

LASERS

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1.5–1.6 μm semiconductor lasers with an asymmetric periodic optically coupled waveguide

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Abstract. **High-power 1.5–1.6-μm semiconductor lasers with an asymmetric periodic optically coupled waveguide are developed and their current–voltage, light–current, and spectral characteristics are experimentally studied. The characteristics of these lasers are compared with the characteristics of traditional lasers based on double separate-confinement heterostructures. It is shown that the developed lasers have lower divergence and almost the same threshold and power characteristics as conventional lasers with Fabry–Perot resonators. The developed lasers with a cavity length of 1.6 mm and a mesa-stripe contact width of 3 μm mounted in a housing 11 mm in diameter have a power no lower than 200 mW at a pump current not exceeding 700 mA with a divergence of 25–35° versus 45° typical for conventional lasers.**

Keywords: *semiconductor laser, periodic optically coupled waveguide, current–voltage, light–current, and spectral characteristics; wavelength 1.5–1.6 μm.*

1. Introduction

At present, efforts of researchers are aimed at increasing the output optical power of semiconductor lasers emitting in the range of 1.5–1.6 μm. In addition, some practical applications of lasers require a combination of a high power and a narrow directional pattern.

Laser diodes (LDs) emitting in the mentioned spectral range based on double separate-confinement AlGaInAs/InP heterostructures have a high differential quantum efficiency and a high temperature stability. However, their FWHM divergence in the fast axis direction is, as a rule, ~45–50° [1]. The traditional approach to decreasing divergence by using a broadened waveguide, which was successfully used for 0.8–1.1-μm lasers, provides no desired results in the considered case, in particular, it is often possible to increase the output laser power, but the radiation divergence in this case decreases insignificantly.

For example, it was shown in [2] that lasers operating at λ = 1.5–1.6 μm with a cavity length of 1.6 mm and a mesa-stripe width of 3 μm have a power of 300 mW and higher in the case of mounting in housings 11 mm in diameter and higher than 400 mW in the case of C-mounts. The C-mount lasers with a cavity length of 2.6 mm and a mesa-stripe width of 100 μm based on the same heterostructure as in work [2] emitted cw radiation with a power exceeding 4 W at a pump current of 15 A [3]. The vertical FWHM divergence was ~45° [2, 3] for lasers based on an asymmetric heterostructure with a broadened waveguide. High-power lasers based on a different AlGaInAs/InP heterostructure design with a broadened waveguide and a wavelength of 1.5–1.6 μm had a FWHM divergence of 48° [4]. Thus, it is necessary to search for alternative designs of heterostructures for high-power AlGaInAs/InP LDs with a narrow directional pattern.

The use of periodic optically coupled waveguides makes it possible to considerably decrease the beam divergence of LDs. In particular, the authors of [5] reported about a decrease in the FWHM divergence from 44 to 11.2° achieved by using a system of four passive waveguides with a period of 1.0 μm in lasers with λ = 850 nm. The use of a system of sixteen passive waveguides with a period of 0.29 μm made it possible to decrease the divergence in the fast axis direction from 46 to 23° for 980-nm lasers [6].

To develop high-power LDs, it is necessary to provide efficient heat removal from the active region, because of which preference is often given to asymmetric structures, in which the active region is as close to the surface as possible [7]. In this case, it is reasonable to form the passive waveguide on the substrate (n-side). This approach allowed the authors of [8] to decrease the divergence of an LD with λ = 1040 nm to 22°.

At present, to decrease the divergence of lasers with periodic optically coupled waveguides, one uses a concept proposed in [9], which is based on a laser heterostructure that contains a one-dimensional photonic crystal (PC), i.e., a periodic structure consisting of alternating layers with different refractive indices with a periodicity defect, which makes it possible to achieve radiation with a low divergence in the plane perpendicular to the p–n junction. In this case, the active region is positioned within the defect, and the PC periodic structure itself is on the substrate side.

Lasers with a one-dimensional PC (λ = 645 nm) in a repetitively pulsed regime demonstrated an output power of 20 W at a pump current of 18 A (mesa-stripe contact width ~100 μm, length 1500 μm). The beam divergence in the perpendicular plane was 7–8° versus 17° for conventional lasers. A laser with a mesa-stripe 4 μm wide and 1500 μm long emitted cw radiation with a power of 120 mW at a pump current of 0.23 A with a slope efficiency of 0.83 W A^{-1} and an angular divergence of ~6.5°. IR lasers (980 nm) with a divergence of 4.2° were demonstrated in [10].

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The authors of [11] described a laser (λ = 980 nm) with a mesa-stripe width of 7 μm and a crystal length of 3 mm, the single-mode power of which was 2 W at a pump current of 1.5 A and the angular divergence was 7.2° in the horizontal plane and 10.3° in the vertical plane.

A high-power LD with a PC and an optimised structure was considered in [12]. The output power of this laser in a pulsed regime (40 μs, 40 Hz) at a pump current of 12 A was 10 W at FWHM divergences of 10.8° in the vertical plane and 9.6° in the horizontal plane. The power in the cw regime amounted to 5.75 W at a pump current of 8 A and divergences of 10.5° and 5.7° in the vertical and horizontal planes, respectively.

The review of the literature shows that the concept of an asymmetric periodic optically coupled waveguide is rather promising for decreasing the beam divergence of high-power LDs. At the same time, the results available in the literature belong to lasers emitting in the range of 0.63 – 1.1 μm, while wavelengths of 1.5 – 1.6 are not considered.

In the present work, we use the described approaches to application of periodic optically coupled wavelengths for fabricating 1.5 – 1.6 μm lasers with a narrow directional pattern. High-power lasers with an asymmetric periodic (multilayer) optically coupled waveguide are developed and studied for the first time. As a basis, we used the heterostructure described in [2] and replaced the waveguide on the substrate side (*n* waveguide) by a periodic waveguide with alternating layers with high and low refractive indices (four and seven periods).

2. Experiment and discussion of results

We have grown three heterostructures (types A, B, and C). All the structures have two strain-compensated quantum wells with a residual strain of +1.4%. To improve heat removal, the active region was formed in the active waveguide close to the p-emitter. The A-type heterostructure contained a broadened asymmetric waveguide described in [2]. In the B-type heterostructure, the waveguide on the n-side was replaced by seven pairs of alternating layers with low and high refractive indices (period 0.43 μm). The C-type heterostructure was similar to the B-type heterostructure but contained only four pairs of layers with the same period. The schematic band diagrams of the studied heterostructures are shown in Fig. 1.

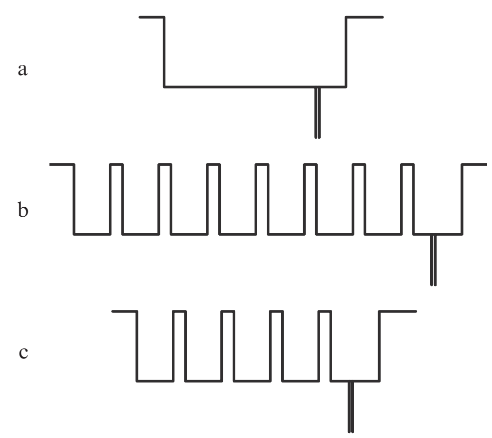

Figure 1. Schematic band diagrams of the waveguide region of the studied (a) A-, (b) B-, and (c) C-type lasers.

Using these heterostructures, we fabricated LDs with a mesa-stripe contact width of 3 μm and cavity length L = 1.6 mm. The cavity faces were coated with high-reflection and antireflection films with reflectivities of ~100% and 5%, respectively. As in [2], the LDs were mounted on copper contact plates. The technologies of metallisation of contact plates were identical. The LDs were soldered with indium with the active regions down. The contact plate with the LD was mounted into a cylindrical housing 11 mm in diameter. The housing was mounted on a heat sink, whose temperature was maintained constant using an electronic stabilisation system at 20, 30, and 40 °C ($T = T_0 + \Delta T$, where T_0 = 20 °C and ΔT = 0, 10, and 20 °C). The current – voltage characteristics (CVCs) and light – current characteristics (LCCs) of the LDs were measured at these fixed temperatures and a constant pump current.

Figure 2 presents the CVCs and LCCs of the A- and B-type lasers at temperatures of 20 and 40 °C. One can se that the LCCs of the B-type lasers lie somewhat higher than the LCCs of the A-type lasers. Note that the lasing threshold of the B-type lasers is lower than that of the A-type lasers. The output power from one mirror at pump currents of 700 mA exceeds 200 mW. The difference in the LCCs of the lasers is more pronounced: the larger voltage drop of the B-type lasers in comparison with the A-type lasers leads to a saturation of the LCCs of the B-type lasers at currents exceeding 700 mA.

This behaviour of the characteristics is also typical for the C-type laser, i.e., their lasing threshold is lower than that of the A-type lasers. The output power from one mirror at pump currents of 700 mA exceeded 200 mA, but the beam divergence was higher than the divergence for the B-type lasers.

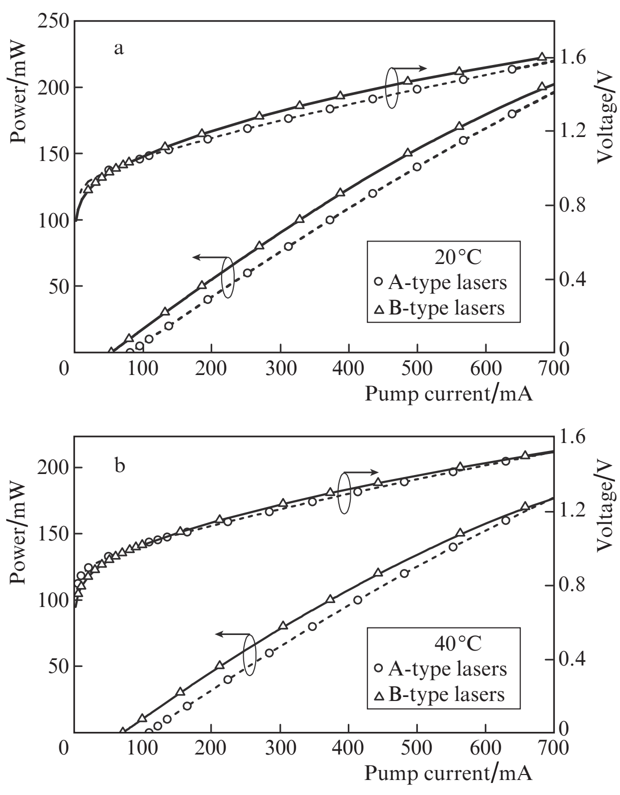

Figure 2. CVCs and LCCs of the A- and B- type lasers at T = (a) 20 and (b) 40 °C.

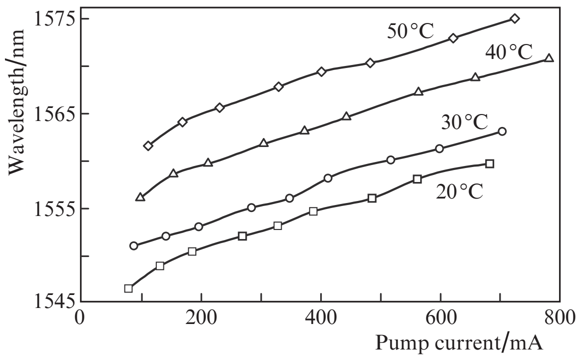

Figure 3. Spectral characteristics of the B-type laser at different temperatures.

Table 1. Output characteristics of lasers of different types.

LD type	P/I /mW mA^{-1}	FWHM divergence/deg		Polarisation degree	
		⊥	‖	P_{max}/P_{min}	$10\lg(P_{max}/P_{min})$ /dB
A	50/220	45.1	6.8	269	24.3
	100/390	45.3	7.6	646	28.1
B	50/183	30.4	7.3	676	28.3
	100/321	31.7	7.7	661	28.2
C	50/196	31.3	7.3	282	24.5
	100/328	32.1	7.9	372	25.7

Note: P_{max} and P_{min} are the maximum and minimum powers of radiation passed through the polariser at its two mutually perpendicular positions.

The spectral characteristics of the B-type lasers in the temperature range of 20–50 °C behave similarly to the spectral characteristics of the A-type lasers, namely, they have one wavelength peak, which shifts to longer wavelengths with increasing pump current and temperature (Fig. 3).

Note that the laser powers obtained in this work are as high as the powers obtained in [2], but this is true only at pump currents not exceeding 700 mA and output powers below 200 mW.

The investigations of the divergence of the three types of LDs in two planes showed that the far-field divergence of the B- and C-type LDs in the plane perpendicular to the p–n junction at output powers of 50 and 100 mW is 25–35°.

Figure 4 shows the experimental and calculated far-field radiation intensity distributions of the B-type LD at an output power P = 100 mW. One can see that the experimentally measured divergence well coincides with the curve calculated according to [13].

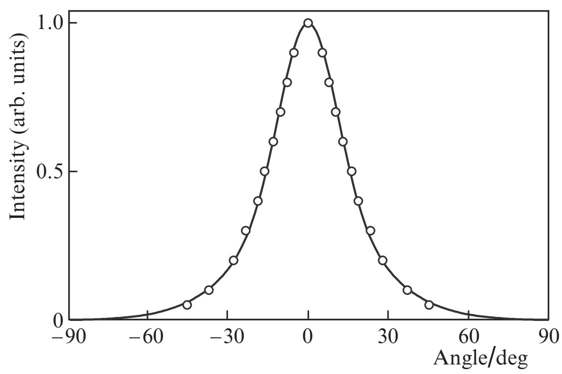

Figure 4. Experimental (points) and calculated (curve) far-field radiation divergence at P = 100 mW.

Table 1 lists the average values of radiation divergence perpendicular (⊥) and parallel (‖) to the p–n junction for LDs with L = 1.6 mm at P = 50 and 100 mW for different pump currents I and polarisation degrees.

Comparison of the divergences presented in Table 1 for the A-type lasers ($\theta_{\perp} \approx 45°$ and $\theta_{\|} \approx 6.6°$) with the corresponding characteristics for the B-and C-type lasers ($\theta_{\perp} \approx 30.4°$ and $\theta_{\|} \approx 7.3°$) shows that the introduction of a periodic optically coupled waveguide decreases the radiation divergence in the plane perpendicular to the p--n junction and almost does not affect the divergence in the plane parallel to the p–n junction; in addition, an increase in the number of periods of the multilayer waveguide leads to a narrower directional pattern.

Thus, it is shown that the use of lasers with an asymmetric periodic optically coupled waveguide makes it possible to decrease the beam divergence from 45° to 25–35° at almost unchanged threshold and power characteristics typical for conventional lasers with a Fabry–Perot resonator.

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