Polarization dependences of electroluminescence and absorption of vertically correlated InAs/GaAs QDs

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Polarization Dependences of Electroluminescence and Absorption of Vertically Correlated InAs/GaAs QDs

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Abstract. The involvement of heavy-hole ground states in optical transitions for light polarized both in the plane perpendicular to the growth axis (*x–y*) and along the growth direction *z* of the structure has been observed in vertically correlated quantum dots (VCQDs). The degree of polarization anisotropy depends on the height of VCQDs, which is related to the *z* component of the wave function of heavy-hole ground states

Keywords: Vertically correlated quantum dots, superlattice, polarization anisotropy, electroluminescence, absorption.
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INTRODUCTION

The polarization of emitted and absorbed light is the important characteristic of semiconductors. It was shown that optical transitions between electrons in the conduction band and holes in the valence band may exhibit polarization anisotropy due to the existence of two kinds of holes: heavy (hh) and light (lh) holes. In nanoheterostructures, the quantum confinement effect leads to a separation of the energies of lh and hh holes with different effective masses. InAs/GaAs QDs feature stronger confinement in the QD growth direction ([001]). For QDs with this confinement symmetry, hh is the ground state of the valence band. An optical transition from this state to a state in the conduction band absorbs only the transverse electric (TE) mode of light, polarized in the plane perpendicular to the growth axis [1]. The transverse magnetic (TM) mode of light, polarized along the growth direction, hardly exists for QDs. In the case of multilayer stacked InAs/GaAs QDs, it was found that tunnel coupling and the increase of the number of QD layers leads to the TM polarization mode enhancement, compared with the TE mode.[2]. The observed changes in the polarization mode intensities were attributed to the influence of the biaxial strain [2] and to a change in the symmetry of the system under study with an increase in the number of QD layers [1]. In QDs there may be valence band mixing at small wave vectors and polarization anisotropy is decreased.

In this communication, we report on a study of the optical polarization anisotropy of electroluminescence (EL) and absorption spectra of systems with different numbers of tunnel-coupled In(Ga)As/GaAs VCQDs. Our study reveals differences between the optical properties of structures with large and small numbers of QD layers.

RESULTS AND DISCUSSION

Samples containing uncoupled and tunnel-coupled In(Ga)As/GaAs VCQDs were grown by molecular-beam epitaxy with self-organization effects. The QD arrays were grown by 3- and 10-fold deposition of 2.3 In(Ga)As monolayers. The thicknesses of the GaAs spacers between the QDs (d) were d = 30 nm for the system of ten uncoupled QDs, d = 6 nm for ten tunnel-coupled QDs, and d = 3 nm for three tunnel-coupled QDs. The EL and absorption measurements in systems with InAs/GaAs VCQDs built into a double-section laser with emission and absorption sections were made at room temperature with waveguide propagation of light in the plane perpendicular to the structure growth direction. Figure 1 shows EL and light absorption spectra from the emission and absorption sections. The spectra were measured for two polarization directions: in the plane perpendicular to the growth axis (*x–y* plane) and along the structure's growth direction (*z* axis). The features observed in the spectra were expected for a structure with ten layers of uncoupled of QDs (Fig. 1a). In fact, this structure behaves, if consider its physical properties, as a structure with a single layer of QDs. High-resolution transmission electron microscopy studies demonstrated that the QDs have the form of truncated pyramids with pronounced confinement in the QD growth direction (*z*), a lateral size of ≈ 20 nm, a QD height of ≈ 4 nm [3]. For QDs with this shape, the ground states in the valence band, involved in optical transitions with perpendicular polarization, are pure hh states whose wave functions lie in the plane (*x–y*) perpendicular to the *z* direction.

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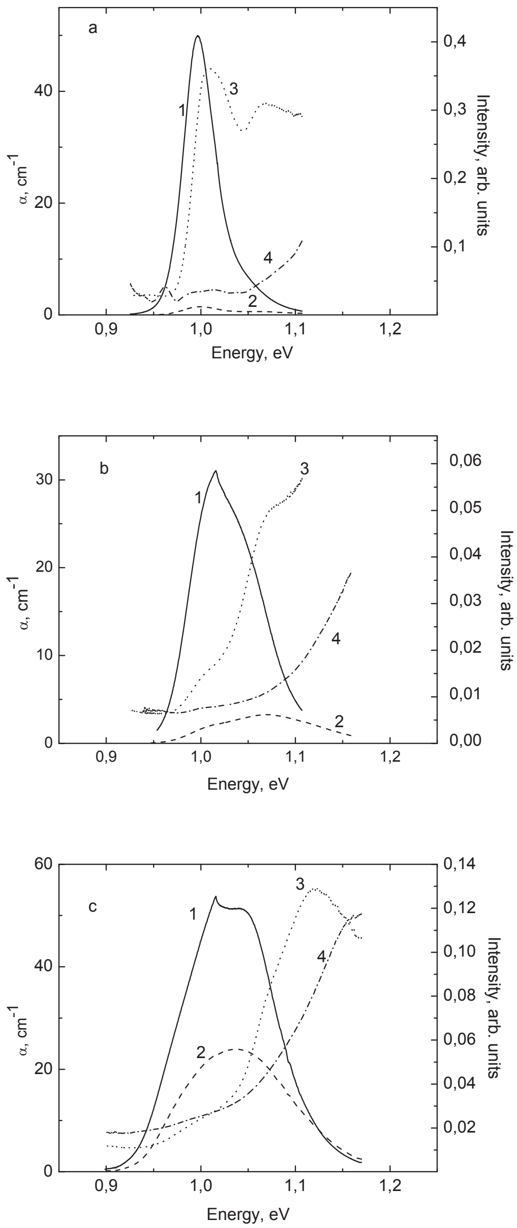

FIGURE 1. EL (*1* – perpendicular polarization and *2* – parallel polarization] and absorption (*3* – perpendicular polarization and *4* – parallel polarization) spectra for InAs/GaAs QD structures: (a) with ten layers of uncoupled QDs, (b) with three layers of tunnel-coupled QDs, and (c) with ten layers of a tunnel-coupled QDSLs.

In a system with three layers of VCQDs the tunnel coupling of the electron ground states in three QDs leads to their hybridization (Fig.1b). Here, the electron wave functions are not localized within each QD; they are delocalized and extend over three QDs. This system is QD molecule [3]. The QD molecule has a height determined by the sum of the heights of three InAs QDs plus the GaAs spacer width, which is 12 nm, and a lateral size of ≈20 nm, the same as that for the single QD layer structure. In this case lateral confinement will play a more significant role and will change the spatial symmetry of the hole wave function The structure with ten tunnel coupled layers of In(Ga)As/GaAs QDs exhibits the Wannier–Stark effect and is a QD superlattice (QDSL) [3]. For this structure the tunnel coupling of the electron ground states in QDs favors the formation of a QDSL miniband (Fig. 1c).

The conclusion drawn from these results is that in structures with a QD molecule, the degree of the polarization anisotropy of EL and absorption is smaller than that for a structure with uncoupled QDs. The polarization anisotropy decreases even more for the QDSL and reaches a value of 0.4 for EL and 0.29 for absorption. The change in the optical anisotropy is caused by the vertically electronic coupling effect between different layers QDs. In addition, the appearance of the EL and absorption spectra was observed for light polarized in the plane perpendicular to the growth axis (*x*–*y*) in the same spectral range as that for light polarized along the growth direction (*z*) of the structure. No transitions involving lh holes whose states lie close to the band edge in GaAs and are spaced ≈ 200 meV from hh hole states [2] were observed in the EL and absorption spectra (Fig. 1a). We have not observed valence band mixing effect in the optical spectra. The behavior of the measured signals allows us to conclude that the optical transitions for light polarized in the plane perpendicular to the growth axis and in the plane along the structure growth direction involve ground states of heavy holes [1], whose wave functions have, in addition to the *x* and *y* components, a *z* component. The existence of this component is attributed to an increase in the height of the system of tunnel-coupled QDs at their constant lateral length and to a change in the symmetry of the system.

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