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Giant Efficiency of Fröhlich Interaction in Self-Assembled Quantum Dots

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Abstract

A transition is being observed from an inhomogeneously broadened photoluminescence band under non-resonant excitation of InAs/GaAs Self-Assembled quantum Dots (SADs) into up to five phonon-assisted emission bands under selective excitation. A similar effect is obtained from photoluminescence excitation experiments (PLE). We interpret the phonon-assisted PL as being due to a giant efficiency of the Fröhlich interaction between an exciton polarized by strain in the SAD and LO-phonons. The model is consistent with the pronounced p-type polarization of the emission observed in our cleaved-side PL-measurements. Further support is obtained from our calculations in which a different localization of the electrons and holes is assumed: The limiting case of this theoretical framework gives a Huang-Rhys factor of $\sim$0.1, which is the same order of magnitude as the experimental value.

1. Introduction

The properties of the growth [1,2] of strain induced InAs islands on GaAs as well as their optical properties [3,4] have been under investigation for several years. The size of the dots is not uniform, resulting in an inhomogeneously broadened photoluminescence (PL) band. However, under selective (or resonant) excitation dots of a certain size can be excited and the broadened band evolves into multi-phonon emission peaks [5,6,7]. In this paper we present new results on the electron-phonon processes in Self-Assembled quantum Dots (SAD's), both experimentally and theoretically.

2. Sample

The quantum dots are grown on an exactly oriented [001] CrO-doped GaAs substrate. First a buffer layer of GaAs was grown at 760°C, followed by 2.0 MLs InAs deposited at 555°C. At this layer thickness we exceed the critical layer thickness for InAs on GaAs and hence the InAs growth changes to 3D mode. The SADs were then capped by a GaAs layer grown at 760°C. Within this top layer we inserted an AlGaAs window to prevent any surface electrical field. Considering the photoluminescence data and calculations, the size of the dots is determined to be from 70 $\AA$ to 120 $\AA$ at the base and from 25 $\AA$ to 40 $\AA$ high.

3. Experiment

The PL and PLE experiments are performed with a tuneable Ti-Sapphire laser pumped by an Ar+ laser. A non-resonant PL-spectrum is measured by exciting above the bandgap of GaAs. The observed inhomogeneously broadened PL band is centred around 1.311 eV and has a full width at half maximum of 65 meV. Under resonant excitation of the dots, i.e., exciting dots of a certain size, clear multi-phonon emission processes are observed. The spectra in Figure 1 show up to five emission bands. The first peak in the upper three spectra consists of two features, one sharp peak at 36.10.5 meV (no.1, GaAs-like LO-phonon) and a shoulder at 32.9±0.5meV (no.1a, InAs-like LO-phonon) below the excitation energy. The involvement of the

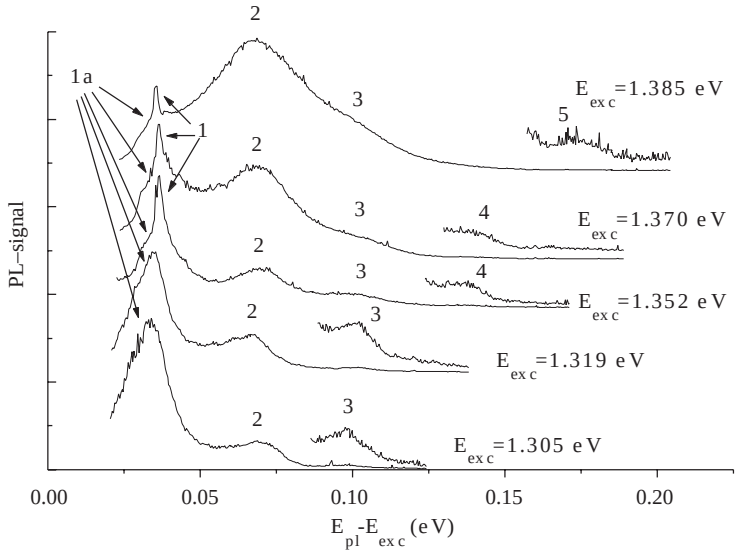

Figure 1. In the resonant photoluminescence spectra of the SAD's up to five multi-phonon emission bands are observed (nos.1-5). The band attributed to the InAs-like phonon is labelled with no.1a.

GaAs like LO-phonon can be explained by the fact that, at these excitation energies, small dots are excited for which the envelope wavefunction leaks out more into the surrounding GaAs matrix than for the larger dots. This is also consistent with the lower two spectra in which the sharp feature is not observed since larger dots are excited. The bands 2 through 5 (see Figure 1) are evenly spaced by 32.9±0.5 meV. Photoluminescence excitation measurements give a similar result (see Figure 2), with also up to five multi-phonon emission bands being observed (nos.1a, 2-5) when detecting at the spectral position of the largest dots (the lowest spectrum). The first band in the lower spectra does not show the sharp feature at a GaAs-like LO-phonon energy above the detection energy, which is in agreement with the PL-spectra shown above, while for detection at the spectral position of the smaller dots the sharp feature of the first band is observed again (no.1). The bands 2 and 3 in the lower two spectra (see Figure 2) are attributed to InAs-like LO-phonons, while the other bands have a GaAs-like LO-phonon energy.

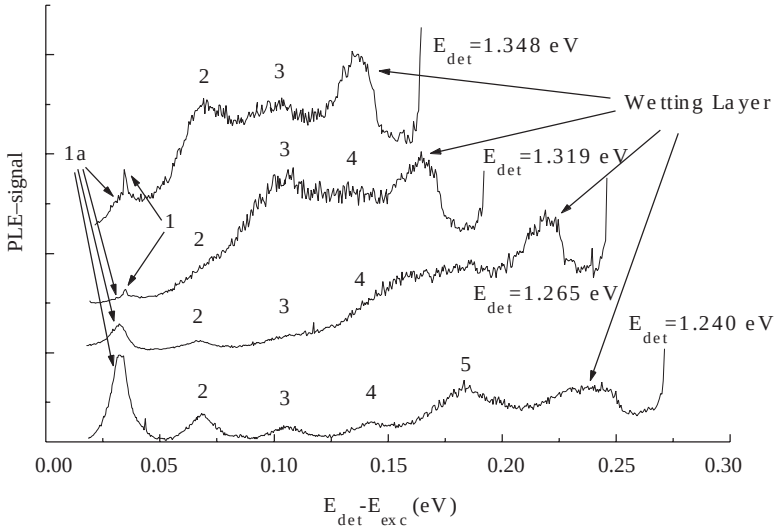

Figure 2. Photoluminescence excitation spectra of the SAD's. When detecting at the spectral position of the largest dots up to five multi-phonon emission bands are observed (nos.1a, 2-5). Detection at the spectral position of the smaller dots shows the sharp feature attributed to a GaAs-like LO-phonon emission indicated with no.1.

We interpret the observed multi-phonon processes as being due to a giant efficiency of the Fröhlich interaction. The Huang-Rhys factor as determined from the PL-measurements is very high: 0.25. If we do not consider any strain distribution the overlap between the electron and hole envelope wavefunction is as large as 95%, giving a Huang-Rhys factor of 0.05, which is too low compared to the experimental value. However, spatial separation of the electron and hole due to a non-uniform strain distribution [8] will align the exciton and result in an enhanced dipole moment along the growth direction. This dipole enhances the polar coupling to LO-phonons, leading to high probabilities of phonon-assisted

optical transitions. The assumption regarding the presence of a non-uniform strain distribution is consistent with the pronounced p-type polarization observed in our cleaved-side measurements. Further support is obtained from our calculation in which a different localization of the electrons and holes is assumed. The limiting case of this theoretical framework, i.e., an electron completely delocalized in space, gives a Huang-Rhys factor of $\sim$0.15, which is the same order of magnitude as the experimental value. However, since this is the upper limit there are still other factors to be considered in order to achieve a better agreement with the experiments.

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