Single quantum dot photo-diodes: two-level systems with electrical contacts

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Abstract

Semiconductor nanostructures have attracted a lot of interest recently due to their possible applications in optoelectronics, nanoelectronics, quantum information processing and chemical/biological sensing. There are many different experimental approaches to realize well controllable nanostructure devices. In the past few years we have concentrated our efforts on the fabrication of such devices based on self-assembly of quantum dots.

One emphasis is the control of charge and spin population in such quantum dots. Here often spectroscopy techniques are used to measure the quantum dot electronic states. Conventional optical spectra, probing many dots at the same time, are broadened inhomogeneous due to variations in size, shape, and composition. Sharp spectral lines in absorption and emission, which are important for most of the novel applications, are only observed when individual quantum dots are studied. The work on single dot spectroscopy started nearly a decade ago [1-7]. In the past 6 years several hundred papers appeared in the literature, reporting on various aspects of single dot spectroscopy demonstrating the vastly growing interest in this field of research [8]. Spectroscopy with high spatial resolution concomitant with separation of dots in space or in transition energy has been used to study the population of single or coupled dots populated with one or a few electron-hole pairs. Photoluminescence (PL) and photoluminescence excitation spectroscopy (PLE) with and without applied magnetic field allows the identification of ground-state and excited electronic levels as well as phonon-assisted processes. The formation of biexcitons (2 electrons and 2 holes in the dot) and filling of higher states is observed in PL with increasing excitation power [2, 9] and via a resonant 2-photon absorption process [2]. In special electrically tunable semiconductor structures it is also possible to study charged excitons and to obtain a well defined controllable population of the dots [10, 11, 12]. In magnetic fields characteristic features with respect to the spin population and spin dynamics are observed, which may be also of interest to future quantum information processing. The sequential decay of excitons in a single quantum dot can be used for example as triggered single photon source [13-16]. Very recently also coherent effects of excitons and biexcitons in individual quantum dots have been observed in time-resolved spectroscopy manifesting itself for example in Rabi oscillations [17, 18]. Under resonance excitation also spectrally sharp and tunable photocurrent is obtained in reverse biased single dot photodiodes [19, 20]. Such photodiodes are first single dot optoelectronic devices which resemble a quantum mechanical two-level system with electric contacts. Very recently Rabi oscillations in the photocurrent have been demonstrated using such single dot photodiodes [21].

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