Polarization dependence of the electron photoemission from the W(110)-Ba system at submonolayer coverages

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The dependence of the integral photoelectron emission current of the (110)W face on the degree of the submonolayer coverage by barium is found to be quite different for *s* and *p* polarizations of visible exciting light. The difference is explained on the basis that the *p*-polarized light excites emission from a band of surface electron states induced by the adsorption of barium.

The surface states of metals and of submonolayer surface coverages typically exhibit highly anisotropic electronic properties along the direction normal to the surface. It thus becomes possible in principle to use polarization methods to study the surfaces, in particular, to study manifestations of surface states in photoemission processes. The work which has been carried out in this direction has dealt exclusively with electron surface states, which have been studied through polarized synchrotron excitation of photoemission.

In this letter we report the observation of an electron emission which is active for a strictly determined polarization of the exciting light and which depends on the surface concentration of adsorbed atoms. Taken together, the data constitute evidence for the discovery of a band of surface electron states of the crystal-adsorbate system, whose position with respect to the Fermi energy E_F varies with increasing surface concentration of the adatoms.

We have studied the photoemission of the W(110)-Ba system as a function of the extent of submonolayer coverage, $\theta < 1$. The lowering of the tungsten work function φ during the adsorption of barium makes it possible to excite emission with visible light. The dependence $\varphi(\theta)$ of the W(110)-Ba system is nonmonotonic, having a minimum at[1] $\theta = 0.4$. At an excitation energy $h\nu \lesssim 3.0$ eV, there should accordingly be a maximum in the dependence of the photocurrent I on the degree of coverage θ.

The present experiments consist of measuring the integral photoemission current during continuous exposure of the (110)W face in a beam of atomically pure barium. The emission is excited by focused laser beams at various wavelengths: 4416 Å (2.81 eV), 4765 Å (2.60 eV), 4880 Å (2.54 eV), 5145 Å (2.41 eV), and 6328 Å (1.96 eV) at a power level no greater than 10 mW. The *s*- or *p*-polarized laser beam strikes the crystal at an angle of 45° (Fig. 1a). The measurements are taken in a high vacuum ($\sim 10^{-10}$ torr).

The curves of the photocurrent, $I_s(\theta)$, have the same shape for all energies of the *s*-polarized exciting light (see, e.g., curve 1 in Fig. 1). The maxima on the curves coincide along the coverage scale, while the half-widths and intensities of the maxima are proportional to the energy of the exciting photons. Comparison of the $I_s(\theta)$ curves with the known dependence $\varphi(\theta)$ shows that for the *s*-polarized excitation the emission is formed as a result of a nonmonotonic change in the work function. We also studied the photoemission and thermionic-emission currents in a common deposition cycle. We found that the maxima of $I_s(\theta)$ coincide with those of the thermionic-emission current, furnishing evidence that there is an emission of electrons from the substrate during the *s*-polarized excitation. The absence of a structure from the $I_s(\theta)$ curves suggests that the density of electron states near the Fermi surface which are participating in the photoemission has no significant structural features.

During *p*-polarized excitation at $h\nu = 2.81$ eV, the curve of the photoemission current $I_p(\theta)$ has a more complicated structure, with two maxima (curve 2 in Fig. 1). The first, A_1, corresponds to $\theta = 0.4$, while the second and higher maximum, A_2, occurs at higher degrees of coverage. The height of A_2 depends on the magnitude of

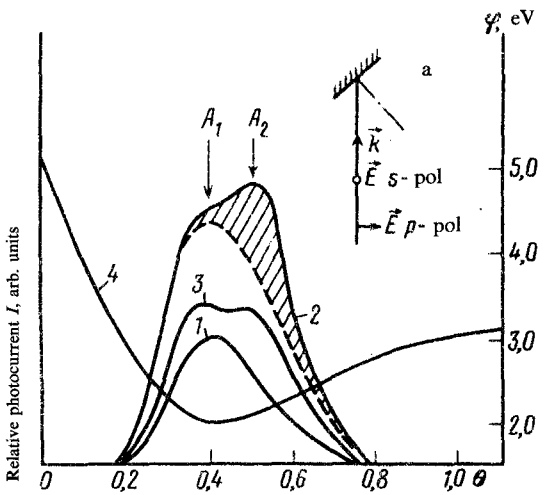

FIG. 1. Integral photoemission current I versus the degree of coverage θ for the W(110)-Ba system. 1—$I_s(\theta)$ for *s*-polarized excitation at $h\nu = 2.81$ eV; 2—$I_p(\theta)$ for *p*-polarized excitation at $h\nu = 2.81$ eV; 3—$I(\theta)$ for mixed *s*-*p* excitation at $h\nu = 2.81$ eV; 4—the work function $\varphi(\theta)$ for the W(110)-Ba system, from Ref. 1.

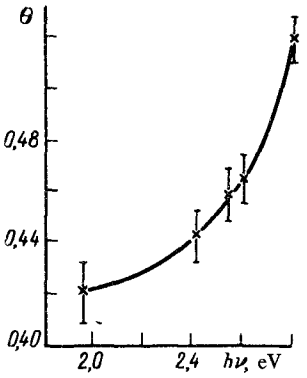

FIG. 2. Position of peak A_2 of the photoemission current for various p-polarized laser lines.

the normal component of the electric vector of the light wave. A smooth transition from p polarization to s polarization involving a decrease in the normal component leads to a gradual smoothing and the eventual disappearance of peak A_2 (curve 3 in Fig. 1).

The electron emission which is responsible for peak A_2 arises at $\theta > 0.3$ (the hatched part of curve 2) and intensifies as the surface coverage increases. After the value $\theta = 0.4$ is reached, the increase in the emission stops because of an increase in the work function. Consequently, at $\theta > 0.3$ states appear in the electron structure of the W(110)-Ba system below E_F, which interact only with the normal component of the electric field of the light wave. The further increase in the density of these states with increasing surface coverage of the barium is masked by an increase in the work function, whose effect is to contract the energy region below E_F which is active in the photoemission. Since this energy region is determined not only by the work function but also by the energy of the exciting photon, the position of photoemission peak A_2 along the coverage scale depends on the energy of the exciting laser line (Fig. 2).

This study of the photoemission during excitation by polarized light thus reveals a change in the density of electron states near E_F for the W(110)-Ba system due to adsorption. We know that adsorption gives rise to additional electron states, into which levels of isolated atoms transform upon adsorption.[2] At a surface concentration of adatoms sufficient for the overlap of electron shells, a band of electron states forms, with a position and other characteristics that depend on the interaction of adsorbed material in the layer.

We know that the 6s quasilevel of an isolated Ba adatom on the W(110) face lies 1 eV above E_F (Refs. 3 and 4). The $5d^1$ and $5d^3$ states lie in the same energy region. The dipole moment of the adatom is estimated[1,5] to be 7.8 D. The interaction between barium adatoms comes into play at[1] $\theta > 0.2$.

We can accordingly assume that in the coverage range of interest here, $\theta > 0.3$, a surface band due to adsorption changes its energy position with increasing barium concentration, in fact falling below E_F. This process is accompanied by an increase in the filling and density of the hybridized electron states that form the surface band. The energy shift of the band as a function of θ corresponds to the known decrease in the

induced dipole moment of Ba, and it also agrees with theoretical calculations[6] of the electron states of the W(001)-Cs system.

We note in conclusion that the polarization of the exciting light must be monitored in a study of, or in the use of, the photoemission curves $I(\theta)$.

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