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STRUCTURAL FEATURES OF THE SOLID SOLUTION (GaAs)1-x-y(Ge2)x(ZnSe)y WITH QUANTUM DOTS (0≤x≤0,17; 0≤y≤0,14)

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SEMICONDUCTOR PHYSICS

СТРУКТУРНЫЕ ОСОБЕННОСТИ ТВЕРДОГО РАСТВОРА $(GaAs)_{1-X-Y}(Ge_2)_{x}(ZnSe)_y$ С КВАНТОВЫМИ ТОЧКАМИ (0≤X≤0,17; 0≤Y≤0,14)

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Аннотация. *Рентгенодифракционное исследование показало, что полученная пленка имеет сфалеритную структуру и является монокристаллической с ориентацией (100). Параметр кристаллической решетки пленки составлял* a_f = *0,56697 нм. Атомно-силовая микроскопия показала возможность получения полупроводниковой гетероструктуры с квантовыми точками методом жидкофазной эпитаксии.*

Ключевые слова: *эпитаксия, полупроводник, гетероструктура, монокристалл, сфалерит, ориентация, нанокристалл.*

STRUCTURAL FEATURES OF THE SOLID SOLUTION $(GaAs)_{1-x-y}(Ge_2)_x(ZnSe)_y$ WITH QUANTUM DOTS (0≤x≤0,17; 0≤y≤0,14)

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Abstract. *X-ray diffraction studies showed that the resulting film has a sphalerite structure and is single-crystal with the (100) orientation. The lattice parameter of the film is* a_f *= 0.56697 nm. By atomic force microscope was shown the possibility of obtaining a semiconductor heterostructure with quantum dots by the method of liquid phase epitaxy.*

Keywords: *epitaxy, semiconductor, heterostructure, single crystal, sphalerite, orientation, nanocrystal.*

It is known that the semiconductor heterostructures are now widely used for fabricating detectors and converters of optical radiation. They are an integral component of such important optoelectronic devices as heterojunction lasers. This has resulted in the intense development of the physics and technology of two-layer and multilayer semiconductor heterostructures. Nowadays, three methods are used to obtain semiconductor heterostructures: liquid-phase epitaxy (LPE), chemical vapor deposition (CVD), and molecular-beam epitaxy (MBE). In the most widely used method LPE, an epitaxial layer is deposited from a solution-melt, which is in contact with the surface of a substrate for obtaining A^3B^5 films. As a solvent, elements of Group 3 of the periodic table are used more often. CVD is used mainly for growing epitaxial heterostructures based on A^3B^5 semiconductors. In MBE, epitaxial layers are grown by deposition onto a substrate of atoms or molecules, the fluxes of which are formed in ultrahigh vacuum. In all methods, a necessary condition for obtaining high-quality heterostructures is compatibility of the lattice parameters of the substrate and the film, and also of the coefficients of linear thermal expansion of the materials [1, 2]. The physical properties of heterostructures and the characteristics of devices on their basis depend mainly on the internal stresses and defects in the epitaxial layers. Thus, determination of the optimum technological conditions, the structural parameters, and the physical properties of particular heterostructures is important from both physical and technological viewpoints. In this context, we present here the results of investigations carried out over the last years on the growth conditions, the structure, and the surface characteristics of the $(GaAs)_{1-x-y}(Ge_2)_x(ZnSe)_y$ with quantum dots semiconductor alloy.

The epitaxial films of $GaAs)_{0,69}$ $(Ge_2)_{0,17}(ZnSe)_{0,14}$ have been obtained by the method of liquid-phase epitaxy. The substrates were served by the plates made from arsenide gallium with diameter of 20 mm and the thickness of 350 microns, carved in the crystallographic direction (100) doped tin with concentration of $(3\div5)\cdot10^{17}$ cm^{-3}. Temperature range of the crystallization amounted at $640\div740$ ^oC, at the velocity of growing was υ = 0,1 micron/min. The grown films with the conductivity of p-type had the thickness of d = 10 micrometers. The surface condition of the grown epitaxial layers was investigated by atomic-force microscope. The structural studies of the grown films, as with the substrates so the films were performed at 300 K on an improved X-ray diffractometer DRON-3M (CuK_α - radiation, λ = 0.15418 nm) according to the scheme θ - 2θ in the mode of step scanning. The chemical composition of the epitaxial layers has been determined from the data of X-ray-structural analysis.

On the fig.1 three-dimensional images of the surface of epitaxial films of $(GaAs)_{0,69}(Ge_2)_{0,17}(ZnSe)_{0,14}$ are presented. In fact, that the formation of islet (nanostructures) is composed from the components (ZnSe) on the surface of the epitaxial layer in the growth process, that is stay formed the quantum dots almost the same size and different heights are formed (Fig. 1). These quantum dots are created the local electrostatic field at the distance 100÷150 nm, that the intensity is $E = 10^7\div10^9$ V/cm. According to Franz-Keldysh effect, such the strong local electric field should lead to the change in the band gap of the solid solution around the quantum dots [3].

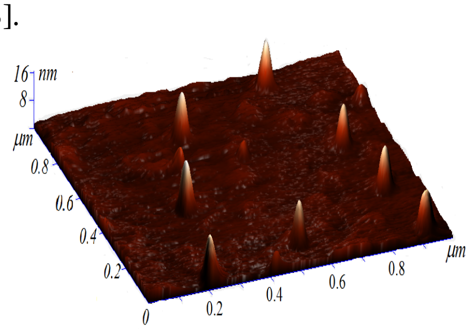

Fig.1. Three-dimensional images of the surface of epitaxial films $(GaAs)_{0,69}(Ge_2)_{0,17}(ZnSe)_{0,14}$ obtained by the atomic-force microscope.

In Fig. 2, we show the X-ray diffraction pattern of the GaAs substrate. It can be seen that there are several selective structural reflections with different intensities in the diffraction pattern. The analysis showed that the substrate surface corresponds to the (100) crystallographic plane. The presence of a series of selective reflections of the {*H*00} type (where *H* = 1, 2, 3...) with high intensities on the X-ray diffraction pattern is evidence of this; the structural lines are $(200)_{GaAs}$, with *d/n* = 0.2814, $(400)_{GaAs}$ with *d/n* = 0.1412, and $(600)_{GaAs}$ with *d/n* = 0.09422 nm. Their β components can be seen at the scattering angles 2θ = 28.2°, 2θ = 58.8°, and 2θ = 95.2°, respectively. In the diffraction spectrum at average scattering angles, the structural reflection $(220)_{GaAs}$ with *d/n* = 0.1998 nm is still observed at 2θ = 45.4° with a low intensity. The high intensity (2 x 10^5 pulse·s^{-1}) of the main reflection $(400)_{GaAs}$, a relatively narrow width (FWHM = 0.0039 rad), and the flat minimum of the inelastic background are evidence of a high degree of perfection of the substrate crystal lattice. The experimentally determined value of the substrate lattice parameter is a_{GaAs} = 0.56532 nm, which is very close to its tabulated value of a_{GaAs} = 0.5646 nm [4].

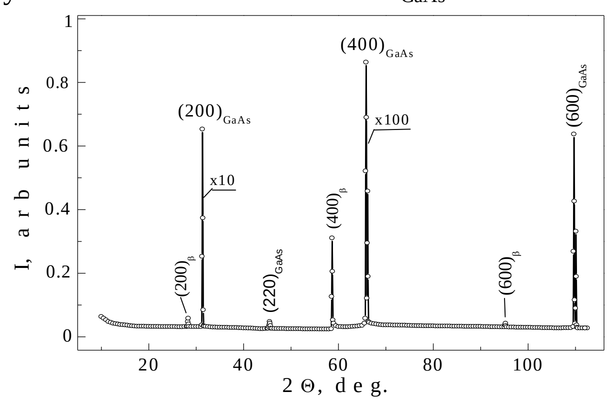

Fig.2. X-ray diffraction pattern of the GaAs substrate

In Fig. 3, we show the X-ray diffraction pattern of an epitaxial film of the $(GaAs)_{0,69}(Ge_2)_{0,17}(ZnSe)_{0,14}$ solid solution. It substantially differs from the X-ray diffraction pattern for the substrate and an increase in the intensity of the main reflection (400) at 4.5% is observed in it; the intensities of reflections (200) and (600) are increased by 1.7 and 1.4 times, respectively, and the intensity of the reflection (220) is increased insignificantly. New structural lines with *d/n* = 0.1268 nm (2θ = 74.9°), *d/n* = 0.1263 nm (2θ= 75.2°) and *d/n* = 0.1001 nm (2θ = 100.8°) are simultaneously observed, as well as nonmonotonic character of the inelastic-background level in the regions of small and average scattering angles. A relatively narrow width (FWHM = 4.36·10^{-3} rad) and a high intensity (2 x 10^5 pulse·s^{-1}) of the main reflection (400) and also the presence of other even orders of reflection on the X-ray diffraction pattern, testify to a high degree of perfection of the film crystal lattice. This means that the grown film has the sphalerite structure (ZnS-type structure) and is single-crystal with the (100) orientation. The size of subcrystallites (blocks) in the film estimated from the width of this peak amounts to about 52 nm. The lattice parameter of the film that defined according to the three reflections - (200), (400) and (600) by means of the extrapolation function Nelson Reilly $\xi = (1/2)\cdot[(Cos^2\theta/\theta + (Cos^2\theta/Sin\theta)]$ [5] and it is a = 5,6568 Å. The structural maximum (440) with d / n = 0.1001 nm belongs to the crystal lattice of Ge nanocrystals with size ~ 44 nm. The value of the lattice parameter of the nanocrystals Ge that determined from X-ray picture amounted a_{Ge} = 5.6625 Å. The experimentally determined value of the parameter lattice of zinc selenium and arsenide gallium amounted a_{ZnSe} = 5.6697 Å and a_{GaAs} = 5.6697 Å, respectively. The size of the nanocrystals impurity phase of ZnSe estimated according to the width of the peak (600) is about 59 nm. It is shown that by the thickness of the film and the content of molecules Ge_2 and ZnSe varies within the range $0 \le x \le 0.17$ and $0 \le y \le 0.14$, which reduces the elastic stresses due to the mismatch parameters of lattice between the substrate and the film [6].

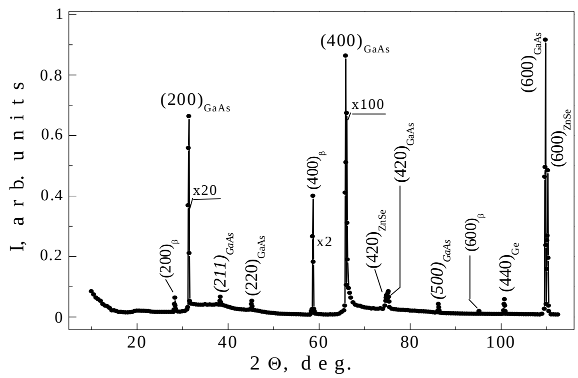

Fig.3. The X-ray picture of the epitaxial film of $(GaAs)_{0,69}(Ge_2)_{0,17}(ZnSe)_{0,14}$

Thus, on the basis of analysis of the technological modes of the synthesis of epitaxial layers of the $(GaAs)_{0,69}(Ge_2)_{0,17}(ZnSe)_{0,14}$ alloy on GaAs substrates and the results of the performed investigations, it is possible to make the following conclusions:

- the optimum technological modes are determined for the growth of structurally perfect epitaxial layers of the $(GaAs)_{0,69}(Ge_2)_{0,17}(ZnSe)_{0,14}$ alloy with 10 μm thick on GaAs substrates (cooling rate of 1÷1.5 deg/min, temperature of 730÷640°C, and growth rate of0= 0.15 μm/min);
- the grown $(GaAs)_{0,69}(Ge_2)_{0,17}(ZnSe)_{0,14}$ films have the sphalerite structure and are single-crystal with blocks 52 nm in size and an orientation corresponding to the (100) substrate orientation;
- molecules of ZnSe and Ge partially replaced molecules of GaAs in the defect-capable areas matrix on the borders and border areas of the section, followed by segregation of germanium ions and zinc selenium molecules to form nanocrystals (quantum dots).

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