H-6-2

Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp810-811

Towards Cavity QED with InSb spin qubits

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Abstract

One-dimensional microwave transmission line cavities can be used as a quantum bus to couple distant qubits on a chip. The strong coupling of single photons to superconducting qubits[1] has been widely studied but this regime remains to be demonstrated clearly for electron spin qubits. Motivated by a proposal to use strong spin-orbit interaction (SOI) to couple electron spins confined in a quantum dot to the cavity field[2] we study double quantum dots (DQDs) fabricated from InSb nanowires placed within a cavity. We fabricate half wavelength superconducting transmission line cavities using dc-magnetron sputtered Niobium films. Using a micron scale alignment technique we place two InSb nanowires onto prefabricated gates at either end of the cavity where the electric fields are highest. The charge states of the two double InSb QD devices are probed with the cavity transmission demonstrating the dispersive readout of the device.

1. Introduction

The most advanced cavity Quantum ElectroDynamics (QED) work to date utilizes superconducting qubits[1], which have a large dipole coupling to the cavity field but suffer from short coherence times (typically <100μsec). Recently however interest has grown in the application of this technology to combine different qubit systems in a quantum bus. In such a system a spin based qubit could be employed as a quantum memory thanks to the comparatively long coherence times. Strong coupling with ensembles of spins in NV centers has been demonstrated[3,4] but to date the strong coupling regime with single spins in spin qubits has not been realized despite recent progress in this direction[5-8]. Studies of qubit devices have focused on charge qubits which display strong couplings due to a large dipole but short coherence times preventing the demonstration of the desired strong coupling regime.

To realize the strong coupling regime we require the coupling between qubit spin state and photon in the cavity to be faster than both the coherence time of the spin state and the lifetime of the photon in the cavity. The fabrication of high quality cavities has been widely reported with quality factors ~ 1,000,000 indicating photon lifetimes of 100's of μsec. The main obstacles to the strong coupling regime

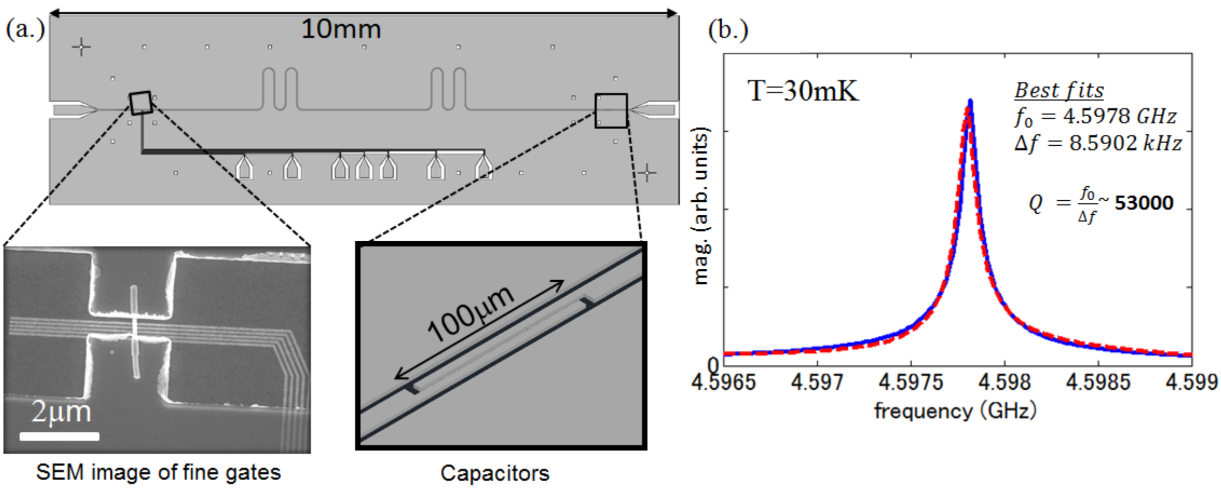

Fig. 1. (a) Schematic of a 1/2 wavelength resonator fabricated from thin Nb film. The cavity if formed from two interdigited capacitors. Nanowires are deposited with alignment onto a set of gates at the ends of the cavity as shown in the inset scanning electron microscope (SEM) image. (b) Example of the resonator transmission. The dashed line indicates a Lorentzian fit used to evaluate the Quality factor.

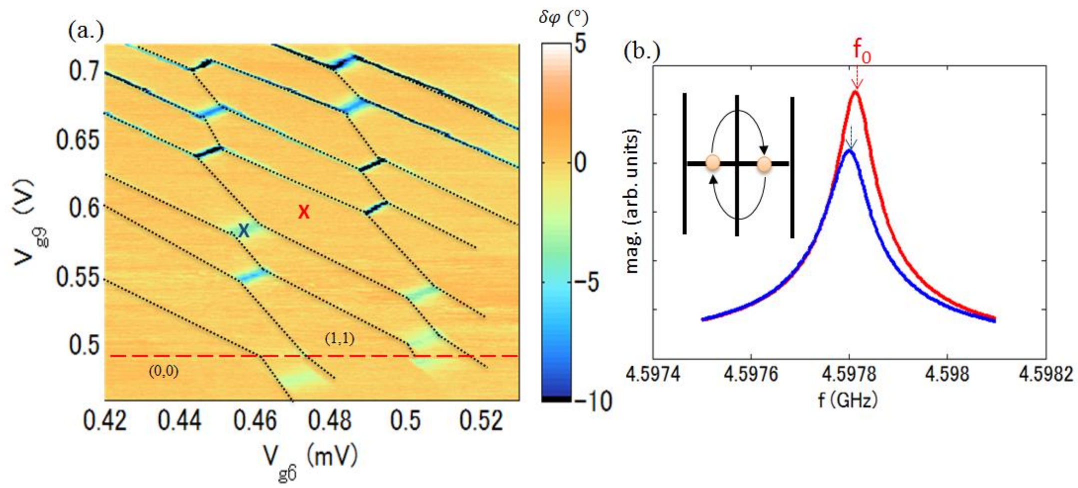

Fig. 2. (a) Example of the InSb nanowire double QD charge states probed using the resonator transmission. The transmission frequency is fixed at the center frequency of the resonance in the Coulomb blockade at the red X. The shift of the phase measured in the transmission is then plotted as a function of the plunger gates for the two QDs. Dashed lines are a guide to the eye indicating the honeycomb structure of the stability diagram. The red dashed line indicates a reproducible charging jump. The filling of the double QD is indicated in parenthesis (n,m) where n and m are the electron number in right and left QD. (b) Examples of the transmission measured at the blue and red X in (a).

are then the spin qubit coherence time and the coupling strength of the spin state to the cavity field, a state typically manipulated with magnetic fields. The coupling strength between a single isolated spin due to the cavity-induced magnetic field is very weak (~10-100 Hz) and so a novel strategy is needed to achieve strong coupling. To facilitate a strong coupling between the cavity electric field and a single spin we intend to utilize narrow gap semiconductor materials (InAs or InSb) which exhibit strong spin-orbit interaction (SOI). The electric field of the cavity will periodically shift the electron wavefunction inside the QD causing the SOI to generate an effective ac-magnetic field which will drive spin resonance and mediate the coupling between photon and spin. Estimates of the expected spin-photon couplings based on realistic device designs are ~1MHz [9].

2. Device Fabrication

Devices are fabricated using a micronscale alignment process inspired by the techniques often used to transfer Graphene and other exfoliated 2D crystals onto different substrates[10]. Initially InSb nanowires are deposited onto a polymer stack of PVA/PMMA on Si. The PMMA film is then peeled from the PVA leaving a freestanding transparent film with nanowires. This is then position and aligned using a homemade system to place a single nanowire onto the target gates inside the transmission line cavity, Fig. 1. Using this process we can place a single selected nanowire onto a set of gates with a precision of approximately 1 μm.

3. Results and Discussion

We operate resonators fabricated from liftoff of sputtered Niobium films on highly resistive Si substrates which typically display Q-factors in the range 10,000 to 50,000 at T=30mK, Fig. 1(b). For in-plane magnetic fields we can operate the resonators without significant loss of Q-factor up to around 100mT which when combined with the high g-factor of the InSb (g~10-50)[11] places the device in a suitable regime to match the Zeeman splitting with photon energy. Using the resonator we demonstrate the operation of the device for dispersive readout of the double QD charge states. By studying the resonator transmission we observe dispersive shift of the resonator center frequency and also dissipative effects due to losses through the DQD. By measuring either the shift of resonance amplitude or phase at a fixed frequency we can map out the charge stability diagram as shown in Fig. 2 (a).

3. Conclusions

We fabricate 1/2 wavelength transmission line resonators with InSb nanowires using a micron scale alignment technique to place selected nanowires at points with high cavity electric field. We will show the dispersive readout of the quantum dot charge states and discuss prospects for achieving the coupling of spin and photon.

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