Quantum Electronics **50** (9) 830–833 (2020)

https://doi.org/10.1070/QEL17376

Superluminescent diodes in the spectral range of 1.5–1.6 μm based on strain-compensated AlGaInAs/InP quantum wells

D.R. Sabitov, Yu.L. Ryaboshtan, V.N. Svetogorov, A.A. Padalitsa, M.A. Ladugin,
A.A. Marmalyuk, M.G. Vasil'ev, A.M. Vasil'ev, Yu.O. Kostin, A.A. Shelyakin

Abstract. **Superluminescent diodes based on AlGaInAs/InP separate-confinement double heterostructures with strain-compensated quantum wells are investigated. The influence of elastic strains in the active region on the output characteristics of the devices is analysed. It is shown that such a design of a superluminescent diode allows an optical power of more than 5 mW, a radiation spectrum width of more than 60 nm, a degree of output radiation polarisation up to 30 dB to be obtained at the output of a single-mode fibre, and has a great potential for further improvement.**

Keywords: *superluminescent diode, quantum well, elastic strain compensation, AlGaInAs/InP.*

1. Introduction

At present, superluminescent diodes (SLDs), semiconductor sources of low-coherence radiation with increased brightness and a wide spectral line, are finding wider and wider use. For a number of practical applications, in addition to a high output power, SLDs are required to operate at elevated temperatures and often have an increased width of their spectrum. A particular difficulty is the creation of such devices with a radiation wavelength of 1.4–1.6 μm, since, in contrast to the near-IR range (0.8–1.0 μm), this spectral range is characterised by an increased intensity of Auger recombination. The latter worsens the external quantum efficiency, reduces the level of a maximum achievable output power and causes a strong temperature dependence of the output characteristics of the SLDs. The negative role of the Auger process was noted by many researchers developing laser diodes (LDs) in this spectral range [1–5]. A characteristic feature of SLDs is high concentration of charge carriers in the active region, especially in the extreme operation modes that make Auger recombination processes more probable.

Traditionally, SLDs in the spectral range of 1.5–1.6 μm are based on GaInAsP/InP separate-confinement double heterostructures with a bulk layer [6–8] or quantum wells (QWs) in the active region [9–11]. Variations in the QW parameters make it possible to obtain a wide spectral line of radiation (100–200 nm) [12, 13]. At the same time, there is a need for devices with an increased output power, increased operating temperature, and high degree of radiation polarisation. Such parameters can be achieved using heterostructures based on AlGaInAs/InP, which proved themselves well in the fabrication of LDs in the spectral range of 1.3–1.55 μm with an increased power and temperature stability. Thus, by improving the electronic confinement in the AlGaInAs QW, it was possible to increase the quantum efficiency and the limiting operating temperature of the LD [1, 14, 15]. The use of a strained active region in an LD of this type allows reducing the effect of Auger recombination processes and improving the output characteristics [16–18]. Generation of misfit dislocations is a natural limitation of the value of admissible elastic strains. It is possible to shift the boundary of crystal defect formation by using strain-compensated quantum wells, when elastic strains in the QW layer are compensated for by strains of the opposite sign in the barrier layer [19, 20]. LDs based on strain-compensated QWs have demonstrated improved performance [21–23]. It should be noted that the possibility of forming a strain-compensated active region largely depends not only on the parameters (thickness and composition) of the layers, but also on the growth conditions. This work is devoted to the use of AlGaInAs/InP heterostructures with a strain-compensated active region for making SLDs in the spectral range of 1.5–1.6 μm.

2. Experimental

SLDs were fabricated based on AlGaInAs/InP separate-confinement double heterostructures by MOVPE. The AlGaInAs/InP heterostructure contained an active region with several QWs. The geometry of the active region was chosen so that the maximum emission was in the spectral range of 1.5–1.6 μm. The level of introduced elastic strains of the opposite sign in the QW (compressive strain, $\varepsilon_{\rm QW} = +1.4\%$) and the barrier (tensile strain, $\varepsilon_{\rm bar} = -0.4\%$) was calculated to increase the optical gain while maintaining a high crystal perfection, which was confirmed by the achievement of the maximum intensity of the photoluminescence signal of the samples. Schematic diagrams of the conduction band of the active region of the SLD and the periods of the crystal lattice of its constituent layers are shown in Fig. 1.

D.R. Sabitov, Yu.L. Ryaboshtan, V.N. Svetogorov, A.A. Padalitsa, M.A. Ladugin LLC Sigm Plus, ul. Vvedenskogo 3, 117342 Moscow, Russia; e-mail: D.Sabitov@siplus.ru;
A.A. Marmalyuk LLC Sigm Plus, ul. Vvedenskogo 3, 117342 Moscow, Russia; National Research Nuclear University MEPhI, Kashirskoe sh. 31, 115409 Moscow, Russia;
M.G. Vasil'ev, A.M. Vasil'ev, Yu.O. Kostin, A.A. Shelyakin Kurnakov Institute of General and Inorganic Chemistry, Russian Academy of Sciences, Leninsky prosp. 31, 119991 Moscow, Russia

Received 1 June 2020; revision received 19 June 2020
Kvantovaya Elektronika **50** (9) 830–833 (2020)
Translated by V.L. Derbov

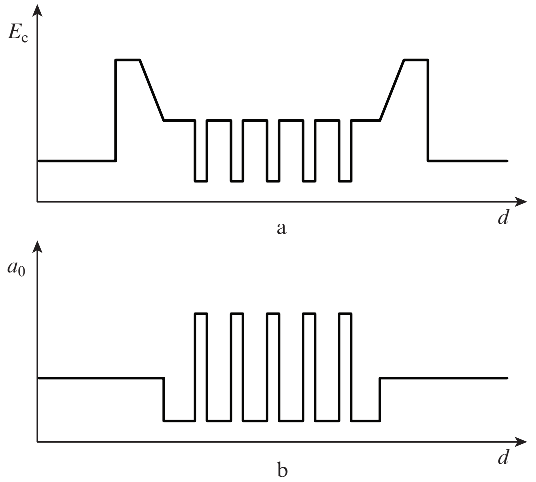

Figure 1. Schematic representation of (a) the conduction band E_c and (b) the period of the crystal lattice a_0 of the active region of the SLD (d is the thickness of the active region).

For low-coherence radiation sources, it is critical to obtain a minimum level of parasitic modulation of the output signal by Fabry–Perot resonances, which requires the maximum possible suppression of positive optical feedback. To this end, we used an SLD design close to that described in Ref. [10], including a straight active channel inclined to the facet, antireflection coatings of the facets, and a wedge-shaped radiation absorber at the inoperative end of the crystal. The manufactured chips were mounted p-side up on a copper heat sink, which, in turn, was installed in a standard DBUT case with a Peltier thermoelement. The SLD radiation was introduced into a Panda-type single-mode fibre using an end microlens. All measurements were carried out in continuous mode at various temperatures using a Maiman SF8150 driver.

3. Results and discussion

Typical current–voltage and light–current characteristics of fabricated SLDs based on AlGaInAs/InP heterostructures with strain-compensated quantum wells at different stabilisation temperatures are shown in Fig. 2. The operating voltage was, as a rule, 1.5–1.8 V. The optical power was measured at the output of a single-mode fibre. At room temperature, the devices emit up to 5 mW of power, which is sufficient for various practical applications [24]. With an increase in temperature, the quantum efficiency and the output power of the emitter decrease. Nevertheless, at a temperature of 45 °C the output power approaches 2 mW, which makes it possible to use SLDs for solving many tasks without using forced thermal stabilisation. Thus, in [25], it is noted that SLDs with a power of ~0.1 mW at the output of a single-mode fibre are in demand for light-emitting modules operating in a wide temperature range without thermal stabilisation.

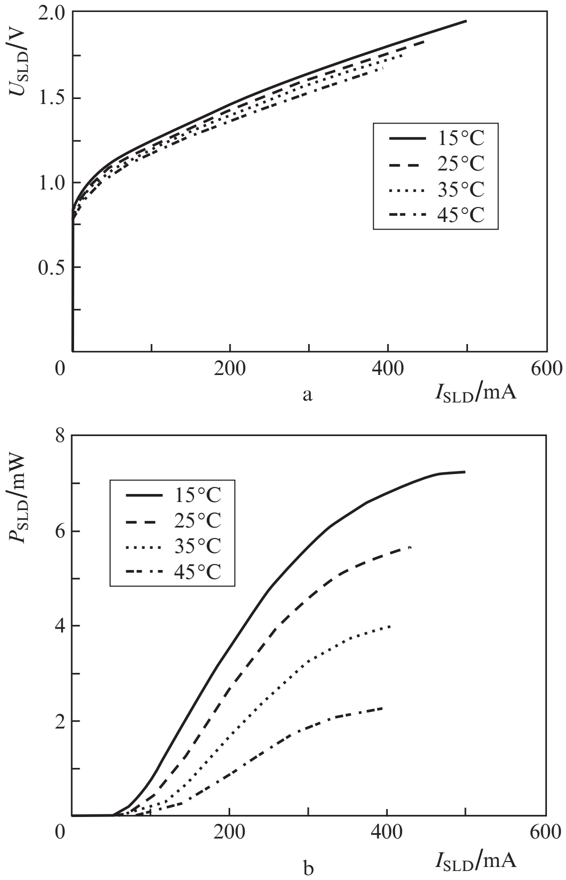

Figure 2. (a) Current–voltage and (b) light–current characteristics of SLDs measured at different stabilisation temperatures.

Figure 3 shows the evolution of the SLD emission spectrum with an increase in the injection level. An increase in the current density leads to an insignificant shift of the maximum and an increase in the emission spectrum width at the level of 0.5, which should be taken into account when designing devices with a given emission spectrum at a certain optical or consumed power. The change in the spectrum at different stabilisation temperatures is shown in more detail in Fig. 4. It is seen that at injection currents above 200 mA the wavelength of the maximum of the emission spectrum changes little, while its half-width continues to increase and reaches 60–70 nm.

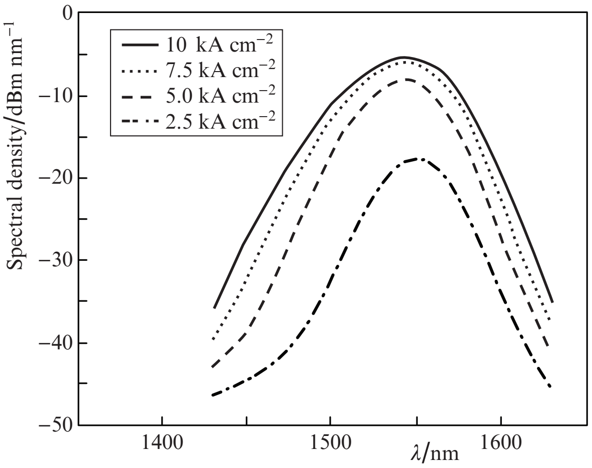

Figure 3. Evolution of the spectral characteristic of SLDs as a function of the injection current density.

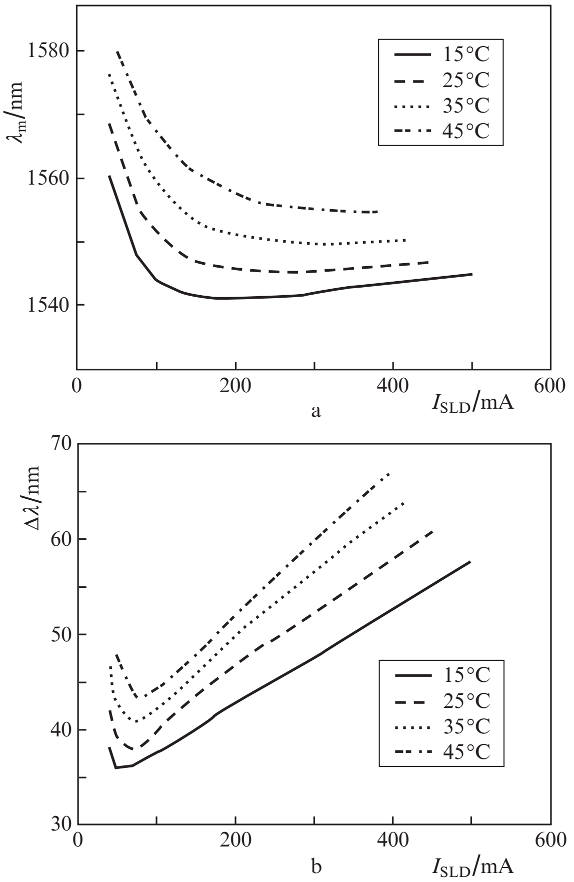

Figure 4. Dependences of (a) the emission wavelength and (b) spectrum width of SLDs on the injection current at different temperatures.

The measures taken to suppress optical feedback made it possible to reduce the amplitude of the parasitic modulation of the emission spectrum to a level of 0.15 dB over the entire range of operating injection currents. Part of the spectral curve near the intensity maximum, taken with a high resolution to estimate the modulation depth, is shown in Fig. 5.

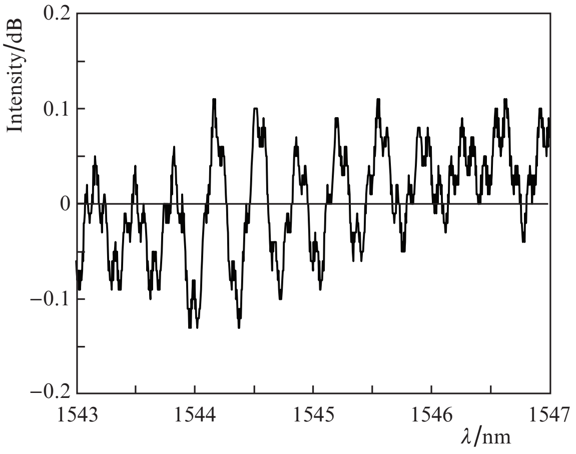

Figure 5. High-resolution portion of the spectral curve near the maximum of the emission line.

Analysis of the temperature dependences of the output parameters shows the possibility of using the developed SLDs in cases without a Peltier element at an output radiation power of ~100 μW. SLDs with such characteristics can be in demand, for example, in the production of miniature optical gyroscopes, where small size and low cost of the final product are important while ensuring the required power and stability of the source wavelength.

The degree of polarisation of radiation output from the single-mode fibre was measured using a Santec PEM-330 polarisation extinction meter. It is known that the transition from a bulk active region to a quantum-well one promotes an increase in the polarisation extinction of radiation (TE/TM) due to the separation of light and heavy holes [9]. The typical value of this parameter for SLD based on the QW of the considered spectral range is 10–20 dB. A decrease in the level of elastic strains in quantum wells, for example, by introducing barriers (or using QWs) with strains of opposite signs, helps reduce this ratio and obtain polarisation-independent SLDs and semiconductor optical amplifiers [26–28]. In this work, on the contrary, the elastic strains in the quantum wells were increased so that the polarisation extinction of the radiation increased and amounted to 25–30 dB.

4. Conclusions

The output characteristics of SLDs based on the AlGaInAs/InP heterostructure are studied. It is shown that the use of strain-compensated quantum wells in the active region makes it possible to fabricate SLDs with a power of more than 5 mW at the output of a single-mode optical fibre, a spectral half-width of 50–70 nm, and a degree of polarisation of the output radiation of 25–30 dB. It is shown that the use of such heterostructures allows SLDs to be produced with a favourable set of operational characteristics for various practical applications. Further research will be devoted to studying the reliability of the developed SLD. It is also of interest to study SLDs based on an AlGaInAs/InP heterostructure with an active region consisting of QWs of various thicknesses and compositions, which should make it possible to increase the width of the emission spectrum (see Ref. [29]).

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 the Presidium of the Russian Academy of Sciences (Scientific Foundations for the Synthesis of New Functional Materials Programme I.15.1).

References

1. Zah C.-E., Bhat R., Pathak B.N., Favire F., Lin W., Wang M.C., Andreadakis N.C., Hwang D.M., Koza M.A., Lee T.-P., Wang Z., Darby D., Flanders D., Hsieh J.J. *IEEE J. Quantum Electron.*, **30** (2), 511 (1994).
2. Minch J., Park S.H., Keating T., Chuang S.L. *IEEE J. Quantum Electron.*, **35**, 771 (1999).
3. Piprek J., Kenton White J., SpringThorpe A.J. *IEEE J. Quantum Electron.*, **38**, 1253 (2002).
4. Lyutetskiy A.V., Borshchev K.S., Pikhtin N.A., Slipchenko S.O., Sokolova Z.N., Tarasov I.S., *Semiconductors*, **42**, 104 (2008) [*Fiz. Tekh. Poluprovodn.*, **42**, 106 (2008)].

5. Veselov D.A., Ayusheva K.R., Shashkin I.S., Bakhvalov K.V., Vasil'eva V.V., Vavilova L.S., Lyutetskiy A.V., Pikhtin N.A., Slipchenko S.O., Sokolova Z.N., Tarasov I.S. *Quantum Electron.*, **45**, 879 (2015) [*Kvantovaya Elektron.*, **45**, 879 (2015)].
6. Noguchi Y., Yasaka H., Mikami O., Nagai H. *J. Appl. Phys.*, **67**, 2665 (1990).
7. Pikhtin N.A., Il'in Yu.V., Leshko A.Yu., Lyutetskiy A.V., Stankevich A.L., Tarasov I.S., Fetisova N.V. *Tech. Phys. Lett.*, **25**, 598 (1999) [*Pis'ma Zh. Tekh. Fiz.*, **15**, 16 (1999)].
8. Wang S., Wang W., Zhu H., Zhao L., Zhang R., Zhou F., Shu H., Wang R. *J. Cryst. Growth*, **260**, 464 (2004).
9. Kondo S., Yasaka H., Noguchi Y., Magari K., Sugo M., Mikami O. *Electron. Lett.*, **28** (2), 132 (1992).
10. Song J.H., Cho S.H., Han I.K., Hu Y., Heim P.J.S., Johnson F.G., Stone D.R., Dagenais M. *IEEE Photonics Technol. Lett.*, **12**, 783 (2000).
11. Mamedov D.S., Prokhorov V.V., Yakubovich S.D. *Quantum Electron.*, **33**, 511 (2003) [*Kvantovaya Elektron.*, **33**, 511 (2003)].
12. Lin C.-F., Wu B.-R., Laih L.-W., Shih T.-T. *Opt. Lett.*, **26**, 1099 (2001).
13. Lin C.-F., Su Y.-S., Wu C.-H., Shmavonyan G.S. *IEEE Photonics Technol. Lett.*, **16**, 1441 (2004).
14. Golikova E.G., Kureshov V.A., Leshko A.Yu., Livshits D.A., Lyutetskiy A.V., Nikolaev D.N., Pikhtin N.A., Ryaboshtan Yu.L., Slipchenko S.O., Tarasov I.S., Fetisova N.V. *Tech. Phys. Lett.*, **26**, 913 (2000) [*Pis'ma Zh. Tekh. Fiz.*, **26**, 40 (2000)].
15. Zhang Y., Chen W., Wang A., Jiang H., Liu C., Liu S. *IEEE J. Quantum Electron.*, **37**, 923 (2001).
16. Lui W.W., Yamanaka T., Yoshikuni Y., Seki S., Yokoyama K. *Appl. Phys. Lett.*, **64**, 1475 (1994).
17. Wang J., von Allmen P., Leburton J.-P., Linden K.J. *IEEE J. Quantum Electron.*, **31**, 864 (1995).
18. Andreev A.D., Zegrya G.G. *Semiconductors*, **31**, 297 (1997) [*Fiz. Tekh. Poluprovodn.*, **31**, 358 (1997)].
19. Miller B.I., Koren U., Young M.G., Chien M.D. *Appl. Phys. Lett.*, **58**, 1952 (1991).
20. Ogasawara M., Sugiura H., Mitsuhara M., Yamamoto M., Nakao M. *J. Appl. Phys.*, **84**, 4775 (1998).
21. Lin C.-C., Liu K.-S., Wu M.-C., Shiao H.-P. *Jpn. J. Appl. Phys.*, **37**, 3309 (1998).
22. Pan J.-W., Chen M.-H., Chyi J.-I. *J. Cryst. Growth*, **201/202**, 923 (1999).
23. Wu M.-Y., Yang C.-D., Lei P.-H., Wu M.-C., Ho W.-J. *Jpn. J. Appl. Phys.*, **42**, L643 (2003).
24. *Handbook of Optical Fiber Sensing Technology*. Ed. by J.M. López-Higuera (New York: John Wiley & Sons Ltd, 2002).
25. Mamedov D.S., Prokhorov V.V., Shramenko M.V., Yakubovich S.D. *Quantum Electron.*, **32**, 593 (2002) [*Kvantovaya Elektron.*, **32**, 593 (2002)].
26. Mikami O., Noguchi Y., Magari K., Suzuki Y. *IEEE Photonics Technol. Lett.*, **4** (7), 703 (1991).
27. Newkirk M.A., Miller B.I., Koren U., Young M.G., Chien M., Jopson R.M., Burrus C.A. *IEEE Photonics Technol. Lett.*, **4**, 406 (1993).
28. Silver M., Phillips A.F., Adams A.R., Greene P.D., Collas A.J. *IEEE J. Quantum Electron.*, **36**, 118 (2000).
29. Andreeva E.V., Il'chenko S.N., Ladugin M.A., Marmalyuk A.A., Pankratov K.M., Shidlovskii V.R., Yakubovich S.D. *Quantum Electron.*, **49**, 931 (2019) [*Kvantovaya Elektron.*, **49**, 931 (2019)].