Microdisk lasers based on GaInNAsSb/GaAsN quantum well active region

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Abstract. Microdisk lasers based on novel InGaAsNSb/GaAsN quantum well active region are developed and studied under optical pumping. Room temperature lasing at 1.55 µm in 2.3 µm in diameter microdisks with InGaAsNSb/GaAsN QW is demonstrated.

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. [2]. 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 [3]. However since the ground state QDs optical gain is limited due to the finite number of the QDs the decrease of the resonator diameter to a limiting value results in lasing via excited states of QDs. Quantum well (QW) active region provides higher gain compare to QDs. Thus the use of QW active region may help to work out the problem of gain saturation when the laser’s size are scaled down. In this work we have studied microdisk lasers based on single diluted InGaAsNSb/GaAs(N) QW active region.

The anomalous reduction in both bandgap and lattice constant of GaAs, with the introduction of dilute amounts of nitrogen was reported in work [4]. In 1996, Kondow et al. [5] recognized that introducing appropriate amounts of nitrogen and indium into GaAs shifts the emission wavelength to the technologically important 1.3 µm regime. Growth of GaInNAs-based lasers emitting at 1.55 µm proved much more difficult, since it was usually observed that the incorporation of nitrogen deteriorates the optical properties due to ion damage [6, 7], nonradiative traps [8, 9], and phase separation [10, 11]. Yang and coworkers found that adding antimony as a surfactant during GaInNAs growth improved morphology and device performance, and allowed longer wavelength devices [12]. This is due to the reactive surfactant properties of antimony, which reduce the group III surface diffusion length suppressing phase segregation and roughening and thereby improving alloy

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homogeneity [13]. CW laser operation is demonstrated in GaInNAsSb/GaAs lasers at room temperature [14,15] and at temperatures up to 80°C with $T_0 = 70K$ [16]. Compared with an InGaAsP/InP system, GaInNAsSb/GaAs has a larger conduction-band offset which leads to a higher characteristic temperature [17].

We investigated the microdisk lasers at different temperatures (78-300 K). The single-mode lasing at room temperature in microdisk laser based on GaInNAsSb/GaAsN quantum well active region with diameter 2.3 $\mu$m is demonstrated.

2. Experiment

The epitaxial structure with InGaAsNSb/GaAsN QW was grown by MOCVD on n-doped GaAs substrate. The active region comprises InGaAsNSb QW inserted in the GaAsN strain compensating layers. The active region was placed in the middle of the GaAs waveguide confined from both sides with 10 nm thick Al$_{0.3}$Ga$_{0.7}$As barriers to prevent carrier leakage. Total thickness of the waveguide layer was 240 nm. This waveguide layer was grown on the top of the 1500-nm-thick Al$_x$Ga$_{1-x}$As layer that later forming a pedestal of the microdisks ($x=0.7-0.8$). Microdisks of different diameters from 2.3 $\mu$m to 7 $\mu$m were fabricated using photolithography and two step wet etching. The structures were investigated under optical pumping with YAG: Nd laser ($\lambda = 532$nm).

Figure 1. $\mu$PL spectra of a single GaInNAsSb/GaAs(N) QW at 78K and at room-temperature.

Figure 2. Temperature dependence of integrated PL intensity and FWHM of spectra GaInNAsSb/GaAs(N) QW

3. Results

The microphotoluminescence ($\mu$PL) spectra of the lasers were studied in a temperature range from 78 K to 300 K. The $\mu$PL spectra at different excitation power of unprocessed sample with single GaInNAsSb/GaAsN QW obtained at 78K and room temperature are shown at figure 1. The wavelength of PL spectra maximum is 1.52 $\mu$m at room temperature and 1.42 $\mu$m at 78K. Increase of the temperature result in intensity drop only in 15 times revealing low non-radiative recombination in the epitaxial structure. The dependence of integrated $\mu$PL intensity and full width at half maximum (FWHM) on the temperature are shown at figure 2. At the temperature 78K the FWHM is 25 meV that reveals good homogeneity of the GaInNAsSb/GaAsN layers composition and thickness.

The $\mu$PL spectrum of the microdisk with diameter $D = 2.3$ $\mu$m obtained at 78 K is shown at fig.3. Scanning electron micrograph of the microdisk laser is shown in insert in fig.3. Sharp line observed at the spectra corresponds to high quality whispering-gallery (WG) mode. Lasing was observed for dominant resonance line at 1.47 $\mu$m. In fig. 4 shows the dependence of integrated intensity and FWHM of the resonant line for 2.3 $\mu$m microdisk on the pump power. The threshold pump power is 220 $\mu$W. The FWHM of the 1.47 $\mu$m line near the threshold is 30 pm and is limited by the resolution of the measurement system. We can estimate the quality factor (obtained from $\lambda/\Delta\lambda$) to be...
more than $4 \times 10^4$. Free spectral range (FSR) and threshold power as a function of the microdisk diameter are shown at Fig.5. Decrease of the resonator diameter from 7 µm to 2.3 µm results in increase of the resonator FSR from 26 nm to 80 nm. The obtained values agree very well with theoretically predicted dependence $\text{FSR} \sim \lambda^2/(n_{\text{eff}}^2(2\pi R))$. Reducing the diameter of the resonator leads to a decrease of the threshold power proportionally to the squared diameter of the microdisk.

The lasing on WG mode of the resonator was observed in temperature range from 78 K to room-temperature. The Fig.6 shows temperature dependence of the threshold power of the microdisk laser. The µPL spectra of the microdisk with diameter $D = 2.3$ µm at different pump powers obtained at room-temperature are shown in insert in Fig.6. The threshold pump power is 0.5 mW.

To conclude, microdisk lasers with novel active region based on GaInNAsSb/GaAsN QW were investigated in a temperature range 78-300K. Room temperature single-mode lasing in microdisk laser with diameter 2.3 µm is demonstrated.
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