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Semiconductor AlGaInAs/InP lasers with ultra-narrow waveguides

A.A. Marmalyuk, Yu.L. Ryaboshtan, P.V. Gorlachuk, M.A. Ladugin, A.A. Padalitsa,
S.O. Slipchenko, A.V. Lyutetskiy, D.A. Veselov, N.A. Pikhtin

Abstract. **Laser diodes based on AlGaInAs/InP heterostructures with an ultra-narrow waveguide are developed. It is shown that the use of this waveguide in conjunction with profiled doping ensures a balance between internal optical losses and heat resistance. Laser diodes with a stripe contact 100 μm wide demonstrate at room temperature an output optical power exceeding 4 W in a continuous-wave mode and exceeding 20 W in a pulsed mode.**

Keywords: *AlGaInAs/InP heterostructure, MOVPE, laser diode, eye-safe spectral region.*

1. Introduction

Presently, semiconductor lasers with a high optical power become more and more important for many practical applications. In particular, a pronounced tendency is observed to use eye-safe lasers emitting at wavelengths longer than 1.4 μm instead of near-IR lasers. Semiconductor lasers for systems whose radiation may contact human eye also do not stand aside. In this connection, it is very interesting to find a way to increase the output power of semiconductor lasers emitting in the wavelength range of 1.5–1.6 μm. A promising approach to solving this problem is to use heterostructures with broadened waveguides in order to decrease optical losses. In particular, an increase in the output power of laser diodes (LDs) based on the mentioned heterostructures was demonstrated for LDs emitting at wavelengths of 800–850 nm [1, 2], 940–1060 nm [3, 4], and in the considered range of 1500–1600 nm [5, 6]. At the same time, it was shown in some works that, in devices with significant heat release, it is preferable to use lasers with a narrow waveguide, which leads to a decrease in the series and thermal resistances playing the key role in such sources. The efficiency of this approach was demonstrated when fabricating laser diodes emitting at wavelength of 800–900 nm [7, 8].

The present work is devoted to the study of the feasibility of heterostructures with narrow waveguides for designing high-power lasers operating in the spectral range 1500–1600 nm that are characterised by a lower efficiency and lower characteristic temperatures, and, hence, by a stronger dependence of the output characteristics on the active region temperature.

2. Experiment

The quantum-well separate-confinement heterostructures AlGaInAs/InP were formed by MOVPE. The waveguide width varied from 0.05 to 0.2 μm. The active region consisted of two strain-compensated InGaAs quantum wells. The band diagram of the heterostructure is schematically shown in Fig. 1. From the obtained heterostructures, we fabricated LDs with a stripe contact 100 μm wide and a cavity 1000–3000 μm long. The faces of the cavity were coated with antireflection and reflection coatings with reflection coefficients $R_1 \approx 0.05$ and $R_2 \approx 0.95$. The LDs were mounted on a copper heat sink, and their output characteristics were studied in pulsed (pulse duration 100 ns, repetition rate 1 kHz) and continuous-wave modes at a heat sink temperature of 25 °C.

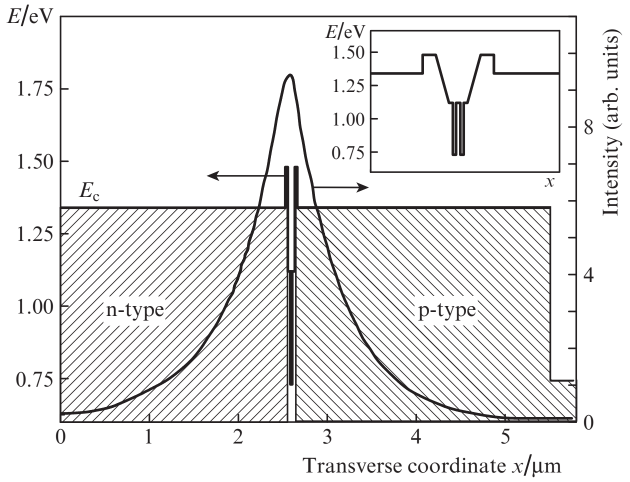

Figure 1. Schematic band diagram of the laser heterostructure with an ultra-narrow waveguide and electromagnetic field intensity distributions for the zero mode. The inset shows a part of the band diagram on an enlarged scale.

3. Discussion of results

Analysis of semiconductor materials (GaInAsP, AlGaInAs, InP) suitable for producing LDs emitting in the considered range (1.5–1.6 μm) clearly shows that the thermal conductivity of InP

A.A. Marmalyuk Sigm Plyus Ltd, ul. Vvedenskogo 3, korp. 1, 117342 Moscow, Russia; National Research Nuclear University 'MEPhI', Kashiskoe sh. 31, 115409 Moscow, Russia; e-mail: almarm@mail.ru;
Yu.L. Ryaboshtan, P.V. Gorlachuk, M.A. Ladugin, A.A. Padalitsa Sigm Plyus Ltd, ul. Vvedenskogo 3, korp. 1, 117342 Moscow, Russia; e-mail: yu.ryaboshtan@siplus.ru, gorlachuk@bk.ru;
S.O. Slipchenko, A.V. Lyutetskiy, D.A. Veselov, N.A. Pikhtin A.F. Ioffe Physicotechnical Institute, Russian Academy of Sciences, ul. Politekhnicheskaya 26, 194021 St. Petersburg, Russia; e-mail: SergHPL@mail.ioffe.ru

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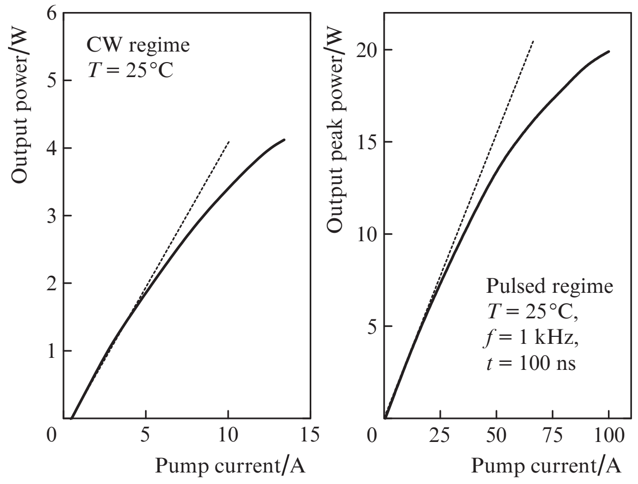
[0.65–0.7 W (cm K)$^{-1}$] is considerably higher than that of GaInAsP and AlGaInAs solid solutions [0.04–0.1 W (cm K)$^{-1}$] [9]. This leads to the conclusion that the maximum narrowing of the waveguide will ensure the best heat removal from the active region and cause an increase in the output power. In the case of a narrow waveguide, a considerable portion of the electromagnetic radiation propagates in the doped emitting layers (see Fig. 1), which increases the internal optical losses. These losses can be decreased by using profiled doping.

The active region in the studied heterostructures consisted of two InGaAs quantum wells, whose optical confinement factor was approximately equal to the corresponding factor typical for heterostructures with broadened waveguides [6]. Strained quantum wells are widely used to decrease nonradiative Auger recombination and interband carrier absorption in the valence band. A mismatch between the well and barrier lattice constants leads to the formation of biaxial strains in the quantum well and, as a result, to a change in the band diagram of the heterostructure. The distortion and splitting of the valence subbands lead to a decrease in the effective mass of holes and, hence, to a decrease in the density of states in the valence band. This results in a decrease in the valence intersubband absorption and in the Auger recombination probability [10, 11]. In the present work, we used strained quantum wells with partial compensation of elastic strains in barriers, which have opposite strain. This approach makes it possible to achieve high elastic strains in quantum wells without their relaxation with the formation of misfit dislocations.

Typical radiative characteristics the LDs in the cw and pulsed modes are presented in Fig. 2. The measurements were performed on stripe lasers with a cavity length of 2.5 mm and a mesa-stripe contact width of 100 μm. It is found that the output power of LDs based on heterostructures with ultra-narrow waveguides at a heat sink temperature of 25 °C reaches 4 W in a cw mode and 20 W in a short-pulse mode.



a b

Figure 2. Light–current characteristics of lasers in (a) cw and (b) pulsed modes. Wavelength is 1550–1565 nm.

At the same time, the optical losses in the considered LDs with ultra-narrow waveguides (3–4 cm^{-1}) should only slightly increase in comparison with the losses in LDs with conventional broadened waveguides (~2 cm^{-1}) [12, 13], which is achieved, first of all, due to the profiled doping of InP cladding layers. On the other hand, as was mentioned above, the conditions of heat removal from the active region improve with waveguide narrowing, which should positively affect the output characteristics. Thus, we have two oppositely acting factors, whose role to a large extent depends on the specific features of the LD design. In the considered case, the decrease in the thermal resistance allows one to increase the output power saturation limit in the cw mode.

Additional factors favourable for increasing the power of such LDs in a pulsed mode are a decrease in optical losses on free charge carriers, which fill the waveguide at high pump powers, and a decrease in leakage currents related to these carriers [12, 13]. A sharp decrease in the waveguide width considerably decreases the concentration of free carriers in waveguide layers, which may be advantageous for the maximum achievable output power.

The spectral characteristics of the cw LDs at different pump currents are given in Fig. 3. As the pump current increases from the threshold value to $I \approx 5$ A, the maximum laser wavelength shifts by 14–16 nm.

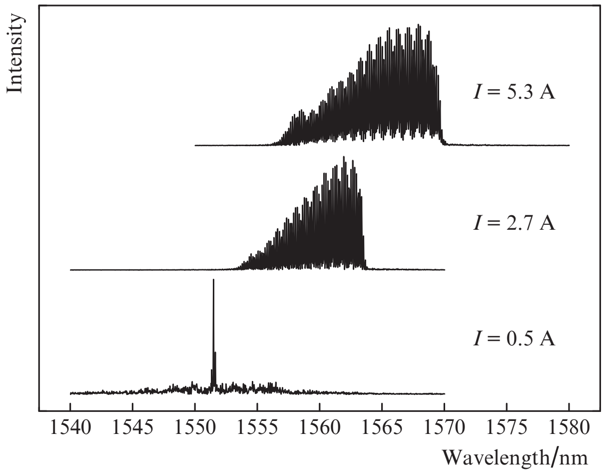


Figure 3. Spectral characteristics of cw LDs at different pump currents.

The AlGaInAs/InP heterostructures with ultra-narrow waveguides demonstrated that they are promising for fabricating high-power LDs emitting at wavelengths of 1.5–1.6 μm. The developed LDs are especially advantageous in the case of operation in a short-pulse mode. The presented results were obtained within the framework of researches aimed at the creation of high-power lasers based on heterostructures with narrow waveguides. Apparently, even more significant achievements in this direction can be expected for multielement emitters, i.e., arrays of these LDs.

4. Conclusions

In this work, we have developed AlGaInAs/InP heterostructures with ultra-narrow waveguides and fabricated laser diodes from these heterostructures. These devices allowed us to achieve an output power up to 4 W in a cw mode and up to 20 W in a short-pulse mode. It is shown that improvement of the conditions of heat removal from the active region of the laser diode leads to an increase in the output power in the cw mode despite an increase in the internal optical losses. Narrowing of the waveguide decreases the optical losses on carriers filling the waveguide at high pump levels and makes it possible to achieve a higher output power in a pulsed mode.

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