ANGULAR-RESOLVED ELASTIC PEAK ELECTRON SPECTROSCOPY for ANALYSIS of NANOSCALE SOLIDS

V.T. Barchenko[1] V.V. Luchinin[1], O.I. Grebnev[1], V.P. Pronin[2], I.V. Ryzhov[2]

1 Saint Petersburg Electrotechnical University «LETI», Russia, Saint-Petersburg
2 Herzen State Pedagogical University of Russia, Russia, Saint-Petersbur

ABSTRACT

The possibilities of the quantitative analysis of elemental composition of multi-components solid state surface with resolution on depth in a mode of measurement of elastic electron scattering coefficient in a narrow solid angle is analyzed.

Key words: electron spectroscopy, elastic electron scattering, surface composition.

INTRODUCTION

Now electron spectroscopy is an essential tool for analyzing the surface area of solids. In this case, all methods of electron spectroscopy in one way or another need knowledge of the elementary processes of interaction of electrons with solids, including the elastic interaction of electrons with solids. Without knowledge of the quantitative principles of elastic scattering of electrons we can not solve problems of quantitative diagnostics of surface and near-surface area of solids. Meanwhile, analyzing the characteristics of flows of the elastically reflected electrons, we can develop techniques that can itself solve quantitatively certain problems of diagnostics of solids.

RESULTS AND DISCUSSION

The development of nanotechnology is impossible without progress in methods of analysis of nanostructures. Electron spectroscopy in all modifications is the most significant method of such analysis. In recent years one method of electron spectroscopy – elastic peak electron spectroscopy (EPES) is being intensively developed. One of its modification is called angular resolved elastic peak electron spectroscopy (AREPES) [1-3]. In this article we discuss the potential of AREPES in the mean electron energy range for investigation element composition of disordered solids. The reporting depth in this energy range varied from fractions to several dozens of nanometers. One of the most important advantages of AREPES is relative simplicity of experiment results interpretation by means of analytical calculations and Monte Carlo method.

The task of this study was to find the sensibility of AREPES in determining the surface content. The results presented in figure 1 are received by means of calculation of the coefficient of elastic electron scattering in a narrow spatial angle for Au covered by a monolayer of C. The results were received based on Monte Carlo method. As seen from the figure fractions of C monolayer result in substantial change in the coefficient of elastic electron scattering.

For analytical calculation of the coefficient of elastic electron scattering $r(\theta)$ for multicomponent solids we used phenomenological model of multiple scattering. In the context of this model we calculated $r(\theta)$ using formula (1):

$$r(\theta,\varphi) = \frac{(1-P(\varphi))\cdot(1-P(\alpha))}{(1+\dfrac{\cos\varphi}{\cos\alpha})} \cdot \lambda \cdot \sum_z n_z \sigma_{yz} \sum_i W_i S_{iz}(\theta) \qquad (1)$$

Where φ, θ are the electron incidence and scattering angles, $\alpha = \pi - \theta - \varphi$ is the electron escape angle, $P(\alpha)$, $P(\varphi)$ are the probabilities of surface losses, λ is the effective mean free path of electrons in the target: $\lambda = \lambda_y\lambda_\mu/(\lambda_y + \lambda_\mu)$, where λ_μ and λ_y – are the electrons mean free path to the elastic and inelastic collisions, n_z is the atomic concentrations of zith component, σ_{yz} is the corresponding integral cross section for elastic scattering, Wi is the probability of electron escape into vacuum after ith scattering event; and $S_{iz}(\theta)$ is the normalized probability of electron scattering by angle θ after the ith event.

To find out the responsiveness of the method we used disordered structures based on Pb xOy. Based on experimentally measured and calculated using formula (1) values of $r(\theta)$ we showed that with measurement accuracy ~ 1% for $r(\theta)$ one can find depth profiles of element concentration with similar accuracy. In measures we used NIST electron elastic-scattering cross-section database [4].
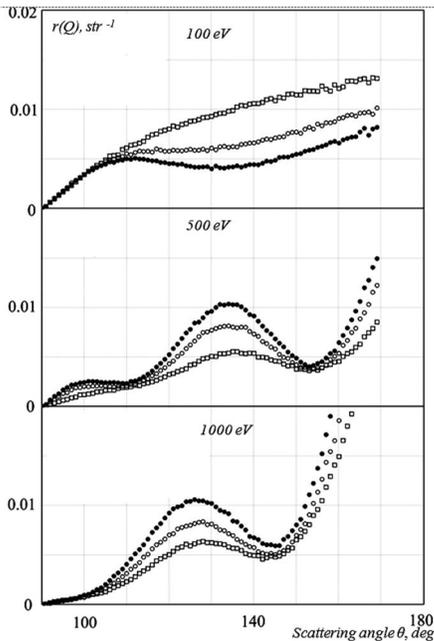
Fig. – 1 Monte Carlo simulation of probability of elastic electron scattering for: gold (• • • •); gold with monolayer of carbon (□ □ □ □); gold with 0.5 monolayer of carbon (O O O O)

Taking into account a significant difference of the [2] and [5] results, we can conclude the following:

1) The fraction of electrons elastically reflected by a solid surface is large enough, and in the considered energy range it is a few percent of the incident electron beam;

2) If an element has high atomic number Z, the integral coefficient of elastic reflection r in the considered electron energy range varies non-monotonically with energy, reaches the maximum at $E_{max} \sim Z2/8$ (eV), and then decreases with increasing electron energy. The elements with low atomic number Z show monotonic decrease of the dependence $r(E)$;

3) If $E \leq 1,5$ keV, the r coefficient is a nonmonotonic function of the atomic number Z of the tested sample. When energies of incident electrons are high, r is an increasing function of Z. For example, if $E = 2$ keV, r = 0,08% for carbon, $r = 0,3\%$ for aluminum, while $r = 4\%$ for gold.

CONCLUSIONS

Practical implementation of the EER (Elastic Electron Reflection) spectroscopy options can be achieved in the experimental apparatus meeting the following requirements.

1. Due to the high sensitivity of the EER characteristics to surface contamination, they should be measured in ultrahigh vacuum with the residual gas pressure p <10-7 Pa.

2. The device should measure the absolute values of the EER coefficient in the narrow solid angle, that usually requires special calibration of the electron detector-analyzer.

3. As an electron analyzer in the narrow solid angle, it is advisable to use an analyzer with the retarding field allowing to measure the total current of elastically reflected electrons.

4. The energy resolution of the analyzer $\Delta E/E$ should be at 0.1% to ensure sufficient accuracy of the absolute values of the EER coefficient in the narrow solid angle.

5. Necessary angular resolution of the analyzer $\Delta\theta$ depends on the differential cross sections of electron elastic scattering $d\sigma y(\theta)/d\Omega$ on the atoms of a solid and must not exceed 2°.

6. As an electron detector, it is advisable to use a detector operating in the mode of registration of individual pulses, which allows measurements at low currents of the primary electron beam and provides respectively non-destructive nature of the analysis.

7. When analyzing the elemental composition, it is advisable to do measurements at angles of electron incidence φ to the sample close to normal and the scattering angles $\theta > 150°$. In this area of angles there are no special spatial distributions of elastically reflected electrons, almost no effects of electron

refraction on the solid border, and the effects of surface roughness are minimized.

8. To do the experimental determination of the surface loss probability, the device should ensure measurements of the absolute values of the $r\theta(\theta)$ coefficient in a wide range of incidence angles φ.

Note that the correct solution of surface diagnostic problems by elastic electron reflection spectroscopy, in particular the problems of determining the analysis depth, needs knowledge of the differential cross sections of elastic scattering of the electrons on the atoms in the condensed state, which may significantly differ (especially if angles of scattering are small) of those for isolated atoms .

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