

Hybrid QD-Resonator Circuit QED: From Strong Light-Matter Interaction to Microwave Photon Detection

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Semiconductor quantum dots in planar germanium (Ge) heterostructures have emerged as a leading platform for hole-based quantum processors. We demonstrate strong coupling between a hole charge qubit defined in a planar Ge double quantum dot (DQD) and microwave photons in a high-impedance SQUID-array resonator [1]. We observe vacuum Rabi mode splittings up to 260 MHz and cooperativities approaching 100, tunable via the double-dot configuration. Exploiting the resonator's frequency tunability, we probe Coulomb-correlation-induced energy renormalization in Ge quantum dots.

Looking toward future spin-resonator coupling, scalable hybrid architectures require the integration of low-loss superconducting cavities with Ge/SiGe heterostructures, which typically introduce pronounced microwave losses. We have developed a fabrication strategy in which the Ge/SiGe stack is locally etched down to high-resistivity silicon and connected via a tapered mesa, enabling superconducting resonators to access the quantum well while preserving high internal quality factors, comparable to silicon references [2]. This provides a practical route toward coherent superconductor-semiconductor devices in planar Ge.

The hybrid QD-resonator interaction can be harnessed not only for coherent coupling but also for microwave photon detection. Because microwave photons carry extremely low energy ($\sim\mu\text{eV}$), direct photon-to-charge conversion is challenging. A GaAs double quantum dot charge qubit coupled to a high-impedance Josephson-junction-array cavity coherently absorbs incoming

photons and generates a measurable electrical current [3]. We achieve photon-to-charge conversion with efficiencies approaching 70% in the single-photon power level and characterize operation across 3-5.2 GHz via independent tuning of the DQD and cavity frequencies. This establishes hybrid QDs-resonator circuit-QED devices also as a versatile resource for quantum microwave optics and sensing.

References

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