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G. A. EFENDIEV, F. I. ALIEV

STUDY OF THE KINETICS OF THE REACTION BETWEEN In AND Sb FILMS BY THE KINEMATIC METHOD OF ELECTRON DIFFRACTION

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The formation of a compound under conditions in which one of the elements is condensed onto a thin layer of another element is a complex physicochemical process and at present has been studied quite insufficiently. In paper ([1]) the authors report that, by successive deposition of In and Sb at −160°, they obtained a multilayer object. From the irreversible decrease in electrical conductivity upon heating, they concluded that InSb was formed. As can be seen, they judged the formation of the compound indirectly, from the change in electrical conductivity. For a direct study of the interaction of thin In and Sb films we chose the method of fast-electron diffraction. In view of the high sensitivity of electrons to the scattering substance, with their aid it is possible to record the onset of the reaction and its subsequent course.

Electron diffraction patterns from a double layer (In + Sb) 300 Å thick, obtained by successive condensation of the elements at room temperature, showed the presence of an InSb compound about ∼ 100 Å thick and of residues of In and Sb. This fact indicates partial formation of the compound during deposition of the second element onto the layer of the first, without additional annealing.

Further growth of the InSb layer formed during annealing of the double films was studied by the kinematic method of electron diffraction, developed by us on the EG apparatus ([2]).

For this purpose, isothermal kinematic electron diffraction patterns were obtained from these objects at 200, 240, and 250°. In Fig. 1 (see insert to p. 1109) one such electron diffraction pattern, taken at 240°, is presented. The speed of motion of the plate was $V = 3/4$ mm/sec.

On the basis of an analysis of the intensity of the InSb lines, we came to the

Kinematic electron diffraction pattern from a double layer (In + Sb), obtained at 240°. The scale at right reads "annealing time in seconds" with marks 0, 20, 40, 60, 80, 100, 120; reflections 111 and 311 are labeled for InSb.

Figure 1: Kinematic electron diffraction pattern from a double layer (In + Sb), obtained at 240°. The scale at right reads "annealing time in seconds" with marks 0, 20, 40, 60, 80, 100, 120; reflections 111 and 311 are labeled for InSb.

conclusion that from their change one can judge the kinetics of the reaction between In and Sb. Indeed, as indicated in ([3]), the local intensity of a Debye ring falling on a small segment Δ is equal to

$$I_{hkl} = I_0 \lambda^2 \left| \frac{\Phi_{hkl}}{\Omega} \right|^2 V \frac{d_{hkl}^2 \cdot \Delta}{4\pi L \lambda} P.$$

It follows from this that for lines with indices hkl, under the condition that I_0 and $2L\lambda$ are constant, $I_{hkl} \sim V$, where $V = Sh$ is the irradiated volume, h is the film thickness, and S is the cross section of the electron beam.

With a constant beam cross section, $I_{hkl} \sim h$, i.e., the intensity of a diffraction line is proportional to the thickness of the film.

Of course, it must be noted that this dependence remains valid under conditions of coherent and kinematic scattering. The absence of a noticeable background on the electron diffraction patterns indicates the coherence of scattering. At accelerating voltages of 60–75 kV, films with an average thickness up to 400 Å provide this condition. The kinematic character of the scattering is investigated separately by means of the criterion given in paper (([3]), p. 120).

Fig. 1. Kinematic electron diffraction pattern from a double layer (In + Sb), obtained at 240°.

To determine the law of growth of InSb, the above-mentioned kinematic electron diffraction patterns were photometered in different regions, in other words, at certain time intervals. Fig. 2 shows such a microphotogram, obtained from the kinematic electron diffraction pattern presented in Fig. 1. From this microphotogram one can clearly see the increase in the intensity of the 111 and 311 lines of the InSb compound. By means of a small calculation, the line intensity was converted into the thickness of the substance. From the graph of the growth of the InSb thickness as a function of the annealing time of the double layer (In + Sb) at different temperatures (Fig. 3), it is seen that the kinetics of phase formation between In and Sb obeys the parabolic law

$$h^2 = 2pt,$$

Fig. 2. Microphotogram from different regions of the kinematic electron diffraction pattern (In + Sb)

Fig. 3. Growth of the InSb thickness as a function of annealing time

where h is the thickness of the InSb being formed, t is the annealing time, $p = 2(D_{\text{In}} + D_{\text{Sb}})$, i.e., twice the sum of the diffusion coefficients of In and Sb through the InSb compound [4].

For $(D_{\text{In}}+D_{\text{Sb}})$ the following values were obtained: at $t = 200^\circ$, $4{\cdot}10^{-15}$ cm^2/sec; $t = 240^\circ$, $2 \cdot 10^{-14}$ cm^2/sec; $t = 250^\circ$, $5 \cdot 10^{-14}$ cm^2/sec.

These data lie between the data of [5] and [6] for the diffusion of the components in the InSb compound.

At the same time it was established that the reaction between the In and Sb layers is associated with the crystalline state of the primary layer onto which the secondary layer is deposited. It is known that thin Sb films obtained by slow vacuum deposition at room temperature are amorphous [7].

When In is condensed onto such an amorphous Sb layer, the reaction proceeds faster, and the Sb that has not entered into the reaction does not remain amorphous, but passes into the crystalline state. Apparently, the energy released during the condensation of In and during the formation of InSb heats the amorphous Sb layer and in this way creates conditions for its crystallization.

With rapid deposition, Sb layers crystallize with orientation relative to the substrate. When In is condensed onto such an oriented Sb layer, the InSb compound is formed in the form of a polycrystal.

The data obtained characterize the possibilities of the kinematic method of electron diffraction in the study of the kinetics of the reaction between films.

Institute of Physics
Academy of Sciences of the Azerbaijan SSR

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Note: Figure translations are in progress. See original paper for figures.