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Multimode semiconductor lasers with surface distributed feedback

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Multimode semiconductor lasers with surface distributed feedback (DFB) emitting at a wavelength of 1040 nm have been developed. The DFB period is 20 μm. This design allows one to abandon the complex technological processes of two-stage epitaxy and electron lithography. For laser samples with antireflection coatings on both mirrors, a narrowing of the lasing spectrum to two competing modes located on both sides of the Bragg wavelength has been demonstrated. Its temperature stability was less than 0.1 nm/K. The presence of competing Fabry–Perot modes indicates an insufficient value of the coupling coefficient for the samples.

Keywords: Semiconductor laser, distributed feedback, lasing spectrum, laser resonator.

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Introduction

High-power semiconductor lasers are a key element of cutting-edge industry and digital technology. They have record high efficiency, reliability, compact size, which gives them advantages over other sources of laser radiation. Classical ridge semiconductor lasers with aperture size 100 μm generate optical power of the order of several tens of watts. At the same time, one of the disadvantages of semiconductor lasers is a relatively broad and temperature unstable generation spectrum [1,2]. The width of the laser generation spectrum and its multimode composition are due to a small spectral intermode distance and the same output losses for the longitudinal modes of the Fabry–Perot resonator with lengths of more than 1 mm which are typical for current high-power lasers. The shift of the generation spectrum with a change in temperature or pump current is related to the temperature dependence of the bandgap width of the active region (quantum well). The distributed feedback (DFB) formed by periodic modulation of the dielectric permittivity along the resonator axis is used to select longitudinal modes of the semiconductor laser resonator. In standard DFB lasers, the modulation is formed within the heterostructure layers, and its period corresponds to the 1–2 order of Bragg diffraction ($\Lambda \approx 150-300$ nm for the generation wavelength $\lambda \approx 1\,\mu$m) [3–5], which requires expensive electron lithography technology and a two-step epitaxial growth process, which makes the manufacturing process much more complicated.

Modern approaches in the design of laser heterostructures emitting in the wavelength range 900–1100 nm [6], have made it possible to achieve record-low internal optical losses ($\alpha_{\text{int}} < 0.5\,\text{cm}^{-1}$), which allowed increasing the resonator length to values of 3 mm and more. This enables the formation of dielectric permittivity modulation with a large period while preserving the number of periods. Increasing the period allows, first, to switch to a simpler photolithography technology, and second, to form an ohmic contact within the period between the lattice teeth, which makes it possible to switch to surface DFB and skip the two-step epitaxial growth process [7–8].

At the same time, the new design of the surface DFB requires that its parameters and the design of the heterostructure be optimised to achieve the necessary value of the coupling coefficient, which determines the threshold conditions for the generation of selective modes. In this study, high order multimode lasers with surface DFB based on AlGaAs/GaAs/InGaAs heterostructure were produced. For the obtained samples, generation spectra were measured at different injection current values and different temperatures.

Description of the samples

Experimental samples were formed from an AlGaAs/GaAs/InGaAs heterostructure grown by MOCVD epitaxy on a GaAs substrate. The heterostructure consisted of a waveguide $Al_{0.15}Ga_{0.85}As$ with a thickness of 1.2 μm, emitters $Al_{0.22}Ga_{0.78}As$ and an active region formed by a single quantum well $In_{0.27}Ga_{0.73}As$ with a thickness of 9 nm, providing a maximum electroluminescence at a wavelength of 1040 nm. The surface DFB was formed by contact photolithography and reactive ion etching methods. The period of the DFB was 20 μm, and the width of the etched groove was 1.2 μm. An ohmic *p*-contact was applied between the grooves (Fig. 1, *a*). The depth of the groove corresponded to the position of the waveguide-emitter heterojunction and was more than 1.9 μm (Fig. 1, *b*). The DFB bar was covered by an SiO_2 layer to protect against electrical leakage through the etched layers of the heterostructure. The width of the strip contact was 100 μm.

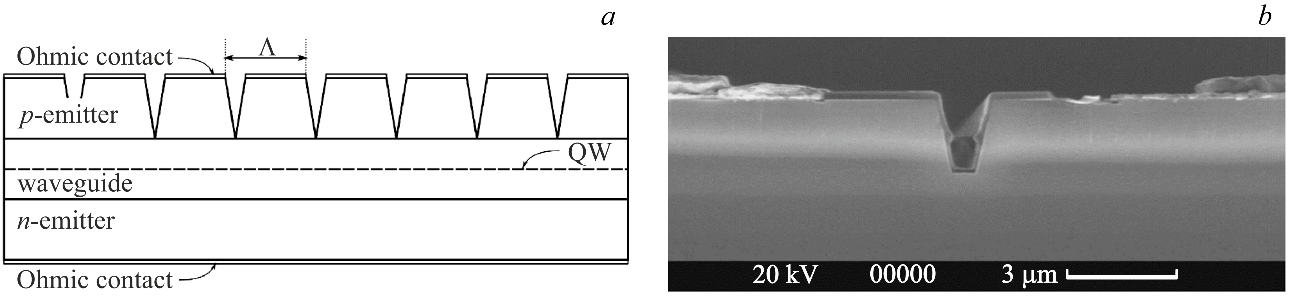

Figure 1. (*a*) Schematic representation of a distributed feedback (DFB) laser with designations of the heterostructure layers; (*b*) scanning electron microscope image of the surface distributed feedback groove.

Samples with resonator lengths of 1, 2, 3, and 4 mm with naturally cleaved faces, with an antireflection coating applied to one face of the resonator, and with antireflection coatings on both faces of the resonator were investigated. The samples were mounted on p-side down copper heat sinks to measure the performance in continuous wave. The spectra were measured using a Thorlabs OSA 202 spectroanalyser with a resolution of 14 pm.

Results of the study

Continuous wave generation spectra were measured for the obtained samples at different temperatures. For samples with naturally cleaved faces, both DFB-related modes and Fabry–Perot modes were observed in the spectra. This mode competition is due to the low coupling coefficient of DFB, which causes approximately equal threshold conditions of DFB modes with Fabry-Perot modes. To increase the generation threshold of Fabry-Perot modes, the samples with applied antireflective coatings were investigated. For samples with a single antireflective coating and one naturally cleaved faces ($R_1 = 0.05$, $R_2 = 0.32$, where R_1, R_2 are the reflection coefficients of the output and rear cavity face, respectively), generation of only DFB modes was observed at resonator lengths 3 mm and more. Two competing modes with a minimum threshold on opposite sides of the Bragg wavelength were observed in the spectra.

For these samples, the spectra were measured at different temperature (Fig. 2). The measurements showed that the temperature shift of the long-wavelength edge of the spectrum is less than 0.1 nm/K. The intermode distance in the temperature range of 12–20°C does not change and is 0.19 nm, and then increases dramatically to 0.51 nm, indicating mode rearrangement and change in the coupling coefficient.

The temperature dependences of the generation spectrum were measured in a wider range (Fig. 3) for samples with two coated cavity faces. As the temperature increased, the spectrum shifted to the long-wavelength side at the same rate. When a significant mismatch between the DFB modes and the gain spectrum of the active region was

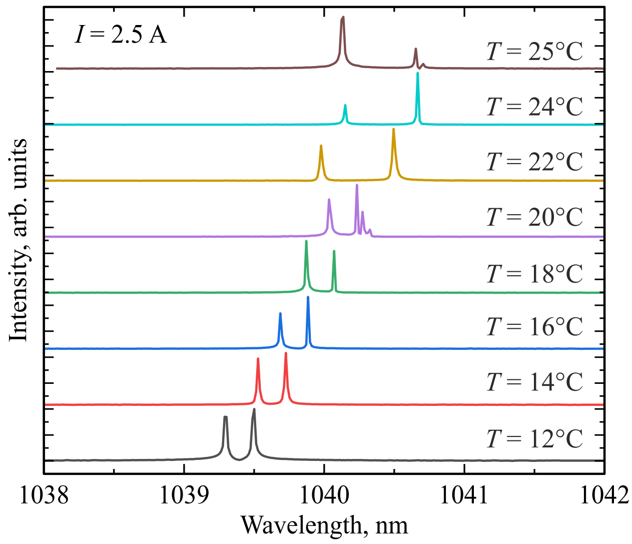

Figure 2. The generation spectra of a DFB laser with one antireflective and one naturally cleaved cavity faces at different temperatures, as shown in the figure, at a pump current of $I = 2.5$ A.

achieved, parasitic generation of very weak intensity Fabry-Perot –modes was observed. With further temperature increase, the generation was carried out at the new Bragg order of the DFB. The distance between the Bragg orders was 7.3 nm, which agrees well with the calculations. The intermode distance for the two lowest-threshold modes for each Bragg order did not change as the temperature increased, indicating no change in the coupling coefficient.

Thus, multimode semiconductor lasers with surface DFB emitting at wavelengths on the order of 1040 nm have been obtained. The competition between DFB and Fabry–Perot modes indicates that the coupling coefficient is too low for the formed surface lattice.

In further studies we are going to optimise the laser heterostructure design to increase the optical confinement factor of the waveguide mode in the DFB region.

A narrowing of the generation spectrum was demonstrated for samples with antireflecting coatings. Its temperature stability was less than 0.1 nm/K. The spectra consist of

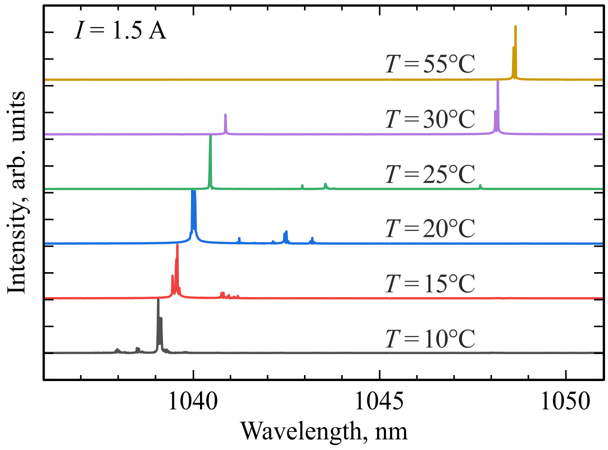

Figure 3. Generation spectra of a DFB laser with both antireflection coated cavity faces at different temperatures, shown in the drawing, at pumping currents $I = 1.5$ A.

two competing modes located on either side of the Bragg wavelength.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] I.S. Shashkin, A.Y. Leshko, V.V. Shamakhov, N.V. Voronkova, V.A. Kapitonov, K.V. Bakhvalov, S.O. Slipchenko, N.A. Pikhtin, P.S. Kopiev. FTP, **55** (4), 344 (2021). (in Russian) DOI: 10.21883/FTP.2021.04.50736.9565

[2] Y. Zhao, Z. Wang, A. Demir, G. Yang, S. Ma, B. Xu, C. Sun, B. Li, B. Qiu. IEEE Photonics J., **13** (3), 1500708 (2021). DOI: 10.1109/JPHOT.2021.3073732

[3] Z. Dong, Y. Zhao, Q. Zhang, C. Wang, W. Li, S. Liu, X. Ma. J. Semicond., **37** (2), 024010 (2016). DOI: 10.1088/1674-4926/37/2/024010

[4] A. Maaßdorf, C.M. Schultz, O. Brox, H. Wenzel, P. Crump, F. Bugge, A. Mogilatenko, G. Erbert, M. Weyers, G. Tränkle. J. Cryst. Growth, **370**, 226 (2013). DOI: 10.1016/j.jcrysgro.2012.08.012

[5] C.M. Schultz, P. Crump, H. Wenzel, O. Brox, A. Maaßdorf, G. Erbert, G. Traänkle. Electron. Lett., **46** (8), 580 (2010). DOI: 10.1049/el.2010.3347

[6] S.O. Slipchenko, D.A. Vinokurov, N.A. Pikhtin, Z.N. Sokolova, A.L. Stankevich, I.S. Tarasov, Z.I. Alferov. Semiconductors, **38**, 1430–1439 (2004). DOI: 10.1134/1.1836066

[7] J. Decker, P. Crump, J. Fricke, A. Maaßdorf, M. Traub, U. Witte, T. Brand, A. Unger, G. Erbert, G. Tränkle. IEEE Photonics Technol. Lett., **27** (15), 1675 (2015). DOI: 10.1109/LPT.2015.2435251

[8] V.V. Zolotarev, A.Y. Leshko, V.V. Shamakhov, D.N. Nikolaev, V.S. Golovin, S.O. Slipchenko, N.A. Pikhtin. Semicond. Sci. Technol., **35** (1), 015009 (2020). DOI: 10.1088/1361-6641/ab5435.

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