Solid State Communications, Vol. 8, pp. 1479–1481, 1970. Pergamon Press. Printed in Great Britain

DETERMINATION OF THE ELECTRON ESCAPE DEPTH IN GOLD BY MEANS OF ESCA

Yves Baer *, Per Filip Hedén, Jan Hedman, Martin Klasson and Carl Nordling

Institute of Physics, University of Uppsala, Uppsala, Sweden.

(*Received* 26 *June* 1970 *by J.L. Olsen*)

The intensity of core electrons photoexcited by soft X-ray has been determined as a function of the thickness of deposited metal films. An escape depth of (22 ± 4) Å is obtained for 1.2 keV electrons in gold. The possible impact of this result on band structure studies is discussed.

IN MANY applications of the ESCA† technique employing solid samples, there is a need to know the thickness of material involved in the photoemission process, i.e. the escape depth of the photoexcited electrons. This kind of information is essential if a decision is to be made concerning the bulk or surface origin of an ESCA result. From the experimental point of view, knowledge of the escape depth would be of value in determining the importance of surface cleanliness. The escape depth is closely related to the inelastic mean free path, and is capable of yielding valuable information concerning the interaction of relatively high energy electrons with the bound electrons of the material.

Previous ESCA studies relating to surface sensitivity have involved organic multilayer samples.[1] The results show that the unscattered electrons escape from a depth of less than 100 Å. The determination of the inelastic mean free path at low energies (less than 12 eV above the Fermi level) has been performed by a variety of techniques such as tunnel-emission,[2] direct electron transmission,[3] and u.v. photoemission.[4] Two recent approaches [5,6] based on u.e. photoemission have been published; in one of these the thickness dependence of energy distribution and yield curves is used to determine the mean free path. This technique requires the preparation of thin and homogeneous films. The band structure of substrate and film material have to be significantly different in order to make their separation possible. It is worth pointing out that the presence of secondary and inelastically scattered electrons might complicate somewhat the interpretation of the experimental results.

We report in this paper on film thickness dependence of ESCA spectra. In this technique the electrons are photoexcited by a characteristic X-ray line, in the present study MgKα ($\hbar\omega$ = 1253,6 eV). Gold films of different thicknesses have been evaporated on highly polished chromium surfaces, the latter in fact being covered by a thin oxide layer. No attempt has been made to remove the oxide because it seems to be a suitable baking for Au deposition.[7] The films themselves have not been subject to close scrutiny, however for thicknesses greater than 15 Å the consistency of our results indicates that a sufficient degree of homogeneity has been obtained. The thickness determination has been performed by a standard interferometric method, a technique which is accurate only for film thicknesses greater than 200 Å. It was thus necessary to produce in one evaporation two films, a thin one as sample and a thick one for the purpose of calibration. A chopper was used

* On leave from Eidg. Techn. Hochschule, Zürich.

† Electron Spectroscopy for Chemical Analysis.

to monitor the thickness ratio of the two films. The accuracy in the determination of the thickness of the film used as sample is probably not better than 15 per cent. Two core levels close to the Fermi level have been chosen, in Au the $4f_{7/2}$ level (binding energy E_b = 83 eV), and in Cr the 3p level (E_b = 43 eV). The intensities $I_f(d)$ of the signals corresponding to these two core levels have been measured as a function of the thickness of the Au film. They have been normalized to the bulk intensity I_∞ determined immediately before and after the film measurement. The analysis of the data is greatly simplified by the fact that the core spectra considered do not overlap and that the corresponding photoexcited electrons have approximately the same kinetic energy (1.2 keV). The X-ray attenuation is negligible in the thickness range considered so that the intensity of the electrons originating from the Au film, and of those originating from the Cr and passing through the Au film are given by:

$$\text{Au}: \quad \frac{I_f(d)}{I_\infty} = I_{Au}(d) = Q - e^{-d/\Lambda}$$

$$\text{Cr}: \quad \frac{I_f(d)}{I_\infty} = I_{Cr}(d) = e^{-d/\Lambda}$$

where Λ is the escape depth and d the film thickness. These relations are valid only for electrons suffering no energy losses, a condition which is fairly well staisfied in ESCA core spectra. A straightforward check of the consistency of this model is given by the relation $I_{Au}(d) + I_{Cr}(d) = 1$ which was found to be satisfied for each d with an accuracy better than 7 per cent. As shown in Fig. 1, the value of $\Lambda = (22 \pm 4)$ Å has been obtained by fitting the theoretical curves to the experimental values. The scatter is acceptable in the light of the experimental uncertainties.

The attenuation length in Au of 10 eV electrons has been determined by different techniques [5,3] and is also found to be around 20 Å. In this energy range the inelastic mean free path is exclusively determined by processes involving electrons of the valence band. This predominance of small energy losses is one of the reasons for the accumulation of scattered and secondary electrons on the low energy side

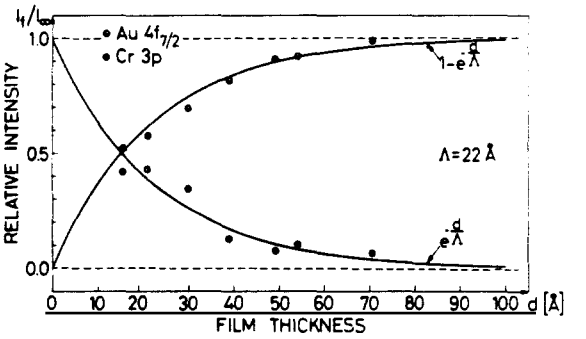

FIG. 1. Core level intensities obtained from thin gold films deposited on a chromium substrate. The intensities are related to the bulk intensity of the corresponding element.

of UPS energy distribution curves.[8] The ESCA band spectrum of gold [9] contains a very low contribution of scattered electrons, the reason being that the dominating energy loss mechanism is the ionisation of more strongly bound electrons. In Fig. 2, uncorrected UPS and ESCA band spectra of gold are compared; the most interesting feature for the present discussion is the different background following the band, illustrative of the fact that the order of magnitude of the energy losses is a more important factor than the escape depth. The relative insensitivity of ESCA to surface contamination can also be explained by similar arguments.

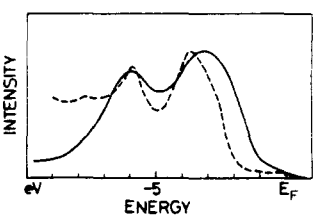

FIG. 2. Energy distribution of valence band electrons of gold photoexcited by radiations of different energies $\hbar\omega$.
Broken line: $\hbar\omega$ = 26.9 ev. reference 13.
Full line : $\hbar\omega$ = 1253.6 eV. reference 9.

In some UPS studies [4,10] a lifetime-broadening of the form $\Delta E = \hbar v_g / 1(E)$ has been introduced, where $1(E)$ is the electron mean free path and v_g the group velocity Values of ΔE = 0.6 eV or less are reported at these low energies;

no conclusive experimental evidence in support of this mechanism is presently available however and the sharpness of the flank corresponding to the Fermi level in the energy distribution curve of of Pd [10] throws doubt on the validity of this type of broadening. Using the value of the escape depth determined in the present study, we obtain a lifetime-broadening of the order of 6 eV, a result which is in glaring disagreement with the value of 1.3 eV obtained for the observed half-width of the $4f_{7/2}$ electron line in Au. Furthermore, for films thinner than the escape depth, the broadening should be even greater. No effect of this kind has been detected in the course of the present investigation, leading to the conclusion that the total experimental broadening and the hole lifetime account for the observed line-width. The sub-division of the photoemission process into three steps might be somewhat artificial; more elaborate formalisms [11] including main-body effects [12] will probably provide a more valuable basis for the understanding of such problems.

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L'intensité de lignes d'électrons de niveaux atomiques photoexcites par rayons X mous a été mesurée pour des couches métalliques minces de différentes épaisseurs. Cela permet de déterminer dans l'or une profondeur d'extraction de (22 ± 4) Å pour des électrons de 1,2 keV. Les implications de ce résultat dans les études de structures de bandes sont discutées.