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Substrate-emitting semiconductor laser with a trapezoidal active region

N.V. Dikareva, S.M. Nekorkin, M.V. Karzanova, B.N. Zvonkov, V.Ya. Aleshkin, A.A. Dubinov, A.A. Afonenko

Abstract. **Semiconductor lasers with a narrow (∼2°) directional pattern in the planes both parallel and perpendicular to the p–n junction are fabricated. To achieve a low radiation divergence in the p–n junction plane, the active region in this plane was designed in the form of a trapezium. The narrow directional pattern in the plane perpendicular to the p–n junction was ensured by the use of a leaky mode, through which more than 90% of laser power was coupled out.**

Keywords: *semiconductor laser, active region, quantum well, leaky mode.*

1. Introduction

An extremely important laser characteristic is the directional pattern. In semiconductor lasers of the standard stripe design, the divergence is ∼10% in the p–n junction plane and 30% in the perpendicular plane. Fibre lasers and amplifiers must be pumped by laser beams of high quality, which is usually achieved by using rather complex schemes with astigmatic lenses. Because of this, it is desirable to improve the output laser beam quality, namely, to narrow the directional pattern and achieve identical divergence in both planes.

The creation of semiconductor lasers with an ultrawide waveguide with [1] and without [2, 3] confining layers, as well as of substrate-emitting lasers [4–6], solved the problem only partially. The lasers with ultrawide waveguides have a radiation divergence of ∼20°. The leaky-mode diode lasers are characterised by a very low divergence (1–2°) in the plane perpendicular to the structure (p–n junction), but the divergence of their radiation in the plane of the structure corresponds to the divergence of standard stripe heterolasers (∼10°).

A narrow directional pattern in the heterostructure plane was realised in distributed feedback lasers. The angular divergence of their radiation in the structure plane is ∼1°, the position of the spectral maximum almost does not depend on the pump current density, and lasing occurs in the single-frequency regime [7]. However, the fabrication technology of these lasers is rather complicated.

One more (simpler) method of formation of low-divergence radiation is the use of a trapezoidal (horn-like) active region of the laser [8]. The operation principle of lasers of such geometry is based on the fact that the fundamental transverse mode has the minimum diffraction divergence, while the higher modes are better coupled out of the widening active region and efficiently decay in inactive layers. The divergence of these lasers is about 2° in the direction of the p–n junction, but is high in the perpendicular direction.

In this work, we experimentally study the spectral and spatial characteristics of substrate-emitting semiconductor lasers with a trapezoidal active region. This laser design allows one to considerably narrow the directional pattern and approximately equalise the angular divergences in both planes.

2. Experimental results and discussion

The InGaAs/GaAs/InGaP laser heterostructure with ten quantum wells in the active region was grown by MOS-hydride epitaxy under atmospheric pressure. The parameters of the structure layers are listed in Table 1. The thin (67 nm) n-type InGaP cladding layer allows the most part of laser radiation (more than 90%) to tunnel from the waveguide to the substrate. To compensate high leakage losses, we used ten quantum wells in the active region [9]. Based on this heterostructure, we made laser diodes with the active region 1 mm long. The faces of laser chips were neither antireflection nor reflection coated, and the cleaved edges of the structures served as mirrors. The active region of the heterolasers had the form of a trapezium with bases (cleaved mirrors) 25 and 125 μm long (Fig. 1). To avoid overheating of the device, the laser chips were soldered to a copper heat sink using indium solder.

The laser characteristics were measured upon pulsed electric current pumping (pulse duration 360 ns, pulse repetition rate approximately 1.43 kHz). The spectral characteristics of the laser diodes are presented in Fig. 2. It is seen that the laser diodes of the proposed design emit narrow-band radiation. The spectral bandwidth was 2 nm at a pump current of 13 A and 3 nm at a current of 15 A. Lasing was observed at a wavelength of 963 nm; the lasing threshold was 10 A.

The spatial characteristics were measured in the lasing regime in the planes parallel and perpendicular to the p–n junction. All the measurements were performed at room temperature. In the far field in the plane parallel to the p–n junction, at a pump current of 11 A we observed a multilobe direc-

N.V. Dikareva, S.M. Nekorkin, M.V. Karzanova, B.N. Zvonkov Scientific-Research Physicotechnical Institute, N.I. Lobachevsky Nizhnii Novgorod State University, prosp. Gagarina 23, 603950 Nizhnii Novgorod, Russia; e-mail: nekorkin@nifti.unn.ru, zvonkov@nifti.unn.ru;
V.Ya. Aleshkin, A.A. Dubinov Institute for Physics of Microstructures, Russian Academy of Sciences, GSP-105, 603950 Nizhnii Novgorod, Russia; N.I. Lobachevsky Nizhnii Novgorod State University, prosp. Gagarina 23, 603950 Nizhnii Novgorod, Russia; e-mail: sanya@ipm.sci-nnov.ru;
A.A. Afonenko Belorussian State University, prosp. Nezavisimosti 4, 220050 Minsk, Belorussia; e-mail: afonenko@bsu.by

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Table 1. Parameters of laser heterostructure layers.

Layer number	Layer type	Doping and composition	Thickness/nm
1	Substrate	n^+-GaAs	–
2	Buffer	n-GaAs	954
3	Cladding	n-InGaP	67
4	Waveguiding	n-GaAs	318
5	Waveguiding	i-GaAs	32
6	Compensating	i-GaAsP	18
7	Waveguiding	i-GaAs	32
8	Quantum well	InGaAs	8
9	Waveguiding	i-GaAs	32
10	Compensating	i-GaAsP	32
11	Waveguiding	i-GaAs	32
12–27	8-fold repetition of layers 8–11		
28	Quantum well	InGaAs	8
29	Waveguiding	i-GaAs	32
30	Compensating	i-GaAsP	16
31	Waveguiding	i-GaAs	32
32	Waveguiding	p-GaAs	318
33	Cladding	p-InGaP	504
34	Contact	p^+-GaAs	220

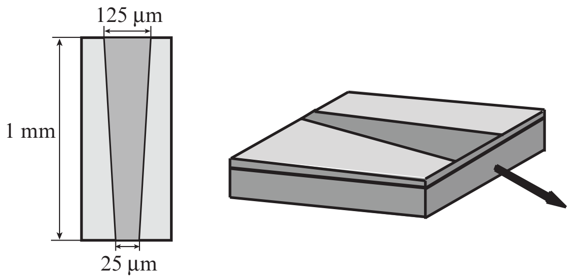

Figure 1. Dimensions of the trapezoidal active region and its position on the laser chip.

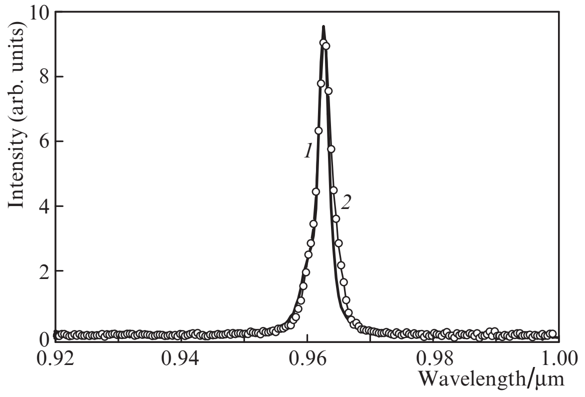

Figure 2. Spectral characteristics of substrate-emitting laser diodes with a trapezoidal active region at pump currents of (*1*) 13 and (*2*) 15 A.

tional pattern with one lobe having an order of magnitude higher intensity than the other lobes, a divergence angle of 3°, and an angular position of 1°. Such a small deviation of the main directional pattern lobe from zero is typical for the considered structures [10–12]. At a current of 11 A, the angular position of the radiation intensity maximum was 2.5° and the directional pattern was narrowed to 1.5° (Fig. 3).

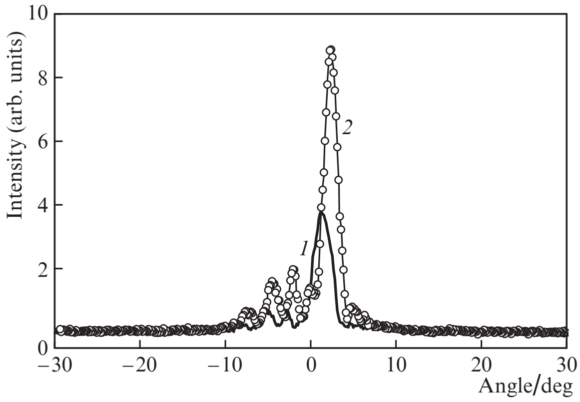

Figure 3. Directional pattern of the laser in the plane parallel to the p–n junction at pump currents of (*1*) 11 and (*2*) 12 A.

The directional pattern in the lasing regime in the plane perpendicular to the p–n junction has one narrow (2°) lobe typical for lasers with considerable leakage through the substrate, with an angular deviation of 4° from the normal (at a pump current of 10 A) due to radiation leakage through the substrate (Fig. 4). As the current increases to 15 A, the directional pattern narrows to 1.5°, while the angular position of the radiation intensity maximum remains unchanged. The observed peak with the angular position ∼24° is caused by rereflection of radiation from the substrate.

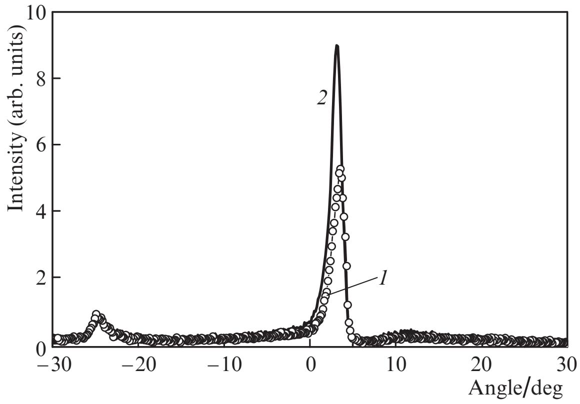

Figure 4. Directional pattern of the laser in the plane perpendicular to the p–n junction at pump currents of (*1*) 10 and (*2*) 15 A.

Thus, it is experimentally shown that the semiconductor lasers with a trapezoidal active region and a considerable leakage to the substrate can generate a low-divergence radiation in a narrow range of pump currents.

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References

1. Slipchenko S.O., Podoskin A.A., Vinokurov D.A., Bondarev A.D., Kapitonov V.A., Pikhtin N.A., Kop'ev P.S., Tarasov I.S. *Fiz. Tekhn. Poluprov.*, **47** (8), 1082 (2013).

2. Aleshkin V.Ya., Dikareva N.V., Dubinov A.A., Zvonkov B.N., Karzanova M.V., Kudryavtsev K.E., Nekorkin S.M., Yablonskii A.N. *Kvantovaya Elektron*., **43** (5), 401 (2013) [*Quantum Electron*., **43** (5), 401 (2013)].
3. Aleshkin V.Ya., Afonenko A.A., Dikareva N.V., Dubinov A.A., Kudryavtsev K.E., Morozov S.V., Nekorkin S.M. *Fiz. Tekhn. Polupr*., **47** (11), 1486 (2013) [*Semiconductors*, **47** (11), 1475 (2013)].
4. Zvonkov N.B., Zvonkov B.N., Ershov A.V., Uskova E.A., Maksimov G.A. *Kvantovaya Elektron*., **25** (7), 622 (1998) [*Quantum Electron*., **28** (7), 605 (1998)].
5. Aleshkin V.Ya., Babushkina T.S., Biryukov A.A., Dubinov A.A., Zvonkov B.N., Kolesnikov M.N., Nekorkin S.M. *Kvantovaya Elektron*., **40** (10), 855 (2010) [*Quantum Electron*., **40** (10), 855 (2010)].
6. Nekorkin S.M., Zvonkov B.N., Kolesnikov M.N., Dikareva N.V., Aleshkin V.Ya., Dubinov A.A. *Vestnik NNGU im. Lobachevskogo*, **1** (1), 30 (2012).
7. Bogatov A.P., Drakin A.E., Batrak D.V., Güther R., Paschke K., Wenzel H. *Kvantovaya Elektron*., **36** (8), 745 (2006) [*Quantum Electron*., **36** (8), 745 (2006)].
8. Avrutskii I.A., Akhlestina S.A., Dianov E.M., Zvonkov N.B., Lin'kova E.P., Maksimov G.A. *Kvantovaya Elektron*., **23** (8), 701 (1996) [*Quantum Electron*., **26** (8), 682 (1996)].
9. Ushakov D.V., Afonenko A.A., Aleshkin V.Ya. *Kvantovaya Elektron*., **43** (11), 999 (2013) [*Quantum Electron*., **43** (11), 999 (2013)].
10. Bogatov A.P., Drakin A.E., Stratonnikov A.A., Alaverdyan Yu.S., Ustinov A.V., Shveikin V.I. *Kvantovaya Elektron*., **27** (2), 131 (1999) [*Quantum Electron*., **29** (2), 131 (1999)].
11. Bogatov A.P., Drakin A.E., Lyakh A.A., Stratonnikov A.A. *Kvantovaya Elektron*., **31** (10), 847 (2001) [*Quantum Electron*., **31** (10), 847 (2001)].
12. Nekorkin S.M., Zvonkov B.N., Karzanova M.V., Dikareva N.V., Aleshkin V.Ya., Dubinov A.A. *Kvantovaya Elektron*., **42** (10), 931 (2012) [*Quantum Electron*., **42** (10), 931 (2012)].