Mid-infrared studies of PbTe/CdTe quantum dots in the regime of macro- and micro-photoluminescence

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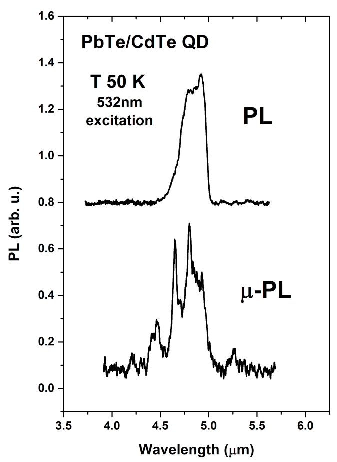
The progress in understanding of optical properties of quantum objects like quantum dots (QD) or nanowires (NW) was achieved as a consequence of developing of micro-photoluminescence and scanning microscope cathodo-luminescence techniques. Both techniques give the opportunity to study individual quantum objects or verify the local properties of extended two-dimensional systems. Unfortunately, the transmission of standard optical elements - even in the case of advanced glass microscopic objectives - is limited to the visible or near infrared region i.e. up to light wavelength ≈ 2µm. Thus, in experimental practice only the QD based on wide gap semiconductors are investigated by these methods. In this paper we compare the experimental results obtained in the regime of macro- and micro-photoluminescence (µ-PL) for narrow gap PbTe quantum dots with CdTe barriers. Here the mirror microscope objective with spectral range from 0.5 to 20 µm was used for light collection in the case of µ-PL measurements. Since the energy band gap of PbTe is 190 meV at 4 K, the PbTe/CdTe quantum dots are optically active in the mid infrared region 3÷5µm [1]. Moreover, because of the small effective mass ($m^*_c \approx 0.04$) and large dielectric constant ($\varepsilon_0 \approx 1000$) the quantum effects can be observed even for relatively big PbTe dots as compared to wide gap ones. Typical photoluminescence experiment (PL exited and collected from the top of the sample, laser spot diameter ≈300 µm) performed at 50 K on the sample containing PbTe quantum dots with average diameter ≈80 nm reveals the strong, ground state emission blue-shifted by about 60 meV as compared to the bulk PbTe due to quantum confinement. This emission exhibits wide, asymmetrical shape typical for the ensemble of QDs with distribution of spatial sizes. Moreover, in strong excitation conditions, we observe additional line with lower amplitude shifted ≈15 meV further in energy, which we attribute to the first exited state transitions in PbTe QDs [2]. When the photoluminescence is collected from the edge of the sample, internal structure of the ground state line becomes visible. It results from significant decrease of the number of quantum dots covered by the laser spot, as the thickness of the layer with quantum dots is of the order of 1 µm. Further limitation of the amount of excited dots was achieved using mirror microscope objective for photoluminescence measurements. In this case we clearly observe the separation of the PL signal into several sharp lines (see Figure). Such behavior is typical for the emission from individual quantum dots in wide gap III-V or II-VI semiconductors in the regime of µ-PL. This result opens the way for investigation of single nano-objects of narrow gap semiconductors.



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[2] Xu T. N. et. al., Phys. Rev. B 76, 155328 (2007).