Emission versus absorption of self-assembled InAs/GaAs quantum dots

G. Sęk, W. Rudno-Rudziński, J. Misiewicz
Institute of Physics, Wrocław University of Technology
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

S. Raymond, Z. Wasilewski, P. Hawrylak
Institute for Microstructural Science, National Research Council of Canada
Ottawa, Ontario, Canada K1A OR6

M. J. da Silva, A. A. Quivy
Instituto de Física, Universidade de São Paulo
CP 66318, 05315-970 São Paulo, SP, Brazil

The aim of this work was to compare the state filling effects observed in emission-like and absorption-like spectra obtained for InAs/GaAs self-assembled quantum dots. A common way to measure the emission spectrum is photoluminescence (PL). In the case of quantum dots, it is very easy to fill the lower states using excitation with high enough power density. Hence, there appear the successive emission peaks in PL spectra related to the radiative recombination between the respective electron and hole states in the dots. It is possible to observe several well resolved peaks, even in macro-photoluminescence experiment (on many dots), depending on the particular dots properties as dots size, their geometry or possible dot-dot coupling. The excitation power dependence of photoluminescence has been measured so far by many authors on various quantum dot samples, always revealing the transitions connected with higher-order states. Unfortunately, the intensity of the PL peaks cannot be directly related to the density of states. Therefore, the absorption type of experiment is necessary to be performed. Standard absorption (transmission and reflectivity) is not able to give any “fingerprints” of the QD states due to very weak absorption of each particular dot. There are some reports on the observation of QD transitions in photocurrent spectra, (or in PLE [1]) but this needs special sample preparation and electric contacts. Our proposition to measure the absorption-like spectra is to use the modulation spectroscopy – a differential technique of extremely high sensitivity to optical transitions in low-dimensional semiconductor structures. The effectiveness of these methods, especially their contactless forms, in application to self-assembled QDs has been already proven by several groups [2-5]. We have carried out high-excitation photoluminescence together with photoreflectance on several different InAs/GaAs QD samples. The first step was to observe the QD-related transitions in PR spectra at room and/or low temperature, what requires an unusually high sensitivity and good signal to noise ratio of the experimental setup, due to very low $\Delta R/R$ signal from the dots (on the level of 10^{-6} or even lower). Therefore, experimental complications appeared always for samples on doped substrates, for which a below GaAs band gap oscillation-like signal (interference effect) has been observed. For standard InAs self-organized dots on GaAs, which usually have a plain density of dots below 10^{10} cm^{-2} the PR signal is weak and it is not always possible to observe more than the fundamental transition at room temperature, whereas at low temperature the pump-beam laser induced photoluminescence suppresses the modulation signal. Finally, very rich room temperature PR spectrum has been obtained for high density InAs/GaAs dots designed for 1.3 μm. For this structure, it was possible to realize the second step, namely the states filling by using an additional laser beam in PR experiment with power density high enough to saturate the lower QD states and to observe a reduction of the PR signal intensity related to the lowest QD transitions. Not all the details of our preliminary results have been explained yet, but generally the three-beam PR spectra versus the power density of the additional laser beam show how the successive levels in the quantum dots really fill up in absorption.

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