Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Edge-emitting lasers based on coupled large optical cavity with high beam stability

To cite this article: A Serin *et al* 2017 *J. Phys.: Conf. Ser.* **929** 012077

IOP Conf. Series: Journal of Physics: Conf. Series **929** (2017) 012077 doi:10.1088/1742-6596/929/1/012077

Edge-emitting lasers based on coupled large optical cavity with high beam stability

A Serin[1,2], N Gordeev[2,3], A Payusov[2,3], Y Shernyakov[2,3], N Kalyuzhnyy[2], S Mintairov[2] and M Maximov[2,3]

[1] Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya, 29, 195251, Saint Petersburg, Russia
[2] Ioffe Institute, Saint Petersburg, Russia
[3] St. Petersburg Academic University, Saint Petersburg, Russia

E-mail: spbgate21@gmail.com

Abstract. In this paper we present a study on temperature and current stability of far-field patterns of lasers based on the coupled large optical cavity (CLOC) concept. Previously it has been shown that the CLOC structures allows effective suppressing of high-order mode lasing in broadened waveguides. For the first time we report on transverse single-mode emission from the CLOC lasers with 4.8 μm thick waveguide. Using broadened waveguide allowed us to reduce the divergence of the far-field patterns down to 14° in continuous-wave (CW) regime. Far-field patterns proved to be insensitive to current and temperature changes.

1. Introduction

Nowadays high-power semiconductor lasers with high-quality beam are desired for a large number of applications, such as material processing, solid-state laser pumping, frequency conversion, medical surgery etc. [1] because of their small size, efficiency, and reliability. Most designs of such devices utilize broadened waveguides in order to reduce the output beam divergence and to lower the power density on the laser facets. The latter is critical to avoid catastrophic optical mirror degradation (COMD) [2]. One obstacle that makes it difficult to expand the waveguide is the appearance of high-order transverse modes, which negatively affects the device characteristics such as the beam quality and divergence. A number of approaches has been developed in order to eliminate high-order mode oscillations in thick waveguides of high-power semiconductor lasers [3-7]. However, along with high-order mode suppression, many of these approaches either too sensitive to changes of the refractive indices of the waveguide layers [3-6] or tend to have significant overlap of the fundamental mode with the highly doped cladding layers, which leads to additional optical loss [7]. Some of the approaches are free of these negative effects, but they could be used to eliminate only one high-order vertical mode [8].

Recently novel waveguide design that allows selective eliminating of high-order modes in broadened waveguides was suggested, and transverse single mode lasing from 2.5μm thick waveguide was demonstrated [9]. This new concept is based on coupled optical waveguides and thus named as coupled large optical cavity (CLOC). In this paper, we present a study of lasing parameters of the advanced CLOC lasers having two passive waveguides. Also, stability of far-field pattern of CLOC based lasers with temperature was investigated for the first time. It is shown that the CLOC laser beam is robust against overheat, typically found in high-power lasers.

2. Experiment

The laser wafer (figure 1) was grown by metal-organic vapor phase epitaxy on *n*-GaAs (100) substrate. An $Al_{0.1}Ga_{0.9}As$ active waveguide (thickness 4.8μm) incorporating two InGaAs quantum wells (wavelength 1.04μm) and two thin GaAs passive waveguides with the thicknesses of 310 nm and 375 nm were sandwiched between two p- and n-doped $Al_{0.2}Ga_{0.8}As$ claddings. The passive waveguides were separated from the active waveguide by 400 nm $Al_{0.2}Ga_{0.8}As$ layers. All the layers except the active waveguide were doped to the level of $2\times10^{18}cm^{-3}$. The active region was shifted toward the p-side to lower series resistance and optical loss on free holes accumulated in the waveguide. In order to minimize the resistance, 2μm of the active waveguide from the n-side was n-doped up to the concentration of $5\times10^{16}cm^{-3}$.

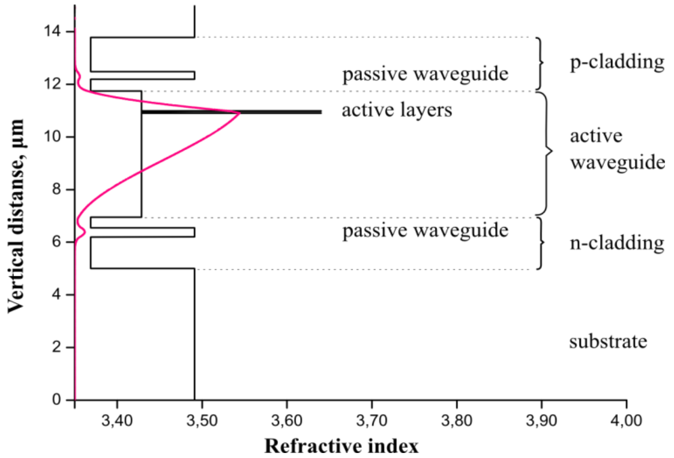

Figure 1. Refractive index profile of the CLOC laser (black line) and simulated fundamental mode intensity profile (red line).

Besides the fundamental mode in active waveguide, its first and second eigenmodes had rather large optical confinement factors (OCF) due to the waveguide thickness and shifted active region. Therefore, two passive waveguides where designed to select the first and second modes. Figure 1 shows refractive index profile and simulated intensity profile for the fundamental mode in the vertical direction. One can see that the fundamental mode penetrates into the additional passive waveguides, which may cause some additional optical loss.

The laser wafer was processed into 50-μm-wide shallow-mesa ridge lasers using etching through the p-contact and partly through the p-cladding layers. Devices with different cavity length where obtained by cleaving the processed wafer. Laser parameters were measured both in pulse (750 ns, 5 kHz) and CW regimes. Samples where mounted p-side down on copper heat sinks to reduce overheat. A Peltier cooler was used to control the temperature of the mounted samples during experiments.

3. Results and Discussion

All tested devices emitted on the fundamental vertical mode, which was confirmed by the far-field measurements. The dependence of the inverse differential efficiency on the cavity length allowed us to estimate the internal quantum efficiency 80% and the internal loss, which was 5.5 cm^{-1}. Threshold current density was 1 kA/cm^2 for the 2 mm long devices. High threshold current density resulted from the reduced fundamental mode OCF. We attribute rather high internal losses to the free carrier absorption in the partially doped waveguide and to the possible diffusion of zinc from the p-doped layers into the p-side of the active waveguide. Figure 2 shows measured L-I curve for the mounted 1.5 mm CLOC laser in the CW regime. Maximum output power of 1.8 W was limited by thermal roll-over.

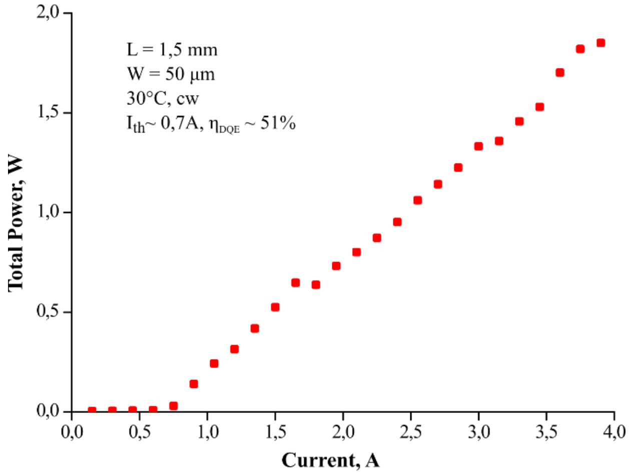

Figure 2. L-I characteristic of the CLOC laser measured in the CW regime.

Figure 3(a) shows far-field patterns of the 1.5 mm device obtained in the CW regime at different driving currents. One can see that single-lobe patterns remain stable throughout entire pumping current range. The obtained results are in good agreement with the simulation (inset in figure 3(a)). Full width at half maximum (FWHM) versus CW current is plotted in figure 3(b) for 1.5 mm and 2 mm devices. Divergence of 12-14° is very close to the diffraction limit for the 4.8µm emitting aperture. Thus, we attribute the small fringes at ±20 degrees to the fundamental mode penetration into the additional passive waveguides rather than to the presence of high-order modes. Further optimization of the structure may eliminate this effect.

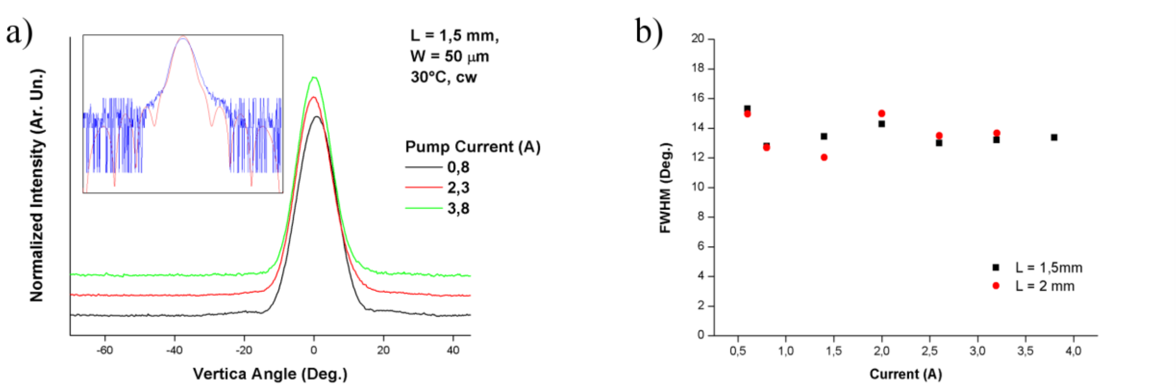

Figure 3. Far-field patterns (a) and FWHM (b) of CLOC lasers, obtained in CW regime at different currents. The comparison of calculated and measured far-field patterns is shown on the inset of (a) in semilogarithmic scale.

Far-field patterns measured in the pulsed regime where used to analyze temperature behavior of the lasing mode. Driving current was 10-15% over the threshold and had been adjusted according to the temperature dependence of threshold current temperature dependence for each device. Figure 4(a) shows measured far-field patterns at different temperatures. The FWHM dependence on the temperature is plotted in figure 4(b). Current and temperature changes do not cause any pronounced modifications of the beam divergence.

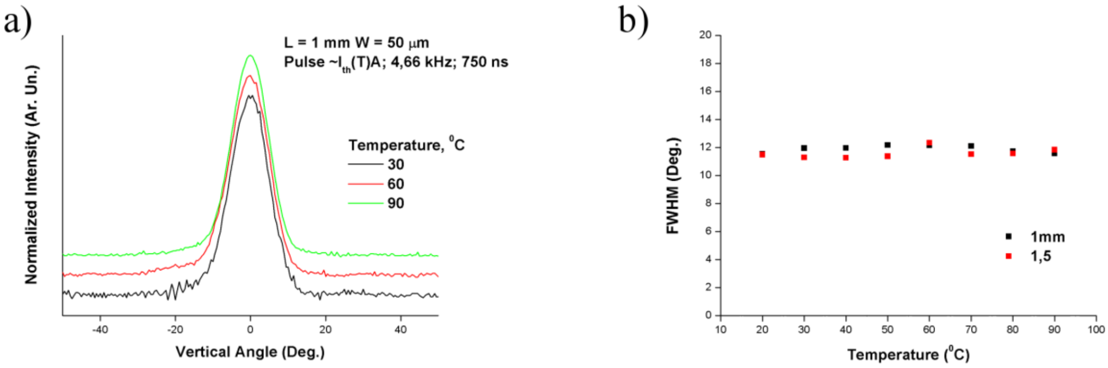

Figure 4. Far-field patterns (a) and FWHM (b) of the CLOC lasers obtained in pulsed regime at different temperatures.

4. Conclusions

We have demonstrated for the first time transverse single-mode operation of the CLOC lasers possessing 4.8 μm thick waveguide with two additional passive waveguides. The CLOC structure allowed obtaining current and temperature insensitive narrow far-field patterns with the diffraction limited divergence of 14 degrees and the CW output power of 1.8 W. We believe that the CLOC structures is a simple, universal, and efficient solution that could be used to advance characteristics of high power diode lasers.

Acknowledgment

The authors acknowledge the support from the Russian Foundation for Basic Research (project No 16-29-03279) and the Ministry of Higher Education and Science of the Russian Federation (project No 3.9787.2017/8.9).

References

[1] W. Schultz *et all* (2000) IEEE J. Sel. Top. Quant. Elect. 6(4) 696
[2] D. Botez (1999) Appl. Phys. Lett. 74 3102
[3] Md Miach *et* all (2015) IEEE J. Sel. Top. Quantum Electron. 21(6) 4900206
[4] G. Lin *et all* (1996) IEEE Photonics Technol. Lett. 8 1588
[5] A. Pietrzak *et all* (2011) IEEE J. Sel. Top. Quantum Electron. 17(6) 1715
[6] B.S. Ryvkin *et all* (2013) J. of Appl. Phys. 114 013104
[7] V.A. Shchukin *et all* (2011) IEEE Quantum Electron. 47(7) 1014
[8] N.A. Pikhtin *et all* (2004) Electronics Letters 40(22) 1413
[9] N.Yu. Gordeev *et all* (2015) Optics Letters 40(9) 2150