Location qubits in a multi-quantum-dot system

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A physical platform for nodes of the envisioned quantum internet has been long-sought. Here we propose such a platform, along with a conceptually simple and experimentally uncomplicated quantum information processing scheme, realized in a system of multiple crystal-phase quantum dots. In our work [1], we introduce novel location qubits, describe a method to construct a universal set of all-optical quantum gates, and simulate their performance in realistic multi-quantum-dot structures, including the main decoherence sources. Our results from numerical studies show that location qubits can maintain coherence 5 orders of magnitude longer than single-qubit operation time, and single-qubit gate errors do not exceed 0.01%.
Crystal-phase quantum dots possess several characteristics essential for quantum internet nodes: (i) designability of individual qubits; (ii) scalability to multiple qubits; (iii) ease of incorporation with a photonic interface for long-distance communication; and, (iv) nanoscale footprint of devices — for large scale integration. Its designability is particularly remarkable — devices can be fabricated with an accuracy of a single atomic layer [2].
In our scheme, we take advantage of type-II band alignment in crystal-phase quantum dots and exploit spatially indirect excitons to construct all-optical initialization and coherent manipulation (single-qubit and two-qubit gates) of location qubits. We will also present our latest experimental results.
Our scheme paves a clear way towards constructing multi-qubit solid-state quantum systems with a built-in photonic interface, such as a multi-qubit quantum register — a key building block of the forthcoming quantum internet.

References

[1] D. Li and N. Akopian, Location qubits in a multi-quantum-dot system (2021), arXiv:2107.05960 [quant-ph].
[2] J.-C. Harmand, G. Patriarche, F. Glas, F. Panciera, I. Florea, J.-L. Maurice, L. Travers, and Y. Ollivier, Atomic step flow on a nanofacet, Phys. Rev. Lett. 121, 166101 (2018).

Figures

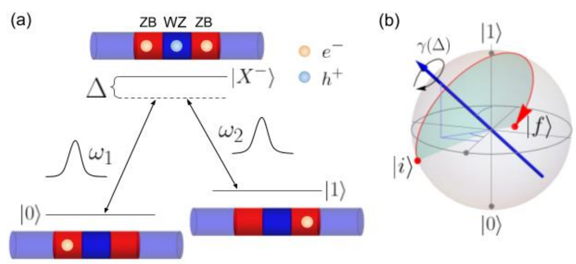

Fig. 1: (a) The all-optical manipulation scheme of a location qubit. A section of a semiconductor nanowire (GaAs or InP) in the Wurtzite (WZ, blue) phase with a pair of crystal-phase quantum dots in the zincblende phase (ZB, red). On such a structure we define a location qubit. Two laser pulses ω_1 and ω_2 of different wavelengths drive the left and right optical transitions respectively. They are both far detuned from the common excited state by Δ. (b) Equivalent representation of the coherent manipulation scheme on a Bloch sphere. Hadamard gate is shown as an example. A state rotates with respect to an axis (blue) defined by the ratio and phase between the driving pulses. The rotation angle γ is a function of the detuning Δ.