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AlGaAs/GaAs laser diode bars (λ = 808 nm) with improved thermal stability

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Abstract. **Two series of AlGaAs/GaAs laser heterostructures have been grown by metal-organic vapour phase epitaxy, and 808-nm laser diode bars fabricated from the heterostructures have been investigated. The heterostructures differed in waveguide thickness and quantum well depth. It is shown that increasing the barrier height for charge carriers in the active region has an advantageous effect on the output parameters of the laser sources in the case of the heterostructures with a narrow symmetric waveguide: the slope of their power – current characteristics increased from 0.9 to 1.05 W A^{-1}. Thus, the configuration with a narrow waveguide and deep quantum well is better suited for high-power laser diode bars under hindered heat removal conditions.**

Keywords: *laser diode bar, two-dimensional laser diode array, metal-organic vapour phase epitaxy, quantum well.*

AlGaAs/GaAs laser diode bars (LDBs) are widely used as laser sources in advanced optoelectronic systems, especially for pumping solid-state lasers. Nd:YAG lasers are typically pumped by 808-nm LDBs [1]. Such LDBs should meet stringent requirements as to their output power and thermal stability because a predetermined emission wavelength, falling within an appropriate absorption band of the dopant, should be maintained.

The small spacing between the emitting regions of LDBs, especially at large fill factors, and their high output power lead to intense heat generation. As a result, the temperature of the laser crystal rises even in a quasi-cw mode, causing an increase in threshold current density and a drop in differential quantum efficiency [2]. To maintain their output characteristics at a preset level under such conditions, the emitters should possess improved thermal stability.

One possible way of solving this problem is by varying the active-region design in order to improve electron localisation in the quantum well (QW) [3]. This approach was successfully used in the case of heterostructures for laser diodes emitting in the range 1010 – 1070 nm (as shown by Shashkin et al. [4], a large energy depth of QWs prevents electrons from delocalising over waveguide layers, thereby reducing the internal optical loss). In the present work, this approach is developed for heterostructures that ensure lasing at λ = 808 nm. It should be taken into account that changes in waveguide layer composition may have various consequences. On the one hand, increasing the barrier height for charge carriers improves electron confinement in the QW and, hence, increases the quantum efficiency and characteristic temperature. On the other, increasing the percentage of AlAs in the AlGaAs barrier, as is needed to increase the QW depth, leads to an increase in background oxygen concentration. Oxygen impurity atoms act as nonradiative recombination centres, reducing the internal quantum yield and output power and leading to overheating of the active region and mirrors of the laser [5, 6].

Another promising way of improving the output characteristics of the LDBs under consideration is by reducing their internal optical loss through the use of broad waveguides [7, 8]. This approach has proven to be effective in producing discrete laser sources with increased output power. Its advantages are, however, not so obvious in LDB fabrication, where heat dissipation issues are critical and the use of broad waveguides increases the electrical and thermal resistance of the system.

We examined both approaches to active-region design optimisation with application to LDB fabrication. To this end, five Al$_x$Ga$_{1-x}$As/GaAs laser heterostructures (HS's) of two types, with a narrow symmetric and a broad asymmetric waveguide, were grown by metal-organic vapour phase epitaxy. In addition, we varied the QW barrier height in the two types of heterostructures. Figure 1 schematically shows their energy band diagrams. The HS's were used to fabricate LDBs, and their electrical parameters were then assessed.

In the former group of HS's (samples 1 – 3), we used narrow symmetric waveguides ~0.4 μm in overall thickness (Fig. 1a). This configuration is typical of LDs emitting in the 808-nm range [9]. In addition to an HS with the standard waveguide layer composition Al$_{0.32}$Ga$_{0.68}$As (sample 1), we grew aluminium-enriched HS's: Al$_{0.37}$Ga$_{0.63}$As (sample 2) and Al$_{0.40}$Ga$_{0.60}$As (sample 3). Note that the calculated QW barrier height was found to increase from 139 meV in the standard configuration to 190 and 213 meV in samples 2 and 3, respectively. Accordingly, we increased the mole fraction of AlAs in the emitter layers, without changing the difference Δx between the waveguide and emitter in order to maintain the optical confinement factor at a constant level across the active region.

The latter group of HS's (Fig. 1b) had a broad asymmetric waveguide ~1.5 μm in total thickness, also with different waveguide layer compositions: Al$_{0.32}$Ga$_{0.68}$As (sample 4) and Al$_{0.37}$Ga$_{0.63}$As (sample 5).

The HS's were used to fabricate gain elements with a contact width w = 80 μm and a cavity length $L_{\rm c}$ = 1400 μm. The front and back facets of the cavity had optical coatings with

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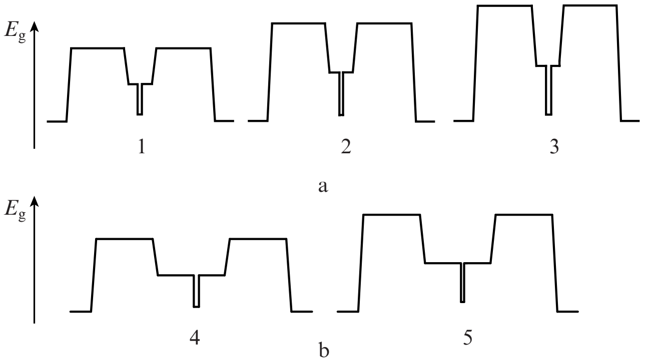

Figure 1. Schematic energy band diagrams of (a) samples 1–3 (narrow symmetric waveguide) and (b) samples 4 and 5 (broad asymmetric waveguide).

reflectances $R_1 \approx 0.05$ and $R_2 \approx 0.95$. The elements were assembled into 30-element LDBs 4 mm in length, with a fill factor of 60%. Measurements were performed under quasi-cw pumping (pulse duration, 200 μs; repetition frequency, 20 Hz).

To check the effectiveness of the above optimisation strategies, we obtained power–current characteristics of the LDBs with the two HS configurations. In the first series of experiments, we used the former group of samples: with a narrow waveguide and increasing QW depth. Figure 2a shows the light power–current (L–I) characteristics of those LDBs. The samples of this group had threshold currents in the range 10–12 A. It is seen in Fig. 2a that their output optical power increases steadily with increasing pump current. The slope of the L–I curve for samples 1, 2 and 3 (in the order of increasing QW barrier height for charge carriers) is 0.9, 0.96 and 1.05 W A^{-1}, respectively.

In addition, we evaluated the thermal stability of the LDBs. A key measure of the thermal stability of laser diodes is their characteristic temperature T_0. Increasing the QW barrier height in the HS's was found to increase T_0: from 95 K in sample 1 to 110 and 120 K in samples 2 and 3, respectively.

Figure 2b shows the power–current characteristics of the broad asymmetric waveguide LDBs. As would be expected, the threshold current increases with waveguide layer thickness, which is due to the decrease in the optical confinement factor in the active region. The threshold current of the two bars is 17 A. With increasing barrier height, the slope of the L–I curve decreases from 1.06 (sample 4) to 0.96 W A^{-1} (sample 5). The characteristic temperature of these samples was determined to be 105–110 K.

The behaviour of these samples is the opposite of that of the samples in the former group. It is known that increasing the mole fraction of AlAs in AlGaAs solid solutions degrades their quality, primarily because of the oxygen incorporation during the growth process and the formation of oxygen-related deep levels [10, 11]. It seems likely that, with increasing waveguide layer thickness, this adverse effect becomes stronger. An additional factor that may have an adverse effect on the slope of the L–I curve is the very small, but significant, increase in thermal and series resistance, due to the expansion of the waveguides and the increase in total HS thickness.

The approach aimed at reducing the internal optical loss through the use of broad waveguide layers is an effective tool for raising the output power of discrete laser diodes, which usually operate under good heat removal conditions. In our case, because of the small spacing between the emitting regions of the LDBs, the heat generation rate is markedly higher and heat removal is substantially hindered, so the broad-waveguide diodes cannot demonstrate their advantages. In this situation, a more effective approach is to increase the degree of electron confinement in the QWs, while maintaining the waveguide thickness small.

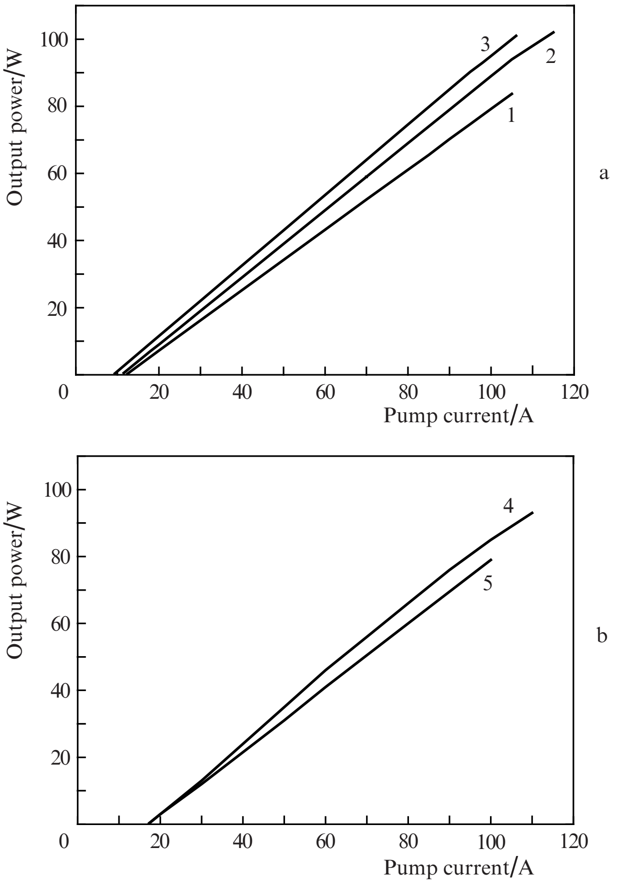

Figure 2. (a) Power–current curves of the narrow waveguide LDBs (1) with the standard HS configuration and (2, 3) with HS's having an increased QW barrier height and (b) those of the broad asymmetric waveguide LDBs (4) with the standard HS configuration and (5) with HS's having an increased QW barrier height.

Thus, HS's with narrow symmetric and broad asymmetric waveguides have been grown by metal-organic vapour phase epitaxy. The quantum well depth has been varied by increasing the percentage of AlAs in the waveguide. It has been shown that increasing the barrier height for charge carriers has an advantageous effect on the output parameters of the LDBs in the case of the HS's with a narrow symmetric waveguide (an increase in the slope of their L–I characteristics from 0.9 to 1.05 W A^{-1}). At the same time, the samples with a broad asymmetric waveguide showed no expected improvement. This may be due to the extra thermal and series resistance associated with the increased HS thickness. Therefore, the most suitable HS configuration for the application in question is that with a narrow waveguide and deep QW.

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