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Spectral composition of radiation from microlaser coupled to waveguide

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Abstract. We investigate the mode composition of a microdisk laser coupled with an optical waveguide. The output spectra of emission and light-current characteristic of the microlaser obtained from the output edge of the waveguide are studied. The microlaser demonstrates single-mode emission in consecutive ranges of injection currents, that are alternated with pronounced mode hoping. The intensity of the modes changes non-monotonically with the growth of the pump current. Such a behavior, which we attribute to the laser self-heating, results in numerous kinks in the light-current curve. The kink-free current range in which single-mode lasing is maintained reaches 25 mA.

Keywords: whispering gallery mode, microdisk laser, mode switching, single mode lasing

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Спектральный состав излучения микролазера, сопряженного с волноводом

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Аннотация. Исследован спектральный состав и ватт-амперные характеристики излучения микродискового лазера, связанного с оптическим волноводом. Наблюдалось переключение лазерных мод с ростом тока накачки. При этом в диапазонах тока накачки между переключением мод лазерная генерация имела одномодовый характер. Такое поведение обусловлено саморазогревом лазера и приводит к множественным изломам на ватт-амперной характеристике. Диапазон токов, в котором не наблюдается скачков интенсивности и сохраняется одномодовая генерация, достигает 25 мА.

Ключевые слова: моды шепчущей галереи, микродисковый лазер, переключение мод, одномодовая лазерная генерация

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Introduction

The realization of photonic integrated circuits (PICs) using III-V semiconductors has recently attracted great interest due to the possibility of combining both classical PIC components (waveguides, splitters, interferometers, etc.) and active elements (radiation sources, receivers) on one platform [1]. Microdisk (MD) lasers with an active region based on quantum dots (QDs), characterized by high Q-factor (~10^5) and small size, are promising candidates for signal sources in PICs [2]. The directional light output from such microlasers can be achieved by coupling them with lateral optical waveguides (OW) [3]. The light-current (*L–I*) characteristics of MD lasers obtained from the edge of the coupled OW play a critical role in information processing applications, particularly in the context of promising direct modulation [4]. Here we study the correlation between the current injected to a MD laser, output power and peculiarities of emission spectra transmitted through an OW made of the same heterostructure.

Materials and Methods

The heterostructure under study was fabricated by Metal-Organic Chemical Vapor Deposition on an n^+-GaAs substrate 6°-misoriented off (100) plane. It consists of bottom *n*-doped (Si) and top *p*-doped (Zn) $Al_{0.39}Ga_{0.61}As$ cladding layers of 1.55 μm thickness each, with 620-nm-thick *i*-GaAs waveguiding layer in between and 0.35-μm-thick p^{++}-GaAs contact layer. An active region was located within the waveguiding layer and included five layers of $In_{0.4}Ga_{0.6}As$/GaAs QDs [5] with 40 nm GaAs spacers. MD lasers with diameter of 40 μm, coupled to OW with a length of about 440 μm were formed by electron lithography and plasma reactive ion etching. On top of the microlasers, individual ohmic AgMn/Ni/Au contacts were formed to the p^{++}-GaAs layer. Substrate was thinned and AuGe/Ni/Au metallization was deposited on its bottom side to serve as a common *n*-contact. All MD lasers were studied at room temperature under continuous-wave pumping. To collect electroluminescence (EL) of microlaser coupled to the OW, Mitutoyo ×20 microobjective was focused on the OW end. The EL spectra were registered using an optical spectrum analyzer (Yokogawa AQ 6370C) and light-current (*L–I*) curves were measured using Thorlabs S155C power meter.

Results and Discussion

Fabricated devices demonstrated lasing at room temperature under continuous-wave pumping. The threshold current for microlasers were about 17 mA. Here, we focused on the MD laser that demonstrated single-mode emission at consecutive pump current intervals with mode switching in between. The studied range of pumping currents 0–75 mA was mainly limited by thermal rollover.

A typical *L–I* curve of 40 μm MD laser obtained from the edge of the OW is presented in Fig. 1, *a* as a solid line. Lasing threshold of the studied MD laser was determined to be equal to 17 mA by analysis of the EL spectra. The knee on the *L–I* curve, which typically corresponds to the lasing threshold, is not visible in Fig. 1, *a* due to the high contribution of spontaneous emission. An increase in the pumping current leads to a nonmonotonic growth of the MD laser optical power, i.e. local minima and maxima are observed. To understand the cause of this behavior, we studied the spectral characteristics of the microlaser. Lasing spectra of the MD laser corresponding to different pump currents are shown in Fig. 1, *b*. Lasing starts via the

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mode I, which has a wavelength of about 1051 nm at the threshold current. Further increase of the current leads to a slow redshift of the lasing wavelength up to a pumping current of 27 mA, where an abrupt change in wavelength occurs caused by mode hopping.

The intensities of certain lasing modes, from I to V, are shown in Fig. 1, *a* by symbols. Each data point was obtained by fitting a mode line in the EL spectrum with a Gaussian curve. The behavior of the $L-I$ curves correlates well with the changes in the optical power of the lasing modes. For example, each time the intensity of a certain mode decays, a local minimum is observed on the $L-I$ curve. Some of the observed raises on the $L-I$ curve are correlated with mode switching process, happening at pumping currents, easily identified in Fig. 2, *a*. In between these current values the studied device demonstrates single-mode lasing emission. The other of the observed $L-I$ curve peculiarities coincide with change in lasing mode intensity, as observed at currents 53, 60, 63, 74 and, less pronounced, at 40 mA.

a) *b*)

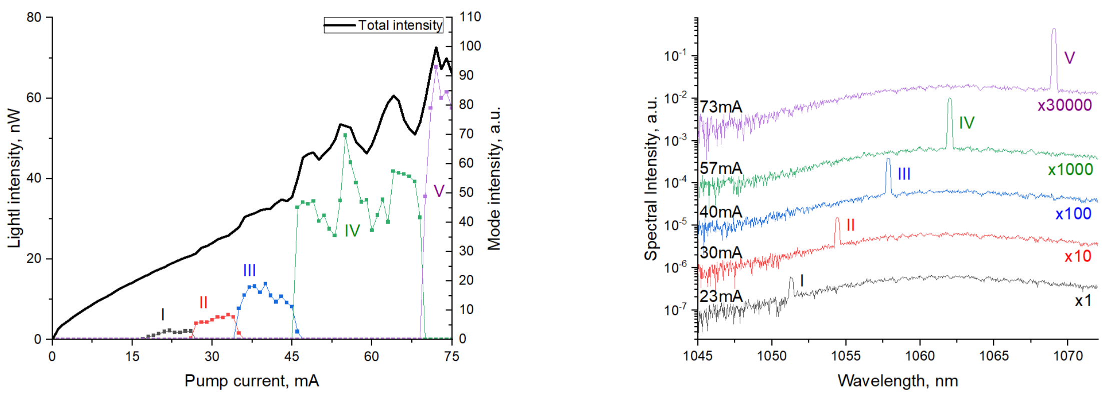

Fig. 1. Intensities of modes (symbols) and light intensity (solid line) of the investigated microdisk laser as a function of pump current (*a*). Spectra at different pump currents (*b*) color codes of modes are the same on both graphs

a) *b*)

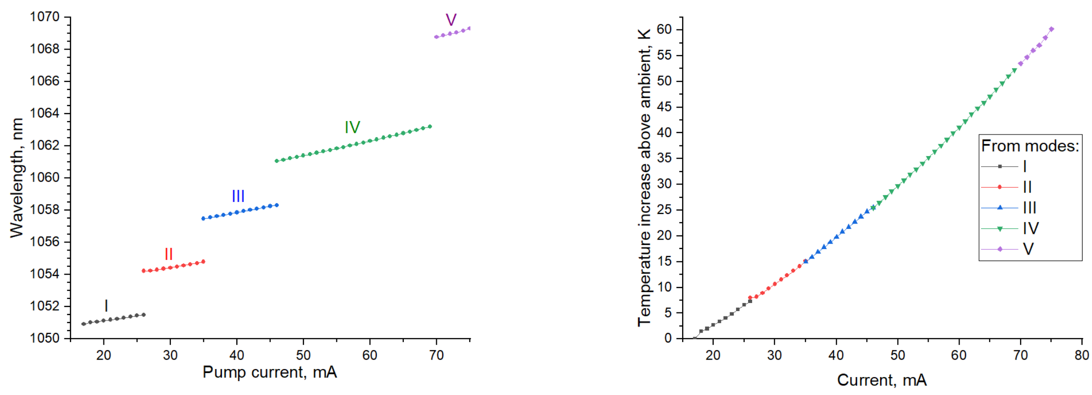

Fig. 2. Dependences of mode wavelengths (*a*) and temperature of laser self-heat (*b*) on pump current

The same slope of the current-induced redshift is observed for all lasing modes, as illustrated in Fig. 2, *a*. To evaluate an increment of the device temperature above the ambient temperature, a temperature coefficient of 80 pm/K obtained in work [6] was used (Fig. 2, *b*). The dependence of excess temperature on current changes from a linear to a quadratic function for higher currents in agreement with the model of Ref. [7]. The temperature increment of 60 K was estimated for the current at which thermal rollover starts.

We associate both redshift and mode hopping with self-heating of the device. On the one hand, the raise of the microlaser temperature causes a drift in the structure refractive index that leads to a redshift of the wavelength of a particular optical mode. On the other hand, self-heating of the device results in a narrowing of the bandgap and, as a result, in a redshift of the active region gain profile. A combination of these effects leads to mode hopping [8]. Increased intensity of modes IV and V compared to modes I–III can be explained by their spectral position lying outside of the OW absorption region. The interval of currents in which the IVth mode persists is 25 mA and is about two times greater than that for other modes. The spectral distance between modes IV and V is also twice the average for the other consecutive pairs of modes.

Conclusion

In this work spectral composition of MD laser radiation collected from the coupled OW was studied. We noticed peculiarities on the $L–I$ curve. Some of them correspond to the laser mode switching and the appearance of the next whispering gallery mode in the EL spectrum. We attribute the mode switching behavior to the self-heating of the device under study, which leads to a redshift in the active region gain spectrum. It was shown that a stable output of single-mode emission of MD laser through a coupled OW can be achieved over a large range of pumping currents (25 mA).

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REFERENCES

1. **Dietrich C.P., et al.,** GaAs integrated quantum photonics: towards compact and multi-functional quantum photonic integrated circuits, Laser & Photonics Reviews, 10 (6) (2016) 870–894.
2. **Kryzhanovskaya N., et al.,** III–V microdisk/microring resonators and injection microlasers, J. Phys. D: Appl. Phys., 54 (45) (2021) 453001.
3. **Lv X.-M., et al.,** Analysis of vertical radiation loss and far-field pattern for microcylinder lasers with an output waveguide, Opt. Express, OE., 21 (13) (2013) 16069–16074.
4. **Kryzhanovskaya N.V., et al.,** Direct modulation characteristics of microdisk lasers with InGaAs/GaAs quantum well-dots, Photon. Res., PRJ, 7 (6) (2019) 664–668.
5. **Maximov M.V., et al.,** Light emitting devices based on quantum well-dots, Applied Sciences, 10 (3) (2020) 1038.
6. **Kryzhanovskaya N., et al.,** Continuous-wave lasing at 100° C in 1.3 μm quantum dot microdisk diode laser, Electronics Letters, 51 (17) (2015) 1354–1355.
7. **Zhukov A.E., et al.,** Impact of self-heating and elevated temperature on performance of quantum dot microdisk lasers, IEEE Journal of Quantum Electronics, 56 (5) (2020) 1–8.
8. **Zhukov A.E., et al.,** Quantum-dot microlasers based on whispering gallery mode resonators, Light Sci Appl., 10 (1) (2021) 80.

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