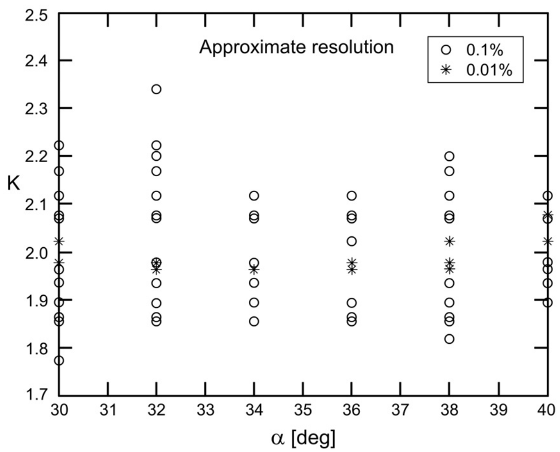

Fig. 3. The relative energy resolution of the analyzer as a function of constant K (defined as the ratio of pass energy to separation voltage), and entrance angle α.

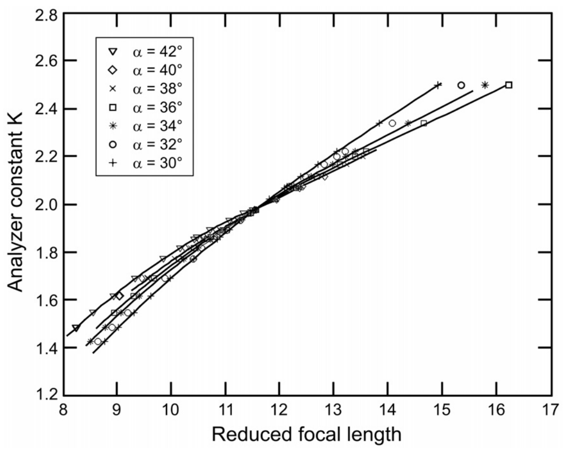

Fig. 4. The analyzer constant K as a function of focal length for the entrance angles in the range 30°–40°.

Figure 4 shows the dependence of K on the distance between the focus and sample for the chosen energy E and chosen values of entrance angle α.

It is clearly visible that all the curves are crossing at one joint point corresponding to $K = 1.97$ and $L = 11.5125$. This means that the TCMA working in the regime of axis-ring focusing is able to separate the electrons in a wide range of entrance angles.

This is well confirmed in Fig. 5, where the dependences of constant K of the analyzer on radius r of an image, are presented.

It is clearly visible that for different electron entrance angles of the analyzer, the crossing point of all the curves appears in a very narrow range of constant $K = 1.97$, similarly as for Fig. 3.

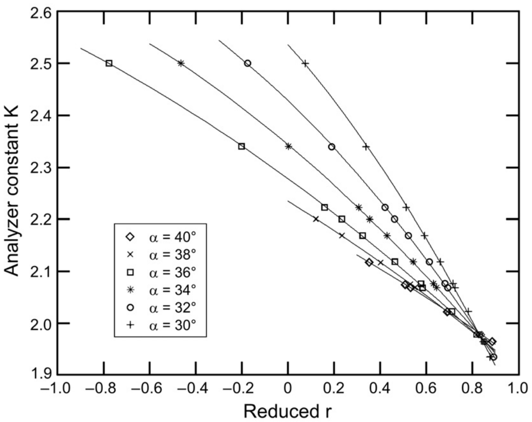

Fig. 5. Constant K versus image radius r.

Thus, our analysis confirmed that, using the TCMA working in axis-ring focusing mode, one can obtain well-resolved energy distribution curves of electrons in a wide range of electron entrance angles of the analyzer without any change in position and size of the analyzing slits, as well as without a change of the deflection potential on the cylinders for the chosen relative energy resolution.

4. Conclusions

From the numerical calculation of electro-optical characteristics of the three cylindrical mirror analyzer working in axis-ring focusing mode, one can conclude that:

– the modified analyzer can reach an extremely high energy resolution at the level 0.01%, or even better;

– this level of resolution is attainable also for a wide range of entrance angles of electrons entering the analyzer, which is a unique achievement of this work;

– for the chosen resolution, the analyzing slit can be twice as large as that of the conventional CMA analyzer;

– it can be interchanged with the conventional CMA without modification of both the vacuum system and the electronics steering system.

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