

Detection of a new modification of Ag in the system InSb(110) + Ag

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A new crystal modification of silver obtained upon deposition of ultrathin Ag films on the surface of InSb(110)- 1×1 at 10 K in extremely high vacuum was detected by the method of low-energy electron diffraction.

There have been very few low-temperature studies of the metal-semiconductor systems published in the literature (see Ref. 1). The first experimental studies of this sort in the particular case of Si(111)- 2×1 + Ag were carried out by Aristov *et al.*¹ In the present letter we report the results of a study of the initial stages of formation of an ultrathin Ag film on the cleaved surface of InSb(110) at a substrate temperature of $T_s \approx 10$ K in extremely high vacuum ($\sim 10^{-10}$ torr). The study was carried out by using the method of low-energy electron diffraction. The average thickness of Ag films was varied, as in Ref. 1, in the range $\theta = 0$ –20 monolayers; a single monolayer ($\theta = 1$) corresponds to the number of atoms in the InSb(110) substrate per unit area, i.e., 6.74×10^{14} cm⁻².

Let us briefly analyze the pattern of low-energy electron diffraction during the deposition of Ag at $T_s = 10$ K. (In our experiments the energy of the primary electron beam was varied between 20 eV and 100 eV; the other details of the experiment are described in Ref. 1.)

At $0 \leq \theta \leq 0.1$ a sharply defined pattern of electron diffraction from the surface of

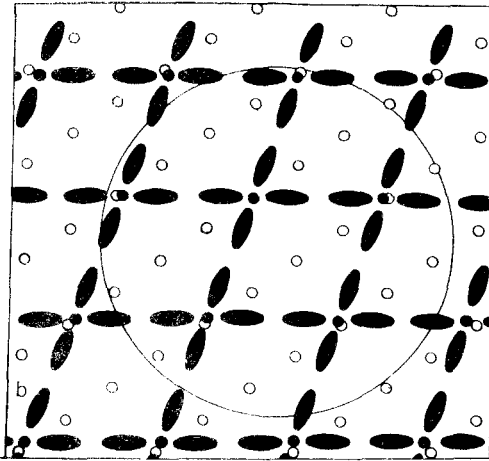
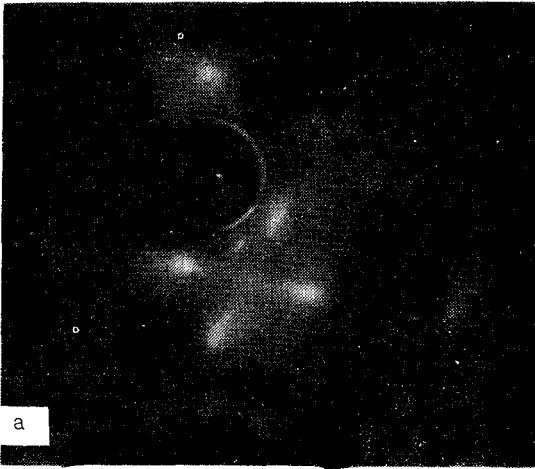


FIG. 1. (a) Diffraction pattern of InSb(110) + Ag($\theta \approx 5$), $E_p = 67$ eV; (b) a diagram explaining the diffraction pattern. \circ —Location of the reflections from the InSb substrates before the deposition of silver; \bullet —principal reflections corresponding to the (110) bcc structure of Ag; \ominus —satellites of the principal reflections of silver.

the InSb(110) substrate is seen. At $0.1 \lesssim \theta \lesssim 1$ the background of the low-energy electron-diffraction pattern increases with increasing θ and the intensity of the InSb(110) reflections decreases at the same time. At $\theta \sim 1-1.5$ only the background is seen, the InSb(110) reflections vanish completely and no new reflections appear. A comment is in order here.

It is justifiable to assume that Ag atoms, which are adsorbed at 10 K, are distributed randomly along the substrate surface,¹ forming a strongly disordered 2D system with a short-range order $\xi_{Ag} \sim a_{Ag}$, where a_{Ag} is the lattice constant of bulk Ag. For this reason, no electron-diffraction reflections from Ag are seen (Fig. 1). The disap-

pearance of the InSb(110) substrate reflections at $\theta \sim 1-1.5$ cannot be accounted for by the "screening" of the InSb(110) surface by an Ag film, which ordinarily occurs at $\theta \gtrsim 3$. The disappearance of these reflections at $\theta \sim 1-1.5$ should therefore be attributed to the breaking of translational symmetry of several atomic layers near the InSb(110) surface as a result of strong chemical interaction of the disordered system of Ag atoms with the substrate immediately after the adsorption of 10 K, in contrast with the Si(111) + Ag system.¹

Let us now consider the behavior of InSb(110) + Ag with further increase of θ .

At $1 \leq \theta \leq 4$ the surface of InSb(110) + Ag remains strongly disordered (amorphous), producing no electron-diffraction reflections. At $\theta = \theta^* = 4-4.5$, however, we see an interesting phenomenon: the system undergoes a transition to an ordered state, and new reflections, which do not reproduce the InSb(110) substrate reflections that had previously disappeared, appear in the low-energy electron-diffraction pattern (see Fig. 1a). We thus seem to be dealing with an (amorphous state)-(crystalline state) phase transition at a constant temperature ($T \approx 10$ K). The thickness of the Ag film is the critical parameter here.

We thus see that there is a critical value, $\theta = \theta^* = 4-4.5$, at which the transition indicated above occurs. With increase in θ , the intensity of electron-diffraction reflections

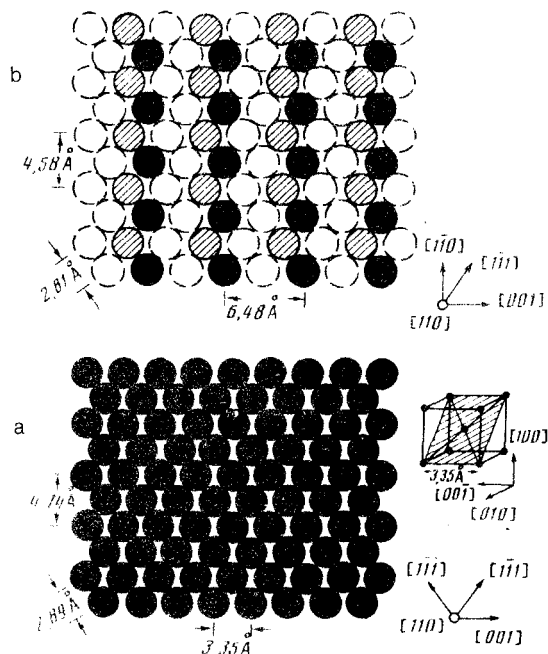


FIG. 2. (a) Schematic representation of a two-dimensional arrangement of Ag atoms corresponding to the diffraction pattern of the principal reflections in Fig. 1. Shown in Fig. 1a is the bcc lattice with a lattice constant ~ 3.4 Å, which has the same arrangement of atoms in the (110) plane; (b) arrangement of In and Sb atoms at the cleaved surface of InSb(110). The dashed line represents the atoms of the second layer; ●—In atoms; ⊙—Sb atoms.

tions increases markedly up to $\theta \sim 5$, and with further increase of θ to $\theta \sim 20$ (cases in which $\theta > 20$ were not studied by us) the intensity of the reflections remains approximately constant. Accordingly, the phase transition is "diffuse" with respect to θ in the interval of θ between ~ 4 and ~ 5 . The diffuse transition apparently is attributable to large fluctuations of the film thickness which occur at low temperature of the substrate.¹

If an array of points in ordinary space is constructed from the principal reflections of the electron-diffraction pattern in Fig. 1a, and if an Ag atom is placed at each point, we will obtain a pattern shown in Fig. 2a. Figure 2a can be compared with Fig. 2b. We see that the arrangement of Ag atoms in Fig. 2a would be virtually the same as the spatial distribution of the atoms in the first and second InSb(110) layers if these layers would lie in the same plane. We can assume, therefore, that after the order is restored, the Ag atoms in the first monolayer will be situated in the "voids" above the atoms of the second InSb layer. The atomic spacing (d) of the Ag lattice shown in Fig. 2a corresponds, within experimental error margin ($\sim 2\%$), to the atomic spacing of bulk silver, which has an fcc structure with a lattice constant $a_{\text{fcc}} \cong 4.1 \text{ \AA}$ and $d \cong 2.9 \text{ \AA}$. It is easy to see, however, that the arrangement of the Ag atoms in Fig. 2a in fact does not correspond to any fcc plane of the Ag lattice but does coincide with the (110) plane of the hypothetical bcc lattice.

We thus obtain the principal result of this study: At $\theta > \theta^*$ and $T_s = 10 \text{ K}$ a bcc modification of Ag with a $\text{bcc} \cong 3.4 \text{ \AA}$ appears on the InSb(110) surface as a result of a structural phase transition.

The results of additional studies of the "unusual" silver films over the entire temperature interval 10–300 K will be reported in a separate publication.

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¹V. Yu. Aristov, I. L. Bolotin, V. A. Grazhulis, and V. M. Zhilin, *Zh. Eksp. Teor. Fiz.* **91**, 1411 (1986) [*Sov. Phys. JETP*, **64**, No. 3 (1986)].

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