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AlGaInAs/InP semiconductor lasers with an ultra-narrow waveguide and an increased electron barrier

V.N. Svetogorov, Yu.L. Ryaboshtan, M.A. Ladugin, A.A. Padalitsa, N.A. Volkov, A.A. Marmalyuk, S.O. Slipchenko, A.V. Lyutetskii, D.A. Veselov, N.A. Pikhtin

Abstract. **Semiconductor lasers based on AlGaInAs/InP heterostructures with an ultra-narrow waveguide and an increased electron barrier layer 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. Additional use of strained wide-bandgap layers as blocking barriers limiting electron leakage from the active region makes it possible to increase the output power at the same pump current. The developed lasers with a stripe contact 100 μm wide demonstrate at room temperature an output optical power of 4.0–4.4 W (pump current 14 A) in a continuous-wave regime and 15–17 W (100 A) in a pulsed regime (100 ns, 1 kHz) at wavelengths of 1450–1500 nm.**

Keywords: *semiconductor laser, heterostructure, AlGaInAs/InP, narrow waveguide, electron barrier.*

1. Introduction

The development of high-power semiconductor lasers emitting in the spectral range 1.4–1.6 μm is complicated by several problems, among which are the insufficient energy depth of quantum wells and a high probability of the Auger recombination processes. With an increase in the pump current, charge carriers in the first case may leave the active region and form leakage currents, which decreases the quantum efficiency of devices. The Auger recombination additionally decreases the radiative recombination and laser efficiency and increases heat release. In turn, an increase in the active region temperature increases carrier injection from quantum wells, causes a further decrease in the quantum efficiency, and enhances this negative feedback. Due to these reasons, a promising approach to the development of lasers of the considered spectral region is related to the implementation of the concept of an elastically strained active region [1, 2], according to which the use of stresses with opposite signs in barriers and quantum wells makes it possible to raise the threshold for generation of misfit dislocations and to increase the depth of quantum wells and the strains in them. An increase in the potential barrier in the quantum wells improves the localisation of carriers in the active region, while an increase in the elastic strains in the quantum wells decreases the Auger recombination effect [3–5]. As a result, semiconductor lasers based on strain-compensated quantum wells demonstrate better characteristics [6–8].

The creation of conditions for improving heat removal from the active region is an efficient method to increase the output power of semiconductor lasers [9]. As applied to the considered spectral range, it was shown [10, 11] that the use of ultra-narrow waveguides leads to a decrease in the series and thermal resistances of laser structures and reduces the effect of the mentioned negative factors. In addition, a decrease in the waveguide width decreases the free carrier accumulation in it [12], which is one of the factors restricting the maximum achievable optical power [13, 14].

Leakage from the active region can be additionally decreased using special barrier layers. As a rule, these layers consist of a wider-bandgap material limiting carrier leakage. It was reported that AlInAs [15–18], AlGaInAs [19], and GaInP [20] barriers, as well as a short-period GaInAs/AlInAs superlattice [21], were successfully used in lasers emitting in the range of 1.3–1.6 μm. In [22], it was proposed to replace the isoperiodic AlInAs layer by a mismatched layer with an increased band gap width. In this case, it is necessary to provide conditions for preventing generation of misfit dislocations in these layers. As a result, an increase in the output power by 10%–20% was demonstrated. In developing this approach, it is interesting to study the influence of an increased electron barrier in the structure with an ultra-narrow waveguide on the output laser characteristics. The present work is devoted to the experimental study of this issue by the example of high-power AlGaInAs/InP lasers emitting in the range 1450–1500 nm.

2. Experimental

The AlGaInAs/InP laser heterostructures were grown by MOVPE. We studied two heterostructures differing by the height of the electron barrier at the waveguide–p-emitter interface. The basic heterostructure consisted of an active region with two strain-compensated GaInAs quantum wells in the centre of an AlGaInAs waveguide 0.1 μm thick. The waveguide was sandwiched between two InP emitter layers. To decrease leakages, AlInAs blocking barrier layers isoperiodic with the InP substrate were formed on the waveguide–emitter interface [10]. In the second heterostructure, analogously to [22], we introduced at the waveguide–p-emitter interface a strained AlInAs barrier layer, whose band gap

V.N. Svetogorov, Yu.L. Ryaboshtan, M.A. Ladugin, A.A. Padalitsa, N.A. Volkov Sigm Plyus Ltd, ul. Vvedenskogo 3, korp. 1, 117342 Moscow, Russia; e-mail: svetogorvlad@mail.ru;
A.A. Marmalyuk Sigm Plyus Ltd, ul. Vvedenskogo 3, korp. 1, 117342 Moscow, Russia; National Research Nuclear University MEPhI, Kashirskoe sh. 31, 115409 Moscow, Russia;
S.O. Slipchenko, A.V. Lyutetskii, D.A. Veselov, N.A. Pikhtin Ioffe Institute, Russian Academy of Sciences, ul. Politekhnicheskaya 26, 194021 St. Petersburg, Russia

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exceeded the corresponding value for the matched barrier of the first heterostructure. The strained barrier layer parameters were taken from [22]. Based on the grown heterostructures, we fabricated semiconductor lasers with a stripe contact width of 100 μm and a cavity length of 2000–2500 μm. The cavity faces were coated with reflection and antireflection layers with reflection coefficients $R_1 \approx 0.05$ and $R_2 \approx 0.95$. The crystals were mounted on a copper heat sink; their output characteristics were studied in a pulsed (pulse duration 100 ns, repetition rate 1 kHz) and cw operation regimes at a heat sink temperature of 25 °C.

3. Results and discussion

It was shown in [11] that lasers with an ultra-narrow waveguide can emit high powers due to a decrease in the thermal load on the active region. As the next step in increasing the output power, it is possible to increase the height of the electronic barrier at the p-waveguide–emitter interface. To verify this suggestion, we fabricated ultra-narrow waveguide lasers of two types, namely, with a standard design [10] and with addition of a strained wide-bandgap barrier by analogy with [22].

The light–current and current–voltage characteristics of the studied lasers are presented in Fig. 1. One can see that the slopes of the light–current characteristics of both laser types are close to each other at the initial stage. However, with increasing pump current, the light–current characteristic of the laser with an increased barrier saturates more slowly and lies above the corresponding dependence for the laser with the standard design. In particular, the difference between these characteristics in the cw lasing regime at a current of 7.5 A is ~0.2 W (~7%) (Fig. 1a). The maximum achievable cw optical power at a pump current of 14 A, stripe contact width w = 100 μm, and cavity length L = 2000 μm was 4 W for samples with the standard design and 4.4 W for samples with the increased barrier. The existence of the additional barrier increased the cut-off voltage of the current–voltage characteristic by 0.15 V with a simultaneous increase in the series resistance of the laser by 4% (Fig. 1b).

The transparency current density (J_0 = 115–130 A cm^{-2}), the internal quantum efficiency (η_i = 0.95–0.96), and the level of optical losses (α_i = 2.5–3 cm^{-1}) turned out to be close for the studied samples.

The typical spectral characteristics of lasers in the cw regime are shown in Fig. 2. The temperature-induced wavelength shift for the laser with an increased electron barrier was 12.5 nm at a pump current of 6.2 A, which approximately corresponds to the overheating of the active region by 42 °C. The wavelength shift for the laser with the standard design at the same current reached 16.2 nm, which corresponds to overheating by ~54 °C. All this testifies to the positive influence of the barrier with an increased band gap on the temperature stability of the laser. Note that the difference in the wavelengths of the studied samples, which have identical quantum

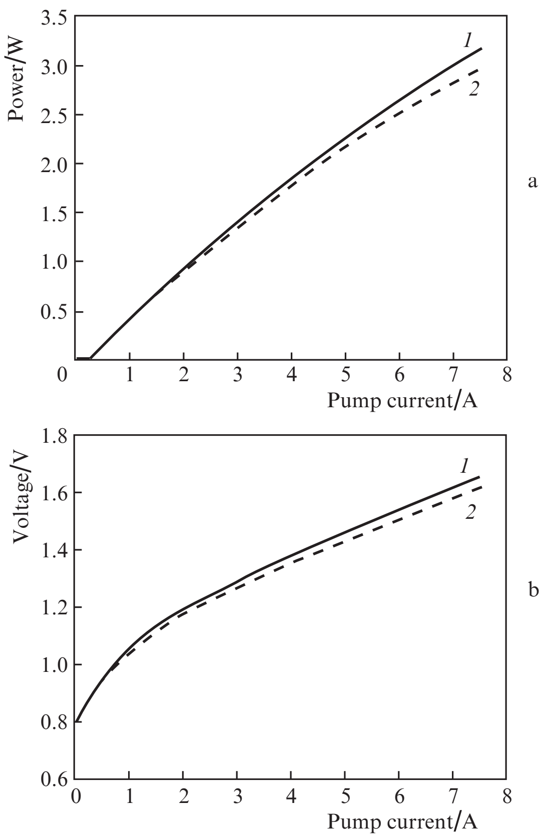

Figure 1. (a) Light–current and (b) current–voltage characteristics of AlGaInAs/InP semiconductor lasers with an ultra-narrow waveguide and (*1*) wide-bandgap and (*2*) standard barriers in the cw regime.

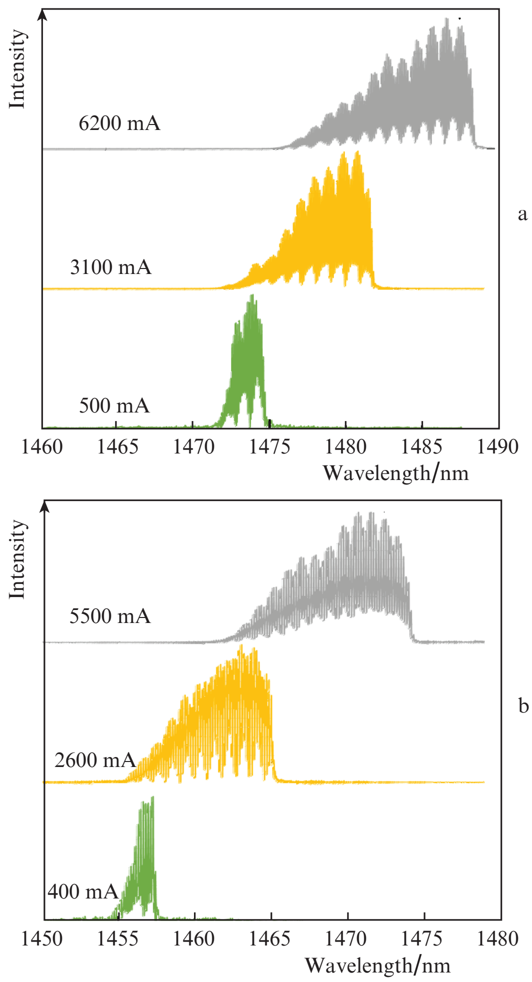

Figure 2. Typical spectral characteristics of AlGaInAs/InP semiconductor lasers with an ultra-narrow waveguide and (a) wide-bandgap and (b) standard barriers in the cw regime at different injection currents.

wells in the active region, can be explained by the existence of the strained barrier.

In the pulsed regime (100 ns, 1 kHz), lasers with an increased electron barrier demonstrated an output power increased by 10%–15% (Fig. 3). In particular, at a pump current of 100 A, these samples with the stripe contact width w = 100 μm and cavity length L = 2500 μm reached an output power of 17.5 W versus 15.5 W for the standard samples with the same dimensions.

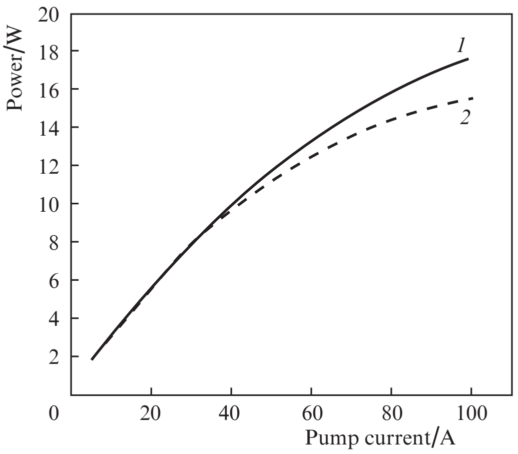

Figure 3. Light–current characteristics of AlGaInAs/InP semiconductor lasers with an ultra-narrow waveguide and (*1*) wide-bandgap and (*2*) standard barriers in a pulsed regime (100 ns, 1 kHz).

Our investigations confirmed that the better localisation of carriers in the active region allows one to achieve higher output powers. In particular, the introduction of a strained wide-bandgap barrier at the waveguide–p-emitter interface noticeably increases the emission characteristics of 1.4–1.6 μm lasers with both ultra-narrow and standard waveguides [22].

Thus, we presented the results of comparative experimental studies of semiconductor lasers based on AlGaInAs/InP heterostructures with an ultra-narrow waveguide and a variable band gap of AlInAs layers used as blocking barriers at the waveguide–p-emitter interface. The lasers with wider-bandgap AlInAs barrier layers demonstrate better electron localisation in the active region and weaker leakage of charge carriers into emitting layers. This leads to an increase in the output power of these lasers by 10%–15% at the same dimensions and pump currents in both pulsed and cw regimes.

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