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Injection edge-emitting microlasers with InGaAs/GaAs quantum dot active region

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Abstract. Spectral studies of electroluminescence have been conducted on edge-emitting lasers with different cavity lengths. Mirrors were formed by focused ion beam technique and cleaving. A wide range of injection currents was used. Active region of the lasers consists of dense arrays of InGaAs/GaAs quantum dots, which enabled to obtain lasing in stripe lasers with cavities as short as 45 μm. A noticeable blueshift of the lasing wavelength was observed with the cavity length decrease, accompanied by an increase in the threshold current density. The maximum modal gain was estimated to be at least 267 cm^{-1}.

Keywords: microlaser, quantum dots, edge-emitter, focused ion beam

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Материалы конференции
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Инжекционные торцевые микролазеры с активной областью на основе InGaAs/GaAs квантовых точек

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Аннотация. В работе исследованы спектры электролюминесценции торцевых микролазеров с активной областью на основе квантовых точек InGaAs/GaAs с различной длиной резонатора в широком диапазоне токов инжекции. Зеркала резонаторов формировались травлением фокусированным ионным пучком или скалыванием по плоскостям спайности. В работе получена лазерная генерация в полосковых лазерах с длиной резонатора 45 мкм. Максимальное модальное усиление активной области оценено не менее 267 $см^{-1}$.

Ключевые слова: микролазер, квантовые точки, полосковый лазер, фокусированный ионный пучок

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Introduction

Currently, semiconductor lasers incorporating quantum dots (QDs) have shown significant promise for optical communication systems [1]. The advantages of QD lasers include their ability to operate at high temperatures, high defect tolerance, low threshold currents, reduced linewidth, and strong resistance to parasitic optical feedback. For applications in photonic integrated circuits, minimizing the laser footprint is desirable for achieving a denser component layout and lower power consumption. Microdisk lasers utilizing whispering gallery modes feature a relatively straightforward manufacturing process, compact size, and low threshold currents [2]. However, they exhibit isotropic radiation output into free space. On the other hand, Fabry–Perot (FP) stripe lasers present an appealing alternative due to their ease of epitaxial synthesis and device fabrication processes, as well as their directional in-plane light output, which facilitates simple butt-coupling of laser radiation into waveguides. However, Stranski–Krastanow QDs, even when stacked in multiple layers, often experience low optical gain, posing challenges in reducing the length of stripe lasers to below several hundred micrometers. Another issue is fabrication of the FP laser mirrors to be compatible with the integration process technology.

In this study, we investigated FP lasers with active region based on dense arrays of InGaAs/GaAs QDs with cavity lengths as short as 50 μm, featuring mirrors created using focused ion beam (FIB) etching technique and 45 μm, formed by cleaving.

Materials and Methods

A laser heterostructure was MOCVD grown on an *n*-GaAs substrate misoriented by 6° towards the [111] direction. The structure contained a 800 nm thick GaAs waveguide, two 1.55 μm thick *n*- and *p*-doped $Al_{0.39}Ga_{0.61}As$ claddings and a 350 nm thick p^+-GaAs contact layer. The active region contained 6 QD layers formed by depositing 2 nm $In_{0.4}Ga_{0.6}As$ and separated one from each other by 40 nm thick GaAs layers. Stripe lasers were formed by photolithography and plasma-chemical etching. To implement electrical contact a multilayer Au-based metallization was used. Short FP cavities were formed either by FIB etching (50–150 μm) or cleaving (45–510 μm).

In the experiment, the electroluminescence (EL) spectra of microlasers were studied. Electrical connection to the *p*-contact of an individual microlaser was achieved using a BeCu microprobe. To reduce the laser self-heating, a pulsed power supply mode was used (duration 500 ns, repetition rate 2 kHz). The laser radiation was collected by a microobjective and directed using fiber to the entrance slit of a grating monochromator combined with a cooled InGaAs array.

Results and discussion

The EL spectra of edge-emitters were studied in the wide range of injection currents at the temperature of 300 K. The obtained EL spectra measured near the lasing threshold are shown in Fig. 1, *a* for FIB etched and in Fig. 1, *b* for as-cleaved lasers. The observed blue shift of the lasing wavelength with a cavity length decrease is attributed to the dependence of the gain spectral maximum on the injection current due to the presence of QD parameters dispersion [3]. The cavity length decrease also leads to an increase in threshold current density, that is associated with increased output losses in short-cavity lasers.

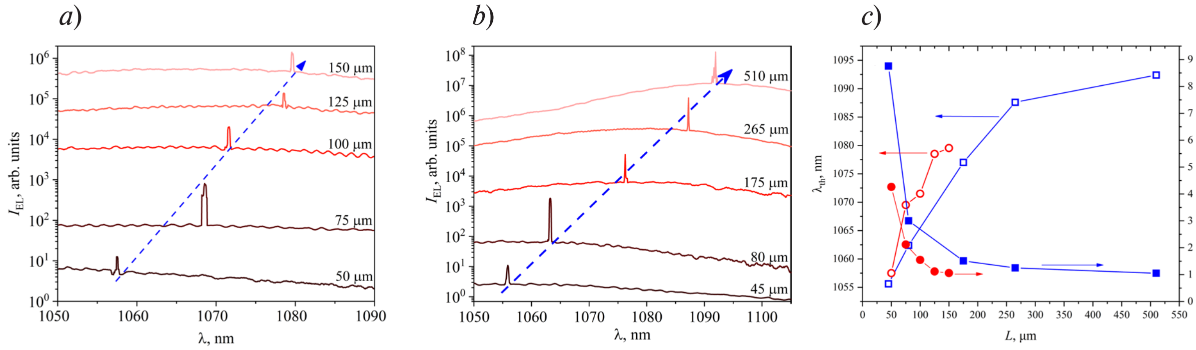

Fig. 1. EL spectra of edge-emitters with different cavity length formed by FIB (*a*) and cleaving (*b*), measured near the lasing threshold, and dependences of lasing wavelength (open symbols) and threshold current density (painted symbols) on the cavity length for FIB-etched (circles) and as-cleaved (squares) edge-emitters (*c*). Curves in (*a*) and (*b*) are vertically shifted for better clarity, blue and red lines also demonstrate shift of lasing wavelength

The obtained dependencies of the lasing wavelength and threshold current density on the cavity length are presented in Fig. 1, *c* for FIB and as-cleaved edge-emitters. One can see that these dependencies have the same tendencies for both FIB and as-cleaved lasers. A slight difference in these parameters can be attributed to a slight difference of the cavity mirrors reflectance as well as slight difference in the temperature arising due to the laser self-heating, since temperature stabilization of microlasers was not used. In the FIB-etched lasers, the threshold current reaches the minimum value of 70 mA for 125 μm cavity length of and remains below 80 mA for 75 to 125 μm cavities.

Since the lasing was observed in stripe lasers with FP cavity as short as 45 μm, the mirror losses can be estimated as 267 cm^{-1}, taking into account cavity mirror reflection coefficient 0.3. Internal losses were estimated as small as 2 cm^{-1} according to the additional studies of differential quantum efficiency in long stripe lasers made of the same epitaxial wafer. As a result, total losses in 45 μm long edge-emitter under investigation should be at least 269 cm^{-1} (note that in short stripes, internal loss is expected to be higher) that corresponds to about 45 cm^{-1} achieved modal gain per one layer of QDs at the lasing threshold. The obtained modal gain per QD layer is in good agreement with other experimental studies [4, 5].

Conclusion

To conclude, edge-emitting lasers with InGaAs/GaAs QDs with a cavity length varied from 45 μm to 510 μm were investigated. The maximum optical loss, at which lasing is still possible, was determined to be not less than 269 cm^{-1}, giving an estimated modal gain of 45 cm^{-1} per one QD layer. It should be emphasized that such high gain of the QDs used makes it possible to implement very short-stripe lasers, including those with FIB-etched mirrors, as it is suitable for the microlaser integration.

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