Nanoscale shape control and optical properties of epitaxial PbTe/CdTe heterostructures

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PbTe/CdTe is a model heterosystem, which attracts a lot of attention due to its unique optical and thermoelectric attributes [1,2]. Lead telluride is narrow gap semiconductor (E_g=190 meV at 4K) with small effective mass. In PbTe quantum dots (QDs) with wide gap CdTe barriers (E_g=1.6 eV at 4K) the quantum effects can be observed for dots with dimensions of the order of 100 nm even at room temperatures. Thus, this material system appears as a candidate for mid-infrared applications [1]. It was also shown that incorporation of CdTe antidots into the PbTe thermoelectric matrix by nanostructuring may improve its thermoelectric effectiveness [2]. As the rock-salt lead telluride and zinc-blende cadmium telluride are completely immiscible at temperatures up to 500 °C, the PbTe/CdTe heterostructure is prototype system for investigation of self-organized QDs creation process.

In this paper we study the nanoscale morphology of PbTe/CdTe multilayer heterostuctures and its impact on optical properties of the samples. The PbTe/CdTe structures were deposited on compliant CdTe/GaAs (100) substrates by molecular beam epitaxy at temperatures from 230 °C to 310 °C. The investigated structures intentionally consist of 25 repetitions of consecutively deposited PbTe and CdTe layers with thicknesses of 8 nm and 25 nm respectively. We show, that in PbTe/CdTe heterosystem, only by manipulating the growth temperature, the control of morphology of final structures can be executed. In this way, the variety of structures were obtained, starting from spheroidal QDs of different diameters, through pillar-like objects oriented perpendicular to the substrate, to very complicated systems of spider-like structures. The photoluminsecence (PL) studies of these structures performed in wide range of temperatures 4-300 K have shown that all samples exhibit optical activity in mid infrared region blue-shifted of about 60-100 meV as comparing to the bulk PbTe due to quantum confinement. Surprisingly, the strongest PL signal is observed (even at room temperature) for the most complicated, spider-like and pillar-like samples. Simultaneously, for such samples the spectral width of the asymmetric PL line is relatively small (less than 20 meV) in comparison with ~40 meV wide, ground state emission for an typical ensemble of spheroidal QDs. Notwithstanding the small width, the detailed analysis shows multi-peak character of observed PL, with different polarization degree of constituent lines. It indicates on emission from nanostructures with varying shape and internal strain. The fairly large size of examined nanoobjects (exceeding 50 nm) is most probably responsible for relatively small spectral width of PL signal as for such objects a rather weak dependence of confinement on spatial sizes is expected. The interpretation of PL results has strong support in calculations of optical transitions in elongated PbTe/CdTe QDs [3].

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