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# Whispering Gallery Mode Emission of Low Density InP/GaInP Quantum Dots

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**Abstract.** GaInP microdisks contained InP/GaInP quantum dots having lateral size ~150 nm and 1-5 $\mu m^{-2}$ were investigated with help of microphotoluminescence technique. Experiments carried out in confocal, time-resolved and low-temperature modes. Comparison of results allowed to conclude that overlap of quantum dot emission area with whispering gallery mode antinode results in faster luminescence lifetime (Purcell effect). Whispering gallery mode lasing was detected. Obtained threshold power values were following 6 μW (Q=4500, T=8.5 K) and 0.4 μW (Q=7400, T=80 K).

## INTRODUCTION

Since an observation of whispering gallery modes (WGM) in semiconductor microdisks [1] by McCall et al this cavity system considered as interesting and attractive object for investigations because of its unique properties. The most works in this area are devoted to microdisks (MDs) with active area based on different type of nanostructures which allows to observe lasing in whole range of visible light [2-4], together with low threshold values [5, 6]. In many works it is emphasized that in a MDs study it is important to take into account microcavity features such as mode distribution, mode coupling and photonic state modification [7]. In several works spontaneous emission modification was observed [8], thus possibility of MD using for single photon sources was discussed [9]. But for such quantum cavity electro-dynamics (QCED) effects study it is important to provide efficient interaction of a

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single emitter with the cavity mode, which includes technological task of controllable growth. In our previous works it was shown, that InP/GaInP quantum dots (QDs) growth by metal-organic chemical vapor deposition (MOCVD) have enlarge size, which provide strong overlap of their emission with cavity mode and allows efficient single dot lasing, even for poor quality factor (Q)[6]. Here we fabricate InP/GaInP QD MD cavity having larger Q and investigate QDs interaction with cavity modes and lasing in this regime.

## EXPERIMENT

Initial structure was growth by MOCVD process. Two structures used to fabricate microdisks. The design was following: initially a 100 nm buffer layer of GaAs was deposited onto GaAs wafer followed by 700 nm AlGaAs layer, then GaInP waveguide was deposited (with two different thicknesses 120 nm and 190 nm), which contained one layer of InP QDs . To form mushroom-shaped microdisk cavities photolithography and wet chemical etching was used. As a result MDs with different diameter D=1.5-3 μm and thickness $h_1$=120 and $h_2$=190 nm was formed. Microphotoluminescence (μPL) experiments were carried out at room and low temperature with help of Horiba T64000 spectrometer and microscope with 50x objective. To cool samples Linkam (80K) and close-cycle helium (8.5 K) cryostates was used. Time resolved experiments were carried out with help of PicoHarp 300 TCSPC module coupled with pulsed LDH (Piqoquant) laser head. WGM analysis was carried out with help of Oxborrow's model using COMSOL software [10]. To estimate theoretical quality factors model modification by using absorbing boundary conditions proposed in work [11] was used.

## RESULTS AND DISCUSSION.

For our enlarged QDs (d~150 nm) with low density ( 1 – 5 μm$^2$) and MDs havingh D=1.5-3 μm it is only few QDs will interact with WGM. μPL spectrum of mushroom-shaped MD (h=190 nm, D=2.7 μm demonstrates sharp narrow lines which correspond TE WGMs with different azimuthal numbers (Fig. 1(a)). To determine correlation between single QD emission and WGM area the confocal microscopy imaging at selected wavelengths was carried out. Fig. 1 (b – top) presents image recorded at $TE_{27,1}$ wavelength 778 nm. Outer white circle corresponds to MD border, inner one corresponds to inner border of WGM propagation area determined from theoretical simulation of this mode (Fig. 1(b bottom). From this image it is seen that its WGM luminescence is determined by three QDs, but only one QD is the dominant. The emission area of this QD is located within WGM propagation area. The registered mode linewidth Δλ=0.19 nm which corresponds Q factor ~4000.

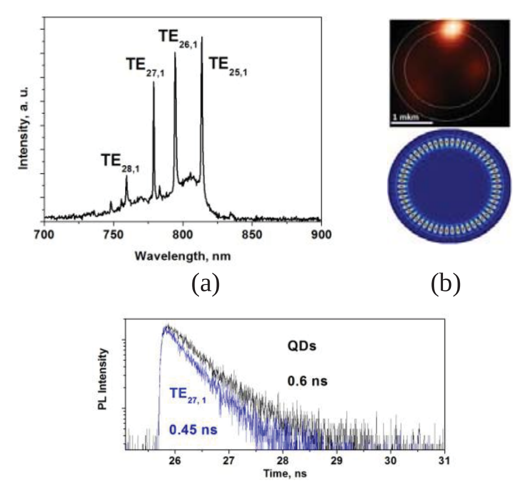


**FIGURE 1.** (a) μPL spectrum of MD recorded at 300 K, pump power 15 μW , (b) –top confocal image of the investigated MD recorded at 778 nm ($TE_{27,1}$ wavelength), (b) – bottom simulation of $TE_{27,1}$ electric field intensity distribution, (c) – time resolved decay curves.

This QD satisfies following requirements: overlapping of QD emission area with WGM antinode, accordance between wavelengths of resonant mode and QD emission. Thus it should be expected that spontaneous emission from this QD which emits into WGM mode is modified because of Purcell effect [8]. To check this we carried out time-resolved μPL experiments. Indeed WGM emission demonstrates a little faster luminescence lifetime $\tau_{TE27,1}$=0.45 ns than that of QD emission in free area $\tau_{QDs}$=0.60 ns.

Figure 2 presents MDs μPL spectra recorded at different power. It was chosen two characteristic cases: thin ($h_1$=120 nm) “low” diameter (D=1.7 μm) microdisk with thick pedestal MD1 and thick ($h_2$=190 nm) “high” diameter (D=2.3 μm) microdisk with thin pedestal MD2. At low power value we observed WGMs. For both cases WGMs were simulated. It is seen that in case of MD1 only $TE_{m,\,1}$ modes are observed, whereas in case of MD2 modes with radial number 2 are observed also. We suppose that this is because of higher diameter/pedestal ratio in MD2 case. Thus QDs locating closer to MD centre are able to emit into modes with higher radial number. Modes quality factors were also estimated theoretically by method described in [11]. Estimated ratio is following $Q1_{TE13,1\ theor}/Q2_{TE22,1\ theor}$=0.2 , which is close to experimentally measured ratio $Q1_{TE13,1\ exp}/Q2_{TE22,1\ exp}$ =0.6.

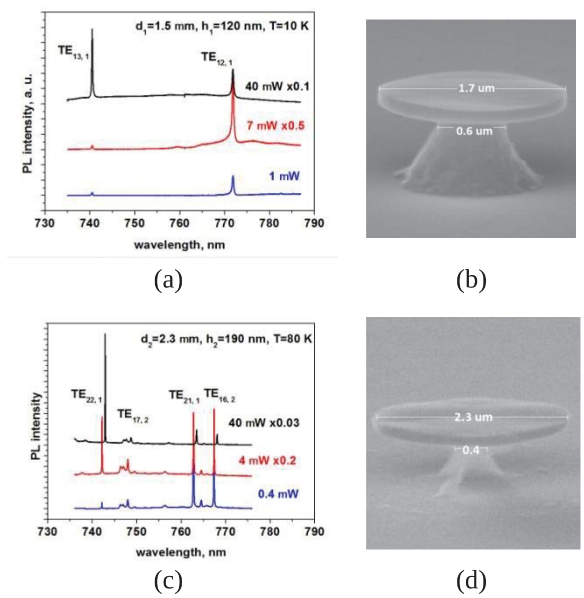


**FIGURE 2.** (a) μPL spectra of MD1 recorded at 8.5 K at different pump power, (b) SEM – microphotography of this MD1, (c) μPL spectra of MD2 recorded at 80 K at different pump power, (b) SEM – microphotography of this MD2.

Increasing of pumping power results in dominant mode arising, which is sign of laser generation. But for MD1 laser generation was observed only at 8.5 K with threshold pump value 7 μW, whereas for MD2 it is possible to achieve laser generation at 80K with by the order of magnitude lower threshold pump value 0.4 μW.

## CONCLUSION

With help of μPL technique we investigated microdisks which contained enlarged low density InP/GaInP quantum dots. It was discovered that lifetime of QD emission into WGM is faster than that into free area. Low threshold lasing was observed. For mode with Q=7400 laser generation threshold pump power value equals 0.4 μW at 80 K.

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