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To cite this version:

D. Wehbi, C. Roques-Carmes. THE EFFECTS OF SURFACE ROUGHNESS ON AUGER ELECTRON SPECTROSCOPY. Journal de Physique Colloques, 1984, 45 (C2), pp.C2-319-C2-322. <10.1051/jphyscol:1984272>. <jpa-00223986>

HAL Id: jpa-00223986
https://hal.archives-ouvertes.fr/jpa-00223986

Submitted on 1 Jan 1984

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THE EFFECTS OF SURFACE ROUGHNESS ON AUGER ELECTRON SPECTROSCOPY

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Abstract - The contribution of surface asperities to AES emission yields is discussed in terms of topography analysis. The methods allowing the distribution of heights, slopes, curvatures and other angular functions to be determined are presented here.

I - INTRODUCTION

Several experimental and theoretical studies have shown that the shape of the energy distribution of electrons emitted under electron bombardment is sensibly affected by the surface topography (1 to 5). For instance, Wu and Butler (1) have shown that Auger electrons yields vary with the extended area. Prutton and al. (2) have proposed a model to correct the energy distribution of electrons emitted under various incidences. The dependence of Auger signals on the incidence angle, \( \alpha \), and the emission angle, \( \beta \), is commonly assumed to be:

\[
\frac{I(\alpha, \beta)}{I(\alpha_0, \beta_0)} = \frac{1}{\cos \alpha} \quad ; \quad \frac{I(\alpha, \beta)}{I(\alpha_0, \beta_0)} = \cos \beta
\]

\( I(\alpha, \beta) \) being the intensity of an Auger signal for a given emission angle, \( \beta_0 \), and a variable incidence angle, \( \alpha \). Similarly \( I(\alpha_0, \beta) \) is the intensity of the Auger signal for a given incidence angle, \( \alpha_0 \), and a variable emission angle, \( \beta \). \( I(\alpha_0, \beta_0) \) is the reference intensity for arbitrary angles \( \alpha_0 \) and \( \beta_0 \). Those relations are valid only if one assumes that the mean free path of Auger electrons, \( \lambda_A \), is much lower than that of primary electrons, \( \lambda_p \).

A more rigorous approach consists in taking into account the local variations of the incidence angle as proposed by Holloway (3). The first step of this approach would be to analyse the influence of topographical defects on secondary and backscattered signals. Various mathematical functions have been proposed to describe:

- The variations of the backscattering yield \( \eta(\alpha) \) as a function of the incidence angle \( \alpha \)

\[
\eta(\alpha) = (1 + \cos \alpha)^{-9/\sqrt{2}}
\]

- The variations of the secondary yield \( \Delta(\alpha) \) as a function of the incidence angle \( \alpha \)

\[
\frac{\Delta(\alpha)}{\Delta(0)} = \exp \left\{ -1.55 (\cos \alpha - 1) \right\}
\]

For large energies of primary electrons (used for electron microscopy) a simplified relation has been proposed (8):

\[
\Delta(\alpha) = \frac{1}{\cos \alpha}
\]

Matsudaira and Onchi have used the same law for Auger peak intensities (9). The additional variations of \( \eta(\alpha) \) and \( \Delta(\alpha) \). The sum \( \Delta'(\alpha) = \Delta(\alpha) + \eta(\alpha) \) can be checked easily from experience (10) since \( \Delta'(\alpha) = 1 - \frac{1}{I_{\text{abs}}}/I_p \)

\( I_{\text{abs}} \) being the absorbed current, \( I_p \) being the primary current.
We think with Holloway (11) that all of the mathematical models developed for the effects of surface roughness on AES are difficult to apply, therefore the surface roughness factor should be measured experimentally. Our approach consists in measuring the different macroscopic parameters of surface roughness in order to connect them with the punctual Auger signal modifications. The experimental procedure of AES measurements already described in a previous paper (12) will not be discussed here. The stress will be laid on the software developed to characterize the surface topography, which is based on the determination of statistic distributions of heights, slopes and curvatures.

II. DETECTION AND QUANTIFICATION OF SURFACE ROUGHNESS

II.1. Experimental technique

Three different profilometers detecting asperities by a stylus or by optical technics (13) (14) (15) are used in our laboratory to measure a large range of irregularities in heights (0,01 to 20 µm). The software used for acquisition and processing of data is independent of the profilometer. The displacements in two normal directions x, y, to the probe direction are monitored by a computer by means of step-to-step motors. Then data are acquired by scanning the surface on 200 lines of 200 points each, with a step between two points varying from 0,1 to 10 µm. The analogic signal is converted into a digital one and stored in a 8 bits memory divided into a 200 by 200 matrix z(x, y).

Several data processings may be used but only those giving the angular parameters defined in the introduction, will be discussed.

II.2. Processing of the z(x, y) three-dimensional recordings

Three-dimensional recordings are used to obtain an attractive picture of the surface topography (fig. 1), but above all as a quantitative digital distribution simulating the surface topography. Statistic functions of the variables heights, slopes or curvatures may be deduced from the digitalized distribution. Each function contributes to the characterization of surface defects affecting the electronic emission.

II.2.1. Functions describing the surface area and asperity heights

i) the extended area

The method employed here to calculate the extended area consists in joining four neighbouring points of abscissa (x, y), (x + 1, y), (x, y + 1), (x + 1, y + 1) by quadrilaterals, then tracing the diagonal joining (x, y) to (x + 1, y + 1) and calculating the area of the two adjacent triangles. The sum of areas of all elementary triangles is the total generated area, St. One can also define the projection of St on the horizontal plane, SD, and the extended area S_D : S_D = \frac{S_t}{S_D} x 100. Using S_D as a first criterion of the AES yields variations with surface roughness, we obtained the same correlation as Wu and Butler.

ii) the level sections

A section of the real surface at a selected level z can be calculated by intersecting the plane of ordinate z with the points of the surface (fig. 2). Such a representation of the surface by one or null is turned to account by comparing it to the contrast of Auger images (12).

iii) histogram of the area densities

By counting the number n(z) of points of the surface being in each level section, one can plot the area density n(z) as a function of z between the two limits of minimal height and maximal height, z_min and z_max, measured on the surface (fig. 3). The symmetry of this distribution can then be characterized by statistical moments of orders 2,3 and 4. The integrated number of points of ordinate z between a given z_l and z_max (bearing area) is correlated to the surface fraction contributing to an integrated Auger image.
11.2.2. Functions describing the distribution of slopes

In order to obtain a three-dimensional recording of slopes, we calculate the equation of the plan tangent to the surface and of its normal, N, in each point M(x, y, z). To each point M a point M'(x, y, cos α) is then associated with α being the angle formed by the vertical direction and the normal N (fig. 4). The vertex of the distribution M'(x, y, cos α) corresponds to points with a horizontal tangent. These points are excited by the primary beam under normal incidence; thus, they will give a maximum electronic emission.

Let β' be the angle formed by the normal N and the axis of the CMA; another population M''(x, y, sin β') can be defined whose vertices correspond to points so that β' tends toward π/2. Hence the vertices of the distributions M'(x, y) and M''(x, y) correspond to points such as α is minimum and β' is maximum. The emission and the collection of Auger electrons are optimized in such points. A further development of the characterisation of the slopes distribution will be to determine the histogram of M' and M'' distributions.

III. CONCLUSION

The surface roughness affects sensibly the whole energy distribution of electrons emitted under electron bombardment (from the peak of secondary electrons to the peak of elastically backscattered electrons); the emission and collection functions are enhanced on surface asperities and suppressed in cavities. Our contribution to the study of topographical effects was to define parameters of the roughness in 3 dimensions and correlate them to the local Auger emission. For that purpose, we determined the distributions of heights (x, y, z), slopes (x, y, cos α) or (x, y, sin β'). We think that a distribution such as (x, y, z, cos α) would be more appropriate to our problem.

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FIGURES

1. 3-D profilometry map of an Al sample polished with emery 600 grade paper.
2. Surface section of the 3-D map shown in fig. 1, at the mean level.
3. Histogram of the area density as a function of heights and cumulative density function.
4. 3-D representation of slopes corresponding to the 3-D map shown in fig. 1.
Figure 1

Figure 2

Figure 3

Figure 4