61

Quantum dot molecules with control of two-electron orbital configuration

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Abstract

Spin-photon interfaces based on III-V semiconductor quantum dots (QDs) offer strong light-matter interaction, robust spin-photon selection rules, and high emission into the zero-phonon line at low temperatures. These properties make QDs a powerful platform for quantum technologies, enabling the generation of entangled photon strings known as linear cluster states via a single electron spin. Extending this concept, tunnel-coupled pairs of QDs—quantum dot molecules (QDMs)—can host two electron spins, allowing the creation of multi-dimensional photonic cluster states. These are key resources for measurement-based quantum computing and memory-free quantum repeaters.

In our experiments, we investigate a single QDM embedded in a p-i-n diode structure, enabling precise electrical control. We apply a sequential optical charging protocol to load two electrons into the QDM and use electric fields to activate orbital coupling between them. Under optical excitation, the two-electron system displays notable features, including spin pumping from singlet to triplet states. We perform a detailed characterization of these behaviors, which are highly sensitive to the orbital configuration of the electron wavefunctions. We observe vastly different behaviors of the orbital wavefuntions under optical pumping depending on the number of electrons present in the system.