Interaction of adsorbed lanthanum atoms on the (112) face of a tungsten crystal

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The investigation of the interaction of adsorbed atoms is one of the most important problems of surface physics. A number of recent theoretical papers[1–3] predict the existence of exchange interaction of the adsorbed atoms via the conduction electrons of the substrate. A characteristic feature of this interaction is that it contains a long-range alternating-sign component due to Friedel oscillations of the electron density. Experimental observation of the interaction of adsorbed atoms via the conduction electrons of the substrate have been reported in the literature,[4] but doubts concerning the results of these investigations were expressed subsequently.[5]

To investigate the interaction between adsorbed atoms, we have used slow-electron diffraction to investigate the structure of lanthanum films on the (112) face of tungsten. The surface of this face is made up of close-packed rows of tungsten atoms, separated by furrows that are deep on an atomic scale. The experimental procedure was the same as in our preceding work.[6] The purity of the atomic lanthanum beam was monitored with a mass spectrometer. The pressure of the active components of the residual gas in the experimental tubes during the times of the experiments with the lanthanum, estimated with the aid of a manometric field-emission projector, did not exceed 10^{-11} Torr.

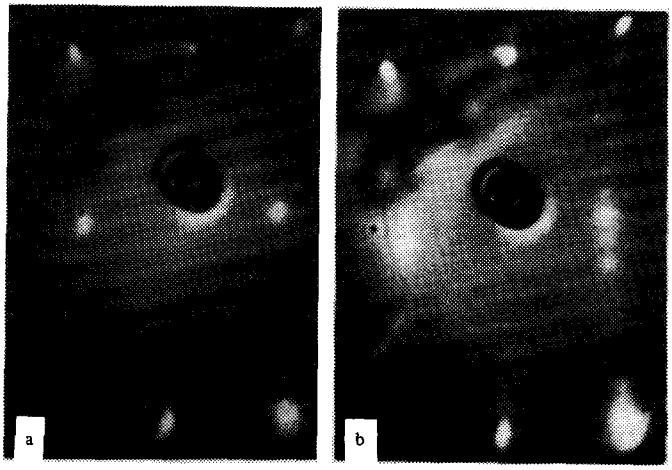

FIG. 1. Diffraction patterns: a—(112) face of tungsten, b—$p(1\times 7)$ structure of adsorbed lanthanum film. Electron energy 35 eV, $T = 77\,^{\circ}\mathrm{K}$.

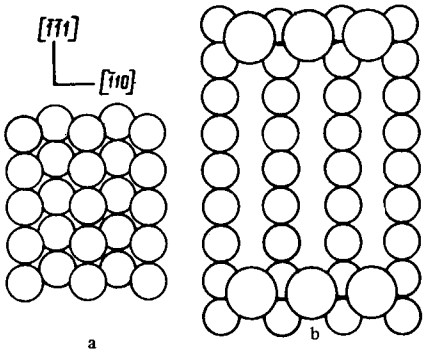

FIG. 2. a and b—models of surface structures corresponding to the diffraction patterns of Fig. 1.

During the course of the investigations we have observed that the interaction of the adsorbed atoms of the lanthanum on the W(112) face is strongly anisotropic. Indeed, in the case of thin coatings the adsorbed lanthanum atoms produce on the (112) face of the tungsten a $p(1\times7)$ structure (Figs. 1b, 2b) that consists of sufficiently dense linear chains that extend across the furrows of the substrate, the distances between the chains is 7 lattice periods of the substrate in the direction along the furrows. The formation of chains of adsorbed atoms of lanthanum indicates that attraction forces exist between adsorbed atoms situated in neighboring furrows. These forces are probably due to exchange interaction of the lanthanum atoms via the unsaturated orbitals of the surface atoms of the substrate.[7]

A very important factor is that the $p(1\times7)$ structure of lanthanum grows in the form of islands. Thus, the quite distinct diffraction reflections of the $p(1\times7)$ structure are observed already at a lanthanum concentration one-quarter the stoichiometric concentration corresponding to this structure. The island character of the lanthanum film indicates that at the interatomic distances realized in the $p(1\times7)$ structure there are minima of the interaction potential of the adsorbed atoms. The mechanism whereby the adsorbed lanthanum atoms interact, which ensures fixation of the chains of the adsorbed atoms at a distance of 7 lattice constants of the substrate (~19.2 Å) from one another, should naturally have a substantially long-range character. At the present time there are two known types of long-range interactions of adsorbed atoms—dipole-dipole repulsion and alternating-sign interaction via the conduction electrons of the substrate.[1-3] Since the adsorption bond of the lanthanum on the W(112) face is characterized by an appreciable dipole moment μ ($\approx 2.4D$ according to an estimate by the Helmholtz formula $\nabla^2\phi = 4\pi n\mu$ from the initial section of the concentration dependence of the work function $\phi(n)$), it follows that a noticable dipole-dipole repulsion of the adsorbed atoms should exist in the adsorbed lanthanum film. To obtain the absolute minimum of the potential of the interaction of the adsorbed atoms, so as to make possible the existence of stable structure islands, it is necessary to include the interaction of the adsorbed atoms via the conduction electrons of the substrate.

We have measured the intensity of the diffraction reflections of the $p(1\times7)$ structure of lanthanum as a function of the crystal temperature. By constructing a telescopic photometer we were able to measure the intensity of a small

central section of the diffraction reflections. From the temperature region of the disorder (~200 °K) we estimated the disordering energy of the structure $E_p \approx 0.5\, kT_p$[8], which amounted to ~0.01 eV in our case. The sufficiently high stability of the $p(1\times 7)$ structure in a lanthanum film adsorbed on the (112) face of tungsten is probably due also to the fact that long-range interaction is effected in it also between adsorbed atoms that are joined to form continuous chains.

It is interesting to note that we have also observed growth of islands of the $p(1\times 7)$ structure of the W(112) face for another adsorbate, strontium, at small coating thicknesses.[7]

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