

Doctoral Dissertation

Hybrid quantum control in single solid-state systems

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Wrocław, September 2026

Abstract

In recent years, hybrid systems have emerged in which various quantum degrees of freedom, enabled by controlled couplings to external fields, allow the storage, processing, and transmission of quantum information, potentially enabling next-generation devices.

Optically active quantum dots are at the forefront of quantum technology applications because of their exceptional optical properties, a broad range of energy scales for charge and spin states, and existing couplings to external fields. Quantum dots are a promising building block for quantum communication, metrology, and information processing, and can also serve as quantum emitters at both cryogenic and room temperatures. Thus, the available interfaces with light, microwaves, nuclear spins, and mechanical waves make quantum dots excellent candidates for components of hybrid systems.

The next logical step is to add controlled coupling with mechanical waves to the existing couplings in quantum dots. Carrier-phonon coupling alone in quantum dots does not induce coherent transitions, but instead it merely modulates state energies, making deterministic state preparation and control of carrier spin or orbital states using acoustic waves alone impossible. This work demonstrates that protocols based on controlled, simultaneous interaction of acoustic and electromagnetic waves with carrier states in quantum dots enable deterministic, coherent control.

The proposed protocols bridge gaps in the theoretical framework regarding charge and spin state control, which may help advance research in carrier acousto-optics in quantum dots. Extending these protocols to fully quantum regimes in the future could enable transferring quantum information from a carrier in a dot to a quantized acoustic mode. This will also represent a step toward transferring information via sound between quantum dots and other solid-state systems, such as between a quantum dot and a superconducting qubit or nitrogen-vacancy centers, which are incompatible with visible light as an information carrier.