Design, fabrication and characterization of hybrid superconducting-semiconducting device for spin-photon coupling in planar Ge

General Information

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Motivation

Quantum computing constitutes one of most attractive research fields today. Taking advantage of unique quantum mechanical properties, such as superposition and entanglement, quantum computers are potentially able to solve in efficient time a completely new set of computational problems. However, the realization of large-scale integration fidelity qubits constitutes one of the most difficult challenges nowadays. Spin qubits in *semiconductor quantum dots* (QD) [1] constitute one of the possible solutions for scaling-up the number of qubits, thanks to their small footprint, CMOS industry compatibility, high-fidelity initialization and readout, single- and two-qubit gates and long coherence times [2]. However, scaling-up to a very large number of qubits without drastically reducing operation and readout fidelity still constitutes the main challenge, especially because of the large cross-talking. One possibility to overcome this issue is represented by *circuit quantum electrodynamics* (cQED), which describes the interaction between a qubit and a single microwave photon stored in an on-chip cavity, i.e., a superconducting resonator [3]. If the coupling between the qubit and the photons is much larger than the losses, the resonator can be used to mediate the interaction between two qubits far away in space, overcoming the limitation of the short-ranged spin-spin interaction and offering a possible path for scalability [4].

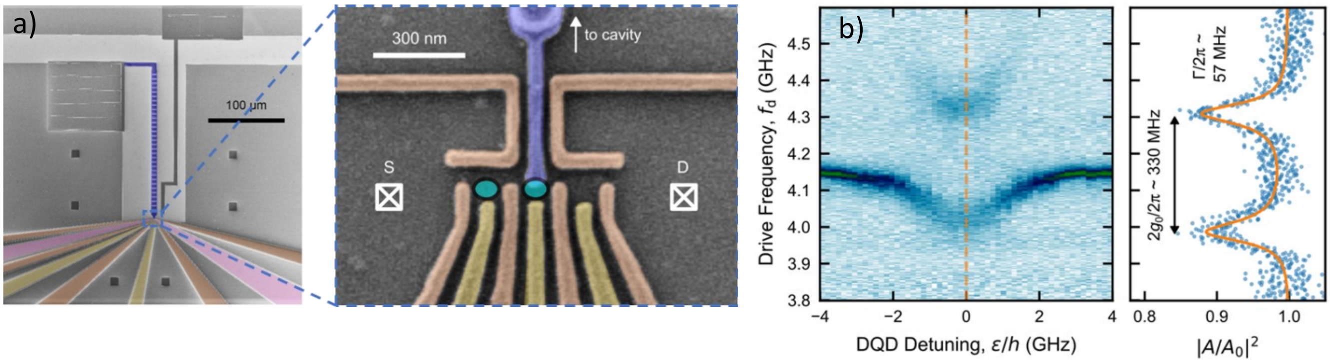

Fig. 1 a) SEM picture of a triple quantum dot (TQD) device coupled to a superconducting frequency-tunable SQUID array resonator. (b) Vacuum-Rabi splitting of the cavity mode, indication of the strong coupling regime.

Description

After the first demonstration of strong charge-photon coupling in planar Ge [5], the short-term goal of the project consists in demonstrating strong spin-photon coupling.
The project covers all the steps of the experiment realization:

1. **Design and Simulation** of different kinds of high-impedance superconducting resonators.
2. **Devices Fabrication** in the cleanroom facilities at EPFL (CMi and IPhys).
3. **Measurements and Data Analysis**. The chips will be tested in one of the four dry dilution refrigerators available at HQC lab, cryogenic systems capable of reaching temperatures down to 10 mK.

Student's Tasks

- Literature search.
- Superconducting devices CAD design and modeling on SONNET.
- Cleanroom fabrication of quantum dots and superconducting resonators.
- Cryogenic measurements and data analysis in Python.

[1] D. Loss, D. DiVincenzo, Physical Review A 57.1 (1998).
[2] G. Zheng, Circuit Quantum Electrodynamics with Single Electron Spins in Silicon (2021).
[3] Blais, A. et al. REVIEWS OF MODERN PHYSICS, VOLUME 93 (2021)
[4] Vandersypen, L. M. K. et al. npj Quantum Inf 3, 1–10 (2017).
[5] De Palma, F., Oppliger, F., Jang, W. et al. arXiv:2310.20661v1 [quant-ph] (2023).