

## Compact microdisk cavity laser with GaInNAs/GaAs quantum well

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**Abstract.** Optically pumped 3-6 $\mu\text{m}$  in diameters microdisk lasers with InGaAsN/GaAs quantum well active region has been studied. Single-mode CW lasing at 78K temperature in microdisk laser with 3  $\mu\text{m}$  diameter is demonstrated.

### Introduction

Since the first demonstration of the semiconductor microdisk laser in the early 1990s [1] a large number of papers devoted to this type of light sources, reporting various active regions, have been published. Most of the results were demonstrated on (GaInAsP)/InP microdisk/microring lasers including successful transfer to the Si substrate using wafer bonding technology [2]. The main advantage of the InP-based material system is its low surface recombination rate which is highly desirable in case of compact microdisk cavity with sidewalls etched through the active region. Alternatively, quantum dots have also emerged as capable of providing suppression of the surface recombination at the disk sidewall even for AlGaInAs-based laser materials, owing to suppression of the carrier diffusion. Moreover, microlasers with InAs/InGaAs quantum dots have demonstrated high temperature stability of the operation parameters with the maximal operation temperature of 107°C under optical pump [3] and 100°C in injection structures [4]. However, quantum dot-based lasers suffer from the saturation of the ground state gain due to the finite numbers of the quantum dots. To overcome the problem of the gain saturation and still take advantages of GaAs-based materials (such as larger band offsets, high refractive index contrast and better thermal conductivity) we propose in this work to use InGaAsN/GaAs quantum well as an active region in microdisk lasers. High-performance InGaAsN quantum well edge-emitting lasers have been realized by both metalorganic chemical vapor deposition and molecular beam epitaxy [5-9] enabling lasing in a broad spectral range from 1.1  $\mu\text{m}$  to 1.6  $\mu\text{m}$ .

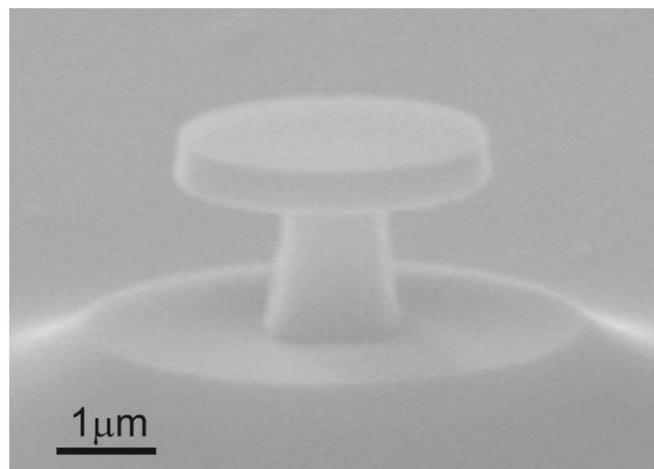
In this paper we demonstrate compact microdisk laser with novel active region based on an InGaAsN/GaAs quantum well. Lasing characteristics of the microdisk lasers with 3-6 $\mu\text{m}$  diameters are studied at different temperatures (78-300 K). We present single-mode CW lasing at 78K temperature in such microdisk laser with 3  $\mu\text{m}$  diameter.



## Experiment

The epitaxial structure was grown by molecular-beam epitaxy on  $n^+$ -doped GaAs(100) substrate. Three layers of InGaAsN quantum wells (QWs) separated with 10-nm-thick GaAs layers were grown as an active region. This QW material has a ground-state emission peak around 1.2  $\mu\text{m}$  at room temperature. The active region was inserted within a 0.2- $\mu\text{m}$  thick GaAs waveguide layer confined by 10-nm-thick  $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$  barriers. A 1- $\mu\text{m}$ -thick  $\text{Al}_{0.8}\text{Ga}_{0.2}\text{As}$  cladding layer was grown beneath the waveguide layer serving as a support pedestal for the microdisk. Microdisks were defined by photolithography and subsequent circular mesa etching in the etching solution, based on a  $\text{K}_2\text{Cr}_2\text{O}_7/\text{HBr}$  composition through the waveguide layer and the  $\text{Al}_{0.8}\text{Ga}_{0.2}\text{As}$  cladding layer. The outer diameter was varied in different structures from  $D=3$   $\mu\text{m}$  to 6  $\mu\text{m}$ . Next, anisotropic HF etching was used to etch  $\text{Al}_{0.8}\text{Ga}_{0.2}\text{As}$  layer and to form a desired diameter of the pedestal underneath the GaAs disk.

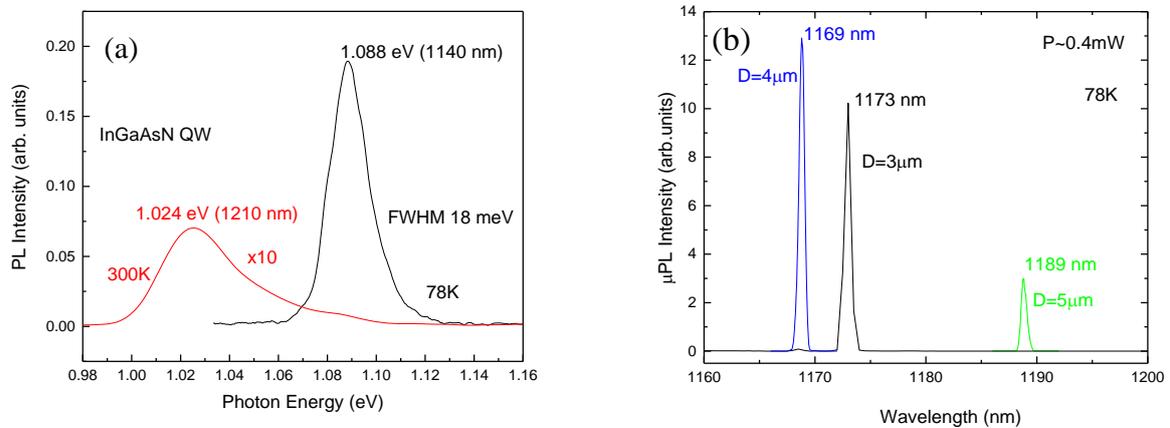
For optical investigations, a CW-operating YAG:Nd laser ( $\lambda = 532\text{nm}$ ) was used. For low temperature measurements the samples were mounted in a flow cryostat. A piezoelectrically adjustable Olympus LMPlan IR objective x10 used to focus the incident laser beam to pump the microresonator homogeneously and to collect micro-photoluminescence ( $\mu\text{PL}$ ) signal from a microresonator. The collected  $\mu\text{PL}$  was then dispersed via a 1000-mm monochromator Horiba FHR and measured by a cooled InGaAs single-channel detector. The overall spectral resolution was 0.1 nm for 900 l/mm grating. Scanning electron micrograph (SEM) of the 3  $\mu\text{m}$  diameter microdisk laser is shown in figure 1.



**Figure 1.** SEM images of the microdisk laser with GaInNAs/GaAs quantum wells active region.

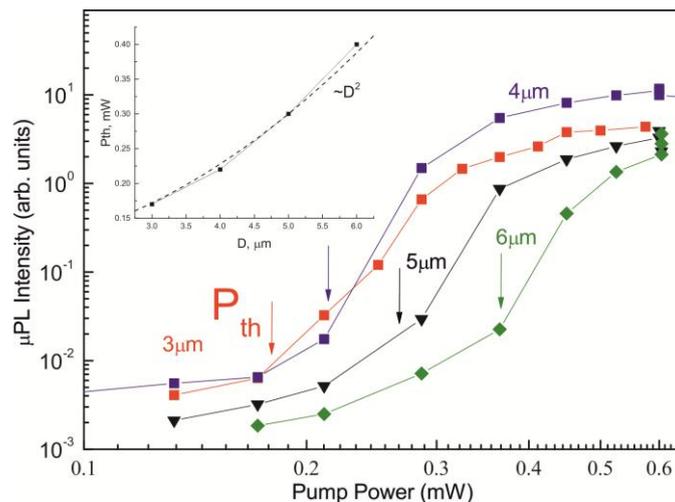
## Results

Optical properties of the QW media were first investigated in an unprocessed (as-grown) sample in the temperature range 78-300 K under low excitation density ( $200 \text{ mW}/\text{cm}^2$ ). We observe insignificant decrease (by  $\sim 8$  times) of QW photoluminescence intensity as temperature increases from 78 to 300 K evidencing high optical quality of the InGaAsN/GaAs QWs (figure 2, a). At low temperature (78K) full-width at half maximum (FWHM) of the spectrum is  $\sim 18 \text{ meV}$  revealing reasonable homogeneity of the QW thickness and composition. Temperature dependence of FWHM demonstrates a monotonic increase to  $30 \text{ meV}$  at 300 K.



**Figure 2 .** Photoluminescence spectra of the unprocessed GaInNAs/GaAs QWs obtained at 78K and 300K (a) and microphotoluminescence spectra of the microdisks based on GaInNAs/GaAs QWs obtained at 78K with 3, 4 and 5  $\mu\text{m}$  cavity diameters (b).

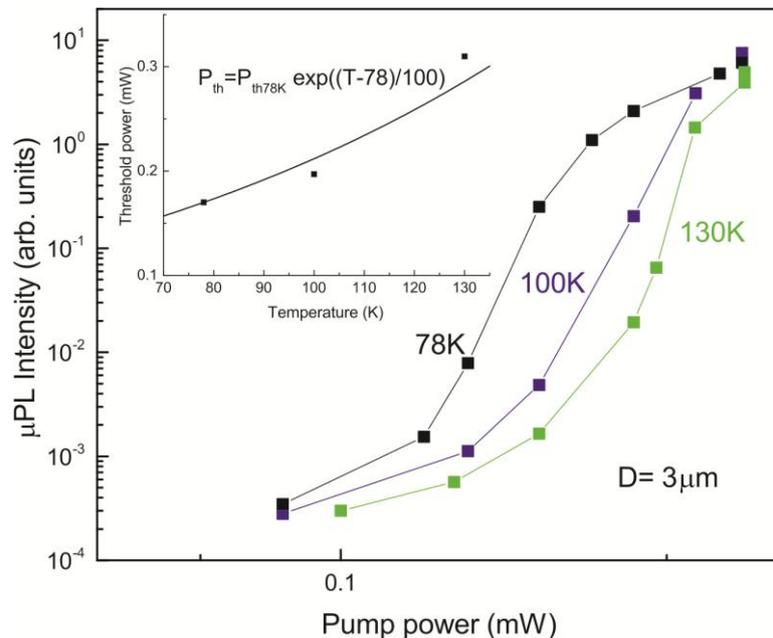
Emission spectra taken at 78 K for the microdisks of different diameter (3...6  $\mu\text{m}$ ) are shown in figure 2, b. A single narrow line corresponding to the one of the whispering gallery mode of the resonator is observed on the long-wavelength side of the QW spectra for all the structures. The output intensity-input pump curves (L-L curves) for these lines are shown in figure 3. Each curve has a pronounced kink indicating the lasing threshold of the microdisk (marked by arrows). The smallest threshold pump power at 78K is 0.17 mW in a microlaser with diameter of 3  $\mu\text{m}$ . Threshold pump power is scaled as  $D^{-2}$  vs diameter of the microlasers. This indicates that the threshold power density remains nearly constant and, hence, no significant growth of optical loss and/or non-radiative recombination takes place with decreasing the disk diameter (see inset in figure 3). The emission is TE-polarized and has narrow far-field diagram in vertical direction.



**Figure 3.** Plot of the WGM mode intensity against excitation power for the microdisks of 3-6  $\mu\text{m}$  cavity diameters. Inset: the threshold pump power against microdisk diameter.

Next, we studied temperature dependence of the lasing threshold for 3  $\mu\text{m}$  in diameter microdisk laser. The threshold power increases from 0.17 to 0.3 mW in the 78-130 K interval. Further increase of

the temperature or pump power results in overheating of the microdisk laser. The temperature dependence of the lasing threshold can be described by fitting the experimental points with  $T_0=100$  K. Such a high threshold characteristic temperature indicates high thermal stability of the microdisk laser based on GaInNAs/GaAs QW active region. Evidently, surface passivation should be applied for further improvement of the laser characteristics.



**Figure 4.** The L-L curves of the 3 $\mu$ m microdisk laser obtained at different temperatures. Insert: the measured threshold power versus operating temperature.

In summary, GaInNAs/GaAs quantum well microdisk lasers with 3-6 $\mu$ m diameter were studied. The lasing at 1173 nm wavelength with a low threshold (170 $\mu$ W) was achieved in 3  $\mu$ m in diameter microdisk at 78K. The lasing was observed up to 130K. Passivation of the surface is required to increase the operation temperature.

### Acknowledgments

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