Quasi-resonant pumping of excitons in a single InAs/AlGaAs quantum dot emitting in red spectral range

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Optical quantum technologies rely on a nonclassical light source capable of emitting a single photon with high degree of indistinguishability, namely, the source able to provide effective photon-photon interactions via the quantum interference to implement two-photon quantum gates [1]. Such gates are currently considered as main elements of state-of-the-art quantum computation algorithms. One of the most promising candidates for such sources are self-organized semiconductor quantum dots (QDs) grown by epitaxial methods, because of their ultra-narrow emission linewidth, fast radiative decay time, high quantum efficiency and ability to be integrated into larger fabricated structures such as micropillar cavities or nanoantennas in order to improve the light collection efficiency [2]. Most of the currently used QD systems (e.g. InP/(Al,Ga,In)P, CdTe/ZnTe, CdSe/Zn(S)Se) operate in a relatively narrow wavelength spectral range. The exception is the (In,Al,Ga)As material system, which allows one to design single photon sources in the wide infrared spectral range between 1.55 μm (InAs/InGaAs) and 890 nm (InGaAs/GaAs). More recently, the authors of [3] have expanded the operational spectral range down to the red visible light at ~ 700 nm by means of InAs/AlGaAs QDs. This range is of interest since it corresponds to large sensitivity of modern single-photon Si avalanche photodiodes operating at room temperature. However, the highest degree of indistinguishability of single photons yet achieved from the InAs/AlGaAs structures with non-resonant over-barrier optical pumping was only about 30% [4]. Indistinguishability of the single photons can be improved by realizing either resonant pumping of the ground state (s-shell) or quasi-resonant pumping of excited states (p-shell, d-shell and so on) of excitons that results in significant reduction of spectral diffusion in the radiation of single QDs and, hence, in enhancement of the degree of indistinguishability [5]. As compared to the pure resonant pumping, implementation of the quasi-resonant one is much simpler technically, while providing reasonably high degree of indistinguishability.

In the present work, we experimentally investigated conditions for quasi-resonant pumping of excitons in self-organized InAs/AlGaAs single QDs emitting at the $700-715$ nm spectral range. Optical properties of individual QDs are investigated by micro-photoluminescence (μ-PL) spectroscopy, which confirms the single-photon nature of the QDs emission. The samples were grown by using molecular beam epitaxy on a GaAs [001] substrate. Self-organized InAs QDs were formed within an AlGaAs matrix by the Stranski-Krastanov method. The excited excitonic states in the grown QDs were revealed by μ-PL spectroscopy using different excitation powers. In the spectra obtained with a low enough pump power we observed a single narrow line corresponding to the recombination of the ground excitonic state. With increasing power, emission peaks related to transitions involving excited levels manifested themselves in the high energy spectral range. For the study of possibility of quasi-resonant pumping through the excited states we used micro-photoluminescence excitation (μ-PLE) spectroscopy. As a result, we were able to correlate the spectral position of the excited states of the exciton with the positions of the peaks corresponding to quasi-resonant excitation. This allowed us to elucidate the basic conditions for the implementation of quasi-resonant excitation and the mechanisms of relaxation of excitons in individual quantum dots. The studies toward improvement of the indistinguishability of single photons emitted by the InAs/AlGaAs quantum dots under the quasi-resonant conditions are currently in progress.

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