Quantum dot molecules as spin-photon interfaces for applications in quantum communication

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Long coherence times, strong light-matter coupling, and tunability lie at the heart of all hardware for distributed quantum information technologies. Spin-photon interfaces based on III-V semiconductor quantum dots (QDs) are a promising platform for such technologies since they combine properties such as light-matter-interactions, robust spin-photon selection rules, dominant emission into the zero-phonon line at low temperatures, and ease of integration into opto-electronic devices. Together, these properties make QDs promising as spin-photon interfaces. Tunnel-coupled pairs of QDs, so called QD-molecules (QDMs), additionally exhibit enhanced coherence times (T_2*) using two-spin singlet-triplet (S-T_0) qubits [1] which are inherently protected against electric and magnetic field noise.

To unlock the increased coherence times of QDMs, we developed and investigated a device, where a single QDM is embedded in a low capacitance p-i-n diode structure (diode area: 10 µm x 25 µm) that allows for fast electrical switching (>500 MHz) and thus fast control of the tunnel coupling. A circular Bragg grating is deterministically positioned via in-situ electron beam lithography on top of a single QDM. In combination with a distributed Bragg reflector below the QDM, we achieve photon extraction efficiencies of up to 24.4% [2].

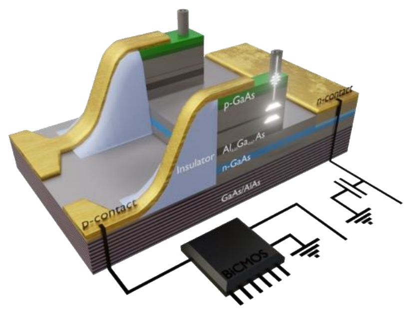

Fig. 1: Diode design - Drawing of a QDM embedded in an ultralow capacitance p-i-n diode structure. The p-contact is guided on top of the via an insulating bridge. The n-contact is annealed for contacting the n-GaAs layer.

Additionally, we demonstrated sequential and all-optical charging of the QDM via tunneling ionization. We showed one- and two-hole charging efficiencies of $(93.5 \pm 0.8)\%$ and $(80.5 \pm 1.3)\%$ are achieved, respectively [3]. Combining the control of the charge status, precise setting and fast switching of the inter-dot coupling, and high photon extraction efficiencies provides a perspective to use our devices for the deterministic generation of one- and two-dimensional photonic cluster states [4].

References

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