Microwave resonators for global control of electron spin qubits

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Introduction

Electron spins in semiconductor quantum dots are excellent candidates for qubits for a scalable quantum computer due to their addressability and electrical control. Silicon in particular is a promising host material due to the possibility of isotopic purification, leading to decreased nuclear magnetic noise, and integration with classical control by leveraging conventional CMOS electronics [1].

One key challenge for a scalable quantum computer is the implementation of single qubit rotations. Both striplines and micromagnets, two conventional methods used for single qubit rotations, require on-chip components that are significantly larger than the footprint of an individual quantum dot, reducing the possibility for the dense packing of qubits.

Here, we show preliminary results for a resonator which produces a strong global RF magnetic field with minimal electric field [2]. This resonator is placed above the quantum device layer, leaving more room for dense packing of qubits. Individual qubits can be tuned into and out of resonance with this global field electrically using the Stark shift.

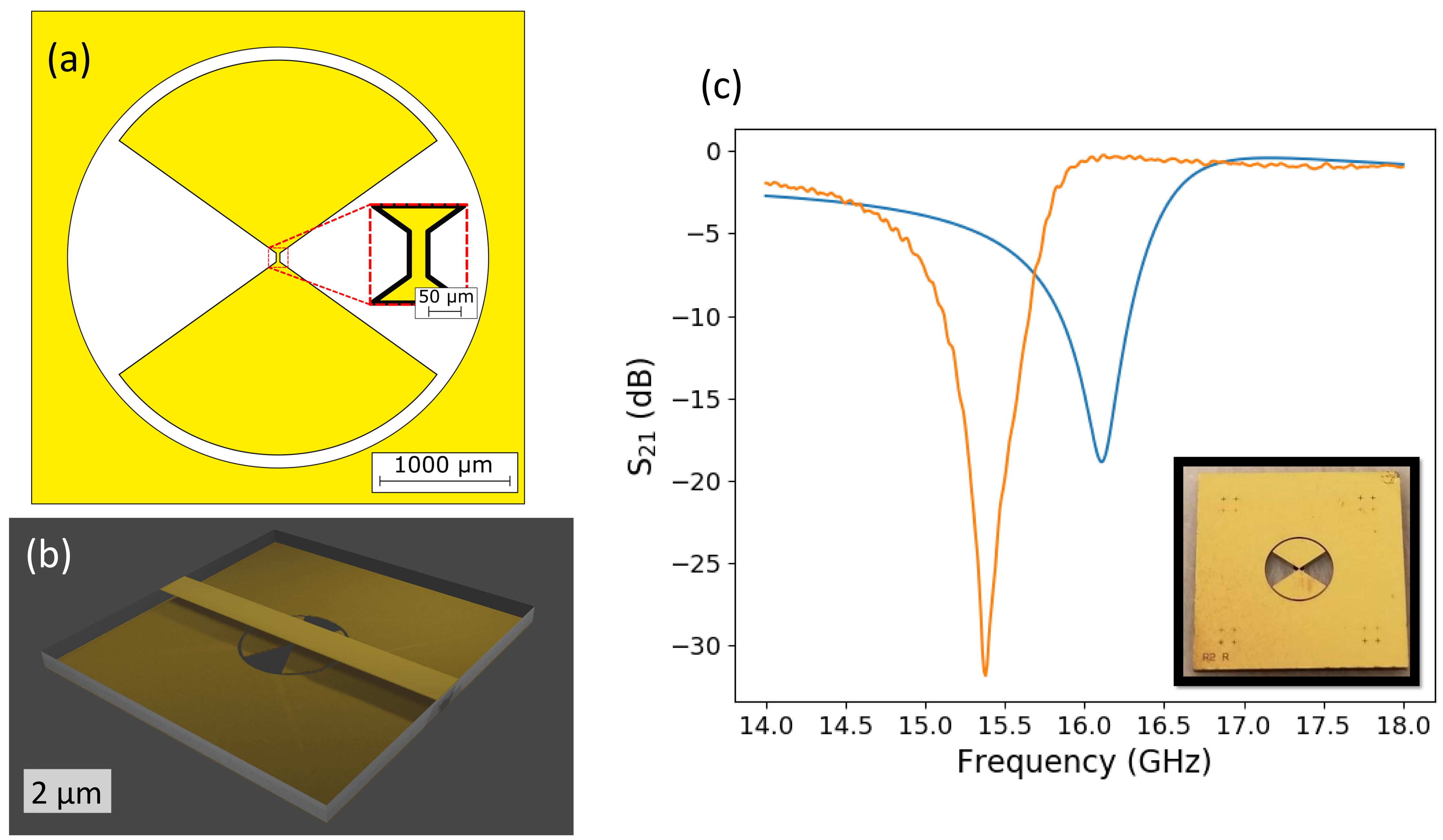

Figure 1: (a) Schematic of the resonator. Inset: Enlarged view of the device region. (b) 3D Rendering of the resonator, showing the stripline used to couple to the resonator. The quantum device layer is below the resonator. (c) Simulated (blue) and measured (orange) transmission through a coupling stripline, showing a strong resonance near 16 GHz. Inset: Image of a fabricated gold-plated copper resonator.

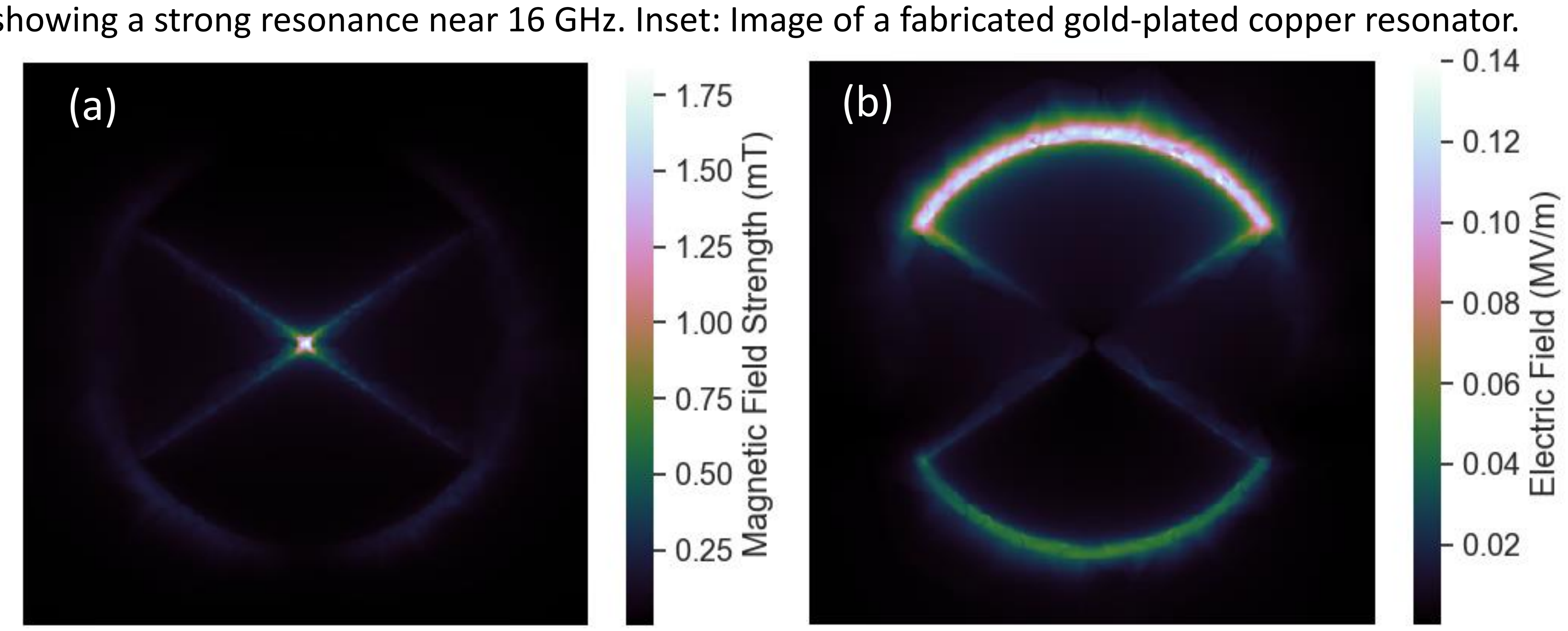

Figure 2: Simulated (a) magnetic field and (b) electric field 10 µm below the plane of the resonator with a 1 W input power. In an area roughly 40 µm by 60 µm near the center of the resonator, the magnetic field intensity is within 75% of the maximum, which could allow for manipulation of over 2×10^5 qubits, assuming a 100 nm device pitch.

Results

Simulations show that a strong magnetic field is produced near the center of the resonator at a resonance frequency near 16 GHz with a quality factor Q~10. The theoretical Rabi frequency is roughly 775 kHz/(mW)$^{1/2}$.

Experimentally, we observed that the resonator has a resonance near 15.5 GHz with Q~10, corresponding to a photon energy of 64 µeV. This Zeeman splitting can be achieved for a g=2 electron in a 0.55 T static field. The difference between experimental and simulated resonance frequencies suggests a discrepancy between material parameters. Further work is needed to understand this mismatch.

Future Work

- Measuring photon-assisted tunneling in a single-electron transistor to quantify undesired RF electric field near device region
- Implementation of additional metal shielding to reduce RF electric field near device region
- Fabricate superconducting niobium resonators
- Demonstrate selective single qubit rotations of an electron confined in a quantum dot

References

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2. N. Dayan, *et al.* Rev. Sci. Instrum. **89**, 124707 (2018).

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