# Room temperature lasing in injection microdisks with InGaAsN/GaAs quantum well active region

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**Abstract.** Injection microdisk lasers based on three InGaAsN/GaAs quantum wells with different diameters of the resonator were fabricated and studied. Room temperature lasing at 1.2 μm is demonstrated for the first time. Dependence of the threshold current on the diameter is discussed.

## 1. Introduction

As the level of integration of electronic chips increases, the number of integrated transistors per unit area becomes increasingly large, and electrical interconnection technologies using electrons as signal transmission carriers face serious challenges [1, 2]. For these reasons, many researchers have turned their attention to optoelectronic devices. Microdisk (MD) lasers are prospective candidates as laser sources for optoelectronic circuits since high quality factors can be achieved even in resonators of a few micrometers in diameter [3,4] at a low lasing threshold. MD lasers have a smaller footprint, lower power consumption, and better high-speed modulation characteristics, as compared with Fabry–Pérot cavity lasers [5]. Moreover, semiconductor MDs attract widespread attention due to their unique fundamental properties, as well as exploitability as ultrasmall modulators, detectors, and sensors. Using quantum dots (QDs) as the active region in such lasers have advantages of low threshold and high thermal stability of characteristics [6]. However, the optical gain of the ground-state optical transition, which can be achieved with QDs, is limited due to finite number of the QDs. This may lead to lasing via the excited states of the QDs or completely prevent lasing. The quantum well (QW) active region provides a higher gain compare to the QDs. Thus the use of QWs may help to work out the problem of gain saturation when the laser`s size are scaled down. Meanwhile, the wavelength of InGaAs QWs is limited to about 1.1 μm. Longer wavelengths, which are more preferable for optical interconnect, can be achieved with nitrogen-containing QWs. Previously, we have demonstrated InGaAsN injection MD lasers capable of lasing up to 170K [7]. In the present work, room temperature operation of such microlasers is demonstrated for the first time.

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## 2. Experiment

The structures studied were grown by molecular beam epitaxy on GaAs (100) substrate. The structure consists of a GaAs waveguide with three $Ga_{0.7}In_{0.3}N_{0.02}As_{0.98}$ QWs separated with 10-nm-thick GaAs layers and have ground-state emission peak around 1.2 µm at room temperature. The thickness of the waveguide with the QW active region is 400 nm, the thickness of $Al_{0.25}Ga_{0.75}As$ cladding layers with gradient doping was 2 µm on both sides of the active region. The structure represents a semiconductor p-i-n diode, with the p-side on top, and the substrate as the n-side. A sketch of the layers sequence is shown in figure 1. The microdisks with a diameter of the resonators ranging from 11 to 31 µm were formed by means of photolithography and chemical plasma etching. SEM image of the MD array is shown in figure 2. The etching depth was about 4 µm. AgMn/NiAu (AuGe/Ni/Au) metallization was used to form ohmic contacts to the p+ GaAs cap layer and the n+ substrate, respectively. The structures were investigated under pulse injection pumping at room temperature. Electroluminescence was excited with 0.05-µs-long injection pulses with 10 kHz repetition rate. Injection current was limited to 300 mA. A piezoelectrically adjustable objective (Olympus LMPlan IR objective ×10 with NA = 0.25) was used to collect the microelectroluminescence signal (µEL) from the microlasers. The collected µEL was then analyzed with a 1000 mm monochromator Horiba FHR coupled with a cooled InGaAs CCD array.

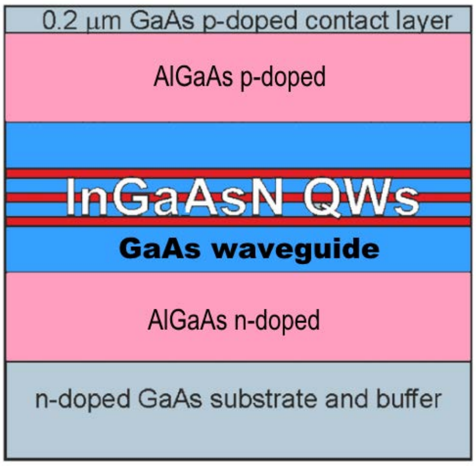


**Figure 1.** Schematic illustration of the heterostructure layers sequence.

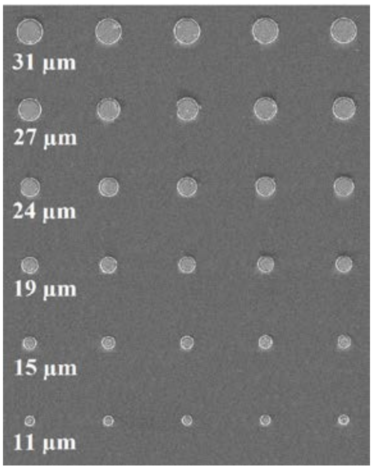


**Figure 2.** SEM image of the MD array.

## 3. Results

At low injection currents, a broad spontaneous emission is observed (figure 3). The ground-state peak is centered around 1.2 µm with full width at half maximum of more than 60 nm. µEL spectra were obtained for all investigated diameters. The spectra of the microdisk laser with diameter D=11 µm at different pump current are shown in Figure 4. The narrow lines corresponding to whispering gallery modes (WGM) of the resonator is observed on the long-wavelength side of the InGaAsN QWs spectra for all the lasers. FWHM (Δλ) was 0.05 nm. The Q-factor was estimated as λ/Δλ to be 24’000.

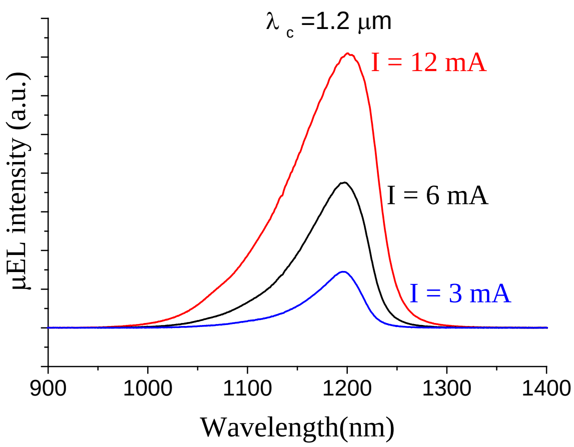


**Figure 3.** Emission spectra obtained at 300 K at different pump current.

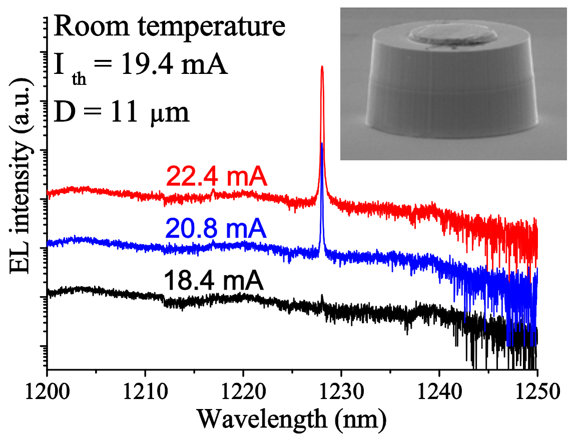


**Figure 4.** The spectra of the microdisk laser (D=11 μm) at different pump current. The spectra are shifted in the vertical direction for clarity. *Inset: SEM image of the microdisk laser.*

Figure 5 shows the dependence of the integrated emission intensities of the lasing WGM line at room temperature on the pump current for the microdisks of different diameters. The threshold current is 19.4 and 65 mA for microlasers with diameters of 11 and 27 μm, respectively.

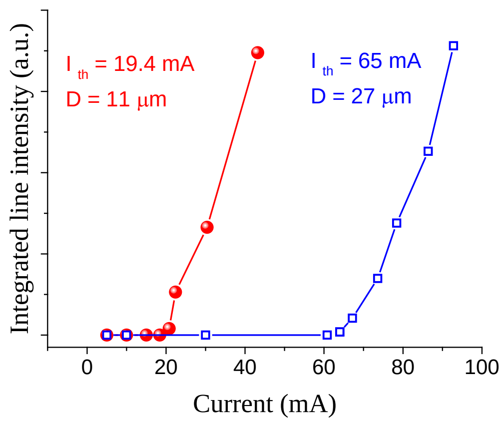


**Figure 5.** Current dependence of integrated line intensity for 11 μm and 27μm in diameter MDs.

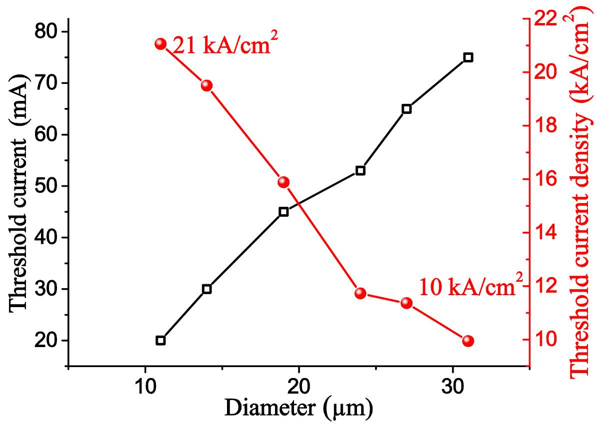


**Figure 6.** Threshold current (solid symbols) and threshold current density (open symbols) as a function of MD diameter.

The threshold current density $J_{th}$ was estimated for all diameters of resonator (figure 6). When the diameter of MDs decreases from 31 to 10.5 μm, the minimal value of $J_{th}$ grows from 11 kA/cm$^{-2}$ up to 21 kA/cm$^{-2}$. The growth of $J_{th}$ with a decrease in D for MD lasers is probably caused by non-radiative recombination at the MD sidewalls. The surface passivation procedure will be probably helpful to reduce the threshold current.

To the best of our knowledge, this is the first demonstration of room-temperature lasing in N-containing microdisk lasers under injection excitation.

**Acknowledgments**
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