# Investigation of the effect of surface passivation on microdisk lasers based on InGaAsN/GaAs quantum well active region

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**Abstract.** Microdisk lasers based on three InGaAsN/GaAs quantum wells with different types of surface passivation are fabricated and studied under optical pumping. Room temperature lasing at 1.3 µm in 7 µm in diameter microdisks with InGaAsN/GaAs QW is demonstrated. We evaluated the thermal resistance as 1 $^{o}$C/mW.

## 1. Introduction

Semiconductors microdisk and microring lasers have been widely investigated as possible building blocks for photonic integrated circuits [1]. The circular symmetry of the cavity results in unique advantages such as low threshold, small foot-print, small mode volume, in-plane emission, control of emission wavelength by the device size, etc. The use of quantum dots (QDs) as active region in such lasers have the advantages of low threshold, high quantum efficiency, and high thermal stability of characteristics [2]. However since the ground state QDs optical gain is limited due to the finite number of the QDs the decrease of the resonator diameter below a certain value (typically several microns) results in lasing via excited states of QDs. Quantum well (QW) active region provides higher gain as compared to QDs. Thus, the use of QW active region may help to overcome the problem of gain saturation when the laser`s size is scaled down. As device dimensions decrease, the recombination of carriers at the semiconductor surface becomes increasingly important [3]. GaAs-based materials are especially prone to nonradiative recombination at unpassivated surfaces. Sulfide treatment of the GaAs surface, as well as other III–V semiconductors, has been demonstrated as an effective method for reducing the surface recombination rate [4]. In this work we have studied microdisk lasers based on InGaAsN/GaAsN QW active region with different types of surface passivation.

## 2. Experiment and results

Epitaxial structures were grown with molecular beam epitaxy on GaAs(100) substrate. Three $Ga_{0.7}In_{0.3}N_{0.02}As_{0.98}$ QWs were separated with 10-nm-thick GaAs layers and have ground-state emission peak around 1.2 µm at room temperature. The active region was placed in the middle of the GaAs layer confined from both sides with 10 nm thick $Al_{0.3}Ga_{0.7}As$ barriers to prevent carrier leakage.

The total thickness of the waveguide layer was about 230 nm. This waveguide layer was grown on top of the 1 µm thick $Al_{0.8}Ga_{0.2}As$ layer that later formed a pedestal of the microdisks. Microdisks were fabricated using photolithography and two step wet etching. A circular mesa was formed by etching in $HBr:K_2Cr_2O_7:CH_3COOH$ solution. The pedestal was formed using diluted HF. The structures were investigated under different optical excitation powers using Nd:YLF laser ($\lambda = 527$ nm) . The samples were mounted in a flow cryostat Janis ST-500, the temperature was varied from 78 to 300K. Microphotoluminescence signal (µPL) was measured by an Optical Spectrum Analyzer AQ6370. The microdisks were passivated to suppress surface non-radiative recombination at microdisk sidewalls. The passivation was performed with aqueous or hydroalcoholic solution of $Na_2S$ or benzene solution $SeS_2$ during different holding time (4 min, 10 min, 20 min) and then, the mesas were washed in water (in benzene for $SeS_2$ solution) and dried in nitrogen. To achieve a good stability of the operation after treatment in sulfur solution, the microdisks were encapsulated with a thin (the thickness was approximately 30 nm) SiN layer deposited by PECVD.

Optical properties of the GaInNAs/GaAs QW were investigated using an unprocessed sample in the temperature range of 78–300 K under excitation of 0.37 mW. We observe a moderate decrease (by 13.7 times) in GaInNAs/GaAs QWs integrated photoluminescence intensity as temperature increases in this temperature interval evidencing high optical quality of the GaInNAs/GaAs QWs (figure 1). Temperature dependence of the PL peak maximum and full width at half maximum (FWHM) are shown in figure 2. At low temperature (78K), FWHM of the spectrum is ~17 meV, revealing reasonable homogeneity of the GaInNAs/GaAs QW thickness and composition. FWHM monotonically increases up to 26 meV as temperature grows to 293K. The ground-state emission peak is around 1.024 eV at room temperature.

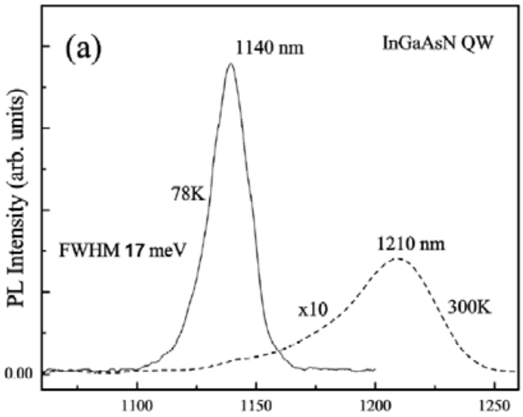

**Figure 1.** µPL spectra of the unprocessed sample with GaInNAs/GaAs QWs obtained at 78K and 300 K.

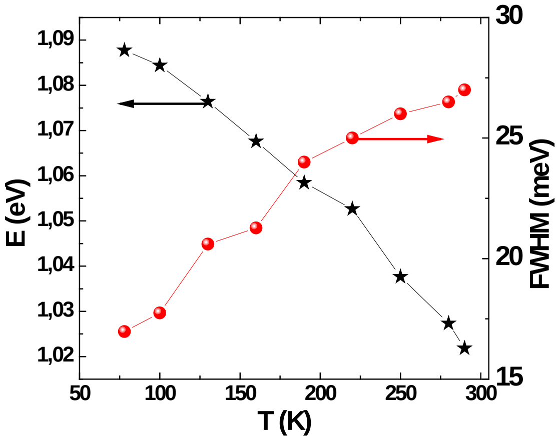

**Figure 2.** Temperature dependence of PL peak maximum and FWHM of GaInNAs/GaAs QW.

Microlasers with a diameter of 7 µm without passivation demonstrated lasing only up to 170 K. A scanning electron micrograph of a 7 µm in diameter microdisk laser is shown in the inset in figure 3. Passivation significantly improves maximal operation temperature and threshold. The highest operation temperature and the smallest threshold were obtained for passivation in hydroalcoholic $Na_2S$ solution. The µPL spectra at RT of the 7 µm in diameter microdisk after passivation in this type of $Na_2S$ solution is shown in figure 3. Sharp lines at the spectra correspond to high quality whispering gallery modes. Lasing threshold was determined from the dependence of the output intensity versus input optical pumping power for the lasing mode. The temperature dependence of the threshold pump power (figure 4) can be approximated by exponential relationship with characteristic temperature $T_0 = 60$ K. Passivation in $SeS_2$ solution showed significantly higher threshold as compared to passivation in $Na_2S$. We evaluated the thermal resistance for the passivated structures as 1 $^{o}$C/mW. A similar value was obtained in [5]. A low thermal resistance can increase the current at which thermal rollover begins and thus, enhance maximal output power.

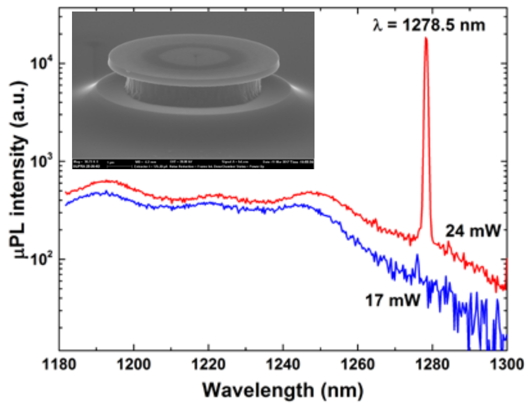

**Figure 3.** µPL spectra of a 7 µm in diameter microdisk laser at RT. Inset: SEM image of the microdisk laser.

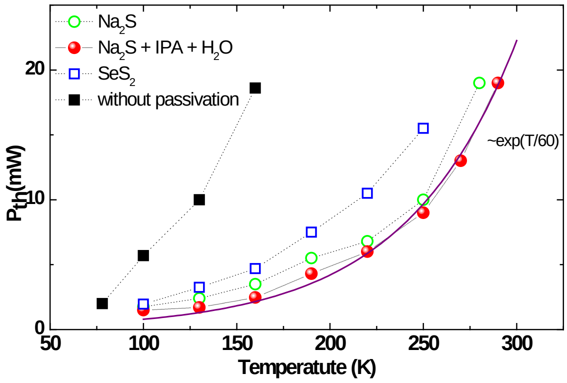

**Figure 4.** Temperature dependence of threshold pump power in case of different types of surface passivation.

**Acknowledgments**
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