

Lead wetting of thin nickel films deposited onto GaAs

N.T.Gladkikh, S.V.Dukarov

Kharkov State University, 4 Svobody Sq., 310077 Kharkov

Received December 22, 1995

The wetting of nickel films deposited onto (111) face of GaAs single crystals with island lead condensates has been studied. The wetting angle, θ , is found to depend on the Ni film thickness, t , and to change within the limits defined by wetting of pure GaAs ($t \rightarrow 0$, $\theta \approx 120^\circ$) and compact-state nickel wetting ($t > 20$ nm, $\theta \approx 20^\circ$). The change of θ is explained as due to the surface heterogeneity arising as a result of chemical interaction between nickel film and gallium arsenide and of nickel dissolution in the liquid lead.

Изучено смачивание островковыми конденсатами свинца пленок никеля, нанесенных на монокристалл арсенида галлия (грань (111)). Установлено, что краевой угол θ зависит от толщины t пленки Ni и изменяется в крайних пределах, соответствующих смачиванию чистого GaAs ($t \rightarrow 0$, $\theta \approx 120^\circ$) и смачиванию никеля в компактном состоянии ($t > 20$ нм, $\theta \approx 20^\circ$). Изменение θ объясняется гетерогенностью смачиваемой поверхности, возникающей в результате химического взаимодействия пленки никеля с арсенидом галлия и растворения никеля в жидком свинце.

Today, a growing number of uses are being found for materials evolved on the basis of ultra-finely dispersed systems. In this connection, studies of phase interactions regularities in such materials determining their functional characteristics, become of ever more interest. The island films form a convenient object to investigate the contact interaction of phases in a highly-dispersed condition. It was found previously that, in highly-dispersed systems, the wetting is depended, both on liquid droplet size [1,2] and on thickness of the substrate film which may be free [2,3] or form an intermediate layer on the surface of a bulk body [2,4–7]. In systems with such an intermediate layer, as its thickness (t) increases, a smooth transition occurs from the wetting of the pure substrate to that of the film material in the bulk state. The critical thickness corresponding to the complete shielding of bulk substrate by the thin film was found to be of 3 to 10 nm for non-interacting systems and to increase considerably as the mutual dissolution or chemical interaction of components takes place [2,4–7].

In this work, presented are the results of wetting study in the triple system "lead microdroplets – nickel film of variable thickness — GaAs single crystal".

The experimental samples were prepared in the vacuum of 10^{-4} Pa by thermal evaporation of metals and condensation onto polished and cleaned (111) faces of GaAs single crystals. The substrate temperature was maintained at 670 K during the experiments what ensured the condensation of nickel according to vapor-crystal mechanism, while that of lead, according to vapor-liquid one. The evaporators and substrate positions were fitted so that, in one experiment, a series of samples could be obtained having the Ni film mass thicknesses from 1 to 50 nm and those of Pb order of 10 mkm. After the condensation was completed, the samples were cooled in vacuum to the room temperature and studied by means of the optical microscope MIM-8M. The wetting angles (θ) were measured by the chipping method [8] on crystallized droplets of 5 to 20 mkm size. At a fixed Ni film thickness value, the measurements were made for 15 to 30 droplets of various size and the results obtained were averaged.

Fig.1 shows microphotos of Pb particles on Ni/GaAs substrate illustrating changes in the morphology of film structure. It is seen that increase in the underlayer thickness results in amalgamation of Pb islands at a constant mass thickness of lead films and in transition from the

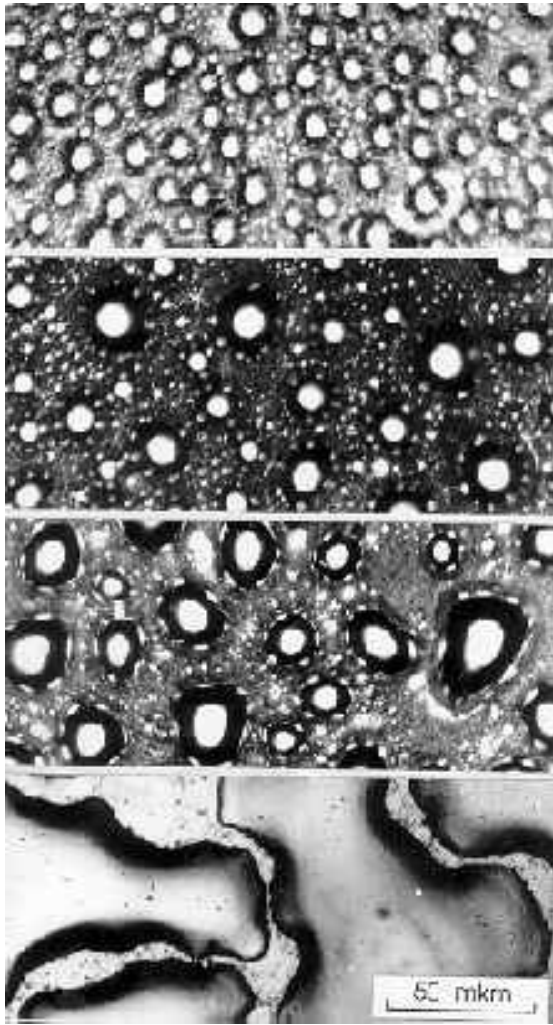


Fig.1. Microphotos of lead particles on nickel films of various thicknesses: 1 nm (a), 4 nm (b), 10 nm (c), 30 nm (d) deposited onto GaAs ($\times 400$).

spherical particles (that are usually observed in the case of poor wetting) to labyrinth-type formations which are characteristic for the liquid phase spreading over a surface.

Experimental data for the wetting of polycrystalline Ni films on GaAs substrate by island Pb condensates are given in Fig.2. Similar to triple systems with an intermediate layer studied before [2,4-7], the wetting angle varies here within a range defined by limiting cases of lead wetting of pure gallium arsenide ($t \rightarrow 0$, $\theta \approx 120^\circ$) and that of massive nickel ($t > 20$ nm, $\theta \approx 20^\circ$). However, as seen from Fig.2, the change of wetting in the Pb/Ni/GaAs system can be subdivided into two stages. First, the wetting angle diminishes to an intermediate value $\theta \approx 75^\circ$, then a plateau on $\theta(t)$ relationship is observed which was not found for similar systems studied previously. Further, the wetting angle changes again and attains the value corresponding to the Pb/Ni system. Comparison

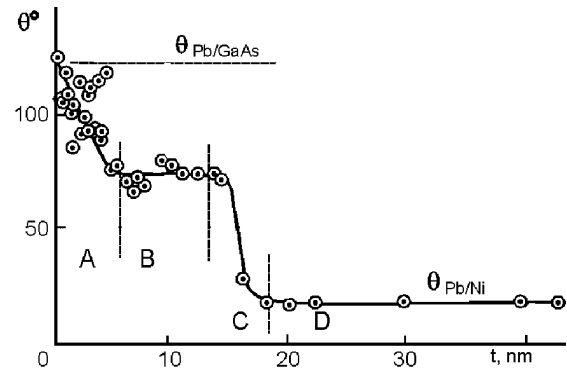


Fig.2. The wetting angle change as depended on the Ni film thickness in Pb/Ni/GaAs system.

of the data obtained with results related to analogous Pb/Ni/Si and Pb/Ni/NaCl systems [6,7] allows the conclusion that the wetting angle change in the Pb/Ni/GaAs system is associated with formation of well-wettable compounds on the Ni film / GaAs single crystal interface as well as with nickel dissolution in the liquid lead. Based on this reasoning, the $\theta(t)$ relationship shown in Fig.2 can be subdivided into four regions where various states of the surface under wetting are realized, these regions being corresponding to t ranges 0—6 nm (A), 6—14 nm (B), 14—18 nm (C) and $t > 18$ nm (D). Two of these regions are transient ones and, within those, the wetting takes place on surfaces having various degrees of heterogeneity occurring due to chemical compounds formation (region A) and dissolution of nickel in liquid lead (region C).

Thus, the mechanism of the wetting angle change in the Pb/Ni/GaAs system can be presented as follows. At $t \rightarrow 0$, the wetting angle $\theta = 20^\circ$ corresponds to the pure GaAs wetting. The condensation of nickel on the GaAs surface results in islands formation of a chemical compound wettable with lead better than pure GaAs. In A region, as the amount of deposited nickel increases, grows the part of surface coated with that compound what causes a smooth reduction of the wetting angle value down to $\theta \approx 75^\circ$. Then the compound film becomes continuous (i.e. shields the substrate completely), and the wetting stops to change (region B). However, only a limited nickel amount may react with substrate at the time of an experiment. Therefore, beginning at a certain film mass thickness $t < 14$ nm, an unreacted nickel layer remains on the substrate; up to $t \sim 14$ nm, that layer dissolves completely in lead, and at $t \sim 14$ nm, some part of it is retained on the substrate. This causes a surface heterogeneity and, therefore, the transient region C arises. At $t > 18$ nm (region D) the nickel film becomes

continuous and the wetting angle maintains the constant value $\theta \approx 20^\circ$.

It is to note that, in Ni/GaAs samples, pure nickel is not detected by electronography [9] that confirms the conclusions, based on the $\theta(t)$ relationship analysis for Pb/Ni/GaAs system.

Thus, in the system consisting of lead microdroplets on nickel film of variable thickness deposited onto gallium arsenide single crystal, a stepwise dependence of the wetting angle on the interlayer thickness is observed due to chemical compound formation on the Ni—GaAs interface.

References

1. N.T.Gladkikh, S.P.Chizhik, L.K.Grigor'eva et al., *Izv.AN SSSR. Metally*, No.4, 73 (1981).
2. N.T.Gladkikh, S.P.Chizhik, V.I.Larin et al., *Poverkhnost'*, No.12, 111 (1985).
3. N.T.Gladkikh, V.I.Larin, S.V.Dukarov, *Adgezia rasplavov i paika materialov*, No.19, 36 (1987).
4. B.D.Kostyuk, Yu.V.Naydich, G.A.Kolesnichenko, in: *Adgezia rasplavov*, Naukova Dumka, Kiev (1974), p.47.
5. B.D.Kostyuk, G.A.Kolesnichenko, S.S.Shaykevich, *Adgezia rasplavov i paika materialov*, No.6, 37 (1980).
6. N.T.Gladkikh, S.V.Dukarov, S.V.Stepanova et al., *Adgezia rasplavov i paika materialov*, No.15, 32 (1985).
7. S.P.Chizhik, N.T.Gladkikh, L.K. Grigor'eva et al., *Adgezia rasplavov i paika materialov*, No.14, 27 (1985).
8. N.T.Gladkikh, S.P.Chizhik, V.I.Larin et al., *Poverkhnost'*, No.11, 124 (1985).
9. N.T.Gladkikh, I.P.Grebennik, S.V.Dukarov et al., *Metallofizika*, **14**, 66 (1992).

Змочування свинцем тонких плівок нікелю на GaAs

М.Т.Гладких, С.В.Дукаров

Вивчено змочування острівцевими конденсатами свинцю плівок нікелю, нанесених на монокристали арсеніду галію (грань (111)). Встановлено, що крайовий кут θ залежить від товщини t плівки нікелю та змінюється у крайніх межах, що відповідають змочуванню чистого GaAs ($t \rightarrow 0$, $\theta \approx 120^\circ$) і змочуванню нікелю в компактному стані ($t > 20$ нм, $\theta \approx 20^\circ$). Зміна θ пояснюється гетерогенністю змочуваної поверхні, яка виникає в результаті хімічної взаємодії плівки нікелю з арсенідом галію та розчинення нікелю в рідкому свинці