Hybrid Circuit Quantum Electrodynamics with Semiconductor QDs

Pasquale Scarlino[1,2]

[1]*Hybrid Quantum Circuit Laboratory, Ecole Polytechnique Federale de Lausanne (EPFL), Lausanne, 1015, Switzerland*
[2]*Center for Quantum Science and Engineering, Ecole Polytechnique Federale de Lausanne (EPFL), Lausanne, 1015, Switzerland*

Semiconductor qubits operate by manipulating the charge and spin degrees of freedom of electrons or holes within quantum dots (QDs). Due to the short-range nature of semiconductor qubit-qubit coupling, the distance between interacting qubits is typically limited to the extent of the wavefunctions of the confined particles, usually a few hundred nanometers. Inspired by techniques initially developed for circuit QED, we have demonstrated the strong coupling limit of individual electron charges confined in GaAs QDs and superconducting resonators. This was achieved by enhancing the electric component of vacuum fluctuations in a resonator with impedance significantly exceeding the standard 50 Ohms found in conventional coplanar waveguide technology [1,2].

Building on this foundational work, we have recently adapted these methods to holes confined in QDs within Ge-SiGe heterostructures [3], a leading material choice for spin-based quantum processors. We have demonstrated strong coupling between a hole charge qubit, defined in a double quantum dot (DQD) system in planar Ge, and microwave photons confined in a high-impedance (Zr = 1.3 kΩ) SQUID array resonator. Our findings include vacuum-Rabi splittings with coupling strengths reaching up to 260 MHz and a cooperativity factor of approximately 100, which varies with DQD tuning. Additionally, by leveraging the tunability of our resonator's frequency, we have been able to investigate the quenched energy splitting characteristic of strongly correlated Wigner molecular states that form in Ge QDs.

This work paves the way for coherent quantum connections between remote hole qubits in planar Ge, which is essential for scaling up hole-based quantum processors.

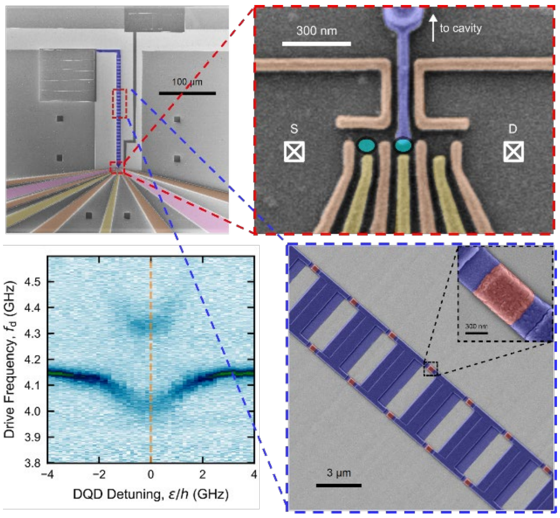

Figure 1, Superconductor-semiconductor hybrid architecture on planar Ge heterostructure. Strong charge-photon coupling at the charge sweet spot. An avoided crossing - the signature of the strong coupling regime - is observed when the DQD-charge transition matches the bare resonator frequency.

[1] A. Stockklauser*, P. Scarlino*, *et al.***,** *Phys. Rev. X* **7**, 011030 (2017).
[2] P. Scarlino*, J.H. Ungerer*, *et al.***,** *Phys. Rev. X* **12**, 031004 (2022).
[3] F. De Palma*, F. Oppliger*, W. Jang*, *et al.***,** *arXiv:2310.20661.*