Quantum Electronics **47** (8) 693–695 (2017)

https://doi.org/10.1070/QEL16441

Laser diode arrays based on AlGaAs/GaAs quantum-well heterostructures with an efficiency up to 62 %

M.A. Ladugin, A.A. Marmalyuk, A.A Padalitsa, K.Yu. Telegin, A.V. Lobintsov,
S.M. Sapozhnikov, A.I. Danilov, A.V. Podkopaev, V.A. Simakov

Abstract. **The results of development of quasi-cw laser diode arrays operating at a wavelength of 808 nm with a high efficiency are demonstrated. The laser diodes are based on semiconductor AlGaAs/GaAs quantum-well heterostructures grown by MOCVD. The measured spectral, spatial, electric and power characteristics are presented. The output optical power of the array with an emitting area of 5×10 mm is 2.7 kW at a pump current of 100 A, and the maximum efficiency reaches 62 %.**

Keywords: *laser diode arrays, efficiency, quantum-well heterostructures, MOCVD, AlGaAs/GaAs.*

1. Introduction

In paper [1], we described efficient high-power laser diode bars (LDBs) emitting in the wavelength range of 800–810 nm, which were developed as a result of upgrading several technologies, namely, MOCVD of quantum-well heterostructures (HS's), formation of active elements, and mounting of LDBs on a heat sink [2–5]. This allowed more energy-efficient use of such multielement semiconductor light sources in modern pump systems, materials treatment and communications.

It is known that most practical applications need high output laser powers, which are today no lower than 1 kW cm^{-2} [6]. Due to the continuously growing requirements to quantum electronics devices, for example, to semiconductor systems for pumping solid-state lasers based on neodymium-doped ytterbium–aluminium garnet (Nd^{3+}:YAG), pulsed lasers with a wavelength of 808 nm must have an optical output power of 2–3 kW and an emitting area of 0.5–2.0 cm^2. Therefore, the desired optical output power density in this case can reach 5 kW cm^{-2}. It is obvious that, to fabricate arrays satisfying these severe requirements, one should also pay close attention to the thermal load imposed on semiconductor bars and laser diode arrays (LDAs) under quasi-cw pumping. Significant load on the heat-sink system is caused by a dense packing of active emitting channels (as a rule, filling factor exceeds 70 %) and a large number of LDBs in the array.

M.A. Ladugin, A.A Padalitsa, K.Yu. Telegin, A.V. Lobintsov,
S.M. Sapozhnikov, A.I. Danilov, A.V. Podkopaev, V.A. Simakov
Joint-Stock Company 'M.F. Stel'makh Polyus Research Institute',
ul. Vvedenskogo 3, bld. 1, 117342 Moscow, Russia;
e-mail: M.Ladugin@siplus.ru;
A.A. Marmalyuk Joint-Stock Company 'M.F. Stel'makh Polyus
Research Institute', ul. Vvedenskogo 3, bld. 1, 117342 Moscow,
Russia; National Research Nuclear University 'MEPhI',
Kashirskoe sh. 31, 115409 Moscow, Russia

Received 31 May 2017
Kvantovaya Elektronika **47** (8) 693–695 (2017)
Translated by M.N. Basieva

Therefore, the present work is devoted to the development, fabrication and experimental study of LDAs with increased powers, improved spectral characteristics and high efficiency.

2. Experimental results

Single-quantum-well epitaxial heterostructures Al$_x$Ga$_{1-x}$As/GaAs were grown by MOCVD, which has been successfully used in production of devices on an industrial scale. A heterostructure optimised with respect to minimal optical losses, cut-off voltage and electrical series resistance is described in [1]. For optimisation, we used such thicknesses of the waveguiding layer that allowed us to obtained internal optical losses at a level of 0.5–1.0 cm^{-1}. For optimal electrical and thermal resistances of the structure, its thickness should not exceed 4 μm. Moreover, an increase in the HS structure thickness may lead to deformation of the epitaxial plate and, therefore, to technological problems at the stage of mounting of an active element onto a heat sink [7]. As a result, the developed design and fabrication technology of a quantum-well active region restricted by Al$_x$Ga$_{1-x}$As barrier layers allowed one to achieve a low transparency current density (j_{tr} = 120 A cm^{-2}) and a high internal quantum efficiency (η_{int} = 99 %).

The measured LDA spectra (Fig. 1) indicate a homogeneous distribution of parameters of the HS layers, because all the LDAs based on this HS were characterised by wave-

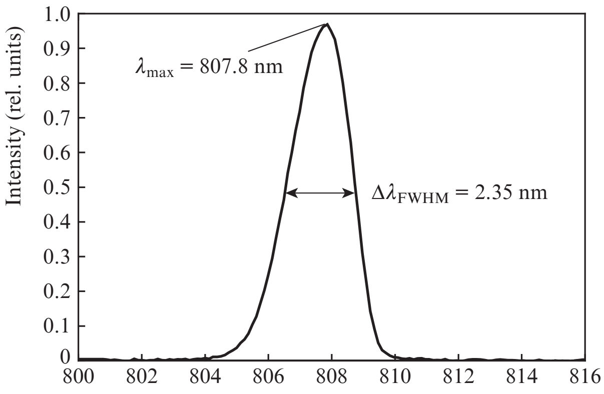

Figure 1. Spectrum of the laser diode array 5×10 mm in size under quasi-cw pumping (200 μs, 22 Hz).

length $\lambda_{\max} \sim 807.5-808.0$ nm and identical spectral FWHM ($\Delta\lambda_{\rm FWHM} \approx 2.3-2.5$ nm). The achieved emission peak position and spectral width allowed better matching of the LDA emission band and the absorption band of active elements of solid-state $\rm Nd^{3+}$: YAG lasers.

Some optimisations were performed at the stage of fabrication of active elements with low-resistance contacts and an increased radiation resistance of mirror facets. The design parameters of the active element, namely, cavity length, stripe contact width, LDB length and the number of LDBs in the LDA, were chosen to achieve a high total efficiency of the LDA at a working pump current ($I_{\rm p} \approx 95-100$ A). Therefore, the LDA was 5 mm wide and 10 mm high. A good emission uniformity of all active elements of the developed LDA is seen from the near-field pattern presented in Fig. 2.

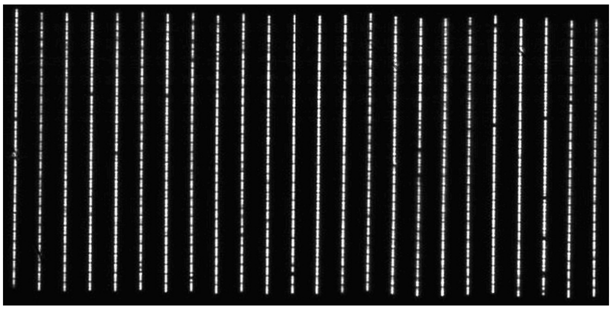

Figure 2. Near-field of the 5×10-mm laser diode array.

To obtain low ohmic resistances, we used a combination of Ti–Pt–Au metallisation layers and assembled the LDA on CuW heat sinks using eutectic Au--Sn solder. The reflection coefficients of the front and rear mirrors of the laser cavity were 0.07 and 0.98, respectively. To decrease the rate of nonradiative recombination at the interface between the semiconductor crystal and the optical coating, we used ion-beam processing of the emitting face in a vacuum chamber.

The electrical, power, spectral and spatial characteristics were measured under quasi-cw pumping ($\tau_{\rm pulse} = 200$ μs, $f_{\rm pulse} =$ 20 Hz). The cut-off voltage U_0 for the LDA was about 37.5 V, while the series resistance $R_{\rm s}$ was around 60 mΩ (Fig. 3). The output optical power of the fabricated LDA with the light emitting area of 5×10 mm reached 2.7 kW at a pump current of 100 A, which is almost a twofold margin with respect to limiting powers (5.0–5.1 kW). The slope of the light–current characteristic was 31–32 W A^{-1}. This corresponds to 1.3 W A^{-1} per one LDB, which almost coincides with the value measured for an individual laser bar in [1].

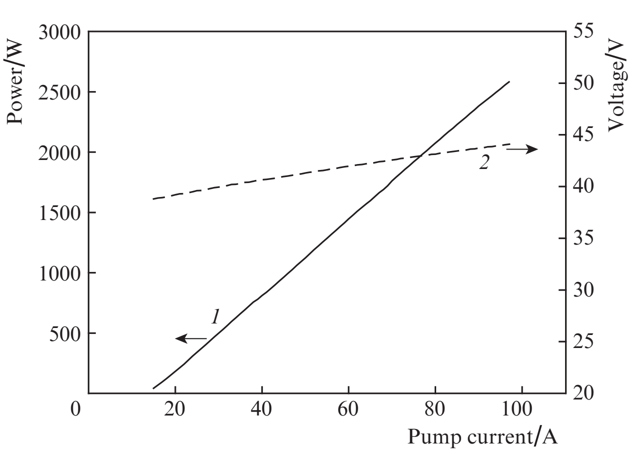

Figure 3. Typical (*1*) light–current and (*2*) current–voltage characteristics of the 5×10-mm laser diode array.

The maximum efficiency was 60%–62% for most samples (see Fig. 4). The threshold pump current was 14 A at an ambient temperature of 20 °C. As temperature increased to 50 °C, the threshold current increased to 17 A. The T_0 parameter, which reflects this temperature dependence, was 105–110 K, which approximately coincides with T_0 for LDBs developed in [1]. The emitter demonstrated successful operation at an increased temperature (T = 50 °C), at which the efficiency slightly decreased (to 55%–56%) and the effective working point shifted to current $I_{\rm p}$ = 105–107 A.

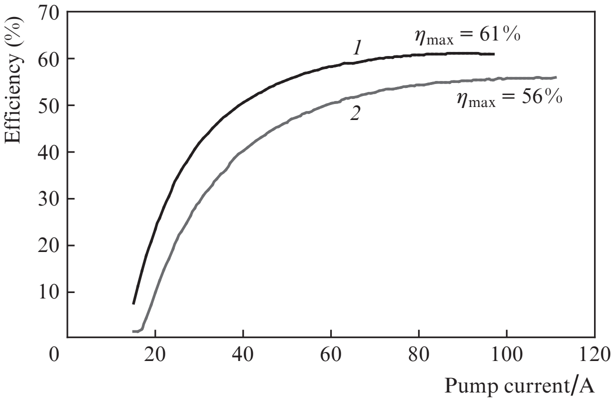

Figure 4. Dependences of the 5×10-mm laser diode array efficiency on the pump current at ambient temperatures of (*1*) 20 and (*2*) 50 °C.

The calculated thermal resistance of the developed LDA was approximately 0.5–0.8 K W^{-1}, while the active region temperature exceeded the heat sink temperature only by 5–10 °C. This value turned out to be higher than that reported for LDBs in [1] due to a noticeably more complicated procedure of assembling a large number of emitting elements. The changing rate of the emission wavelength $\lambda_{\max}$ with ambient temperature was 0.29–0.30 nm K^{-1}, while the spectral FWHM almost did not change in the studied temperature range at pump currents from 20 to 100 A.

The far-field FWHM divergence was 38° in the plane perpendicular to the p–n junction (perpendicular to the plane of epitaxial layers) and 7° in the plane of the p–n junction (parallel to the plane of epitaxial layers) (Fig. 5). These values corresponded to the data measured for each individual LDB in the LDA.

The cumulative result of the optimisation of technological stages is the improvement of the developed array parameters. Compared to the standard LDA design, the external differential efficiency increased by 10%–15%, while the series resistance and working voltage decreased by 10%. The total efficiency of the 5×10-mm LDA at a heat sink temperature of 20 °C reached 62% at a pump current of 95 A, which is considerably higher than the values achieved previously (50%–55%). Currently, the results of ongoing lifetime tests of the LDAs demonstrate their ability to operate in a quasi-cw

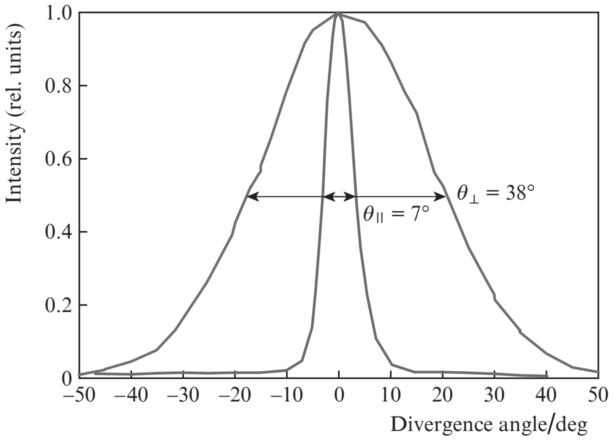

Figure 5. Far-field radiation distribution.

regime for no less than 5×10^{8} pulses without deterioration of the output parameters.

Thus, in this work we proposed and implemented improved design and fabrication technology of high-power 5×10-mm LDAs emitting in the range of 800–819 nm. This multi-element laser is based on AlGaAs/GaAs quantum-well heterostructures with a high internal quantum yield and low optical losses. The output optical power of the LDA in a quasi-cw regime was 2.7 kW at a pump current of 100 A, while the maximum efficiency of most samples was 60%–62%.

Acknowledgements. This work was partially supported by the Competitiveness Programme of the National Research Nuclear University 'MEPhI'.

References

1. Ladugin M.A., Marmalyuk A.A., Padalitsa A.A., Bagaev T.A., Andreev A.Yu., Telegin K.Yu., Lobintsov A.V., Davydova E.I., Sapozhnikov S.M., Danilov A.I., Podkopaev A.V., Ivanova E.B., Simakov V.A. *Quantum Electron.*, **47**, 291 (2017) [*Kvantovaya Elektron.*, **47**, 291 (2017)].
2. Andreev A.Yu., Leshko A.Yu., Lyutetskii A.V., Marmalyuk A.A., Nalet T.A., Padalitsa A.A., Pikhtin N.A., Sabitov D.R., Simakov V.A., Slipchenko S.O., Khomylev M.A., Tarasov I.S. *Fiz. Tekhn. Polupr.*, **40**, 628 (2006).
3. Marmalyuk A.A., Ladugin M.A., Andreev A.Yu., Telegin K.Yu., Yarotskaya I.V., Meshkov A.S., Konyaev V.P., Sapozhnikov S.M., Lebedeva E.I., Simakov V.A. *Quantum Electron.*, **43**, 895 (2013) [*Kvantovaya Elektron.*, **43**, 895 (2013)].
4. Ladugin M.A., Koval' Yu.P., Marmalyuk A.A., Petrovskii V.A., Bagaev T.A., Andreev A.Yu., Padalitsa A.A., Simakov V.A. *Quantum Electron.*, **43**, 407 (2013) [*Kvantovaya Elektron.*, **43**, 407 (2013)].
5. Marmalyuk A.A., Andreev A.Yu., Konyaev V.P., Ladugin M.A., Lebedeva E.I., Meshkov A.S., Morozyuk A.N., Sapozhnikov S.M., Danilov A.I., Simakov V.A., Telegin K.Yu., Yarotskaya I.V. *Fiz. Tekhn. Polupr.*, **48**, 120 (2014).
6. Bachmann F., Loosen P., Poprawe R. *High Power Diode Lasers: Technology and Applications* (New York: Springer Series in Opt. Sci., 2007) Vol. 128, p. 554.
7. Marmalyuk A.A., Ladugin M.A., Yarotskaya I.V., Panarin V.A., Mikaelyan G.T. *Quantum Electron.*, **42**, 15 (2012) [*Kvantovaya Elektron.*, **42**, 15 (2012)].