SURFACE MICROMORPHOLOGY RESEARCH OF LEAD TELLURIDE EPITAXIAL LAYERS, DOPED BY GERMANIUM, GALLIUM AND INDIUM

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The surface micromorphology of PbTe epilayers, doped by Ge, Ga and In has been researched, using Tapping mode of AFM Nanoscope IIIa. All the studied thin films grew layer-by-layer. The source temperature increase caused the presence of step wander in-phase with regular space. The precipitated phases, which probably played a role of doping component getter were observed on the growth surface. Having moved along the epilayer surface, they possibly changed the composition of their traces and this way created quantum wires. Their density and composition can be controlled by technological parameters, so the method of nunowires creation with pre-assigned parameters can be proposed.

Introduction

$A^{IV}B^{VI}$ semiconductors are materials of great scientific and practical interest. They are more suitable for infrared detector creation, as they are more technologically fit, uniform and stable in comparison with $A^{II}B^{VI}$.

Hot wall epitaxy (HWE) method allows to control the vapour pressure of parent materials and to accomplish epilayer growth in conditions, close to thermodynamic equilibrium.

It is known [1] that the growth character of films, which were precipitated from a vapour phase, is mainly specified by substrate and source temperatures, partial pressure of components and the growth rate.

Surface morphology in subnanometer scale characterizes the features of growth mechanism. It is well known, that these features can influence appreciably on the epitaxial layer properties. Particularly, step flow growth mechanism, which usually allows to obtain epitaxial layers of the highest structure perfection, is often accompanied by monoatomic in-phase step wandering [2]. In this case in the areas of creating terraces the mechanism of impurity embedding into the lattice is changed. As a result in the epitaxial film the terrace riser leaves the trace, with the doping level, which differs from other ones. That is why the study of such kinds of specialties is very important to obtain the layers with high electrophysical parameters.

The purpose of the work is to learn the dependence of morphological features of the systems, based on lead telluride on the impurity type and technological parameters.

Experimental

PbTe films, doped by Ge, Ga as well as In ($Pb_{1-x}Ge_xTe$ (x=0.006), $Pb_{1-x-y}Ge_xGa_yTe$ (x=0.06, y=0.003) and $Pb_{1-x}Ge_xTe$:In (x=0.12, C_{In}=0.01)), were grown by modified HWE method on fresh cleavages of BaF_2 (111) in vacuum chamber at pressure about 10^{-5} mm Hg. The four-zone furnace was used. It consisted of hot wall tube and three vapour sources to evaporate the semiconductor and the doping components. Substrate temperatures were varied within

430÷600°C. The thickness of the obtained films was in the interval 1.6÷44 μm.

Crystal lattice identification was carried out by X-ray diffractometry (XRD). The lattice period is practically the same as in bulk material. The films are single-crystalline type. The average angle of block misorientation is within 3.0÷3.3 minutes, the dimensions of the regions of coherent scattering are ~ $6\cdot10^{-5}$ cm and ~ $5\cdot10^{-2}$ cm lengthwise and crosswise to the direction of the wave vector. The nonuniformity of interplane distances $(\Delta d)/d$ was about $(4.9\div7.4)\cdot10^{-5}$. These data confirm high structure perfection of the grown films.

The surface morphology of the deposited films was studied by atomic force microscope (AFM) Nanoscope IIIa (Dimension 3000). Tapping mode was applied for measurements. Commercially available silicon probes CSG10 (produced by NT-MDT) with nominal tip radii ~10 nm were used. The investigations were carried out at ambient conditions.

Results and discussion

During the epitaxial film growth physical and technological parameters determine the character of condensation and postcondensation processes. The growing film surface is the result of complex superposition of all growing processes and, consequently, the level of structure perfection of the film.

It is well known, that for heteroepitaxial growth three types of growth modes can be realized, depending on the specific surface free energies of the substrate-vacuum (E_S), substrate-overlayer (E_I) and overlayer-vacuum (E_L). If $E_S<E_I+E_L$, than the nucleation of three-dimensional (3D) clusters onto the substrate occurs (Vollmer-Weber growth mode). On the contrary, if $E_S>E_I+E_L$, a homogeneous two-dimensional (2D) wetting overlayer is formed (Frank van der Merwe mechanism) [3]. If one includes also the possibility of a lattice-mismatch between the overlayer and the substrate, in many cases after a few monolayers of wetting overlayer the growth changes to 3D island (Stranski-Krastanow mechanism) growth.

In all researched systems the layer-by-layer growth took place. For $Pb_{1-x}Ge_xTe$ (x=0.006) structures, obtained at the source temperature of 502°C and the substrate temperature of 487°C regular array of steps was observed (Fig. 1a). If the source temperature increases up to 518°C, the terrace straightness is disturbed and step wander in-phase with regular space (100÷250 nm width and about 0.68 nm height) becomes predominant. (Fig. 1b).

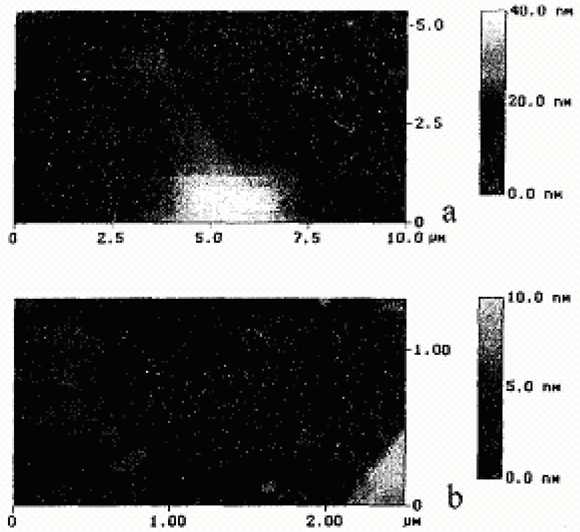

Fig.1 AFM images of PbGeTe film surface, obtained at the substate temperature of 487 °C and the source temperature of 502 °C(a) and 518 °C(b).

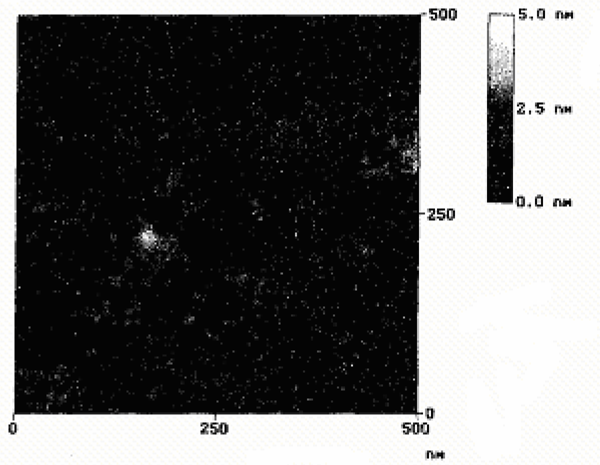

Fig.2. Terrace growth wedge-like protrusion, formed by Ge phase precipitation on PbGeTe film surface.

The step height complies with the PbTe lattice period (~0.64 nm). Besides, the presence of single precipitations of another phase is typical for this surface. Most probably it is germanium phase precipitation, which is caused by the partial pressure boost at the evaporation temperature increase. The lateral size of the precipitations is about 20 nm.

The precipitated phase is an intense getter, which evinces in the wedge terrace bulge, which achieves up to 1.2 nm height (Fig.2). The growth mechanism is to be learned thoroughly, since one can suppose, after precipitation the dopant phase nanoinclusion is displaced towards the step growth, while gettering Pb and Te atoms actively. This gettering stimulates the film growth in the areas, close to the precipitations.

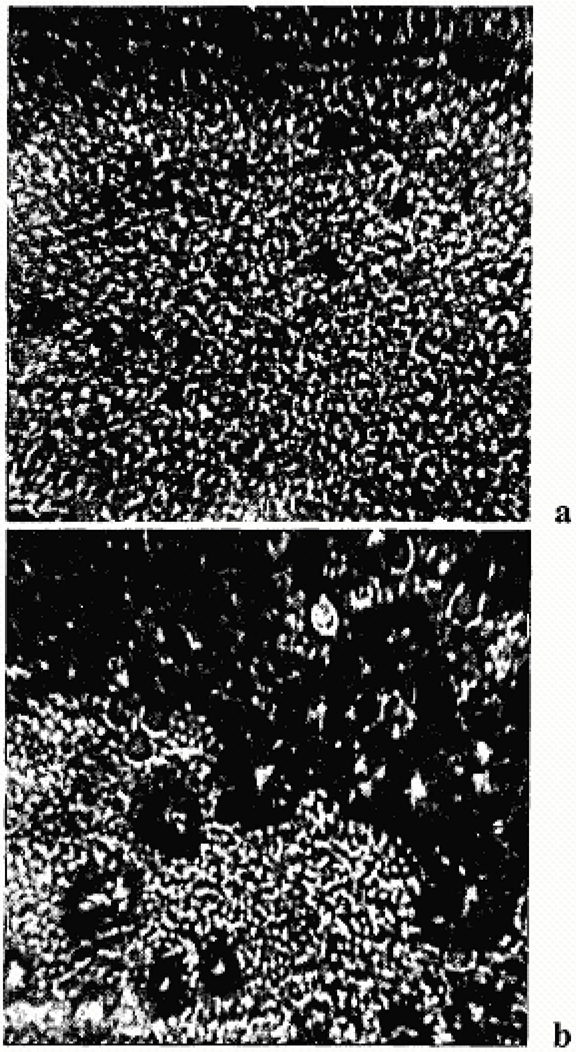

Fig.3. The surface of PbGeTe film, deposited with the additional Te source application at the evaporation temperature of (a) 375°C and (b) 403°C. The image is obtained by the optical microscope. The field width is 560×560 μm.

Component phase precipitations are typical at the process of the film growth in the quasi-closed space [1]. It especially evinces in the case of component doping from the additional sources. In Fig.3 one can see the surface image of PbGeTe film, which is obtained with the usage of additional Te source.

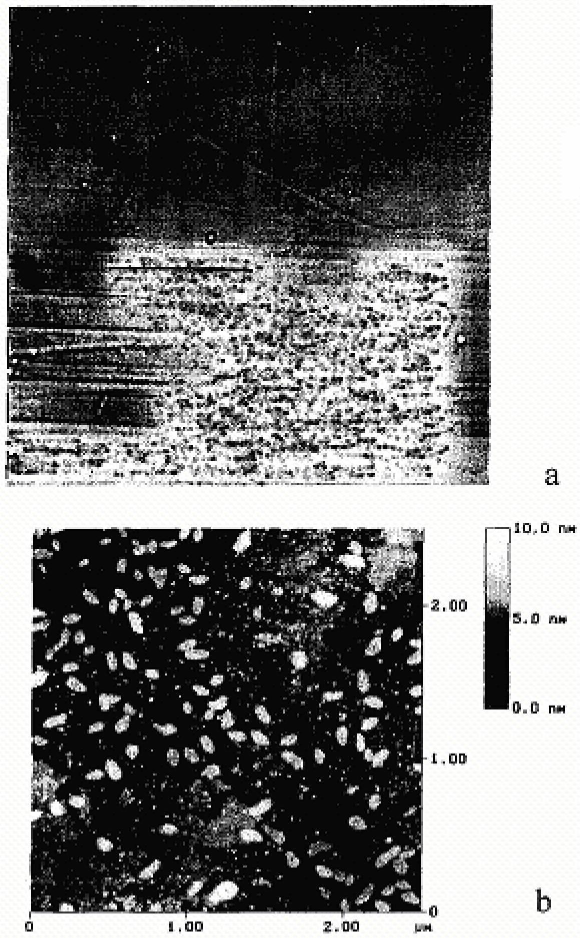

Fig.4. The optical (a) and AFM (b) surface image of the film, deposited with additional Te source application at the evaporation temperature of 542°C.

The film is densely covered with 3D islands, which are caused by precipitated Te phase. The bimodal distribution of the islands in size is observed at the temperature increase. At microlevel growth terraces are not visible practically and the nanoinclusions are also absent. The further temperature increase of the additional source causes the precipitation amount decrease. Since, the precipitations on the film surface, deposited at the additional source temperature of

542 °C are not observed in the optical image (Fig. 4, a). AFM image demonstrates the presence of a great quantity of submicron 3D islands (Fig.4,b).

PbGeTe film growth with the additional Pb source application has the similar character. At the macrolevel the precipitations of the component phase on the film surface is not observed practically. The growth of 3D islands may occur and their density decreases with the additional source temperature increase (Fig.5).

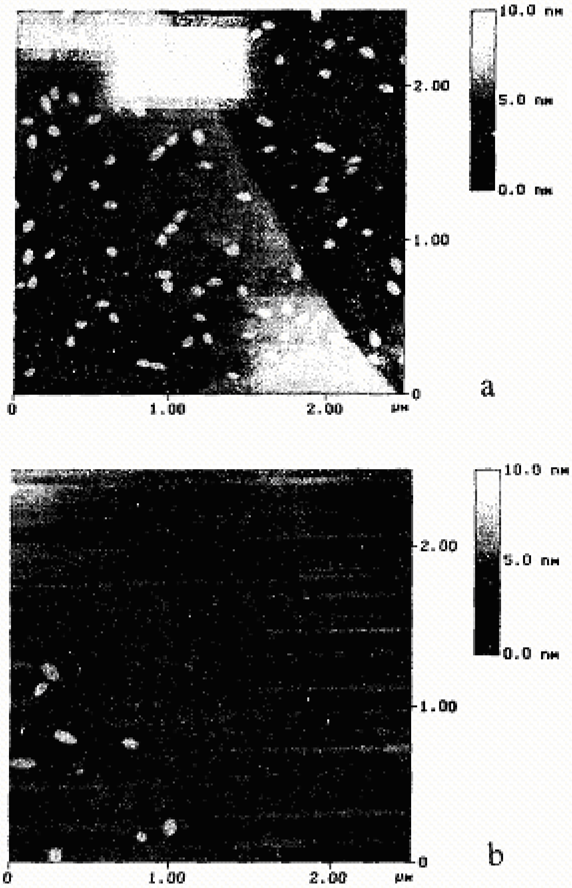

Fig.5. AFM images of PbGeTe film surface, deposited with the additional Pb source application at the evaporation temperature of (a) 600°C; (b) 750°C.

Doping by Ga causes more ordered film growth in comparison with the previous system. On the $Pb_{1-x-y}Ge_xGa_yTe$ (x=0.06, y=0.003) film surfaces monoatomic steps in the width of about 150÷350 nm are observed. If the substrate temperature increases from 427°C up to 447°C and the film growth speed decreases, the epilayers are formed more homogeneously. In this case the films are more structurally perfect.

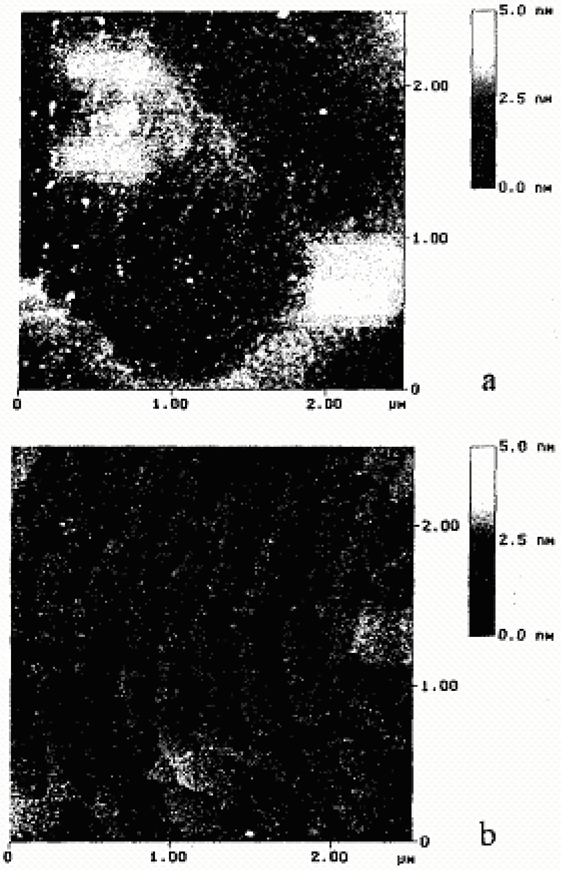

Fig.6. AFM images of PbGeGaTe film surface deposited at the substrate temperature of 427°C and the growth rate 3.5 μm/hour (a); 447 °C and 1.0 μm/hour, respectively (b).

The $Pb_{1-x}Ge_xTe$:In (x=0.12, C_{In}=0.01) epilayer surface, deposited on the BaF_2 substrate at the temperatures of 450÷480°C succeeds the above-mentioned PbGeTe film morphology. Since, as the Ge concentration in this system is greater, the density of Ge nanoinclusions and the resulting wedge-like protrusions is higher (Fig.7,a). The substrate temperature decrease and the source temperature increase causes phase precipitation of the other components (Fig.7,b). Unfortunately, it is impossible to clarify the exact nature of those phases by the applied methods. We can suppose that those phases could be nanobumps of In.

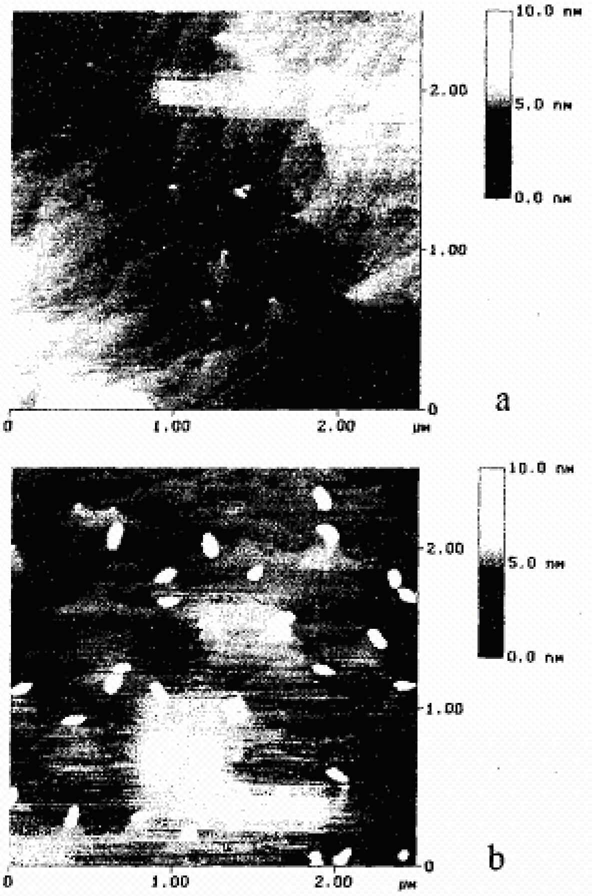

Fig.7. AFM images of PbGeTe:In epilayer surface deposited at the substrate and the source temperatures of (a) 487°C and 501°C, respectively; (b) 450°C and 517°C, respectively.

Conclusions

AFM is one of the most valuable methods for the surface micromorphology research of HWE-grown epitaxial layers. While using tapping-mode of AFM one can obtain high-quality images of thin film surfaces.

Lead telluride epitaxial layers, doped by Ge, Ga and In grow layer-by-layer. Both tracked in the epitaxial film space terraces, and the protrusions have to cause the creation of the "tails" with another doping level. They may be considered as pieces of quantum wires.

The density and composition of those nanowires may probably be controlled by technological growth parameters. This way the prototype of nanowire creation methods can be proposed.

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ВИВЧЕННЯ МОРФОЛОГІЇ ПОВЕРХОНЬ ЕПІТАКСІЙНИХ ПЛІВОК ТЕЛУРИДУ СВИНЦЮ, ЛЕГОВАНИХ ГЕРМАНІЄМ, ГАЛІЄМ ТА ІНДІЄМ.

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Використовуючи дотикову моду атомного силового мікроскопу (АСМ) Nanoscope IIIa, було вивчено морфологію поверхонь епітаксійних шарів PbTe, легованих Ge, Ga та In. Ріст усіх плівок був пошаровим, який з підвищенням температури джерела набував звивистого типу. На поверхнях росту досліджених плівок спостерігалося виділення фаз компонент, що, напевно, відігравали роль гетерів легуючих домішок. Просуваючись по поверхні епітаксійного шару, вони, вірогідно залишають за собою слід, змінюючи склад плівки та утворюючи в такий спосіб квантові дроти.
Оскільки технологічними параметрами вирощування епітаксійних шарів можна регулювати густину та склад гетерів, то ефект утворення останніх можна розглядати як прототип технології формування квантових дротів з наперед заданими параметрами.