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Laser diode bars based on strain-compensated AlGaPAs/GaAs heterostructures

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Abstract. **Traditional (in the AlGaAs/GaAs system) and phosphorus-compensated (in the AlGaAs/AlGaPAs/GaAs system) laser heterostructures emitting at a wavelength of 850 nm are grown by MOVPE and studied. Laser diode bars are fabricated and their output characteristics are studied. The method used to grow heterolayers allowed us to control (minimise) mechanical stresses in the AlGaPAs/GaAs laser heterostructure, which made it possible to keep its curvature at the level of the initial curvature of the substrate. It is shown that the use of a compensated AlGaPAs/GaAs heterostructure improves the linear distribution of emitting elements in the near field of laser diode arrays and allows the power – current characteristic to retain its slope at high pump currents owing to a uniform contact of all emitting elements with the heat sink. The radius of curvature of the grown compensated heterostructures turns out to be smaller than that of traditional heterostructures.**

Keywords: *laser diode bars, epitaxial heterostructures, mechanical stresses, radiation pattern.*

1. Introduction

The AlGaAs/GaAs semiconductor heterostructures (HSs) are widely used in modern laser technique, in particular, for creating laser diodes (LDs) emitting in the spectral region of 700 – 870 nm [1]. This material system is traditionally considered to be ideal from the viewpoint of coincidence of the lattice constants of semiconductor substrate and epitaxial layers. This system, unlike other systems (for example, AlGaInP/GaAs, GaInPAs/InP, and AlGaInAs/InP), does not require additional technological procedures for controlling mechanical stresses during the growth of high-quality crystalline HS layers [2]. However, despite the absence of misfit dislocations, these HSs suffer residual mechanical stresses lower than the threshold of formation of misfit dislocations. The mentioned strains may curve a HS wafer after its thinning in the planar technique of LD fabrication, which is very important for some practical applications. It is these stresses that cause the so-called smile of LD bars [3, 4]. The smile complicates mounting of LD arrays, increases the thermal resistance of devices, and spoils the focusing of laser beams.

An obvious solution of the problem is to reduce mechanical stresses in HSs by controlling the lattice constants of individual layers composing the HS, as is done in AlGaInP/GaAs, GaInPAs/InP, AlGaInAs/InP, and other HSs [2]. One of the possible methods for reducing mechanical stresses in the considered AlGaAs/GaAs HSs is the introduction of phosphorus into the solid solution composition in order to compensate the difference in the lattice constants of deposited layers and substrate.

The aim of the present work is to study the applicability of this approach on the example of AlGaAs/GaAs HSs for LD arrays emitting at a wavelength of 850 nm.

2. Experimental

Epitaxial HSs based on AlGaAs/GaAs and AlGaAs/AlGaPAs/GaAs were grown by MOVPE in a Sigmos-130 setup with a horizontal quartz reactor. As sources, we used trimethylgallium, trimethylaluminium, diethylzinc, silane, arsine, and phosphine. The carrier gas was hydrogen. The HSs were grown on n-GaAs (100) substrates. We studied two types of HSs. Separate-confinement double HSs had two gallium arsenide quantum wells and symmetric $Al_{0.37}Ga_{0.63}As$ waveguides. Emitting layers had the composition $Al_{0.60}Ga_{0.40}As$ (traditional design) in the first case and $Al_{0.60}Ga_{0.40}P_{0.03}As_{0.97}$ in the second case (the molar fraction of phosphorus was calculated from mechanical stresses in HSs).

The structures were studied by X-ray diffractometry using a Vector setup. In addition, we measured the radius of curvature of HSs by optical reflectometry using an EpiCurveTT system.

Using the obtained HSs, we made laser elements with the contact width $W = 150$ μm and the cavity length $L = 1000$ μm. The reflection coefficients of the front and rear facets with optical coatings (R_1 and R_2) were 0.03 – 0.05 and 0.95 – 0.98, respectively. We formed laser bars 5 mm long of ten LDs with a filling factor of 30% and studied their output characteristics.

3. Measurement results

Residual stresses in AlGaAs/GaAs HSs are caused by a difference in the lattice constants of the GsAs substrate and the multilayer composition based on $Al_xGa_{1-x}As$ solid solutions. Therefore, since the lattice constant of AlAs (0.56622 nm) is larger than that of GaAs (0.565321 nm) [5], this difference is nonzero for all the $Al_xGa_{1-x}As$ compositions. Hence, using only this material system, it is impossible to balance mechani-

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cal stresses in HSs. This situation can be resolved by passing from a three- to four-component material system containing an additional element providing the possibility of decreasing the lattice constant. In our case, this element is phosphorous, which, being added to $Al_xGa_{1-x}As$, allows us to extend the range of lattice constant variations due to the fact that the lattice constant of phosphorus-containing binary compounds (AlP and GaP), which enter the composition of the new $Al_xGa_{1-x}P_yAs_{1-y}$ solid solution, is smaller than the lattice constant of the GaAs substrate (a_{AlP} = 0.5451 nm and a_{GaP} = 0.54495 nm [5]).

There exist two methods of creating strain-compensated HSs. Within the first method, for each layer of a $Al_xGa_{1-x}P_yAs_{1-y}$ HS with a given x, one chooses a particular y so that the lattice constant of the layer was equal to the lattice constant of the GaAs substrate. The second method consists in the creation of layers with opposite strains within one HS, so that the total strains were close to zero. In this case, it is important to keep the thickness of strained HS layers below the critical thickness for the chosen compositions. The first variant is rather laborious, because of which we decided on the second method. Among the possible ways of realisation of this approach, we choose the variant with a HS containing AlGaPAs emitting layers. In this case, the active region and the waveguide layers remain unchanged compared to traditional AlGaAs/GaAs HSs, which allows us to more clearly reveal the influence of strain compensation on the output laser characteristics.

To compare the results, we formed two HSs, namely, one traditional HS (AlGaAs/GaAs) and one strained-compensated HS (AlGaPAs/GaAs). Figure 1 shows the X-ray rocking curves for the grown laser structures. One clearly sees that the peak corresponding to the emitter layer of the laser structure (CL peak) shifts with addition of phosphorus. The lattice constant of the phosphorus-containing emitter layer becomes smaller than the substrate lattice constant and the corresponding peak appears to the other side of the substrate peak (Sub). This occurs because the amount of added phosphorus was calculated taking into account that the strains must be compensated not only in one layer but also over the entire HS thickness. Note that the waveguide layer composition was the same in both cases (WG peak).

Depending on the difference in the lattice constants and the thicknesses of deposited layers, the HS can be curved to one or another side and the curvature radius can be positive or negative. To analyse the phenomenon under consideration, it is convenient to use curvature, i.e., the reciprocal of the radius of curvature. The larger the numerical value of the curvature, the larger the actual curvature of the HS.

From the data of X-ray measurements, we calculated the curvature of studied HSs [6]. The calculated results and the curvatures measured by optical reflectometry [7] are given in Table 1. The total thickness of deposited layers in both HSs was 4.75 μm. The mismatch and the curvature of the HS with AlGaPAs layers are an order of magnitude lower compared with standard AlGaAs/GaAs HSs. In our case, the curvature almost completely coincides with the initial curvature of the substrate equal to 0.014 m^{-1}. It is obvious that this approach allows one to reduce total mechanical stresses and, consequently, to decrease the HS curvature.

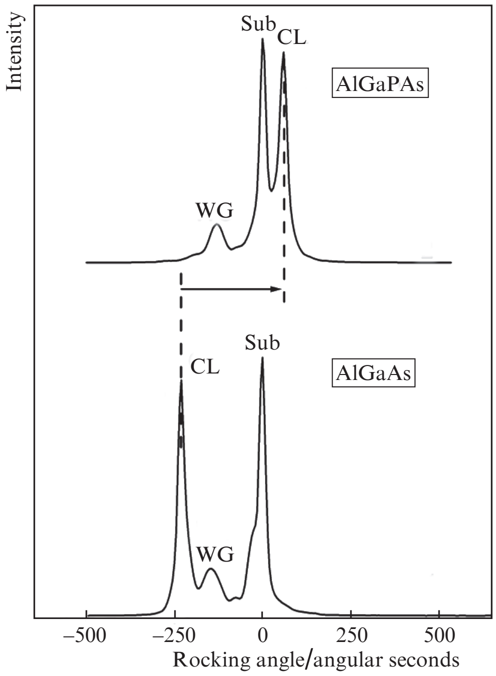

Figure 1. Rocking curves for phosphorus-free (AlGaAs) and phosphorus-containing (AlGaPAs) HSs. Peaks CL, WG, and Sub correspond to the emitter layer, waveguide layer, and substrate.

We made LD bars from the mentioned HSs and studied their characteristics. The photographs of the near-field radiation of LD bars based on standard AlGaAs/GaAs (without strain compensation) and studied strain-compensated AlGaPAs/GaAs HSs are presented in Fig. 2. One can see that the LD bar based on the compensated AlGaPAs structure has no noticeable thermal curvature typical for standard bars.

Figure 3 shows the light–current characteristics of the studied LD bars operating in a quasi-cw regime. The threshold currents of the bars based on the phosphorus-free and phosphorus-containing structures were close to each other, 3.5 and 3.6 A, respectively. As follows from Fig. 3, the efficiencies of the LD bars at the initial stage almost coincide.

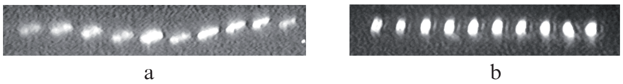

Figure 2. Patterns of the near-field radiation of LD arrays based on AlGaAs (a; nonuniform vertical distribution of emitting elements) and AlGaPAs HSs (b; uniform distribution of emitting elements; near field pattern without smile).

Table 1. Parameters of studied heterostructures.

Material system	Thickness of epitaxial layers/μm	Average mismatch in the HS lattice constants $\Delta a/a$ (%)	HS curvature/m^{-1}	
			X-ray diffractometry	optical refractometry
AlGaAs/GaAs	4.75	–0.0735	–0.12	–0.14
AlGaPAs/GaAs	4.75	0.0093	0.015	0.015

However, at pump currents exceeding 10 A, the ligth – current characteristic of the bar based on the compensated HS retains its initial slope of 1.07 W A, whereas the slope for the standard LD bar decreases to 0.95 W A^{-1}. This is explained by the fact that the bars based on HSs compensated by phosphorus are less distorted and have a better contact with the heat sink over their entire length. This is especially important at high pump currents, when heat release in the laser diode crystal significantly increases. The strain compensation in HSs in this case allows one to decrease the thermal bending of the light – current characteristic. Thus, LD bars based on phosphorus-containing structures demonstrate more stable operation at higher pump currents, which indicates that the use of the considered approach is advantageous and effective.

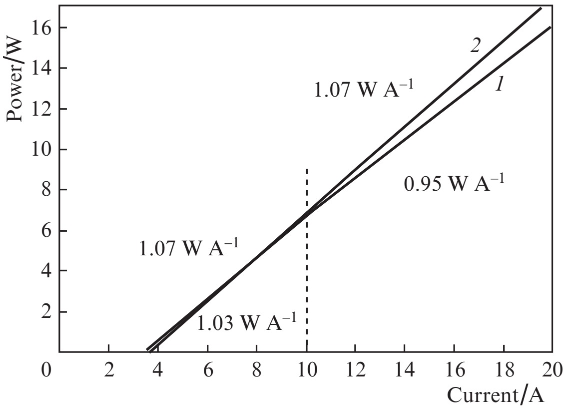

Figure 3. Light – current characteristics of LD arrays (20 Hz, 200 μs) based on phosphorus-free (*1*) and phosphorus-containing (*2*) HSs. At currents above 10 A, curve (*1*) declines due to heating.

4. Conclusions

In the present work, we produced and studied traditional AlGaAs/GaAs laser heterostructures and compensated heterostructures in the AlGaAs/AlGaPAs/GaAs system, as well as LD bars based on these structures and emitting at a wavelength of 850 nm. The measurements of the radius of curvature show that the introduction of phosphorus-containing layers into AlGaAs/GaAs heterostructures reduces mechanical stresses and, hence, prevents curving of multilayer heterostructures. It is shown that the use of compensated AlGaPAs/GaAs heterostructures improves the near field of LD arrays and helps to retain the slope of the power – current characteristic at high pump currents owing to a more uniform (than in AlGaAs/GaAs arrays) thermal contact of all emitting elements (including peripheral) with the heat sink.

References

1. Eliseev P.G. *Kvantovaya Elektron.*, **32** (12), 1085 (2002) [*Quantum Electron.*, **32** (12), 1085 (2002)].
2. Casey H.C., Panish M.B. *Heterostructure Lasers* (New York: Academic Press, 1978).
3. Wang J., Yuan Z., Kang L., Yang K., Zhang Y., Liu X. *Proc. 59th Electronic Components and Technology Conference* (San Diego, 2009) p. 837.
4. Brauch U., Loosen P., Opower H. *Topics Appl. Phys.*, **78**, 303 (2000).
5. Strel'chenko S.S., Lebedev V.V. *Soedineniya $A^{III}B^{V}$. Spravochnik* ($A^{III}B^{V}$ Compounds. Handbook) (Moscow: Metallurgiya, 1984).
6. Bowen D.K., Tanner B.K. *High Resolution X-ray Diffractometry and Topography* (Taylor & Francis, 1998).
7. Brunner F., Knauer A., Schenk T., Weyers M., Zettler J.-T. *J. Cryst. Growth.*, **310**, 2432 (2008).