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Microring lasers with a waveguide coupler

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Abstract. In the present work, we study the possibility of the emission output of a semiconductor microring laser through a radially coupled optical waveguide. Room temperature lasing has been achieved in continuous wave regime with the wavelength of ~1090 nm. The characteristics of microlasers with and without waveguide have been compared. We have performed a spatial scanning with simultaneous detection of the laser radiation at an injection current above the threshold. We have observed an increase in the output power up to two times due to the use of a coupled waveguide.

Keywords: microlaser, microring resonator, quantum well-dots, coupled optical waveguide

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Микрокольцевые лазеры с волноводным ответвителем

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Аннотация. В данной работе исследуется возможность вывода излучения полупроводникового микрокольцевого лазера через радиально связанный оптический волновод. Лазерная генерация при комнатной температуре исследованных структур была реализована в непрерывном режиме на длине волны ~1090 нм. Проведено сравнение характеристик микролазеров с волноводом и без него. Реализовано пространственное сканирование с одновременной регистрацией лазерного излучения при токе накачки выше порогового. Мы наблюдали увеличение выходной мощности до двух раз за счет использования связанного волновода.

Ключевые слова: микролазер, микрокольцевой резонатор, квантовые яма-точки, связанные оптические волноводы.

Финансирование: Исследование выходной мощности выполнено в рамках программы фундаментальных исследований НИУ ВШЭ (Университет ВШЭ), монтаж и пайка поддержаны Министерством науки и высшего образования РФ по проекту № 0791-2020-0002, разработка и моделирование структур финансировались РФФИ и БРФФИ проект № 20-52-04016.

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Introduction

Today the vast majority of integrated circuits are produced by complementary metal-oxide-semiconductor (CMOS) technology based on silicon [1]. Currently, increasing density of transistors on a chip by CMOS technology attracts a lot of attention. A way to achieve this goal is to reduce the transistor size. Thus, problems of scaling and problems with heat dissipation in currently used conductive interconnects have led to the search for their alternative [2]. One of the promising methods is high-speed optical communication [3]. Whispering gallery mode (WGM) semiconductor lasers with microdisk (MD) or microring (MR) optical cavity have high quality factor and low output loss [4]. Other useful properties of WGM microlasers are lateral light output, simplicity of the fabrication, and possibility to use a non-native substrate without complex technological steps [5]. All mentioned above makes microlasers of this design promising candidates for the implementation of compact radiation sources for high-speed optical communication. However, there is a problem of direct and controllable output of the emission from MR and MD lasers [6].

Direct and controllable emission output of WGM microlasers may be achieved by various modifications of MR and MD resonators. It was shown, that small harmonic perturbation of the resonator surface (with amplitude less than 0.01 of the MD radius) leads to more directional output of laser emission [7]. More radical modifications of microlasers, such as a pierced hole in the resonator near its edge may result in a single-mode and narrowly focused emission [8]. However, such destructive modifications can only be used with optically pumped microlasers and also can negatively affect laser characteristics (lasing threshold, heat dissipation, etc.). Another effective method of organizing the directional emission output of MD and MR lasers is optical coupling with other optical elements. Such coupling with plasmonic [9] and dielectric [10] antennas has already been investigated. Generally, the laser emission from such structures is not concentrated in the lateral plane. Also, optical coupling between the MD and MR laser and the optical waveguide (WG) is of great interest. Structures of this type can be integrated on a chip, since light propagates in the lateral direction. Here, we present a study of the implementation of optical coupling between semiconductor lasers with a MR optical cavity and a radially coupled optical WG.

Materials and Methods

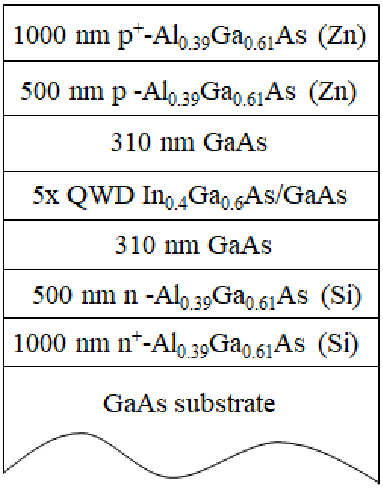

Fig. 1. Scheme of layout of the studied structures

The studied diode MR lasers were fabricated from an AlGaAs/GaAs laser heterostructure synthesized on a *n*+-GaAs substrate with an active region consisting of a 5-layer array of InGaAs quantum wells-dots (QWDs). Photolithography and plasma-chemical etching were used to form MR resonators with a height of about 5 μm and a diameter of 100 and 50 μm radially coupled with multimode WG. The scheme of layout of the structures is presented in Fig. 1. We used AgMn/Ni/Au metallization to form ring contacts to the p+-GaAs layer at the tops of the mesas. The GaAs substrate was thinned to approximately 100 μm, and a solid electrical AuGe/Ni/Au *n*-contact was fabricated on its reverse surface (Fig. 2). More detailed description of the epitaxial structure and fabrication details may be found elsewhere [11].

The absolute value of the output power of the MR laser was estimated by using a Thorlabs FDG1010 1 cm × 1 cm photodiode placed next to the laser under study. To study the spatial distribution of MR laser radiation we formed an electrical contact with a gold wire welded to the *p*-metallization of the laser. The lasers were tested at room temperature in continuous wave regime.

A numerical model of the optical coupling of a MR resonator with an optical WG radially connected to it was developed in COMSOL Multiphysics environment via the finite element method [6]. The optical power output was maximized under conditions when the WG width fits an integer number of the WGM intensity peaks inside the MR. In this work we use 15 μm wide radially coupled WG to support multimode operation.

Results and Discussion

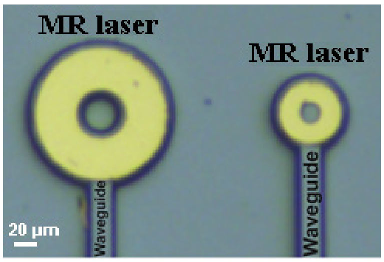

Fig. 2. Photo of injection MR lasers with a diameter of 100 and 50 μm coupled with a WG

The lasing spectra above the threshold of the studied MR lasers with WG are presented in Fig. 3. In order to determine threshold currents, we studied dependences of non-directional lasing line intensity versus injection current (inset to Fig. 3). These dependencies were obtained from the evolution of the emission spectra of the microlasers with and without WG with increasing injection current. Threshold currents for 100 and 50 μm MR lasers with WG were 67.7 mA and 39.4 mA. In the case of microlasers without WG, threshold currents were 32.1 mA and 19.7 mA, respectively. Observed increase of the threshold current for MR lasers with WG we attributed to the growth of the emission output losses.

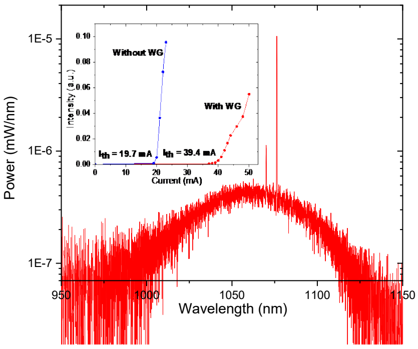

Fig. 3. Emission spectrum above the threshold current
of 50 µm MR laser with radially coupled WG

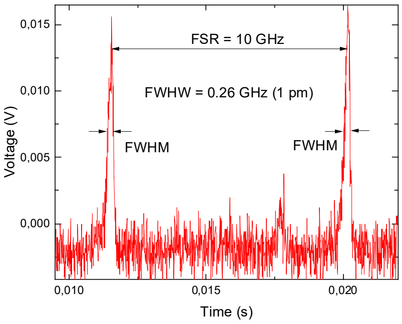

Fig. 4. Signal maxima of 100 µm MR laser obtained
by the scanning Fabry—Perot interferometer method

The inset shows an evolution of non-directional lasing line intensity versus injection current of 50 µm MR laser with and without radially coupled WG

The spectral linewidth of MR lasers with WG was studied by the scanning Fabry—Perot interferometer Thorlabs SA210-8B (Fig. 4). The free spectral range (FSR) of the interferometer was 10 GHz. The time scale of the oscilloscope was calibrated to observe two signal maxima to measure spectral linewidth in terms of optical frequency. The linewidth (full width at the half maximum) of the lasing resonance is about 1 pm. The obtained value of the linewidth is comparable to the MR lasers of the same diameter without WG [12]. Thus, the increased output loss introduced by a radially coupled WG do not affect the quality factor (~10^6) of the MR resonator within our experimental resolution.

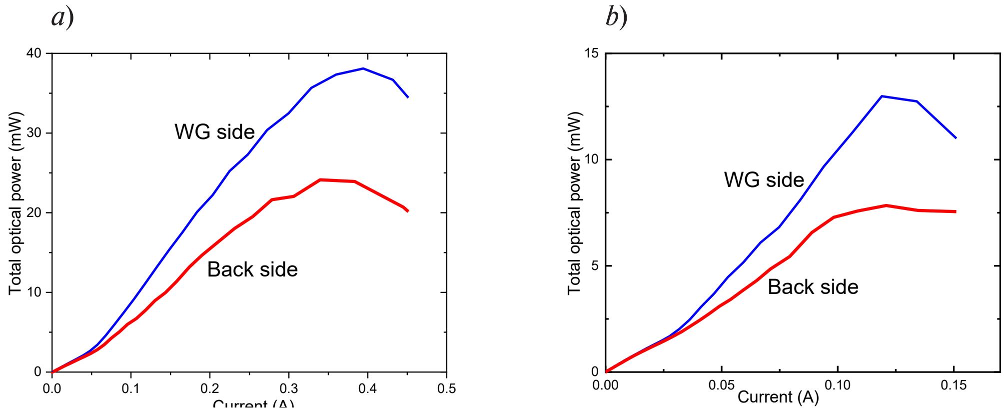

Fig. 5. Watt-ampere characteristics of 100 µm (*a*) and 50 µm (*b*)
MR lasers measured from the side of the WG and from the back side

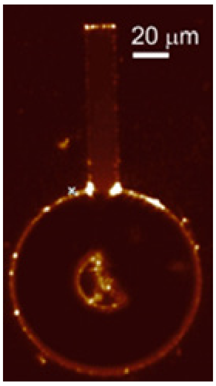

Fig. 6. Spatial distribution
of 100 μm MR laser emission

We measured the values of the absolute output power of MR lasers with a 50 and 100 μm diameter as a function of the injection current (Fig. 5). The dependencies were obtained from the WG side of microlaser and from the opposite side (back side). We observe an increase in the output power from the WG side up to two times, from 24 to 38 mW (peak values) for 100 μm in diameter MR laser and from 7 to 13 mW for 50 μm in diameter MR laser. The maximum power value is limited by the self-heating of the active region and subsequent thermal roll-over. Increase of the laser diameter from 50 to 100 μm results in better heat dissipation and thus in higher output power obtained.

Next, we studied spatial distribution of the laser emission by a confocal scanning optical microscopy in 100 μm microlaser at the injection current (J = 140 mA) above the threshold (J_{th} = 67.7 mA). The image of the output light distribution at wavelength (λ = 1103 nm) is presented in Fig. 6.

The light output from the MR laser was observed along the periphery of the resonator with local intensity maxima caused by roughness on the surface of the resonator. Other two local intensity maxima in the corners between the laser edge and the WG are due to non-directional scattering of light, previously predicted by the numerical analysis of such lasers with WG [6]. We also observe the light distribution along the WG and its output at the cleaved WG edge. The spectra obtained from the edge of the coupled WG and from the laser back side are compared in Fig. 7. We observe higher intensity for the case of WG point. Though the WG contains the same active region as in the laser, its absorption is low at the lasing wavelength, since the lasing occurs at the long-wavelength side of the InGaAs QWD absorption spectra (inset in Fig. 7). Thus, the mentioned above growth of the total optical power from the WG side is not caused only by the scattering of light at the interface between the laser and the WG, but also by the more effective emission from the coupled WG.

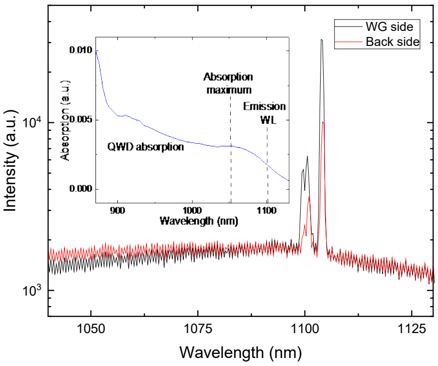

Fig. 7. Lasing spectra of 100 μm MR laser from the point at the end
of the coupled WG and from the opposite point at the back side,
an inset shows the typical absorption spectrum for QWD active region

Conclusion

The output of radiation from the MR laser with a radially coupled WG was demonstrated. The spectral analysis of the radiation of the MR lasers does not reveal any degradation of quality factor in case of radial WG coupling. An increase in the output power up to two times was observed due to the use of the WG. The presence of undesirable omnidirectional light scattering in the region of the interface between the laser and the WG can probably be excluded by an adiabatic coupling of WG and MR laser. Thus, in the future works we suppose to optimise the joint point of the WG and MR laser for the further optimization of the light output.

Acknowledgments

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