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Microdisk lasers with a bridge contact pad formed by wet chemical etching

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Abstract. This study presents an approach for fabricating microlasers with quantum dots on GaAs substrates, featuring a disk resonator, a bridge-type electrical contact, and a supporting mesa structure formed by wet chemical etching. The influence of under-etched ledge in the disk cavity, formed under the metal bridge, as well as the low lateral current spreading due to small electrical contact area on the cavity surface was investigated. It was found that cleaving the under-etched ledge in the disk cavity significantly reduced the threshold current leading to the possibility to continuous-wave laser operation. The low lateral current spreading associated with small metal contact on the disk surface was confirmed by the spatially resolved electroluminescence studies in the cleaved half-disk microlasers.

Keywords: microlasers, bridge contact, whispering gallery modes, wet chemical etching

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Микродисковые лазеры с мостиковой контактной площадкой, сформированной методом мокрого химического травления

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Аннотация. В работе исследованы микролазеры с квантовыми точками на подложках GaAs, состоящие из дискового резонатора, электрического контакта мостового типа и поддерживающей мезаструктуры, сформированные жидкостным химическим травлением. Изучено влияние недотравленного выступа на краю диска, образованного под металлическим мостиком, а также слабое латеральное растекание тока из-за малой площади электрического контакта на поверхности резонатора. Обнаружено, что скалывание недотравленного выступа дискового резонатора значительно снижает пороговый ток, что приводит к возможности работы лазера в непрерывном режиме. Плохое латеральное растекание тока было подтверждено исследованиями электролюминесценции с пространственным разрешением в микролазерах полудисковой геометрии.

Ключевые слова: микролазеры, мостиковый контакт, мода шепчущей галереи, мокрое химическое травление

Финансирование: Исследование было выполнено в рамках программы фундаментальных исследований НИУ ВШЭ на 2025 год.

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Introduction

Semiconductor microdisk lasers with whispering gallery modes (WGMs) and quantum dots (QDs) are promising light emitters for optoelectronic applications, ranging from optical communication systems to biomedical sensing [1]. They offer advantages such as high quality factors, low lasing thresholds, and lateral emission directionality over other microlasers [2]. Recent efforts focus on integrating these microlasers into photonic integrated circuits, requiring reliable electrical contacts. Recently, an approach of the creation of microdisk lasers supplemeted with a bridge-type electrical contact and a support mesa formed by liquid chemical etching was demonstrated [3]. The bridge structure consisted of two mesas connected by a suspended gold beam, one of which is actually a microdisk resonator, and the second one serves to create an external electrical contact. The proposed method opens the way for the fabrication of small-diameter injection microlasers, since it eliminates the need to attach an electrical wire to the upper surface of the microlaser resonator. In previous experiments, relatively high threshold currents of 2 kA/cm^2 were measured, that was attributed to the increased losses due to the formation of under-etched ledge in the disk cavity under the bridge. In the present work we investigate the factors that affect the threshold characteristics of microdisk lasers with bridge contact.

Materials and Methods

The laser heterostructure was synthesized using metal-organic vapor phase epitaxy on an n^+GaAs substrate. It included buffer, emitter, waveguide, and contact layers, with the active region consisting of 6 layers of InGaAs/GaAs QDs. Microlasers were fabricated using standard photolithography supplemented with explosive lithography for dielectric and metal layer formation. Etch depths was 23 μm with laser cavity diameter of approximately 80 μm. A TiO_2-SiO_2 dielectric provided contact pad isolation. Ohmic contacts were made by thermal evaporation and annealing with bridge contacts formed using Cr-Au deposition and gold electroplating. The slope of the resonator wall near the active region of the heterostructure is almost vertical. The image of the formed microdisk with the gold bridge and contact pad is presented in the inset to Fig. 1, *a*. A small ledge in the disk cavity is forming under the bridge.

Aiming to investigate the influence of the ledge on the microdisk emission characteristics we cleaved a facet of the original microdisk from the bridge side in order to exclude the ledge area (see image in the inset to Fig. 1, *b*). Moreover, one can see the metal pad on the disk surface has a small area (inset to Fig. 1, *a*), that can lead to the non-uniform electrical pumping of the cavity. In this case, we also cleaved a half-disk aiming to study the emission intensity distribution over the disk diameter. For measurements, samples were mounted on a copper heatsink. Individual electrical contact to the microlasers was made using a metal microprobe. The microlasers were pumped by current pulses of 500 ns duration with a repetition rate of 3 kHz. Electroluminescence spectra of microlasers were investigated using optical spectrum analyzer.

Results and Discussion

Fig. 1, *a* shows the electroluminescence spectra of the original microdisk laser with bridge electrical contact obtained at the room temperature and different injection currents. At low injection currents the electroluminescence spectra correspond to the spontaneous emission of InGaAs/GaAs quantum dots. As pumping current increases a series of narrow emission lines corresponded to the WGMs appear in the long-wavelength part of the spontaneous emission band that indicated the lasing threshold. It is also confirmed with a kink on the light-current dependence for this microlaser. The threshold current for this microdisk laser is about 80 mA, which corresponds to a threshold current density of about 1.6 kA/cm^2. It should also be noted, that lasing was achieved only under pulsed excitation.

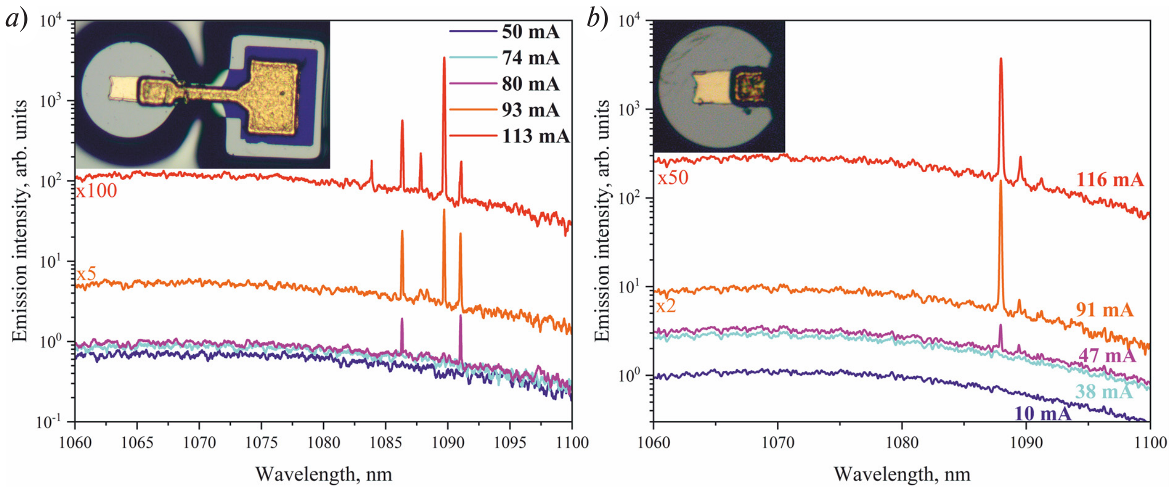

Fig. 1. Emission spectra of microlasers (initial disk (*a*), disk with cleaved facet (*b*)) measured at different injection currents
Insets in (*a*) and (*b*) show top view of microlasers

The room-temperature emission spectra of the microdisk laser with a removed under-ethched ledge via cleaving are shown in Fig. 1, *b*. The several positive peculiarities were revealed. Firstly, the threshold current for this laser became smaller that for original (Fig. 1, *a*). Thus, threshold current of about 47 mA was obtained for the laser with cleaved ledge, which is almost 2 times smaller than for the original one (Fig. 1, *a*). Secondly, the lasing spectra of microdisk with cleaved ledge show fewer WGMs than the original one. These results indicate that the presence of the under-etched ledge under the gold-bridge in the laser cavity actually reduce the cavity quality factor and degrade microlaser threshold characteristics. It should also be noted, that microlaser with the cleaved ledge was able to operate in continuous-wave (CW) regime with a threshold current of about 65 mA. A higher threshold current for CW regime compared to pulsed one is attributed to the increase laser temperature due to the self-heating.

A second limitation arises from the small metal contact that covers only a fraction of the disk top surface, leading to non-uniform lateral current spreading [4]. To visualize this effect, we cleaved a microlaser through its center to form a half-disk and monitored spontaneous emission in different points of its facet. Fig. 2 compares spectra collected at the disk center (point 1) directly beneath the contact and (points 2 and 3) at two peripheral points (see inset to Fig. 2). The emission intensity decays markedly away from the electrical contact, confirming low current spreading outside the electrical contact. Moreover, a redshift of the spontaneous emission band was also observed moving from the disk cavity center to its periphery that is associated with a lower pumping, i.e., a lower carrier concentration in the active region. Thus, an increase in the area of the metal contact should also lead to a significant decrease in the threshold characteristics as well.

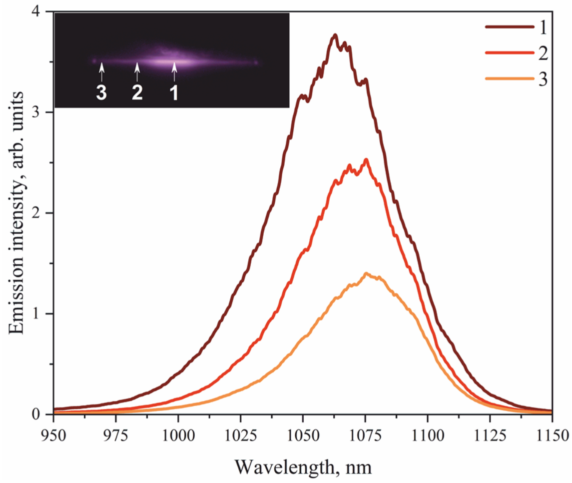

Fig. 2. Emission spectra measured at different points of the half-disk facet at the 10 mA injection current
Inset shows the distribution of the emission intensity over the half-disk edge

Conclusion

The QD microdisk lasers with a bridge electrical contact formed with wet chemical etching are investigated. It was found that removing the under-etched ledge in the disk cavity significantly reduced the threshold current leading to the possibility to CW laser operation. A non-uniform carrier distribution under small-area top contact was revealed. Thus, the direction of optimization of the microlaser design was determined.

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