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Semiconductor narrow-gap nanostructures based on In(Ga)As(Sb,P) quantum dot/dash system

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Nowadays there is a strong demand of heterostructures based on low-dimensional systems (quantum dots (QDs), quantum dashes (Q-dashes), nanowires etc.) for potential applications in optoelectronic devices for detection of various chemical, explosive and biological agents, which have pronounced absorption bands in the infrared wavelength range (2-5 μm). To penetrate in the long-wavelength region ($\lambda>2$ μm) it is necessary to produce nanoobjects inserted in matrices with the energy gap as narrow as 0.7 eV (for example, GaS band InAs). InSb/InAs quantum dot (dash) heterostructures are promising for the fabrication of the optoelectronic devices (light-emitting diodes and photodetectors) which can operate in the range of 3-5 μm.The arrays of InSb QDs and Q-dashes were obtained on InAs(001) substrate by combine technology based on liquid-phase epitaxy (LPE) and metalorganic vapour epitaxy (MOVPE) methods. Bimodal distribution in a size of the InSb nano-objects, low-density (5×10^8 cm^{-2}) large QDs with 12 nm in a height and high-density (1×10^{10} cm^{-2}) small QDs with a height of 3 nm, was observed for both growth technologies. Using of the InAsSbP matrix layers lattice-matched with InAs substrate resulted in the uniform distribution in a height of the InSb QDs due to a considerable change of a surface chemistry. The wetting layer thickness was dependent on matrix layer: 2 nm for the InAs surface and 1.3 nm for the InAsSbP one. LPE-grown coherent small QDs with convex lens-like shape were found to be dislocation-free without any extended defects according with Stranski-Krastanow mode. Transformation of a shape from a truncated pyramid formed by (111) planes and confined by (011) plane at the top to a multifaceted dome formed by (111) and (443) planes with octagon base and a flat top formed by (233) and (113) planes was discovered for the large QDs. A drastic change of the nanoobjects geometry from QD to Q-dash in dependence on MOVPE growth conditions was observed. The InSb Q-dashes with density of 2.5×10^9 cm^{-2} were self-oriented by 500 nm length along [110] direction. These Q-dashes can be considered as intermediate step from QD arrays to horizontal nanowires. Heterostructures with the InSb QDs/Q-dashes buried into the InAs-based matrix exhibited intense electroluminescence (3.34 μm at 77 K and 3.62 μm at 300 K) under both forward and reversed bias. The blue shift of the EL peak from 3.34 to 3.22 μm with increasing of a drive current was observed at low temperatures. The obtained emission band can be ascribed to indirect radiative recombination transitions of electrons from self-adjacent quantum wells on the InAs side with holes localized on the Q-dash states. The interface-induced luminescence dominated for the nanoheterostructures and was comparable in intensity with interband EL in the n-InAs bulk (3.46 μm) at room temperature. For comparison, study of EL properties of the heterostructures with the InSbQDs inserted into the InAs matrix will be presented too. Evolution of the EL spectra and I-V characteristics behavior in dependence on applied external bias (forward and reverse) and heterostructure construction will be considered. Energy band diagram of the type II broken-gap InSb/InAs heterostructure with localized states will be proposed and discussed.

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