

Optical Properties of CdTe QDs in Proximity to a Surface

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Optical properties of CdTe/ZnTe quantum dots are studied as a function of a capping layer thickness by means of time-integrated and time-resolved microphotoluminescence. The samples are grown by MBE and covered with 10 nm and 100 nm capping layer. Despite that the proximity of the surface may result in an enhanced rate of non-radiative processes limiting the quantum dots optical performance, the set of results indicates that reduction of the capping layer thickness down to 10 nm has no effect on the quantum dot emission intensity and decay rate, contrary to the previously reported case of InAs/GaAs quantum dots.

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1. Introduction

Owing to a range of unique optical properties semiconductor quantum dots (QDs) have already found several practical implementations, e.g., as an active material of low threshold, low intensity noise lasers [1, 2].

QDs buried in nm range distance from the surface of the surrounding semiconductor matrix are useful, e.g., in studies of exciton–plasmon coupling or as building blocks of sensing devices [3, 4]. Since the plasmonic mode decays exponentially within tens of nm from the semiconductor–metal interface, the distance of the QDs from the surface should be as small as possible. On the other hand, the proximity of the surface may limit the optical performance of the dots due to enhancement of surface-related nonradiative processes or doping from the surface states [5]. The studies performed on InAs/GaAs QDs studies have shown a sharp reduction of the emission efficiency and exciton lifetime when the QD-surface distance is reduced down to 10 nm [6].

In the present work, we perform time-integrated and time-resolved microphotoluminescence (μ -PL) studies on self-assembled CdTe/ZnTe QDs and show that despite the shape of the QD ensemble emission spectrum changes when the capping layer is reduced from 100 nm to 10 nm, neither total emission intensity nor QD confined exciton lifetime are affected.

2. Samples and experiment

Two studied structures are grown by molecular beam epitaxy on a 1 μ m thick ZnTe buffer deposited on a GaAs (100)-oriented substrate. The CdTe QDs layer formation is obtained by a technique involving deposition and desorption of amorphous tellurium [7]. The structures are completed by the deposition of a 100 nm or 10 nm ZnTe capping layer [8]. The QDs are formed out of 3 or 4 monolayers of CdTe in the case of “100 nm” or “10 nm” sample, respectively.

The samples are placed inside a continuous flow He cryostat at a temperature of $T = 10$ K. Pulses at energy of 2.8 eV and average power 0.05 mW, coming from

frequency doubled Ti:sapphire laser are directed to the sample through the microscope objective (spatial resolution 3 μ m). The resultant emission is collected through the same objective. The spectral distribution of the PL is detected using 0.5 m spectrometer (with grating 600 grooves/mm or 2400 grooves/mm) and a CCD camera (150 μ eV resolution). The evolution of the signal as a function of the time following the excitation pulse is detected on an avalanche photodiode (40 ps resolution) mounted on the second output of the monochromator and connected to a correlated counting card. The emission dynamics is recorded at energies: 2.10 eV and 2.18 eV corresponding to QD ensemble emission and, additionally, at 2.37 eV corresponding to the energy of ZnTe barrier.

3. Results

The microphotoluminescence spectra of both studied samples are shown in Fig. 1. The spectrum of the QD ensemble from “100 nm” sample has a bell-shaped band about 0.1 eV wide and centered at around 2.17 eV. Additional maximum is superimposed at the low energy side of the band. In the case of “10 nm” sample the QDs emission band has a form of a double peak maximum about 0.2 eV wide and centered at around 2.12 eV. A band related to defect emission is present in the energy range between 1.6 eV and 1.9 eV.

As seen in Fig. 1, the emission intensities of QD ensemble integrated over the whole spectrum are comparable for both samples. However, the shape of emission spectra is slightly different. The narrower emission band in the case of “100 nm” sample indicates more homogeneous QDs size distribution. Redistribution of the QDs sizes while they are overgrown with the thicker capping layer might be responsible for this effect. The shift of this band towards higher energy with respect to “10 nm” sample might result from a smaller QDs height resulting from a thinner CdTe layer from which QD are formed [9] and/or more efficient interdiffusion of Zn atoms to QDs during the growth of the capping layer [10].

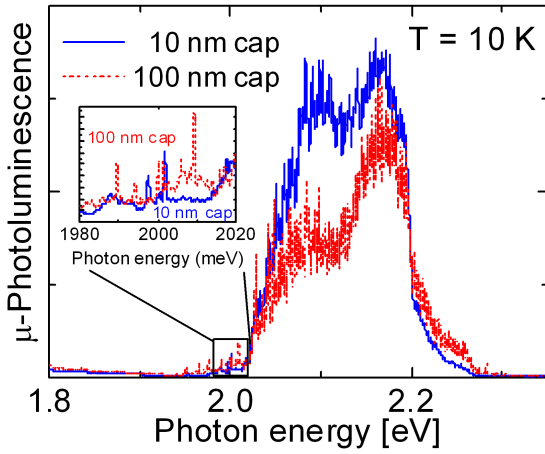


Fig. 1. The μ -photoluminescence spectra at $T = 10$ K of CdTe/ZnTe QDs covered 10 nm and 100 nm capping layer. The inset: close up of the spectra in the range 1.98–2.02 eV displaying individual QD emission lines.

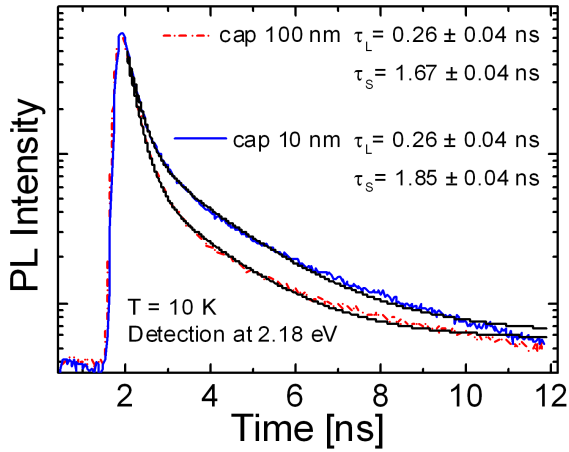


Fig. 2. The intensity of the excitonic emission at 2.18 eV following the excitation pulse for CdTe/ZnTe QDs covered with 100 nm cap (red dotted line) and 10 nm cap (blue solid line). Fitted double exponential decay curves are shown as black solid lines. The determined short (τ_S) and long (τ_L) components of the decay are given.

A close up of the spectra at low energy part of the ensemble, displaying individual QD lines is presented in the inset to Fig. 1. The presence of well separated spectrally transitions indicates that density of QDs, comparable in the case of both samples, is low enough to enable studies of individual QDs.

The time resolved experiment on the QD ensemble reveals two-exponential decay of the emission of the QDs ensemble following the excitation pulse (see Fig. 2). As presented in Fig. 3, a dominant, shorter decay constant τ_S attains about 300 ± 40 ps at 2.10 eV and about 250 ± 40 ps at 2.18 eV, the values typical for CdTe/ZnTe QDs [11–14]. We find that the decay constants

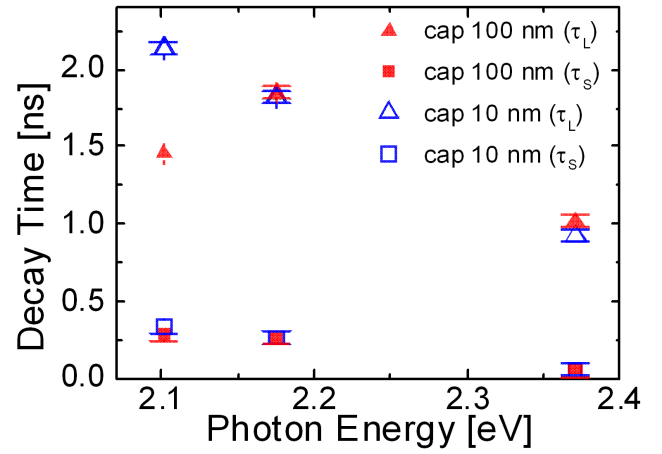


Fig. 3. The short (squares) and long (triangles) constants of the double exponential decay of the excitonic emission at 2.10 eV, 2.18 eV (both in the QD ensemble) and at 2.37 eV (ZnTe barrier), for the sample with 100 nm (full symbols) and 10 nm (empty symbols) capping layer ($T = 10$ K).

determined from the fitting of the QD ensemble emission decay are practically the same in the case of both samples. The slight decrease of the excitonic lifetime with the increasing photon energy indicates a non-negligible transfer of excitons from smaller to larger dots [11].

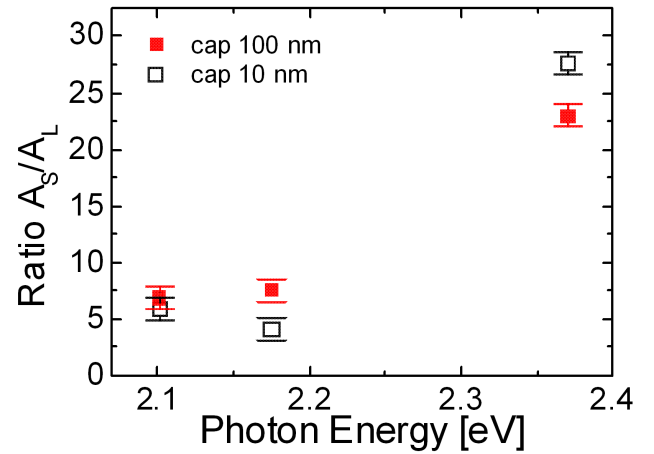


Fig. 4. The ratio of amplitude of shorter (A_S) to amplitude of longer (A_L) component of the excitonic emission decay at 2.10 eV and 2.18 eV (both QD ensemble) and at 2.37 eV (ZnTe barrier), for the sample with 100 nm (full symbols) and 10 nm (empty symbols) capping layer, at $T = 10$ K.

The time constant τ_L of much weaker (see Fig. 4) longer decay component exceeds an order of magnitude the shorter one. The decay of the barrier emission observed at 2.37 eV is nearly purely monoexponential in the case of both samples (see Fig. 4) and lasts for about 40 ± 40 ps.

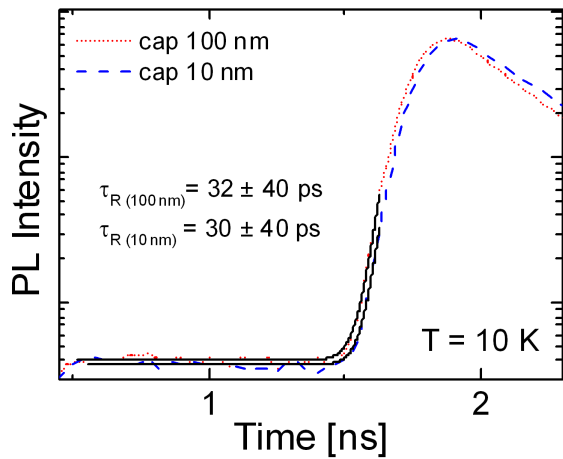


Fig. 5. The rise of the QDs ensemble emission at 2.18 eV for sample with 100 nm cap (red dotted line) and 10 nm cap (blue dashed line) together with respective fitted exponential rise curves. The determined rise time constants are given.

The rise time of excitonic emission at 2.18 eV is determined to be about 30 ± 40 ps in the case of both samples (see Fig. 5). This value agrees within the experimental error with a decay time of the barrier emission, as expected [11, 12, 15].

4. Conclusions

The optical properties of CdTe/ZnTe QDs are studied as a function of their distance to the sample surface. The decay and rise time of the emission are determined for selected energies. The experiment shows that reduction of the thickness of the barrier layer capping the QD layer from 100 nm down to 10 nm does not affect the optical performance of the QDs. Obtained result suggests that CdTe/ZnTe QDs are more robust against reduction of the capping layer thickness than InAs/GaAs QDs [6]. Further studies are desired in order to determine the minimal capping layer thickness enabling a good optical performance of the CdTe/ZnTe QDs.

Acknowledgments

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