Optical study of vertically elongated InGaAs/GaAs quantum dots grown using As_2 and As_4 sources

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Self-assembling quantum dots (QDs) due to atomic-like quantum confinement are particularly attractive for fundamental research and various applications in optoelectronics, such as infrared photodetectors, lasers, optical amplifiers and more. Composition of the material and shape engineering of QDs is the key issue to control the electronic and optical properties. Vertically elongated QDs, also referred to as quantum rods (QRs), are novel heterostructures representing the intermediate confinement between 0-D and 1-D [1].

The QR samples studied were grown on a semi-insulating (001) GaAs substrate by molecular beam epitaxy, that allows one to engineer semiconductor nanostructures and achieve intriguing atomic-like quantum confinement. During growth process, GaAs buffer layer was followed by 200 nm-thick $Al_{0.2}Ga_{0.8}As$ layer. QRs of different height were then formed by depositing N = 10–35 periods of InAs /GaAs superlattice (0.64 and 3 monolayers of InAs and GaAs, respectively) on the QD layer (Fig. 1a) using either As_2 or As_4 source. Thereby, In-rich InGaAs QRs were embedded within In-reduced InGaAs quantum well (QW) and this structure was sandwitched between two 100 nm-thick GaAs layers.

In this work we present an in-depth study of the effect of growth mode by using different As sources alongside with the impact of height of the QR (number of SL periods deposited) on the optical properties of InGaAs quantum rods. Temperature-dependent photoluminescence (TD-PL) and photoreflectance (PR) spectroscopy in 3–300 K temperature was used in the study [2, 3]. Optical spectra of QR structures are dominated by lower energy excitonic transitions related to ground-state (GS) and excited-state (ES) in the InGaAs QRs, along with higher energy optical transitions related to quantum well (QW) states. The analysis of TD-PL spectra shows that as the temperature increases the PL peak energy red-shifts, however, with a different manner/trend as obtained from the Varshni formula. Moreover, we have observed unusual temperature dependence of the GS transition linewidth. The TD-PL spectra are discussed in terms of thermalized redistribution of the carriers among the QRs of different sizes. The analysis of PL intensity dependence on temperature of the As_2- and As_4-grown QRs shows different quenching for each sample. The origin of PL intensity quenching with temperature is discussed referring to the QR electronic energy structure revealed from PR spectra and calculations performed within the effective mass approximation.

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