Quantum Electronics **51** (10) 909–911 (2021)

https://doi.org/10.1070/QEL17635

High-power AlGaInAs/InP semiconductor lasers with an ultra-narrow waveguide emitting in the spectral range 1.9–2.0 μm

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

Abstract. **High-power semiconductor lasers based on AlGaInAs/InP heterostructures and emitting in the spectral range 1.9–2.0 μm are developed. Strain compensation in the active region makes it possible to use InGaAs quantum wells with a compressive strain of about 2.0%–2.5%. The operation of a laser with an ultra-narrow waveguide at wavelengths increasing from 1.4–1.6 to 2.0 μm is studied. At room temperature, the semiconductor lasers with a stripe contact width of 100 μm demonstrates a cw output optical power of 1.0 W with a wavelength of 1.91 μm at a pump current of 6.5 A and with a wavelength of 1.98 μm at a pump current of 7.2 A.**

Keywords: *semiconductor laser, heterostructure, AlGaInAs/InP, ultra-narrow waveguide, 2-μm spectral region.*

1. Introduction

At present, much attention is paid to the development of semiconductor lasers emitting at wavelengths longer than 1.8 μm. These lasers find application in molecular spectroscopy, medicine, lidars, for optical pumping of laser media, and in other fields [1–4]. Lasers of this spectral region are often designed using heterostructures with different types of heterojunctions based on semiconductor antimony-containing solid solutions, which are grown mainly by molecular beam epitaxy [2, 4–6]. Another approach implies the use of heterostructures with strongly strained In(Ga)As quantum wells [7–10] or with InAs quantum dots [11]. These heterostructures do not contain antimony and are grown on InP substrates mainly by MOVPE. In this case, an increase in the laser emission wavelength is accompanied by an increase in elastic strains in InGaAs quantum wells, which, when exceeding critical values, may lead to the appearance of misfit dislocations and thus to deteriorate the radiative characteristics.

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

Received 29 July 2021
Kvantovaya Elektronika **51** (10) 909–911 (2021)
Translated by M.N. Basieva

The boundary wavelength corresponding to the formation of crystalline defects can be increased by using strain-compensated quantum wells (elastic strains in the quantum well layer are compensated by strains of the opposite sign in the barrier layer [12, 13]). In addition, the use of strain-compensated InGaAs quantum wells, required to achieve a desired emission wavelength, weakens the Auger recombination, which is one of the most important processes negatively affecting the working characteristics of semiconductor lasers of this spectral region [14–16].

In our previous works [8, 17] we reported on the development of high-power 1.8-μm semiconductor lasers based on InGaAs/AlGaInAs and InGaAs/GaInAsP quantum-well heterostructures with a broadened asymmetric waveguide. A decrease in the internal optical losses allowed us to achieve an output power of 2.0–2.5 W in a cw operation regime. At the same time, it was shown in [18, 19] that the replacement of a broadened waveguide for an ultra-narrow one in laser of the 1.4–1.6-μm spectral range leads to an increase in the output power due to a slower growth of internal optical losses on charge carriers ejected in the waveguide with increasing pump current, as well as due to a decrease in the series and thermal resistances.

The present work is devoted to the study of applicability of InGaAs/AlGaInAs/InP heterostructures with an ultra-narrow waveguide for development of high-power semiconductor lasers emitting near 2.0 μm.

2. Experiment

The InGaAs/AlInGaAs/InP laser heterostructures were grown by MOVPE. The heterostructure contained an active region consisted of two strain-compensated InGaAs quantum wells positioned in the centre of an AlGaInAs waveguide 0.1 μm thick. The waveguide was sandwiched between InP emitter layers. To decrease leakage, we introduced a strained AlInAs barrier layer, whose band gap exceeded the band gap of the matched barrier [20], at the waveguide–p-emitter interface. The schematic band diagram of the active region is shown in Fig. 1. We studied two types of heterostructures differing by quantum wells. The parameters of InGaAs quantum wells and AlGaInAs barriers were chosen so that the lasers of the first (A) and second (B) types emitted in the regions of 1.9 and 2.0 μm, respectively.

The obtained heterostructures were used to fabricate semiconductor lasers with a stripe contact width of 100 μm and a cavity length of 2000 μm. The crystals were mounted on

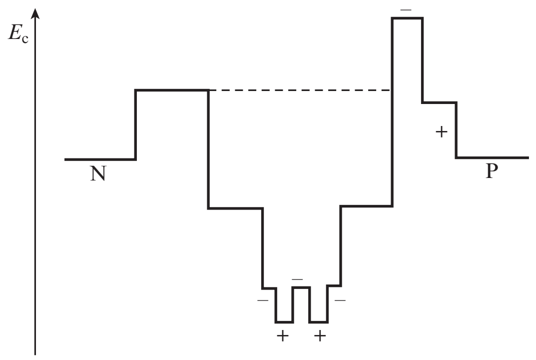

Figure 1. Schematic of the conduction band E_c of the active region of InGaAs/AlGaInAs/InP laser heterostructures (signs '+' and '–' indicate layers with compressive and tensile strains, respectively).

a copper heat sink with the p-side down using indium solder; their output characteristics were studied in a cw operation regime at a heat sink temperature of 25 °C.

3. Results and discussion

The idea of using ultra-narrow waveguides [18, 19] was successfully used for developing high-power semiconductor InGaAs/AlGaInAs/InP lasers emitting at wavelengths of 1.4–1.6 μm. An increase in the band gap of the AlInAs barrier layer at the waveguide–p-emitter interface leads to an increase in the output power [20]. These approaches were used in the present work to create lasers emitting at a longer wavelength. The active region was formed by InGaAs quantum wells with a calculated compressive strain from +2.0% to +2.5% and AlGaInAs barrier layers with a calculated tensile strain from –0.5% to –0.4%. It is important to note that, despite the advantages of ultra-narrow waveguides, these lasers are characterised by increased internal optical losses, which may turn out to be crucial for operation at wavelengths closer to 2.0 μm.

The light–current characteristics of the studied lasers are presented in Fig. 2. One can see that, although the lasers of both types demonstrated an output power of 1 W, the slope efficiency of the long-wavelength samples of type B is expectedly lower. These lasers are also characterised by an increased threshold current (0.75 A) in comparison with 0.60 A for the samples of type A. In addition, one can note a stronger saturation of the output power of lasers of type B with increasing pump current, especially at currents exceeding 6 A.

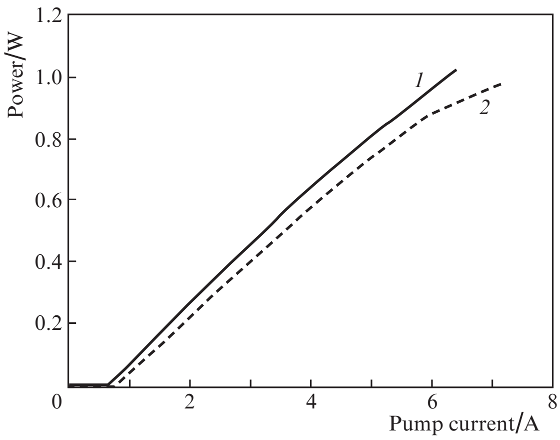

Figure 2. Light–current characteristics of InGaAs/AlGaInAs/InP semiconductor lasers with ultra-narrow waveguides of types (*1*) A and (*2*) B in the cw regime.

The spectral characteristics of samples are presented in Fig. 3. The wavelength of lasers of type A was about 1.91 μm, while the lasers of type B, as expected, demonstrated a longer wavelength, in the region of 1.98 μm.

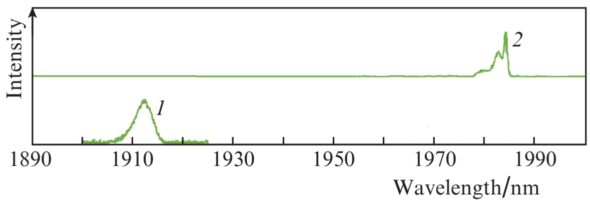

Figure 3. Spectral characteristics of InGaAs/AlGaInAs/InP semiconductor lasers with ultra-narrow waveguides of types (*1*, injection current 1.3 A) A and (*2*, injection current 1.2 A) B.

Thus, the use of MOVPE-grown InGaAs/AlGaInAs/InP heterostructures with strain-compensated quantum wells and an ultra-narrow waveguide allows one to create semiconductor lasers with a cw output power of 1 W in the spectral range 1.9–2.0 μm. To determine the maximum achievable power of these lasers and the specific features of their operation, it is necessary to perform additional investigations.

Acknowledgements. This work was partially supported by the Competitiveness Enhancement Programme of the National Research Nuclear University MEPhI (Agreement No. 02. a03.21.0005) and by the Russian Science Foundation (Grant No. 19-79-30072).

References

1. Kohler D., Kissel H., Flament M., Wolf P., Brand T., Biesenbach J. *SPIE*, **7583**, 75830-F (2010).
2. Tournie E., Baranov A.N. *Semiconductors and Semimetals*, **86**, 183 (2012).
3. Waynant R.W., Ilev I.K., Gannot I. *C. Phil. Trans. R. Soc. A*, **359**, 635 (2001).
4. Godard A. *C. R. Phys.*, **8**, 1100 (2007).
5. Lei W., Jagadish C. *J. Appl. Phys.*, **104**, 091101 (2008).
6. Jung D., Bank S., Lee M.L., Wasserman D. *J. Opt.*, **19**, 123001 (2017).
7. Luo S., Ji H.M., Gao F., Xu F., Yang X.G., Liang P., Yang T. *Opt. Express*, **23**, 8383 (2015).
8. Lyutetskii A.V., Borshchev K.S., Bondarev A.D., Nalet T.A., Pikhtin N.A., Slipchenko S.O., Fetisova N.V., Khomylev M.A., Marmalyuk A.A., Ryaboshtan Yu.L., Simakov V.A., Tarasov I.S. *Semiconductors*, **41**, 883 (2007) [*Fiz. Tekh. Poluprovodn.*, **41**, 883 (2007)].
9. Sato T., Mitsuhara M., Kakitsuka T., Fujisawa T., Kondo Y. *IEEE J. Sel. Top. Quantum Electron.*, **14**, 992 (2008).
10. Kim S., Kirch J., Mawst L. *J. Cryst. Growth*, **312**, 1388 (2010).
11. Kotani J., Veldhoven P.J., Nötzel R. *J. Appl. Phys.*, **106**, 093112 (2009).
12. Miller B.I., Koren U., Young M.G., Chien M.D. *Appl. Phys. Lett.*, **58**, 1952 (1991).
13. Ogasawara M., Sugiura H., Mitsuhara M., Yamamoto M., Nakao M. *J. Appl. Phys.*, **84**, 4775 (1998).
14. Lui W.W., Yamanaka T., Yoshikuni Y., Seki S., Yokoyama K. *Appl. Phys. Lett.*, **64**, 1475 (1994).

15. Andreev A.D., Zegrya G.G. *Semiconductors*, **31**, 297 (1997) [*Fiz. Tekh. Poluprovodn.*, **31**, 358 (1997)].
16. Gilard O., Lozes-Dupuy F., Vassilieff G., Bonnefont S., Arguel P., Barrau J., Le Jeune P. *J. Appl. Phys.*, **86**, 6425 (1999).
17. Lyutetskii A.V., Pikhtin N.A., Fetisova N.V., Leshko A.Yu., Slipchenko S.O., Sokolova Z.N., Ryaboshtan Yu.L., Marmalyuk A.A., Tarasov I.S. *Semiconductors*, **43**, 1646 (2009) [*Fiz. Tekh. Poluprovodn.*, **43**, 1646 (2009)].
18. Marmalyuk A.A., Ryaboshtan Yu.L., Gorlachuk P.V., Ladugin M.A., Padalitsa A.A., Slipchenko S.O., Lyutetskii A.V., Veselov D.A., Pikhtin N.A. *Quantum Electron.*, **47** (3), 272 (2017) [*Kvantovaya Elektron.*, **47** (3), 272 (2017)].
19. Marmalyuk A.A., Ryaboshtan Yu.L., Gorlachuk P.V., Ladugin M.A., Padalitsa A.A., Slipchenko S.O., Lyutetskii A.V., Veselov D.A., Pikhtin N.A. *Quantum Electron.*, **48** (3), 197 (2018) [*Kvantovaya Elektron.*, **48** (3), 197 (2018)].
20. Svetogorov V.N., Ryaboshtan Yu.L., Ladugin M.A., Padalitsa A.A., Volkov N.A., Marmalyuk A.A., Slipchenko S.O., Lyutetskii A.V., Veselov D.A., Pikhtin N.A. *Quantum Electron.*, **50** (12), 1123 (2020) [*Kvantovaya Elektron.*, **50** (12), 1123 (2020)].