# Electrically tunable orbital couplings in MBE grown InAs/InGaAs QD-molecules emitting in O-band

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Epitaxially grown semiconductor quantum dots (QDs) and QD-molecules are a basis for modern photonic quantum technologies. Compared to spin qubits in III-V QDs, singlet-triplet logical qubits in optically active QD-molecules have been recently shown to have enhanced coherence times, due to suppressed coupling to magnetic noise [1]. Recently, excellent single photon source properties have been demonstrated for the InAs/GaAs QD-molecule devices emitting around 930 nm [2]. Nevertheless, precise control of optical and structural properties of QD-molecules is still a critical task for quantum photonics, especially in the telecommunication O- and C-bands (~1.3- and ~1.5-µm, respectively).

We present the first direct experimental observation of electrically tunable quantum orbital couplings in individual vertically staked InAs/InGaAs QD-molecules emitting in the O-band at T = 10K. Individual InAs QD layers were grown by MBE on GaAs(001) substrates in Stranski–Krastanov growth mode and overgrown by 7 nm $In_{0.25}Ga_{0.75}As$ strain-reducing layer. The InAs/InGaAs QD layers, separated by 2–5 nm GaAs barriers, were symmetrically positioned near the center of the intrinsic region of a p-i-n diode, enabling tuning of excitonic transition energies and orbital couplings. The first QD layer was deposited 5 nm above a 68 nm short-period superlattice (SPSL) equivalent to $Al_{0.75}Ga_{0.25}As$ [3], while the second QD layer was capped with a 5 nm GaAs and second similar SPSL. The 90-nm-thick intrinsic GaAs layers were situated between p- and n-GaAs layers and the SPSLs (Fig.1). We observed wide tunability of the emission wavelength exceeding ~20 nm via the quantum-confined Stark in the QD structures with SPSL barriers (Fig.2a). By tuning the internal electric field in the samples containing InAs/InGaAs QD-molecules emitting in the O-band, we observe clear anticrossings of different charge state transitions (Fig.2b). Comparison with theoretical predictions reveals that the excitonic anticrossings arise from tunnel coupling of different orbital states in the molecule and the multiplicity of lines arises from optically induced charging of the molecule.

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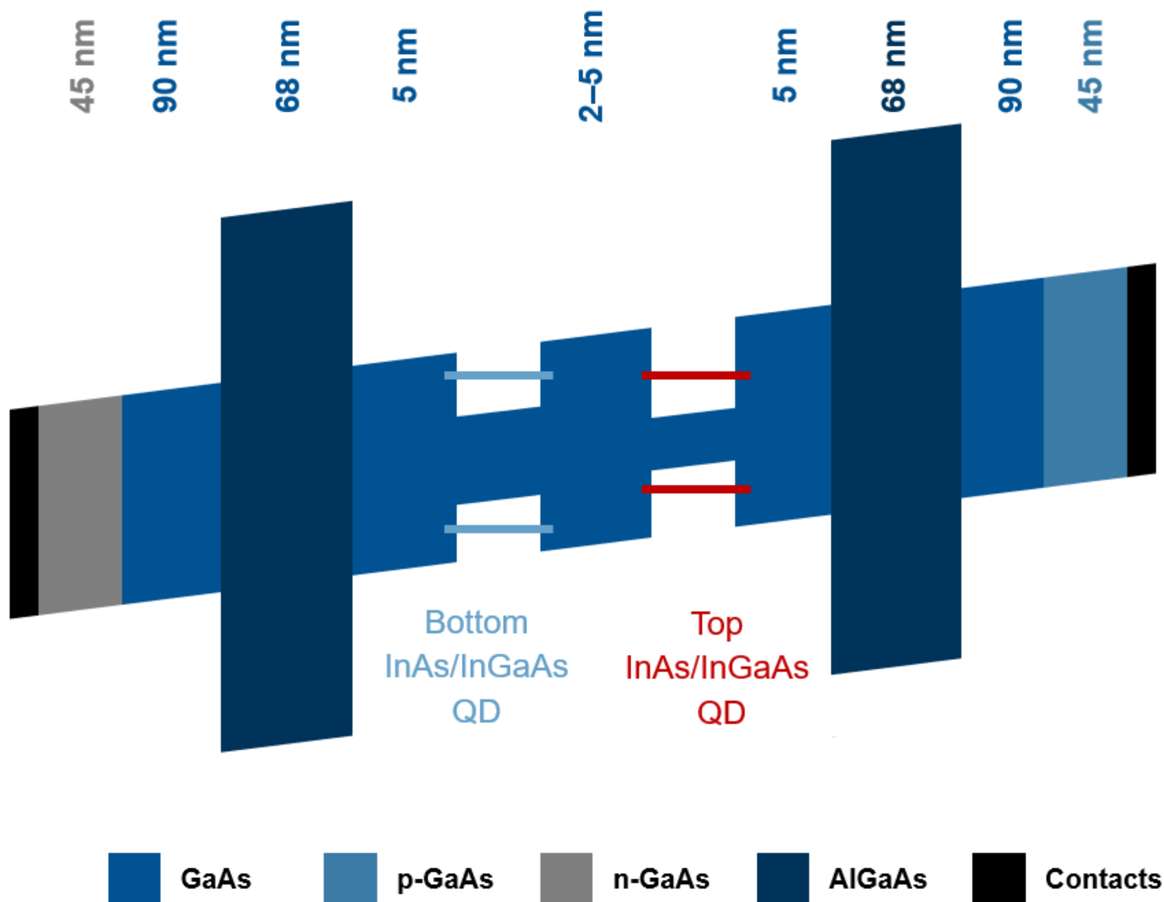


Fig. 1: Schematic of p-i-n diode band diagram with InAs/InGaAs QD-molecule.

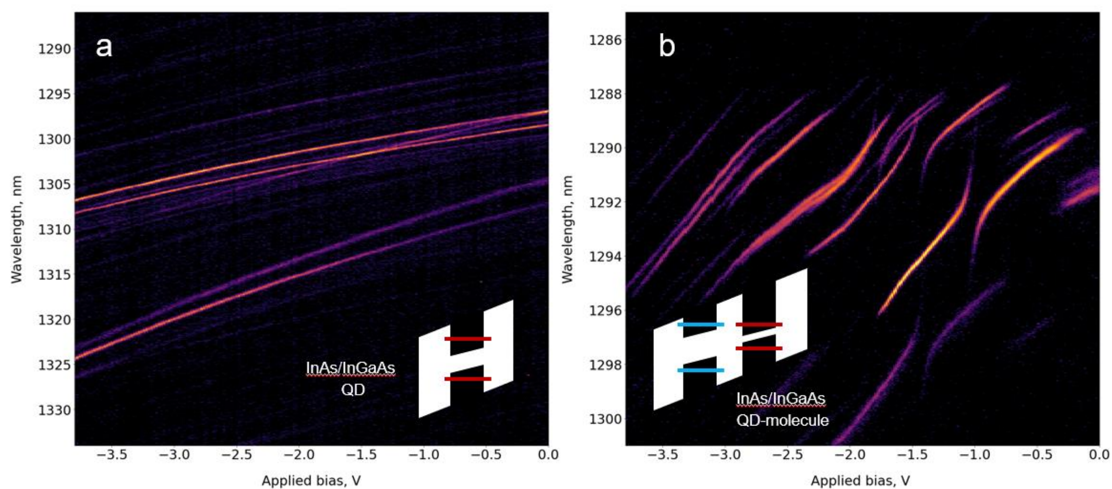


Fig. 2: Voltage-dependent µPL spectra of InAs/InGaAs QD (a) and QD-molecule (b) under continuous-wave 895 nm excitation with a nominal excitation power of 5 µW.