Electrically pumped microdisk lasers with semitransparent conducting pyrolytic carbon film

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Abstract. Electrically driven microdisk lasers with top contacts made of a semitransparent conducting pyrolytic carbon film are developed. Electrical properties of the pyrolytic carbon contact to a *p*-type doped GaAs epitaxial layer are studied. Room temperature electroluminescence spectra from an array of the microdisk lasers and a single 27 μm in diameter microdisk laser are demonstrated.

1. Introduction

Last decade the essential efforts were aimed at the miniaturization of semiconductor lasers. Recently, whispering gallery mode (WGM) semiconductor microlasers based on ring/disk cavities with low threshold (2 uW) [1] and high, up to $7x10^5$, quality factor (Q) [2] have been demonstrated. The lasing operation at 100°C of microring laser as small as 2 μm under optical pumping has been recently reported [1]; room temperature lasing was reported in 1.16 μm GaInAsP microdisk laser [3] and in 1μm InAs/GaInAs quantum dot (QD) microdisk laser [4]. At the same time, the smallest reported diameter of the microdisk laser with current injection operating at room temperature is 6.5 μm [5]. Further reduction of the injection microdisk laser size requires electron beam lithography, planarization stage or air-bridge technology to form an electrical contact to upper (typically, *p*-doped) layers. In this work we study a possibility to use the pyrolytic carbon (PyC) film to make an electric contact to a *p*-doped GaAs cap layer. Room temperature electroluminescence spectra of the microdisk lasers with diameters 15-30 μm, which are electrically pumped through the semitransparent PyC layer, are demonstrated.

2. Experiment

Epitaxial structures were grown with molecular beam epitaxy on an n+ GaAs(100) substrate. Ten layers of InAs/$In_{0.15}Ga_{0.85}As$ QDs were deposited in the middle of a 0.44 μm thick GaAs waveguiding layer confined with $Al_{0.25}Ga_{0.75}As$ claddings. Microdisk resonators with diameters of 15…30 μm were formed by means of chemical plasma etching. Etch depth was about 7μm. AgMn/NiAu (AuGe/Ni/Au) metallization was used to form ohmic contacts to p+ GaAs cap layer (n+ substrate, respectively). A

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schematic illustration of the injection microdisk laser structure is shown in Figure 1. 20-nm PyC film was synthesized using chemical vapor deposition on quartz substrate using CH_4:H_2 gas mixture and then transferred onto PMMA layer. PyC film transmittance was about 50% at $\lambda = 1.3$ µm. To make an electrode to the *p*-type contact, the PyC film was attached to the top of an array of the microdisk lasers. Owing to mechanical strength the film did not show any sagging. Current was injected through the PyC film to the array of the microdisk lasers using a copper tape. Schematic of the microdisk lasers with PyC contact is shown in figure 2. Needle-shaped metal probe was used for current pumping a single microdisk. Lasers were mounted on a copper heatsink and tested at room temperature without external cooling. Emitted light was collected with a piezoelectrically adjustable x10 Mitutoyo MPlan NIR objective.

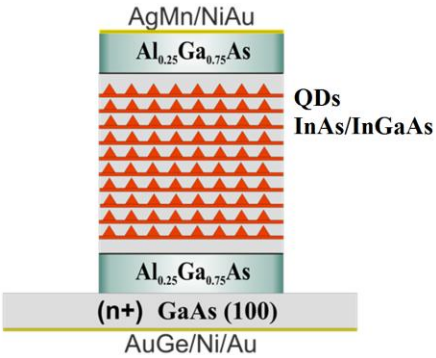

Figure 1. Schematics of the injection microdisk laser epitaxial structure.

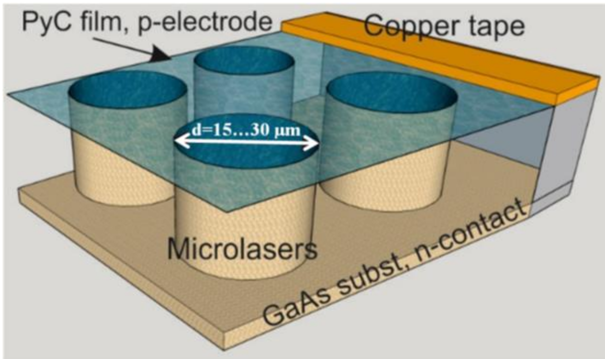

Figure 2. Schematic illustration of the array of microdisk lasers with top PyC electrode.

3. Results

The microlasers demonstrate well pronounced turn-on behavior of current-voltage characteristic with opening voltage under forward bias of U_0 ~1 V and series resistance R_S =1kOhm (fig.3). Figure 4 shows electroluminescence spectra of the microdisk array with diameters of 15-30 µm recorded at different currents. The emission spectrum has a form typical for spontaneous emission of self-organized InAs/InGaAs QDs with the ground-state peak located at 1.26 µm (@ 1 mA). We did not obtain any WGM lasing because all lasers in tha array were excited simultaneously via semitransparent . With increasing pump current, the electroluminescence maxima demonstrates red shifts 0.8nm/mA caused by the heating of the structure. From this shift we can estimate the structure overheating to be 60°C at 15mA, which is nearly the same as was obtained for a single microlaser without the PyC film.

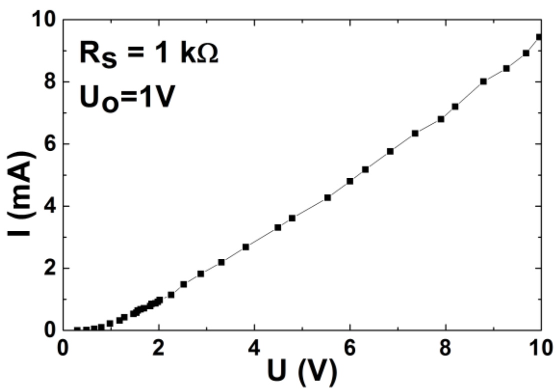

Figure 3. Current–voltage characteristics of the microlasers with PyC electrode.

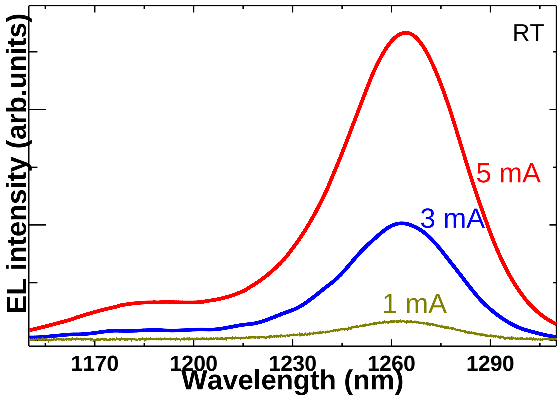

Figure 4. Room temperature electroluminescence from an array of the microdisk lasers with PyC electrode.

Needle-shaped metal probe was used to pump a single microdisk with diameter D = 27 µm (a video camera image is shown in inset to figure 6). Electroluminescence spectra of this microdisk obtained at room temperature with PyC film and without PyC film are compared in figure 5. The emission intensity of the microdisk with PyC film is approximately 35% of that without the PyC film in the whole spectral range. We attribute the losses to the absorption and reflection of the PyC film. The sharp lines observed in the spectra correspond to WGMs of the disk microcavity. Lasing in the PyC-capped microlaser was observed at the same resonance line of 1266 nm as before PyC film placing. Figure 6 shows a dependence of integral intensity of the resonant line on pump current. The threshold current is 5.5 mA in both cases.

To conclude, we demonstrate room temperature lasing of the 27 µm quantum dot microdisk laser with top contact made of a semitransparent conducting pyrolytic carbon film. Electrical properties of the contact between PyC film and p-type doped GaAs epitaxial layer are studied. Room temperature electroluminescence spectra from the array of the microdisk lasers and a single microdisk laser with D = 27 µm are demonstrated.

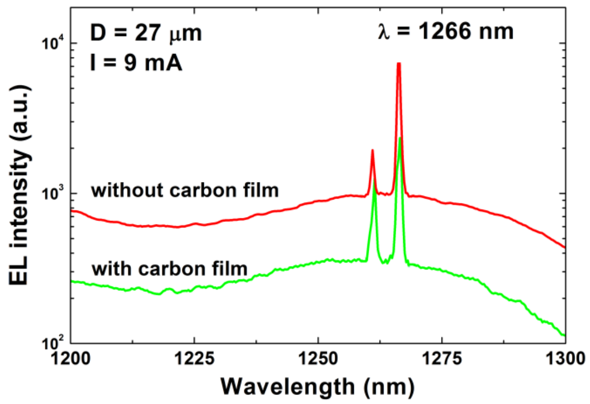

Figure 5. Electroluminescence spectra of the microdisk laser with D = 27 µm obtained at room temperature.

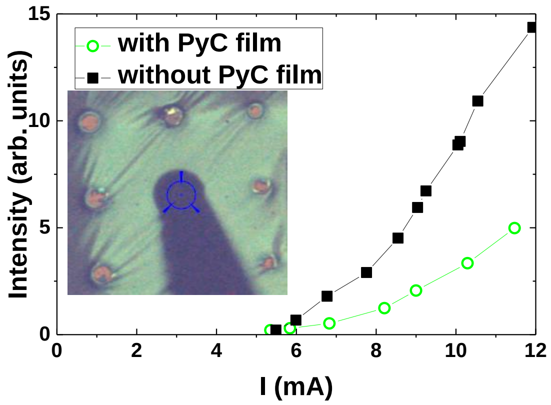

Figure 6. Integrated intensity of the WGM line (λ = 1266 nm) as a functions of the pump current. Inset shows the camera-image of the single microdisk with the needle probe used for electric pumping.

Acknowledgments
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References

[1] Maximov M V, Kryzhanovskay N V, Nadtochiy A M, Moiseev E I, Shostak I I, Bogdanov A A, Sadrieva Z F, Zhukov A E, Lipovskii A A, Karpov D V, Laukkanen J and Tommila J 2014 *Nanoscale Research Lett*. **9** 657.

[2] C.P.Michael, K.Srinivasan, T.J.Johson, O.Painter, K.H. Lewe, K.henessy, H.Kim, E.Hu, *Appl.Phys. Lett*. 90, 051108 (2007).

[3] R.Perahia, T.P.Mayer Alegre, A.H.Savafi-Naeini, O.Painter, *Appl.Phys. Lett,* 95, 201114 (2009).

[4] N.V. Kryzhanovskaya, A.E. Zhukov, M.V. Maximov, E.I. Moiseev, I.I. Shostak, A. M. Nadtochiy, Yu.V. Kudashova, A.A. Lipovskii, M.M. Kulagina, S.I. Troshkov, *IEEE JSTQE*, 21, 1-5 (2015).

[5] Mao M-H, Chien H-C, Hong J-Z and Cheng C-Y 2011 *Opt. Exp.* **19** 14145.

[6] T.Kaplas, Yu.Svirko, *Journal of Nanophotonics*, **6**, 061703, 2012.