Investigation of the spectrum of exciton excited states in self-organized InAs/AlGaAs quantum dots

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Semiconductor quantum dots (QDs) grown by epitaxial methods are considered as a basis for creating quantum photonics devices, such as single photon sources with a high degree of indistinguishability for applications in the field of quantum computing. Most of the currently used quantum dot systems (e.g. CdSe/Zn(S)Se, InP/(Al,Ga,In)P, CdTe/ZnTe) operate in a relatively narrow wavelength range. The exception is the (In,Al,Ga)As material system, which allows one to design single photon sources in the infrared (IR) spectral range from 900 nm (InGaAs/GaAs) to 1.55 µm (InAs/InGaAs). More recently, the authors of Ref. [1] have expanded the operational spectral range to the visible light (down to 632 nm) by means of InAs/AlGaAs QDs. This region is especially attractive since it corresponds to the maximum sensitivity of modern single-photon avalanche photodiodes. The highest degree of indistinguishability of single photons yet achieved in these structures with non-resonant over-barrier optical pumping was about 30% [2]. In order to improve the photons indistinguishability, one primarily needs to realize quasi-resonant pumping of exciton excited states (e.g. p-shell) that results in significant reduction of spectral diffusion in the radiation of single QDs and, hence, in enhancement of the degree of indistinguishability [3].

In the present work, we experimentally investigate conditions for the existence of exciton excited states in the self-organized InAs/AlGaAs QDs emitting at the shortest possible wavelengths in the near IR and red spectral ranges. The structures studied were grown using molecular beam epitaxy (MBE) on a GaAs[001] substrate. Self-organized InAs QDs were formed within an AlGaAs matrix by the Stransky-Krastanov method. A series of samples were fabricated, which differ in Al composition (from 0% to 90%) in the barrier layers and in MBE growth parameters. The excited excitonic states in the grown QDs were revealed by photoluminescence spectroscopy using different excitation pump powers. With increasing power, emission peaks related to transitions involving excited levels manifested themselves in the shortwave spectral region. For a more detailed study of the spectrum of the excited levels, we used photoluminescence excitation spectroscopy, both in the QD ensemble and under the conditions of micro-photoluminescence studies of the single-QD emission spectra. As a result, we were able to unambiguously identify the energies corresponding to transitions with participation of the excited states and, based on the obtained data, to determine criteria for existence of the exciton excited states in the InAs/AlGaAs QDs, depending on the Al composition in the barrier layers and applied MBE growth modes.

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