Photocurrent and Photoluminescence Measurements of InAs Quantum Dots

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Quantum dots are often called artificial atoms due to their nanoscale pyramid or lens shaped structure, which cause a strong three dimensional electron confinement like in atoms. Each quantum dot consists of 10^3 to 10^5 lower band gap material atoms, which are embedded into a matrix of higher band gap material. The δ-function-like density of states and the typical intraband level spacings of 30 to 90 meV turn QDs to promising objects for both applied and fundamental research on zero-dimensional systems.

In this contribution, we report on PL and PC measurements of InAs quantum dots embedded in a quantum dot photodiode. QDs provided with both electric contacts and optical access allows us to vary independently the electric field while measuring the optical or electrical response of the dots. The dot layer is embedded in an intrinsic GaAs region with an ohmic contact on bottom and a Schottky contact on top of the structure (Fig. 1 (a)). In the center of the top contact a 2 µm aperture covered with a 6 nm thick Ti layer serves as an semitransparent shadow mask (optical transmission approximately 60 %) to achieve a homogeneous electric field in the region of the investigated QDs. The band structure under negative bias condition is shown schematically in Fig. 1 (b). Changing the bias from positive to negative voltage reduces the tunneling barrier thickness in z-direction and therefore the tunneling time τ_t of the photoexcited carriers out of dot. When τ_t becomes equal or even smaller than the radiative lifetime of the exciton τ_r (≈ 1 ns) one changes from the PL regime to the PC measurement regime.

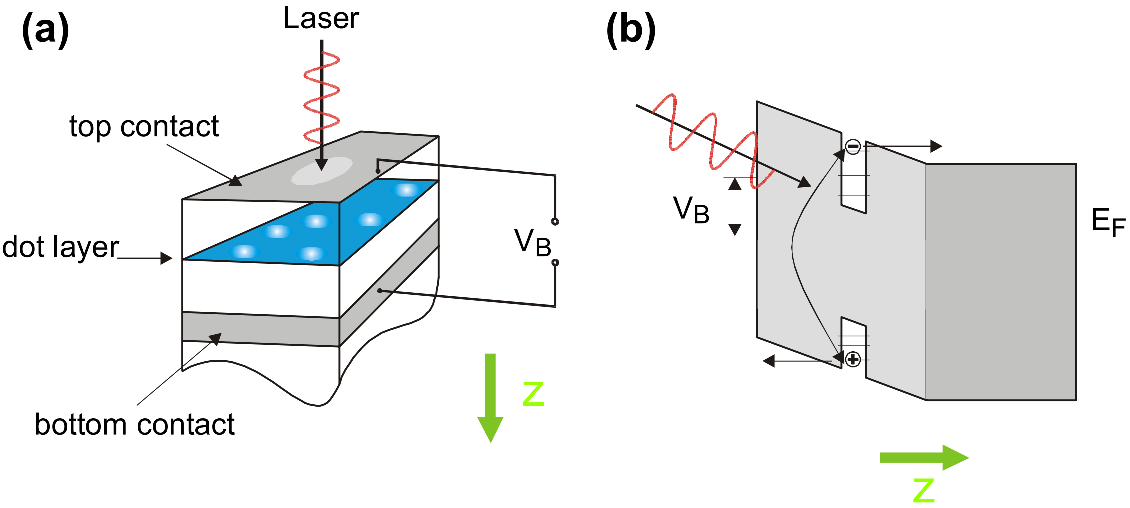

Fig. 1: (a) Sketch of the QD-photodiode. The dots are embedded in an n-i-Schottky diode with a shadow mask on top.
(b) Schematic band diagram under a negative bias v_B .

The experimental setup used in the PL experiments consists of a cw Ti:Sapphire laser (emission at 760 nm), a confocal laser microscope, a low drift LHe flow cryostat, a 850 nm long pass filter, a 0.5 m spectrometer with a nitrogen cooled InGaAs detector, and a remote lock-in amplifier for data acquisition. For the PC measurements we use a tunable cw Ti:Sapphire laser to resonantly excite the QD energy levels, and a self-built current preamplifier with a sensitivity of 10^{-8} V/A for the detection of the PC signal.

Figure 2 shows a typical PL and PC spectrum of the QD's at 4 K. The PL lines in Fig. 2 (a) observed at 1.42 eV and 1.52 eV come from the GaAs matrix and from the InAs wetting layer, respectively. The spectrum shows clearly four, approximately 50 meV separated, luminescence peaks between 1.22 and 1.37 eV, which indicate the ground-state and the excited-state transitions of the InAs QD's. Since the density of the QD's in the sample used is very high ($\geq 10^{11}$ cm^{-2}), the PL of the QD's under weak excitation is much stronger than that from the wetting layer. Increasing the excitation intensity fills up the states in the QD's and therefore leads to radiative relaxation from higher energy levels like the InAs wetting layer or the GaAs matrix (see Fig. 2 (a)). The PC spectrum in Fig. 2 (b) show less spectral features than the PL spectrum in Fig. 2 (a). The increasing PC signal beyond 1.4 eV indicates the absorption of the InAs wetting layer and the absorption tail of the GaAs bulk material as well, and is therefore in good agreement with the PL measurements. The measured PC signal of the dots between 1.4 and 1.1 eV is not only a convolution of the tunneling currents of different states of different dots, but also convoluted with the tunneling probabilities of the carriers in the QD's. This means that the position and the amplitudes of the maxima of the PC signal are not only a function of the excitation power (like in the PL experiments), but also a function of the tunneling probability of the photoexcited carriers and therefore of the applied electric field.

In conclusion, we built a device which enables us the optical and electrical access to InAs QD's enbedded in a GaAs matrix and measured successfully the PL and the PC spectra of these dots.

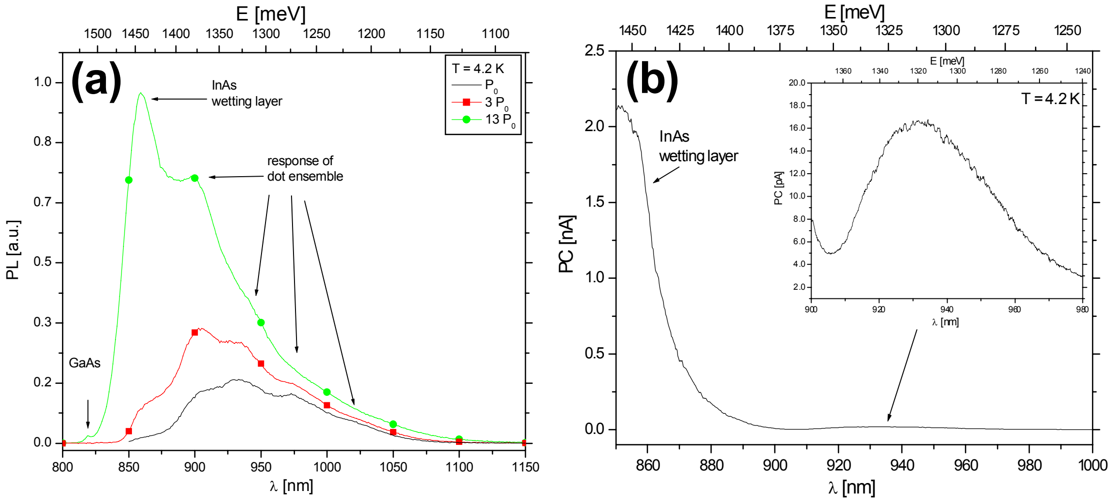

Fig. 2: (a) Broad PL response of the dot ensemble around 930 nm for lower excitation. The maximum shifts with increasing power to higher exciton levels (InAs wetting layer and GaAs).
(b) Position of the maximum of the PC signal is equal to the PL signal under low excitation values.