Output Characteristics of Heterolasers with a Wide Stripe Contact

Victor M. STETSIK [1], Evgenii V. ALISENOK [1], Valerii K. KONONENKO [2], Ivan S. MANAK [1], Sergei S. POLIKARPOV [3]

[1] *Belarusian State University*
[2] *Stepanov Institute of Physics, National Academy of Sciences of Belarus*
[3] *Efremov Scientific and Research Institute of Electrophysical Apparatus*
lavik@dragon.bas-net.by

***Abstract* — Output power characteristics of high efficiency quantum-well heterolasers with a wide stripe contact based on the AlGaInAs semiconductor compounds are studied. It is shown that the laser elements can be applied together with focused and collimated optics for different purposes. In particular, the described laser diodes are suitable as optimal sources for the pumping of the YAG: Nd lasers. Improved output power characteristics and parameters of the heterolasers are provided due to more careful producing the supplied contacts and obtaining the homogeneous distribution of the lasing intensity in the *p–n* junction plane.**

***Index Terms* — AlGaInAs, heterolaser, output characteristic, polarization, quantum well, spectrum.**

I. INTRODUCTION

The generation power of laser diodes is saturated with increasing the pump current as a result in heating the active region. The spreading the injected carriers, the growth of the threshold quantity and the concentration of current carriers in the waveguide layers provide decreasing the laser quantum yield and increasing the internal optical losses. Respectively, the laser output power and efficiency drop. Maximum values of the laser output power are 16 W in CW regime and 145 W at pulsed operation (pulse duration of 100 ns, pump current of 200 A) for typical single laser elements with a wide stripe contact [1].

Development and study of powerful semiconductor injection lasers are important nowadays. High efficiency laser diodes emitting at wavelengths of $\lambda = 0.8$ μm are widely applied in different fields of science and technique. These lasers are directly used not only in industry equipment (spectroscopy, metrology, technology, medicine, *etc.*), but also for purposes of fiber-optical communication and pumping of solid-state lasers [1–3]. Therefore increasing the output optical power, brightness, efficiency, operation time, the receiving of the narrow and stable spectral radiation line, and lowering of the internal optical losses in the laser diodes belong to the major tasks.

The main progress in the development of powerful semiconductor laser sources is attained for laser diode elements based on the GaInAs, GaAsP, and AlGaAs solid solution systems [1–7]. The Al-containing structures and Al-free lasers have similar properties and characteristics as well as some specific drawbacks [1, 3].

In this work, output power characteristics of high efficiency quantum-well heterolasers with a wide stripe contact based on the AlGaInAs semiconductor compounds are studied. In detail, polarization of the emitting radiation and output beam divergence parameters in dependence on the pump current are measured and ways of obtaining the improved laser characteristics and properties are discussed. It is shown that the laser elements can be applied together with focused and collimated optics for different purposes. *e. g.*, the described laser diodes are suitable as optimal sources for the pumping of solid-state lasers and fiber-optical amplifiers. Stable and improved output power characteristics of the heterolasers are made by more soft and careful producing the ohmic contacts and at the achievement of the most uniform distribution of the lasing intensity in the *p–n* junction plane.

II. EXPERIMENTAL

Investigations of the output characteristics of powerful semiconductor lasers operating at the wavelength in the region of 800–810 nm are carried out with samples marking as EZ-1 and ET-2 (St. Petersburg, Russia). The active region of the quantum-well heterostructure lasers includes the AlGaInAs quantum wells of width 10 nm and the $Al_xGa_{1-x}As$ gradient waveguide layers (thickness of 0.15 nm, $x = 0.3 \div 0.6$). Laser elements are soldered to a heat sink by the *p*-type layer, reflection coefficients of the cavity opposite sides are 0.9 and 0.2 [8]. Thermal parameters of the heterolasers were studied before in [9].

The laser diodes are excited in the regime of current pumping by saw-tooth pulses with the duration of 10 ms and repetition frequency of 10 – 1000 Hz. Increasing the current amplitude up to 4 A did not result in change in the sample output characteristics that illustrates a high quality of the laser diodes and quite effective heat removing.

At the study of laser polarization characteristics, the polarization coefficient of radiation $K_P = I_{max} / I_{min}$ is determined as a ratio of the intensity at maximum of the transparence of an analyzer (I_{max} = TE) to the intensity at minimum (I_{min} = TM). Then, it is easily to connect the coefficient K_p with the degree of the radiation polarization *p*, *i. e.*, $p = (\mathrm{TE} - \mathrm{TM})/(\mathrm{TE} + \mathrm{TM}) = (K_p - 1)/(K_p + 1)$.

The paper was partly supported by Belarusian Republican Foundation for Fundamental Research.

Developed laser diodes are possessed of a relatively low degree of polarization. To investigate reasons, which cause small values of the coefficient K_p, the distribution of the intensity and polarization degree in the *p–n* junction plane has been determined by means of a CCD array. From results of measuring the width of the radiation field using the CCD array at a definite distance (2.5 cm), the parameters of far-field lasing diagram are obtained as well.

III. RESULTS AND DISCUSSION

Optical power–current characteristics of the laser diodes are presented (taking into account losses at optics) in Fig 1. The laser power *P* at the pump current $I \approx 3.5$ A is about of $P = 3.5$ W. The lowest thresholds are observed for laser diodes 6ET-2 и 3EZ-1. Dependencies *P*(*I*) are practically standard linear characteristics [5, 6].

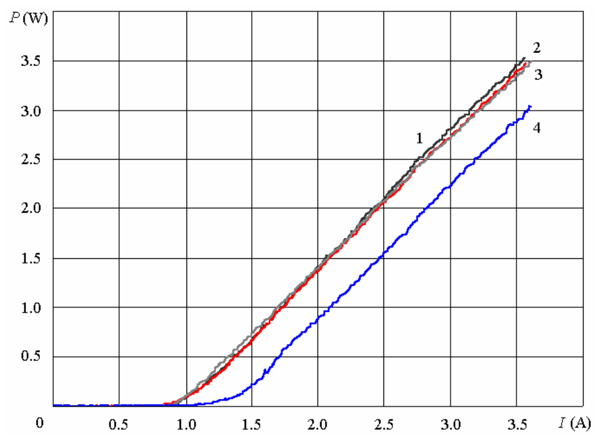

Fig. 1. Output power characteristics *P*(*I*) for heterolasers (1) 5EZ-1, (2) 6ET-2, (3) 3EZ-1, and (4) 13EZ-1.

Dependence of the laser power efficiency η on the pump current *I* (Fig. 2) displays a weak saturation, as compared known results, where at not high currents (2–3 A) a maximum of the efficiency occurs and then at further increasing the current a drop of the value η takes place [5]. The highest efficiency is for lasers 5EZ-1, 3EZ-1, and 6ET-2. However, it is necessary to conclude that operation of this type lasers is undesirable without a compulsory heat removing at the pump above 3 A, because a further increasing the current results in the Joule heating and can to enhance degradation and failure of the structures [1, 3–6].

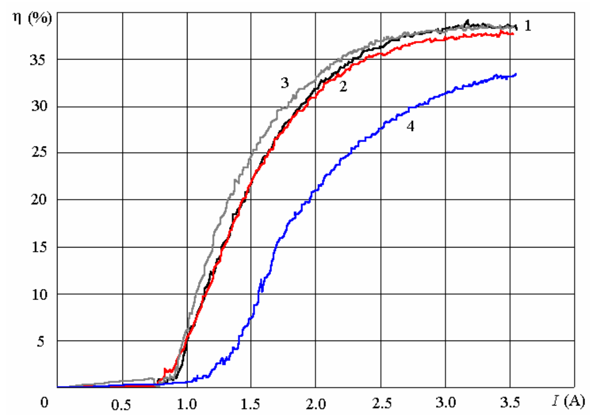

Fig. 2. Dependence of the power efficiency on the current η(*I*): (1) 5EZ-1, (2) 6ET-2, (3) 3EZ-1, and (4) 13EZ-1.

Comparison of dependences of the radiation intensity versus pump current at two orientations of the transparence plane of an analyzer is displayed in Fig. 3 (laser 3EZ-1). Laser diodes 5EZ-1, 3EZ-1, and 13EZ-1 manifest the TE polarization (electrical vector **E** is oriented in the *p–n* junction plane). For quantum-well heterolasers 5EZ-1 and 3EZ-1, the polarization coefficient of radiation is of the order of 30 and 20 respectively. The lowest polarization coefficient of radiation $K_p \approx 8.2$ is for laser 6ET-2 with the TM-type polarization.

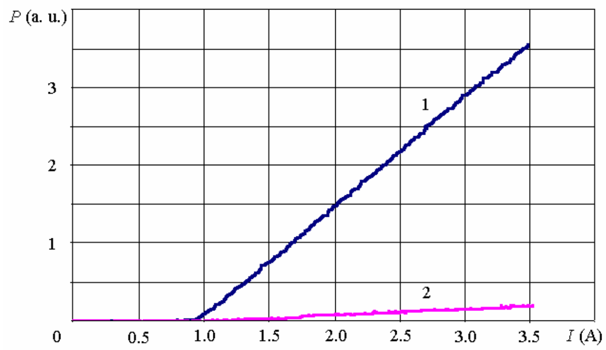

Fig. 3. Dependence *P*(*I*) for laser diode 3EZ-1 at (1) maximum and (2) minimum transparence of an analyzer.

Low values of K_p are connected with a high level of the spontaneous emission and result from nonuniform distribution of the radiation intensity and polarization in the *p–n* junction plane as well too. However, the distribution forms do not practically change versus pump current. As it was detected, the laser elements manifest the width of the lasing region of the order of 250–270 μm that differs markedly from the stripe contact width ≈ 150 μm.

Typical diagram of the laser radiation directivity *P*(θ) in the *p–n* junction plane is shown in Fig. 4. The total angular width at the half of the emission intensity lies from 4 ° for laser sample 3EZ-1 to 11 ° for sample 13EZ-1. Therewith, it is significant that such a distribution of the laser radiation intensity remains invariable with the increase of *I*.

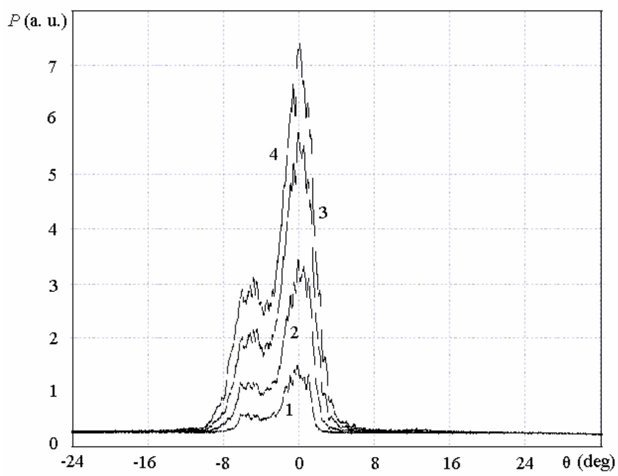

Fig. 4. Far-field pattern for laser 3EZ-1 in the *p–n* junction plane at currents (1) 1.5, (2) 2.0, (3) 2.5, and (4) 3.0 A.

Typical far-field pattern of the radiation in the plane perpendicular to the *p–n* junction is shown in Fig. 5. Values of the total divergence angle in the far-field distribution are from 23 ° for sample 5EZ-1 to 32 ° for sample 6ET-2. With the increase of I the far-field laser beam intensity, which is described practically by the Gaussian function, does not change that manifests conservation of a single-mode character of the lasing.

Study of the radiation polarization in the *p–n* junction plane points that vector **E** varies quasi-periodically along *p–n* junction. This factor reflects markedly at an integral polarization coefficient. So, *e. g.*, for laser sample 6ET-2 the integral polarization coefficient equals $K_p = 8.2$, but in the central region with width of ≈ 50 μm the value K_p is 36.

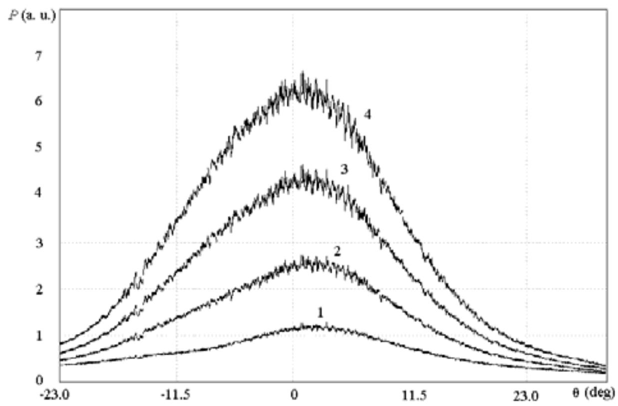

Fig. 5. Far-field radiation pattern for laser diode 5EZ-1 in the plane perpendicular to *p–n* junction at pump currents (1) 1.5, (2) 2.0, (3) 2.5, and (4) 3.0 A.

A possible reason of the nonuniform distribution of the polarization in the *p–n* junction plane is a mechanical influence at ultrasonic soldering the contact supply. Such an influence can be enough strong if to take into account a small depth of *p–n* junction deposition. Thus, at producing the contacts it is necessary to minimize any mechanical influence on the crystal with a view to receive more uniform distribution of the radiation intensity and degree of polarization.

IV. CONCLUSION

Obtained quantities of the output characteristics shown that powerful semiconductor heterolasers with a wide stripe contact based on the AlGaInAs compounds can be effectively applied for various purposes together with focused and collimated optical elements. In particular, these laser diodes are suitable as optimal pump sources for solid-state lasers and fiber amplifiers [1, 3, 8, 9]. Stable and improved output power characteristics and parameters of the heterolasers can be received by means of more careful producing the connection supplies and obtaining the uniform distribution of the radiation intensity in *p–n* junction plane.

ACKNOWLEDGMENT

The authors are thankful to V. V. Parashchyuk for interest in the work and useful discussions.

REFERENCES

[1] A. Yu. Andreev, S. A. Zorina, A. Yu. Leshko, A. V. Lyutetskiy, A. A. Marmalyuk, A. V. Murashova, T. A. Nalet, A. A. Padalitsa, N. A. Pikhtin, D. R. Sabitov, V. A. Simakov, S. O. Slipchenko, K. Yu. Telegin, V. V. Shamakhov, I. S. Tarasov, "High-power lasers (λ = 808 nm) based on the AlGaAs/GaAs heterostructures of separate confinement," Semicond., vol. 43, pp. 519, Apr. 2009.

[2] A. V. Murashova, D. A. Vinokurov, N. A. Pikhtin, S. O. Slipchenko, V. V. Shamakhov, V. V. Vasilyeva, V. A. Kapitonov, A. Yu. Leshko, A. V. Lyutetskiy, T. A. Nalet, D. N. Nikolaev, A. L. Stankevich, N.V. Fetisova, I. S. Tarasov, Y. S. Kim, D. H. Kang, C. Y. Lee, "High-power laser diodes with an emission wavelength of 835 nm on the basis of various types of heterostructures," Semicond., vol. 42, pp. 862, July 2008.

[3] A. V. Aluev, A. Yu. Leshko, A. V. Lyutetskiy, N. A. Pikhtin, S. O. Slipchenko, N. V. Fetisova, A. A. Chelny, V. V. Shamakhov, V. A. Simakov, I. S. Tarasov, "GaInAsP/GaInP/AlGaInP MOCVD-grown diode lasers emitting at 808 nm," Semicond., vol. 43, pp. 532, Apr. 2009.

[4] P. V. Bulaev, A. A. Marmalyuk, A. A. Padalitsa, D. B. Nikitin, A. V. Petrovskii, I. D. Zalevskii, V. P. Konyaev, V. V. Os'kin, M. V. Zverkov, V. A. Simakov, G. M. Zverev, "High-power semiconductor 0.89–1.06-μm lasers with a low emission divergence based on strained quantum-well InGaAs/(Al)GaAs structures," Quantum Electron., vol. 32, pp. 213, March 2002.

[5] P. V. Bulaev, V. A. Kapitonov, A. V. Lutetskii, A. A. Marmalyuk, D. B. Nikitin, D. N. Nikolaev, A. A. Padalitsa, N. A. Pikhtin, A. D. Bondarev, I. D. Zalevskii, I. S. Tarasov, "MOCVD-grown InGaAs/GaAs/AlGaAs laser structures with a broad-area contact," Semicond., vol. 36, pp. 1065, Sept. 2002.

[6] M. Bugajski, B. Mroziewicz, K. Reginski, J. Muszalski, K. Kosiel, M. Zbroszczyk, T. Ochalski, T. Piwonski, D. Wawer, A. Szerling, E. Kowalczyk, H. Wrzesinska, M. Gorska, "High power QW SCH InGaAs/GaAs lasers for 980-nm band," Bull. Pol. Ac.: Tech., vol. 53, pp. 113, June 2005.

[7] D. A. Vinokurov, A. L. Stankevich, V. V. Shamakhov, V. A. Kapitonov, A. Yu. Leshko, A. V. Lyutetskiĭ, D. N. Nikolaev, N. A. Pikhtin, N. A. Rudova, Z. N. Sokolova, S. O. Slipchenko, M. A. Khomylev, I. S. Tarasov, "High-power lasers (λ = 940–980 nm) based on asymmetric GaInAs/GaInAsP/AlGaAs separate-confinement heterostructure," Semicond., vol. 40, pp. 745, June 2006.

[8] K. A. Bulashevich, V. F. Mymrin, S. Yu. Karpov, D. M. Demidov, A. L. Ter-Martirosyan, "Effect of free-carrier absorption on performance of 808 nm AlGaAs-based high-power laser diodes," Semicond. Sci. Technol., vol. 22, pp. 502, May 2007.

[9] Yu. A. Bumai, O. S. Vas'kov, V. K. Kononenko, V. M. Lomako, V. V. Parashchyuk, S. S. Polikarpov, "Thermal analysis of semiconductor lasers in the AlGaInAs–AlGaAs system," Laser and Optical and Electronic Techniques, no. 11, pp. 192, Minsk, 2008.