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DISTINCTIVE FEATURES OF THE THIN-FILM STATE OF THE SUBSTANCE

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Annotation

this article explores the distinctive properties of thin films compared to bulk materials, focusing on dimensional effects that alter their behavior. It discusses how surface area, near-surface atoms, and surface tension impact physicochemical properties. Additionally, it highlights phenomena like decreased melting points and heightened strength in thin films, offering insights into their synthesis and potential applications.

Annotatsiya

Ushbu maqolada yupqa plyonkalarning materiallarga nisbatan o‘ziga xos xususiyatlari o‘rganilib, ularning xatti-harakatlarini o‘zgartiradigan o‘lchovli effektlarga e’tibor qaratildi. Unda sirt maydoni, sirtga yaqin atomlar va sirt tarangligi fizik-kimyoviy xususiyatlarga qanday ta’sir qilishi muhokama qilindi. Bundan tashqari, u erish nuqtalarining pasayishi va yupqa plyonkalarda kuchning oshishi kabi hodisalarni ta’kidlab, ularning sintezi va potentsial qo‘llanilishi haqida tushuncha berildi.

Key words

Thin films, dimensional effects, substructural effects, surface area, near-surface atoms, uncompensated bonds, surface tension, physical phenomena, quantum effects, melting point, disordered structure, metastable phases, nonequilibrium deposition, chemical equilibrium, polycrystalline films, grain size, crystallite size, material synthesis.

Kalit so‘zlar

Yupqa plyonkalar, o‘lchovli effektlar, strukturaviy effektlar, sirt maydoni, sirtga yaqin atomlar, kompensatsiyalanmagan bog‘lanishlar, sirt tarangligi, fizik hodisalar, kvant effektlari, erish nuqtasi, tartibsiz tuzilish, metastabil fazalar, muvozanatsiz cho‘kish, kimyoviy muvozanat, polikristal plyonkalar, don hajmi, kristallit hajmi, material sintezi.

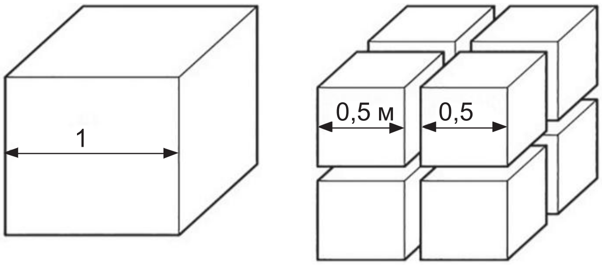
Scientific research in the field of thin films has revealed a fundamental difference between the thin-film state and the bulk ("massive") one, which lies in the presence of dimensional and substructural effects. These factors exert significant influence on grain sizes (crystals), particles, phase components, pores, and various defects within the crystalline structure, thereby affecting the physicochemical properties of the material. The manifestation of dimensional effects in thin coatings is characterized by the following main features:

1. As the size of the structural components decreases, the significance of the interface between the material (thin film) and the environment increases significantly. In solids, the arrangement of atoms in crystals exhibits periodicity in three dimensions. The emergence of a surface, such as thin films, disrupts

this periodicity and fundamentally alters the properties. As evidence of this characteristic, consider a cube with an edge length of 1 meter (see Fig. 1).

Figure 1. Dependence of the role of the surface on the size of the object

The total surface area of this object is 6 m^2 (the product of the height and width of the cube by the number of its faces). If you divide this cube into eight equal parts, then each one of them is a cube with an edge two times smaller than the original one, 0.5 m, and an area of 1.5 m^2, while the total surface area is 12 m^2. Obviously, the volume of a large cube and the total volume of small cubes are the same, but the total surface area is significantly different.



2. With a decrease in the size of the structural components, the proportion of near-surface atoms increases significantly. As the coating size decreases, an increasing proportion of atoms end up at the boundaries or free surfaces. So, for near-surface atoms (A) is proportional to the ratio of the surface area of the material (S) to its volume (V). If we denote the characteristic size of the object in question as R, then

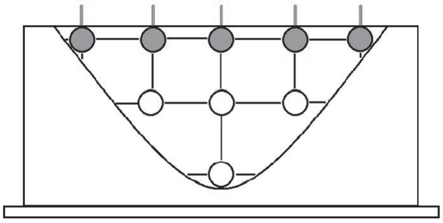
$$A = \frac{S}{V} = \frac{R^2}{R^3}$$

Thus, in a thin material, the proportion of near-surface atoms increases with a decrease in the thickness of its layer.

2. As the size of the structural components decreases, the proportion of uncompensated near-surface atoms increases. In the case of near-surface atoms, unlike those in the volume of a solid, not all bonds with neighboring atoms are involved (see Fig. 2). Consequently, strong distortions of the crystal lattice occur in the near-surface layer, which can lead to a change in its type.

Figure 2. Uncompensated bonds of near-surface atoms in a thin film

4. As the size of the structural components decreases, the effect of surface tension increases. Since surface tension forces act in the near-surface layer, their effect is akin to the application of external pressure, altering parameters such as melting point, freezing point, chemical reaction equilibrium, and interplanar distances.



5. With a decrease in the size of the structural components in thin coatings, there may come a point where their size becomes comparable to the characteristic size of certain physical phenomena.

For example, the thickness of metal films may become comparable or even less than the free path of carriers in transport phenomena, which will lead to a noticeable change in the conductivity of the material. In this case, the scattering of carriers on the surface of the film significantly affects and, as a result, its effective conductivity decreases.

6. Dimensional effects in thin films can have a quantum character when the size of the crystallite becomes commensurate with the de Broyle wavelength.

As an example of the different properties of a thin-layer sample from a "massive" one, consider the effect of the dimensional effect on physical and mechanical properties.

For a significant amount of time, a decrease in the melting point of thin film materials compared to massive samples has been noted, resulting from an increase in the amplitude of atomic vibrations in the near-surface layers. For instance, during the transition of compact silver, melting at a temperature of 1233 K, to crystallites with a size of 100 nm, the melting point decreases to 1110 K. Further reduction in grain size to 20 nm leads to an even greater decrease in the melting point, down to 593 K. It's noteworthy that the freezing point of water droplets at a radius of 2 nm decreases to 234 K (minus 39 °C).

The strength of certain films can be approximately 200 times higher than that of well-annealed bulk samples and typically several times higher than materials subjected to cold treatment.

Such remarkable strength can be attributed to two factors. Firstly, compared to cold-treated materials, polycrystalline films exhibit a more disordered structure, characterized by smaller crystallite sizes. Secondly, when films are sufficiently thin, dislocations within them, traversing the entire thickness, become obstructed at surfaces and consequently contribute minimally to plastic flow.

Numerous alloys and compounds of unconventional composition can be synthesized in the form of thin films. This capability arises from the deposition of thin-film layers under nonequilibrium conditions, resulting in the formation of metastable phases and compositions that exhibit considerable stability at room and elevated temperatures. In contrast, the presence of various phases and compositions in bulk materials is typically governed by chemical equilibrium, such as solubility considerations.

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