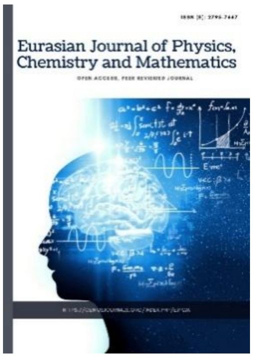

The influence of ytterbium on the optical properties of epitaxial films of GaAs and $Al_XGa_{1-X}As$

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ABSTRACT

The emission characteristics of epitaxial layers of GaAs and $Al_XGa_{1-X}As$ with the addition of the rare earth element Yb were determined using the photoluminescence method. In the exciton regions of $Al_XGa_{1-X}As$ epitaxial films, new photoluminescence maximum lines were determined for the doped ytterbium atoms. The influence of the ytterbium atom concentration on the change in the photoluminescence characteristics of GaAs and $Al_XGa_{1-X}As$ epitaxial films has been determined.

Keywords: photoluminescence, quantum well, temperature.

$Al_XGa_{1-X}As$ and GaAs epitaxial layers were obtained by liquid phase epitaxy with the addition of the rare earth element Yb to a gallium melt. Measurements of electrophysical parameters, photoluminescence, and stoichiometry showed that when introducing rare earth elements, there is an optimal concentration of Yb in the melt ($N^{ж}_{Yb} \sim 0.5 \times 10^{-4}$ atomic fractions) that allows high-quality layers to be obtained. At this concentration, Yb mainly acts as a getter for residual impurities and a catalyst for heterogeneous equilibrium in the melt; its entry into the solid phase in the form of single atoms does not deteriorate the electrophysical parameters of the layers. When small amounts of rare earth elements are added to the melt using liquid phase epitaxy (LPE), super-pure unalloyed layers of GaAs [1,2], InP, and InGaAs are obtained. This method utilizes the effective gettering properties of RE, and the degree of purification depends on the initial purity of the materials, the characteristics of the technological process [2], and the type of RE. However, the question of the form in which REE impurities enter the epitaxial layers (EL) (in the form of single atoms and/or microinclusions) remains controversial. Quantitative direct estimates of the REE content in $A_{III}B_V$ EL depending on its content in the melt are highly contradictory. To understand the influence of RE on the formation of ES properties obtained by the ZFE method and the mechanisms of their incorporation into the solid phase, we conducted experiments on GaAs ES at various concentrations of Yb in the melt [3]. Based on the results obtained, optimal conditions for growing $Al_XGa_{1-X}As$ ES were selected.

GaAs and $Al_XGa_{1-X}As$ ES with a thickness of 6-12 μm were grown under identical conditions from molten Ga on semi-insulating GaAs substrates (100) substrates in a hydrogen flow (~ 15 L/h) at an epitaxy start temperature of ^680°C. The cooling rate was ~ 1.2 °C/min for GaAs ES and 0.7 °C/min for $Al_XGa_{1-X}As$.

Parameters of the studied GaAs and AlxGa1-xAs epitaxial layers

ЭС	d layer, µm	Alloying impurities	N_0 10^{14}	Conductivity type	300 К, см^2/(В с)	n,p sm^{-3}
GaAs	11	-	-	n	2600	7,5x10^{17}
GaAs	8,2	Yb	0,01	n	3840	1,3x10^{17}
GaAs	8,8	Yb	0,18	n	3530	1,3x10^{17}
GaAs	7,3	Yb	0,34	n	3000	4,6x10^{16}
GaAs	6,0	Yb	0,48	n	5000	3,0x10^{16}
GaAs	10,0	Yb	0,49	n	3700	1,4x10^{17}
GaAs	9,2	Yb	0,64	n	4200	7,3x10^{16}
GaAs	10,3	Yb	0,81	n	4400	2,0x10^{16}
AlGaAs	12,8	Al	2.32	n	3400	1,0x10^{17}
AlGaAs	12,0	Al Yb	0,48 2.32	p	400	2,4x10^{14}

The concentration of Yb in the Ga melt ($N^{ж}_{Yb}$) was varied for GaAs layers (0 < $N^{ж}_{Yb}$ < 8 x IO^{14} atomic fractions). Polycrystalline GaAs (AGN-1) was used to saturate the melt with arsenic, and the homogenization time of the melt was >1.5 h, similar to [3]. Graphite cassettes annealed in hydrogen for 5 h at a temperature of ~950°C were used. The parameters of the layers are given in the table. A detailed study of changes in the parameters of GaAs ES depending on the concentration of Yb in the melt showed that many of them, in particular stoichiometry, the position of the maximum of the luminescence edge band and its half-width, mobility, are non-monotonically related to an increase in ($N^{ж}_{Yb}$) . Based on the totality of all experimental results, we have proposed a qualitative model of the influence of rare earth elements on the formation of ES properties and the mechanism of Yb incorporation into the GaAs ES. The concentration interval ($N^{ж}_{Yb}$) can be divided into two regions.

The first area is the concentration of rare earth elements in the melt NжYb ≤0.48 x 10-4 atomic fractions: at minimum concentrations, Yb is mainly a getter for residual impurities and, at the same time, a catalyst for heterogeneous equilibrium in the melt, changing the stoichiometry of the ES; with an increase in ($N^{ж}_{Yb}$), ytterbium enters the solid phase in insignificant amounts in the form of single atoms. When the RSE content increases to $N^{ж}_{Yb}$ 1 > 0.48 x 10~^{4} atomic fractions, i.e., when transitioning to the second region, while remaining a getter and catalyst, Yb enters the ES in the form of microinclusions, with coagulation processes intensifying as ($N^{ж}_{Yb}$), increases. Thus, when using Yb in gallium dispersion, there is a certain range of its concentrations at which it becomes possible to obtain sufficiently pure, stoichiometric GaAs ES with good electrophysical parameters. These ideas were used when selecting the conditions for obtaining $Al_XGa_{1-X}As$ films.

They were grown at an NжYb concentration corresponding to its optimal value for GaAs ES (~(~4.8 x Al_xGa_1-10^{-4} atomic fractions). Obtained under the same conditions and with the same A1 additives in the melt ($N^{ж}_{Ai}$ = 2.32 x 10^{-4} atomic fractions), $Al_XGa_{1-X}As$ ES with and without Yb differed sharply in their electrophysical characteristics (table). At the level of resolution of the X-ray topographic and diffractometric methods used, no changes in the structural perfection of the ES obtained under different conditions were observed.

We managed to achieve fairly high parameters in terms of both mobility and concentration of free charge carriers, which confirms the correctness of the assumptions used in selecting the optimal Yb loadings. Some improvement in their quality (e.g., an increase in the intensity of the edge band of radiation and a narrowing of its half-width), which is obviously related to the influence of Al itself on the formation of film properties [3]. The characteristics of the edge band obtained at temperatures indicate a sufficiently high quality of the $Al_XGa_{1-X}As$. Typical FL spectra for E A l0.03Ga0C.97As with and without Yb at T = 4.2 K are shown in Fig. 1. A comparison of the FL spectra for ES $Al_{0.03}Ga_{0}C_{.97}As$ with and without Yb showed that as the ES parameters improve, there is a slight shift in the position of the edge band maximum towards lower energies (by ~3 meV) without a significant change in its half-width (W ~ 5.8 meV). When processing the FL spectra measured at different temperatures, they indicate a sufficiently high quality of the $Al_XGa_{1-X}As$ 3 ES. Typical FL spectra for E $Al_{0.03}Ga_{0}C_{.97}As$ with and without Yb at T = 4.2 K are shown in Fig. 1.

Fig. 1. FL spectra in the edge region (0.79–0.92 μm) at T = 4.2 K for ES $Al_{0.03}Ga_{0}C_{.97}As$ without Yb (1) and with Yb added (2).

Comparison of the FL spectra for ES $Al_{0.03}Ga_{0}C_{.97}As$ with and without Yb showed that with improvement of the ES parameters, there is a slight shift of the edge band maximum towards lower energies (by ~3 meV) without a significant change in its half-width (W ~ 5.8 meV). This may be due to several processes occurring during the formation of the ES. Thus, it can be assumed that Yb, with an atomic radius significantly exceeding the atomic radius of Ga (rY > rGa), enters the ES, and the resulting compression deformations in the layer (tension deformations in the substrate) cause the maximum to shift toward higher energies, while a decrease in the Al content causes the maximum to shift in the opposite direction. Therefore, it is difficult to make an unambiguous judgment about the change in the value of x, which was determined for $Al_xGa_{1-x}As$ layers without Yb, in ES with Yb. However, it can be assumed that the concentration of A1 in ES is slightly lower.

The composition of solid solutions in AlxGa1-xAs was calculated using the formula ^($Al_xGa_{1-x}As$) = (GaAs) + 1.247x , where x is the molar fraction of A1, Y-so; is the energy position of the maximum edge band of the FL at G = 4.2 K. In the range O < x < 0.1, the influence of internal mechanical stresses arising from the mismatch of the film and substrate lattice parameters ($\varepsilon < 10^{\sim 5}$)was not taken into account. The homogeneity of the AlGaAs ES composition was controlled by layer-by-layer etching. This may be due to both a decrease in the concentration of Al in the epitaxial structure and a slight increase in the concentration of Yb, which is part of the ES [3] (assuming that all Al atoms occupy places in the Ga sublattice -Al(za and all Yb atoms are also located in the Ga sublattice - Yb^{Ga}). However, if we use the ideas about the influence of Yb on the processes of forming the properties of GaAs films, then a decrease in the value of x is very likely, which is consistent with the results of FL. Nevertheless, studies have shown that for a specific rare earth element (in this work, Yb), there is an optimal content in the melt (when the rare earth element does not yet affect the electrophysical parameters), allowing high-quality ESs of both binary and ternary compounds to be obtained for industrial use.

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