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Investigation of high-temperature generation of microdisk lasers with optically coupled waveguide

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The laser generation characteristics of microdisk lasers with optically coupled waveguide operating in continuous wave mode at elevated temperatures are investigated. Laser generation and waveguide effect at temperatures up to 92.5°C were demonstrated. The measured characteristic temperature of microlasers was 65 K in the range of 25−92.5°C.

Keywords: Microlasers, quantum dots, waveguides, microdisk resonators.

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Optical data transmission on a chip has a number of advantages over electrical transmission, such as higher speed, increased resistance to interference, and lower heat generation [1]. In this case, semiconductor microlasers with a disk-shaped resonant cavity supporting whispering gallery modes can be used as a source of optical radiation [2]. However, due to the axial symmetry of microdisc (MD) resonant cavities, their radiation pattern does not have any specific direction, which makes it difficult to implement optical communication on a microchip. One of the ways to achieve directional output of radiation from MD lasers is optical coupling with the main waveguide. Meanwhile, this configuration is planar and can be implemented on an integrated circuit. The use of waveguide-conjugated MD lasers in microchips requires operation at elevated temperatures. Microlasers of this design should have good temperature stability. The literature provides examples of waveguide-coupled MD lasers based on InAlGaAs quantum wells operating at temperatures over room temperature, with a maximum operating temperature of the order of 60°C [3]. Stripe lasers with an active region based on quantum dots (QD) [4,5], as well as discrete QD microlasers [6–8] have improved temperature stability characteristics. However, as far as we know, high-temperature lasing from QD microlasers conjugated to a planar waveguide has not been previously reported.

In this work, the study was carried out on the temperature characteristics of MD lasers with an active region containing an array of InGaAs/GaAs QD and conjugated with an optical waveguide created from the same epitaxial structure in planar geometry. The heterostructures under study were obtained by gas-phase epitaxy from organometallic compounds on a n^+-GaAs substrate, slightly misoriented relative to the (100) axis. Five layers of high-density InGaAs/GaAs QD were used as the active region (Fig. 1, *a*). The properties of such QD and microlasers based on them are described in [9]. To form MD resonant cavities with a diameter of 40 μm and conjugated waveguides, electron beam lithography and plasma-chemical etching were used. At the tops of the mesa lasers and on the waveguide, isolated ohmic contacts to the p^+-GaAs layer were formed using AgMn/Ni/Au metallization. The substrate was thinned to approximately 100 μm and an electrical *n* contact was created on the reverse surface using AuGe/Ni/Au metallization. To ensure efficient output of MD resonant cavity radiation into the waveguide, a junction area of the disk resonant cavity and waveguide with a length of approximately 1 μm was formed in the coupling region (Fig. 1, *b*). The microlasers were surrounded by blocking elements so that when measuring the power output from the end of the waveguide, there would be no illumination by direct laser radiation.

Microdisc lasers with a diameter of 40 μm, conjugated to a waveguide, were placed on a holder equipped with a temperature controller and studied in continuous mode. Using a needle-shaped tungsten probe (W) with a diameter of 15 μm, contact was made with the upper electrode of the microlaser. The current source was a Keithley 2400

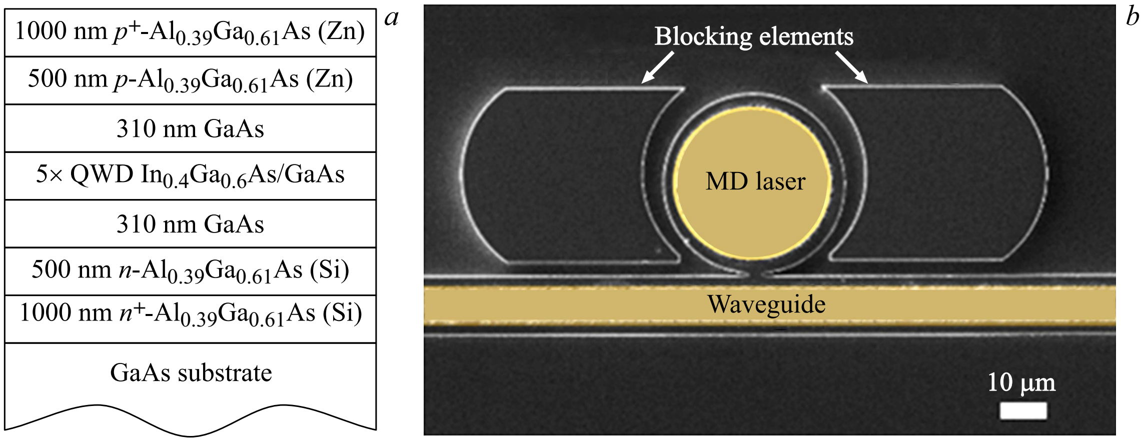

Figure 1. (a) Diagram of layers of the epitaxial structure, (b) image of the studied microlasers conjugated to a waveguide, obtained using a scanning electron microscope.

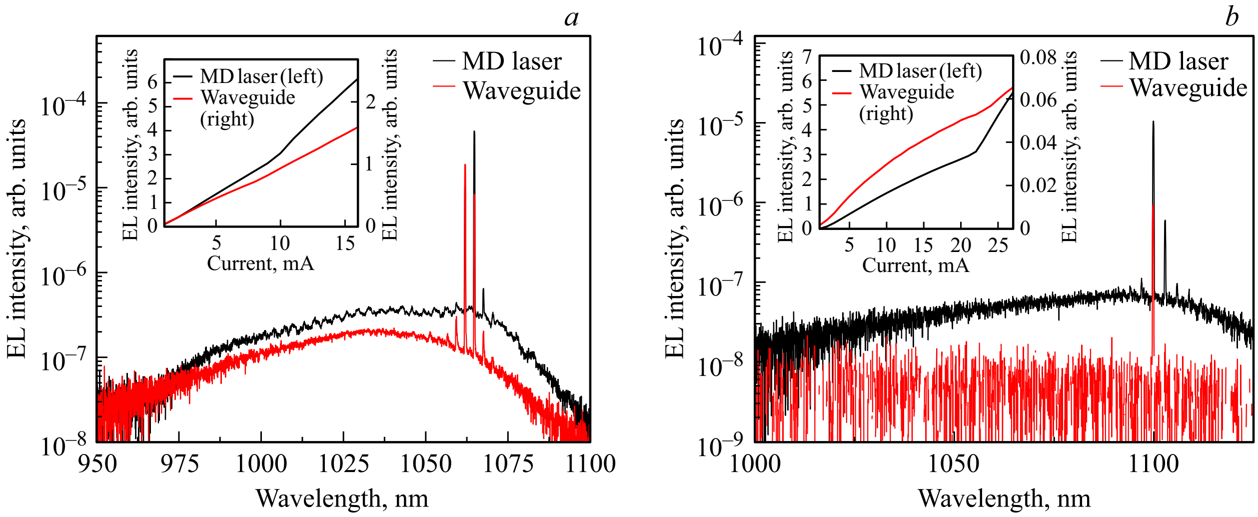

Figure 2. EL spectra obtained from the MD laser and from the end of the waveguide at room temperature (a) and at 92.5°C (b). The insets show the dependence of the output radiation power on the pump current, measured from the microlaser and from the waveguide.

Series SourceMeter® source-meter. Radiation was collected using a Mitutoyo M Plan Apo NIR HR 50× lens in the radiation plane of the MD lasers. Electroluminescence (EL) spectra of microlasers were recorded from the MD lasers themselves, as well as from the end of the waveguide. The radiation was recorded using a Yokogawa AQ 6370C optical spectrum analyzer.

The waveguide effect (i. e., there was input of microlaser radiation into a planar waveguide and its output from the end of the waveguide), as well as laser generation, up to 92.5°C inclusive (Fig. 2). The observed shift of laser emission lines towards longer wavelengths depending on room temperature is associated with heating of the MD laser. The insets to Fig. 2 demonstrate the dependences of the output radiation power on the pumping current, recorded from the microlaser and from the end of the waveguide at room temperature and at 92.5°C. The presence of absorption of resonance radiation in the waveguide leads to the fact that the radiation power recorded at its end , turns out to be less than the power captured by the waveguide. This effect can be partially neutralized by electrically pumping the waveguide.

Figure 3 shows the power characteristics at different temperatures. The inflection point in the given characteristics corresponds to the threshold lasing current. It can be seen that with an increase in temperature, the threshold current increases from 8.2 mA at 25°C to 22.7 mA at 92.5°C. The change in the threshold current density (j_{th}) depending on temperature is demonstrated in the inset to Fig. 3. An increase in temperature leads to an increase in the threshold current and, accordingly, to an increase in the threshold current density, as can be seen in the graph below. The temperature dependence of the threshold current density can be described by the formula $j_{th}(T+\Delta T) = j_{th}(T)\exp(\Delta T/T_0)$. The value T_0 is called the characteristic temperature of the laser and

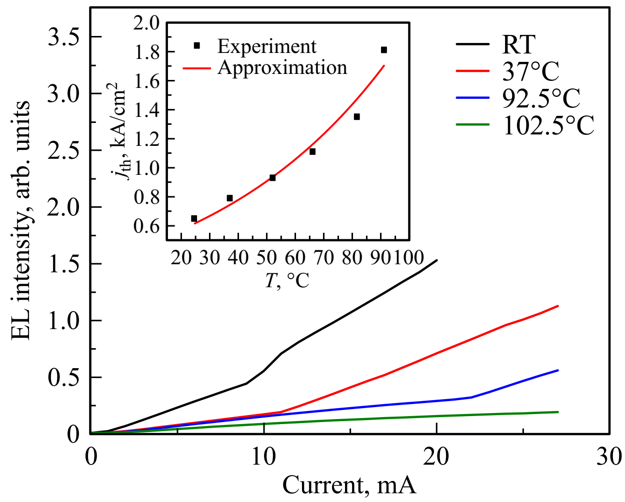

Figure 3. Power characteristics at different temperatures for a 40 μm microlaser. The inset demonstrates the experimental dependence of the threshold current density on temperature and its approximation by an exponential.

determines its temperature sensitivity. The approximation of the experimental dependence in the inset to Fig. 3 is depicted by a red line. In the case of the studied microlaser with a conjugated waveguide, the characteristic temperature for the range 25–92.5°C was 65K̇. For single MD lasers of the same diameter, not conjugated to a waveguide, the characteristic temperature was also ~ 65 K, which suggests that conjugating to a waveguide does not significantly affect the temperature stability of the microlaser.

Thus, the characteristics of lasing in the continuous mode of a 40 μm MD laser conjugated to an optical waveguide at higher temperatures have been studied. Laser generation and waveguide effect for the studied microlaser at a temperature of 92.5°C were demonstrated. The obtained value of the characteristic temperature of the studied MD laser for the temperature range 25–92.5°C was 65 K.

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Conflict of interest

The authors declare that they have no conflict of interest

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