Abstract of Ph.D. thesis of Maciej Molas

"Multiexcitons in semiconductor quantum dots"

In spite of about 25 years of intense research efforts, the semiconductor quantum dots remain to attract a relevant scientific interest and continue to surprise with new and interesting physical properties. Great part of this research has been devoted to optical studies of single objects, which also hold for the subject of this work. It is perhaps surprising, though the main body of optical studies of single quantum dots has been so far focused on emission spectroscopy (photoluminescence) and has been largely related to the recombination of rather simple electron-hole complexes such as excitons (neutral and charged) and biexcitons. Strongly confined quantum dots, such as those studied in this work, may, however, accommodate a large number of (photo-excited) carriers. The studies of energy levels and of recombination processes of single quantum dots, optically filled with up to four electron-hole pairs are the subject of this work. The dots used in the present experiments, formed out of the Ga(Al)As matrix, represent relatively strongly confined zero-dimensional systems, and display several, atomic-like *s*-, *p*-,... shells. The studied dots are fairly bright, their optical response is within a suitable spectral range covered by efficient CCD detectors and accessible with the Ti:Sapphire laser. Single dots can be easily selected in our structures as they exhibit an extremely low surface density ($\sim 10^6$ cm^{-2}). Experimental techniques applied in this work include the methods of single dot spectroscopy, polarization (when necessary linear or circular) resolved techniques, application of (high, up to 28 T) magnetic fields and photon correlation measurements. Distinct, below- and above-dot-barrier laser excitation has been used for photoluminescence experiments. Importantly, the photoluminescence excitations experiments (in magnetic fields) have been carried out, as well.

Depending on excitation conditions (power and wavelength of laser), the investigated dots show a multitude of relatively sharp lines, each dot displaying the same, characteristic pattern of lines, grouped into distinct clusters corresponding to subsequent atomic-like shells. Spectral range covering the *s*- and *p*-shells region has been explored in the present studies. The assignment of spectral lines (identification of electron-hole complexes, carriers number and levels occupation, involved in the initial- and final-state of the recombination process) has been at large provided by the results of polarization (linear) resolved micro-photoluminescence and photon correlation experiments. Those experiments depict three distinct families

of emission lines, each related to recombination of, correspondingly, neutral, positively charged and negatively charged electron-hole (excitonic) complexes. The emission lines observed within a four step cascade of a neutral quadexciton down to the recombination of a neutral exciton and two step cascades of positively charged biexcitons down to the recombination of a singlet and triplet state of positively charged excitons have been studied in details. The fine structure, induced by exchange interactions and preliminarily seen in (linear) polarization resolved emission experiment at zero magnetic field, has been studied for various emission lines (related to s- and p- shells). The evolution of this splitting has been then investigated as a function of the magnetic field. The results are interpreted in terms of the shape anisotropy of dots and an interplay between spin- and orbital-mediated effects, characteristic of different recombination processes. A significant portion of this work has aimed to compare the emission spectra measured at a relatively high excitation power (which include the recombination processes of up to quadexciton complexes) with photoluminescence excitation spectra (which probe the excited states of a single exciton). Such experiments have been also carried out as a function of the magnetic field. As expected the emission spectra of high order excitonic complexes are indeed greatly affected by Coulomb interactions between carriers and in consequence are in general very different from the photoluminescence excitation spectra (quasi absorption) of a neutral and charged exciton. Two types of the magnetic field evolution of detected absorption lines (resonant peaks), the s- and p-shell related, have been measured. The s-shell like resonant peaks were attributed to the transition between the excited hole levels in the valence band and the ground s-shell level in the conduction band. Nevertheless, there exists an emission line which is observed within the p-shell cluster, and which coincides with the absorption line. That "coinciding resonance" is concluded to be an excited excitonic state which recombines radiatively due to efficient blocking of its relaxation towards the ground state.