Quantum Electronics **52** (2) 171 – 173 (2022)

LASERS

https://doi.org/10.1070/QEL17985

Vertical stacks of pulsed (100 ns) mesa-stripe semiconductor lasers with an ultra-wide (800 μm) aperture emitting kilowatt-level peak power at a wavelength of 1060 nm

S.O. Slipchenko, A.A. Podoskin, D.A. Veselov, L.S. Efremov,
V.V. Zolotarev, A.E. Kazakova, P.S. Kop'ev, N.A. Pikhtin

Abstract. **A pulsed source of radiation in the spectral region of 1060 nm with a kilowatt level peak output power is developed based on a vertical stack of microbars of stripe semiconductor lasers with an ultra-wide (800 μm) aperture. The laser stack contains three microbars with three emitters each, which ensures an emitting area of 2.6 × 0.4 mm. The highest radiative efficiency of the stack is 2.48 W A^{-1}. The maximum achieved peak power reached 1400 W under pumping by current pulses with an amplitude of 650 A and a duration of 100 ns and is limited by the current source capacity.**

Keywords: *laser stack, pulsed semiconductor laser.*

1. Introduction

Today, the main motivation for developing pulsed lasers with kilowatt-level output powers is the progress in the development of autonomous transport vehicles, which require efficient, compact, and fast light sources, such as used for designing 3D scanning systems of, for example, pulsed LIDARs. The problem of increasing the output optical power is usually solved by using bars based on multimode semiconductor lasers with an aperture of ~100 μm and by optimising the design of emitters operating in cw or quasi-cw regimes [1], which imposes some requirements on the stack structure due to thermal heating. In this case, the emission brightness is related to the filling factor of this bar, which is determined as the ratio of the emitting aperture width to the laser pulse repetition period. It is clear that, to suppress the optical coupling between the stripe emitters and undesirable accompanying effects, in particular, formation of closed mode structures [2], the passive regions should introduce additional optical losses or form a rather strong lateral waveguide. This may decrease the efficiency and increase the divergence and, hence, the laser radiation brightness.

An approach to solving this problem consists in the use of high-power multimode semiconductor lasers with an ultra-wide emitting aperture [3, 4]. This approach, which is especially efficient for pulsed lasers with pulse durations of 10 – 100 ns, allows one to considerably decrease the thermal load. It was shown in [3] that widening of the emitting aperture to 800 μm leads to non-simultaneous initiation of the laser pulse over the aperture, but the difference between the delay times is 180 – 450 ps depending on the pump level and the cavity length and, therefore, does not affect the laser efficiency in the case of pumping by pulses with durations of 100 ns and longer. In addition, widening of the aperture makes it possible, at a constant cavity length, to considerably reduce the output optical power saturation due to a decrease in the current density at high pump levels.

The aim of this work was to study the possibility of developing vertical stacks based on microbars of stripe lasers with an ultra-wide emitting aperture to generate pulses with a kilowatt-level peak optical power.

2. Experimental samples

The studied samples contained an asymmetric laser heterostructure including p-$Al_{0.3}Ga_{0.7}As$ and n-$Al_{0.15}Ga_{0.85}As$ emitters 1.5 μm thick. The undoped waveguide on the n-emitter side was formed by an $Al_{0.1}Ga_{0.9}As$ layer 1 μm thick, while the waveguide on the p-emitter side was formed by a gradient layer with a thickness of 0.7 μm. The active region was based on two InGaAs quantum wells. In the MOCVD-grown heterostructure, a mesa-stripe lateral waveguide with an aperture width of 800 μm was formed. We studied the radiative characteristics of both single crystals and laser bars (the cavity length in both cases was 2000 μm). The lasers in the bars were positioned with a period of 900 μm. The faces of all studied samples were coated with antireflection (5%) and high-reflection (95%) films. The lasers were pumped by a specially developed current source, which generated current pulses with a duration of ~100 ns, an amplitude variable in the range 10 – 650 A, and a repetition rate up to 1 kHz. The shape and spectrum of optical pulses were recorded using a measuring scheme based on an integrating sphere; an Ophir Wavestar-V spectrometer was placed at one end of the scheme, and a Hamamatsu S9055 silicon pin photodetector, whose signal was recorded by a 2-GHz oscilloscope, was placed at the other end. The same oscilloscope synchronously recorded the control signal of the pulsed pump current. The average optical power was measured using an Ophir 3A-P-FS-12 thermoelectric sensor. The peak optical power was determined based on the measured pulse shape and average power. All experiments were performed at a temperature of 25 °C.

3. Experimental results

In the first part of the work, we performed measurements for single samples mounted p-side down. Figure 1a shows the

---

S.O. Slipchenko, A.A. Podoskin, D.A. Veselov, L.S. Efremov, V.V. Zolotarev, A.E. Kazakova, P.S. Kop'ev, N.A. Pikhtin Ioffe Institute, Politekhnicheskaya ul. 26, 194021 St. Petersburg, Russia; e-mail: Podoskin@mail.ioffe.ru

Received 26 October 2021
Kvantovaya Elektronika **52** (2) 171 – 173 (2022)
Translated by M.N. Basieva

typical shapes of integrated laser pulses recorded at different pump currents. One can see that the optical pulse shape rather closely follows the shape of the current pulse. This can serve as evidence that the chosen design of the stripe contact makes it possible to retain a high radiative efficiency of the Fabry–Perot cavity modes in the entire range of pump currents. The dependence of the peak optical power on the pump current amplitude is shown in Fig. 1b. The slope of the light–current characteristic (LCC) (slope efficiency) of all studied samples in the initial linear region was 0.8–0.85 W A^{-1}. The LCCs begin to noticeably deviate from linearity at currents exceeding 150 A, which corresponds to a current density of ~9.3 kA cm^{-2} and is comparable to the values obtained for emitters with an aperture of 100 μm [5]. This fact indicates that widening of the emitting aperture also does not cause additional optical losses. In addition, as expected, widening of the aperture allowed us to considerably increase the output optical power due to a decrease in the current density and, hence, in the optical losses related to an increase in the concentration of charge carriers in the waveguide [6].

The second part of the work was devoted to experimental studies of the radiative characteristics of vertical stacks based on laser microbars. In the experiments we used microbars containing three emitters with an aperture of 800 μm each. The vertical stack was assembled from three microbars. For convenience of assembling, each bar was mounted on a conducting support 100 μm thick, so that the vertical distance between the outer emitting regions was ~400 μm. The typical shapes of integrated laser pulses recorded at different pump currents are shown in Fig. 2. Similar to the case of a single laser (Fig. 1a), the shapes of integrated laser pulses are rather close to the shape of the pump current pulse. This allows us to conclude that the used design of microbars does not lead to additional optical coupling between the emitters and efficiently suppresses the generation of high-Q modes with low outcoupling losses. Figure 2b shows the LCC of the vertical stack, which demonstrates that the widening of the emitting aperture due to an increase in the number of lasers extends the LCC linearity region to 350 A. In this case, the maximum peak optical output power of the stack reached 1400 W and was limited by the pump current source capacity in contrast to the LCC of a single emitter, when an increase in the current pulse amplitude above 350 A led to a considerable decrease in the slope efficiency (see Fig. 1b). The LCC slope in the linear region for the vertical stack of three microbars was 2.48 W A^{-1}, which corresponds to a multiple increase in the slope efficiency with respect to the single emitter.

The typical integrated spectra of the studied vertical stacks are shown in Fig. 3. One can see that the lasing spectra

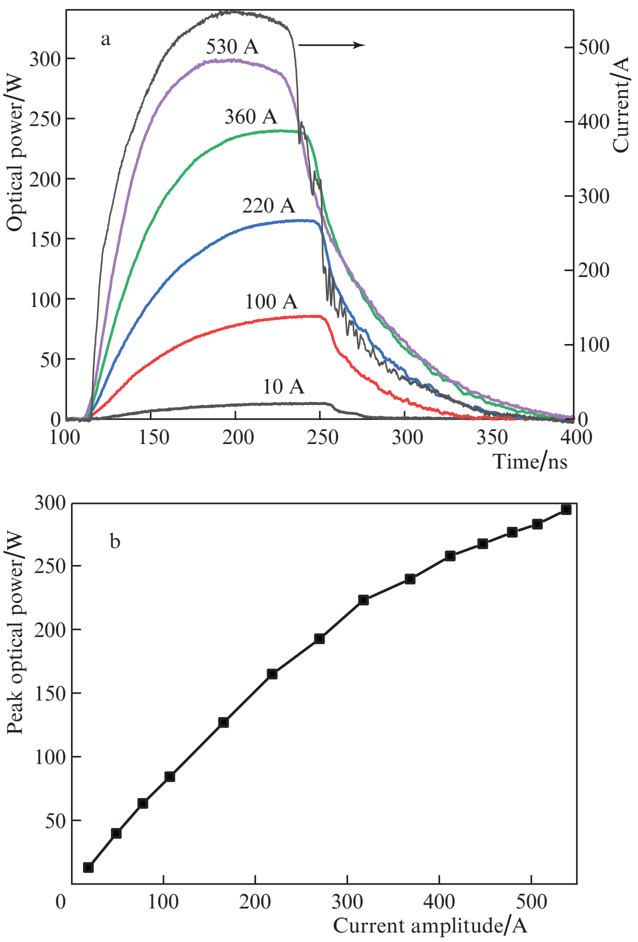

Figure 1. (Colour online) (a) Shapes of integrated laser pulses recorded at different currents and of a pump current pulse with an amplitude of 540 A, as well as (b) LCC of a single crystal with an emitting aperture width of 800 μm and a cavity length of 2 mm.

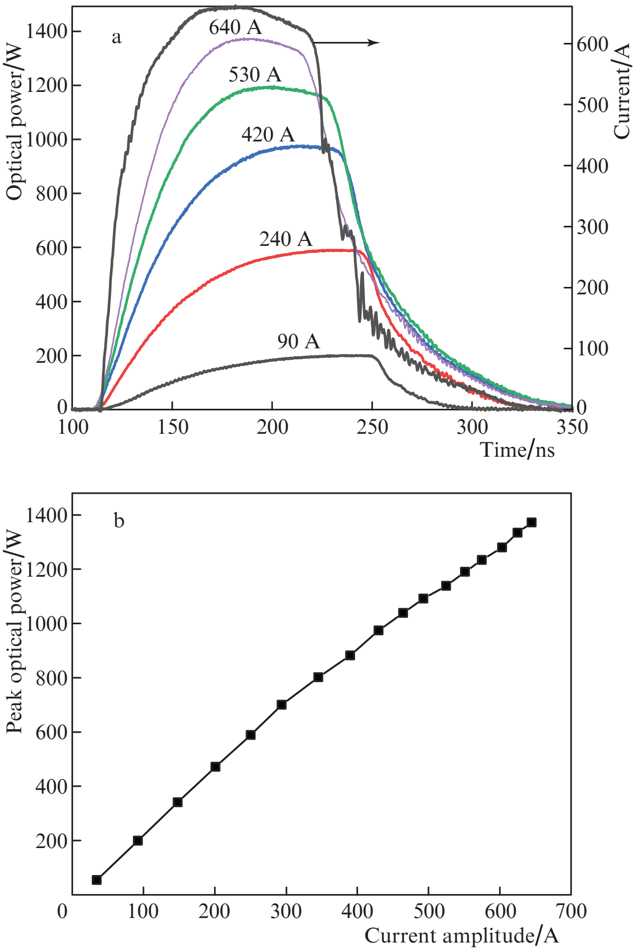

Figure 2. (Colour online) (a) Shapes of integrated laser pulses recorded at different currents and of a current pulse with an amplitude of 650 A, as well as (b) LCC of a vertical stack based on three microbars containing three emitting regions with an emitting aperture width of 800 μm each. The cavity length of each microbar is 2 mm.

are broadened to both the red and the blue as the pump current increases within the entire studied range. The broadening of the lasing spectra with increasing pump current pulse amplitude is typical for semiconductor lasers and results from the different actions of the leading and tailing edges of the pump pulse, as well as from variations in the internal losses with changing pump current amplitude. At the same time, it is important to note the absence of the long-wavelength shift typical for the spectra of cw and quasi-cw lasers with significant heating. In our case, thermal heating of the most part of the laser crystal can be neglected. This fact allows us to conclude that the considered vertical stack design and the used operation regimes are characterised by a low thermal load, which also demonstrates the possibility to further increase the peak power of these stacks.

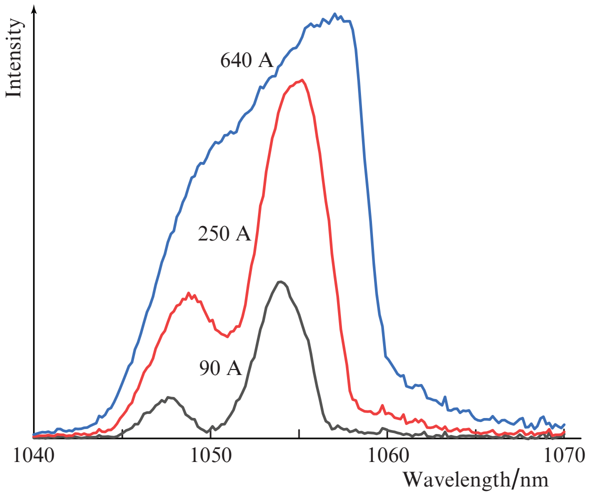

Figure 3. (Colour online) Integrated spectra of the vertical stack pumped by current pulses of different amplitudes.

4. Conclusions

Our studies show that the use of an ultra-wide aperture (the aperture in the present work was 800 μm) is reasonable for developing high-power laser sources operating in pulsed regimes. The main advantage of this approach is related to the possibility of increasing the brightness due to an increase in the filling factor with respect to conventional laser bars. The low thermal load allows one to use the bars of such wide-aperture emitters to create vertical stacks emitting kilowatt optical powers. The absence of apparent restrictions makes it possible to expect efficient operation of the emitters at higher pump currents, as well as to anticipate the appearance of higher-power emitters based on the proposed approach due to the use of bars and vertical stacks with a larger number of elements. In addition, by modifying the assembling technology so that the microbars can be mounted into stacks without conducting supports, it is possible to increase the laser packing density and the emitter brightness by two times.

Acknowledgements. This work was supported by the Russian Science Foundation (Grant No. 19-79-30072).

References

1. Ladugin M.A., Marmalyuk A.A., Padalitsa A.A., Telegin K.Yu., Lobintsov A.V., Sapozhnikov S.M., Danilov A.I., Podkopaev A.V., Simakov V.A. *Quantum Electron.*, **47**, 693 (2017) [*Kvantovaya Elektron.*, **47**, 693 (2017)].
2. Slipchenko S.O., Podoskin A.A., Pikhtin N.A., Tarasov I.S. *Laser Phys.*, **24**, 105001 (2014).
3. Slipchenko S.O., Podoskin A.A., Golovin V.S., Pikhtin N.A., Kop'ev P.S. *IEEE Photonics Technol. Lett.*, **33**, 7 (2021).
4. Platz R., Erbert G., Pittroff W., Malchus M., Vogel K., Tränkle G. *High Power Laser Sci. Eng.*, **1**, 60 (2013).
5. Gavrina P.S., Podoskin A.A., Fomin E.V., Veselov D.A., Shamakhov V.V., Slipchenko S.O., Pikhtin N.A., Kop'ev P.S. *Quantum Electron.*, **51**, 129 (2021) [*Kvantovaya Elektron.*, **51**, 129 (2021)].
6. Veselov D.A., Bobretsova Yu.K., Leshko A.Y., Shamakhov V.V., Slipchenko S.O., Pikhtin N.A. *J. Appl. Phys.*, **126**, 213107 (2019).