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EXPERIMENTAL COMPARISON OF THE INFORMATION DEPTH OF AEAPS, DAPS AND AES

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The information depths of AEAPS and DAPS for the Ti and Cr L_3 , L_2 and L_1 subshell excitation and of AES for the Ti $L_3M_{2,3}M_{2,3}$, $L_3M_{2,3}M_{4,5}$ and Cr $L_3M_{2,3}M_{4,5}$ transitions were determined. A set of Cr samples with Ti overlayers had been prepared *in situ*. Measurements of the LEAPS and HEAPS signal amplitudes were used to derive the AEAPS and DAPS signal intensities. The results showed that both AEAPS and DAPS had lower information depths compared with AES. They are interpreted in terms of the mean free paths of the majority of electrons contributing to the AEAPS signal.

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1. Introduction

Knowledge of the information depth as well as of other characteristic properties of the surface analytical methods makes it possible to choose the one most suitable for a certain purpose. Contrary to AES (Auger Electron Spectroscopy), AEAPS (Auger Electron Appearance Potential Spectroscopy) [1] and DAPS (Disappearance Potential Spectroscopy) [2] belong to less widely used electron spectroscopic techniques, nevertheless, they have been successfully applied in special cases, in which AES fails.

Since the deexcitation mechanism of AEAPS is rather complicated, giving rise to a relatively large number of slow tertiary electrons contributing to the signal [3, 4], it could influence the information depth of the method. Using the well-known overlayer technique we had already made an attempt to determine it in comparison with AES [5], however, due to inferior experimental conditions, the obtained results were not unambiguous and reliable. This work has been carried out under much improved conditions and might serve as a study complementary to the paper of Nishimori et al. [6], devoted to the investigation of the escape depths of electrons contributing to the DAPS and AES signals.

While in DAPS and AES the electrons forming the signal must not lose their initial energy, the AEAPS signal carriers are of two kinds, namely the Auger electrons that can lose any amount of energy and still contribute to the signal, and the above mentioned tertiary electrons created by the Auger electrons during their passage to the surface. Therefore in our work we do not deal with the escape depths of electrons contributing to the AEAPS, DAPS and AES signals, but with the information depth according to the definition proposed to the ASTM E-42 Committee [7], i.e. the distance normal to the surface from which a specified percentage of the detected electrons originates. We assume an exponential behaviour of the signal intensity and specify this percentage to be equal to 63.2%. Then the substrate signal intensity decreases like $\exp(-x/t)$ and the overlayer signal intensity increases like $1 - \exp(-x/t)$, where x denotes the overlayer thickness and t stands for the information depth. Apparently, at the same time the above defined quantity t represents the escape depth of the signal carriers in case of DAPS and AES, while it has nothing to do with the escape depths of electrons contributing to the AEAPS signal. Nevertheless, the definition of the information depth according to [7] is valid in all three cases.

2. Experimental

All experiments were performed in an ultrahigh vacuum chamber at a pressure of about 6×10^{-10} torr. The samples were prepared *in situ* by evaporation from two independent sources at a pressure of about 5×10^{-9} torr in the following way. A relatively thick Cr layer was deposited onto 10 equivalent metal sheets placed on a rotary sample manipulator. These layers — about 50 Å thick — formed the substrates for Ti overlayers. Based on the former results [5] the sequence of the Ti overlayers thickness was chosen as follows: 0 – 1.5 – 3.0 – 4.5 – 6.0 – 7.5 – 9.0 – 12 – 15 and 45 Å. Both evaporators had been calibrated by a quartz oscillator. Consequently, the above mentioned values mean the mass thickness. The supporting metal sheets were not cooled down during the preparation of the samples, the evaporation rate was $(1.5 \pm 0.03) \times 10^{-2}$ Å/s.

Ti and Cr are 3d transition metals and therefore can be easily detected by APS. AP spectra were measured using a special sophisticated spectrometer, described in [9]. It enables us to register separately the APS signal formed either by electrons with energies from zero to an arbitrarily chosen value or by electrons with energies from that value to the primary energy. These modifications of AEAPS are called LEAPS (Low-Energy Electron Appearance Potential Spectroscopy) and HEAPS (High-Energy Electron Appearance Potential Spectroscopy), respectively. Their principle is treated in detail in [8]. The same analysing system makes it possible to register DAP spectra, too. Auger electron spectra were measured using a commercial analysing system PIII Model 10-120, built in the same apparatus. All the Auger spectra presented here were taken at the primary energy of 3 keV, modulation $5V_{pp}$ and time constant 1 s. The latter two values are valid for all the APS and DAPS measurements, however, contrary to the AES measurements, the AP and DAP spectra were registered in the second derivative mode. In both cases, the peak-to-peak height was always taken as a measure of the signal intensity.

Using a special circuitry, developed in the frame of the work [9], it is possible to pick-up the signal intensity directly as a function of the energy limit between LEAPS and HEAPS. From those amplitude dependences the effective coefficient σ_{eff} can be calculated [4]. This represents the number of slow secondary electrons contributing to the AEAPS signal appearing at the disappearance of one elastically reflected electron.

3. Results and discussion

We have measured the above defined LEAPS and HEAPS amplitude dependences for the Ti L_3 , L_2 and L_1 subshells and for the Cr L_3 , L_2 and L_1 subshells for all the 10 samples. Corresponding binding energies are equal to 456, 462 and 564 eV, respectively for Ti, and 575, 584 and 695 eV, respectively for Cr. From those spectra both AEAPS and DAPS signal amplitudes were derived and the coefficients σ_{eff} calculated. Besides, usual DAPS measurements of the Ti L_3 and L_2 and Cr L_3 and L_2 subshells have been performed, too. The DAPS signals of the L_1 subshells were too weak to be directly registered. AES measurements of all the samples have been also carried out, namely the intensities of the signals corresponding to the Ti $L_3M_{2,3}M_{2,3}$ (387 eV), $L_3M_{2,3}M_{4,5}$ (418 eV) and Cr $L_3M_{2,3}M_{4,5}$ (529 eV) transitions have been followed.

TABLE I
Information depths of AEAPS, DAPS and AES for all the investigated subshell excitations or transitions.

Method	Element	Subshell under excitation (or transition)	Information depth [\AA]
AEAPS	Ti	L_3	4.2
		L_2	2.9
		L_1	3.1
	Cr	L_3	4.4
		L_2	3.4
		L_1	5.1
DAPS	Ti	L_3	3.7
		L_2	2.7
	Cr	L_3	6.7
		L_2	5.4
AES	Ti	$L_3M_{2,3}M_{2,3}$	6.0
		$L_3M_{2,3}M_{4,5}$	8.5
	Cr	$L_3M_{2,3}M_{4,5}$	6.0

We have calculated the information depth of each method for each of the treated subshells or transitions. The obtained results are shown in Table I and Table II. The values of the AEAPS information depth are average values calculated

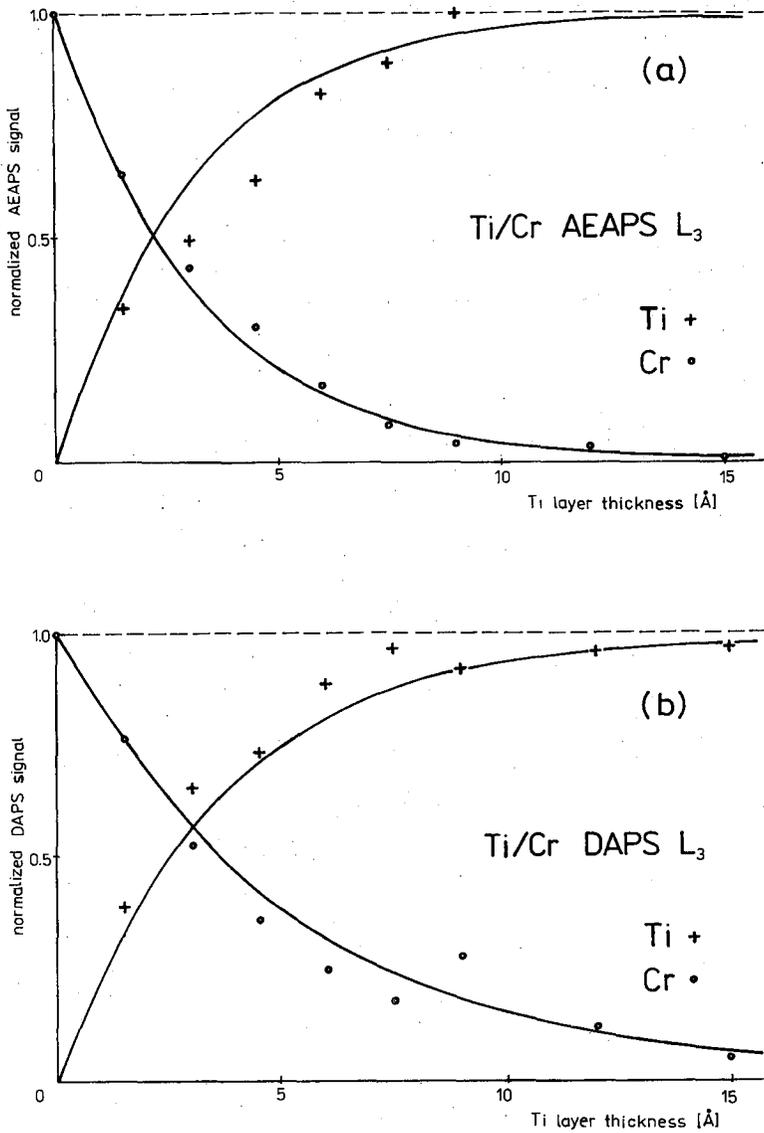


Fig. 1. Examples of the exponential dependences of the signal intensity on the overlayer thickness: a) AEAPS of the L_3 subshell, b) DAPS of the L_3 subshell.

from both LEAPS and HEAPS measurements, the values of the DAPS information ~~from~~ ^{from} DAPS measurements, however, contrary to the AES measurements, the AP and DAP spectra were registered in the second derivative mode. In both cases, the peak-to-peak height was always taken as a measure of the signal intensity.

Table I exhibits an unexpected result, namely a very low information depth of AEAPS. We had expected an information depth of about twice the size of DAPS, because an electron contributing to the DAPS signal must penetrate to the excitation depth and then return to emerge from the sample without any energy loss, while in AEAPS the tertiary electrons created by the Auger ones during their passage to the surface should have had much greater mean free paths and should have been able to escape from greater depths. However, it can be seen from Table I that this is not the case.

An explanation of this surprising fact might be as follows. Most of the slow electrons that are the signal carriers in AEAPS have not as low energies as it has been suspected, but somewhat higher ones, close to the absolute minimum of the mean free path vs. energy curve.

TABLE II
Values of σ_{eff} for the Ti and Cr
 L_3 , L_2 and L_1 subshells.

Element	Subshell under excitation	σ_{eff}
Ti	L_3	3.4 ± 0.9
	L_2	3.5 ± 0.9
	L_1	17.6 ± 4.5
Cr	L_3	2.9 ± 1.3
	L_2	2.6 ± 1.5
	L_1	8.4 ± 0.7

The values of σ_{eff} contained in Table II roughly agree with the former results [4], except for the extremely large σ_{eff} in case of the Ti L_1 subshell. Nevertheless, the standard deviations of the present results of σ_{eff} are rather large. Of course, the creation of tertiary electrons by a certain Auger one can be different in Cr or Ti, i.e. can differ according to the relative thickness of the penetrated Cr and Ti layers. Similar measurements carried out on more complex sandwich samples accompanied by proper, e.g. STM investigation of the samples structure, that could also affect the obtained results, should represent the goal of our future work.

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