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Coupling small spin ensembles to superconducting on-chip resonators: towards a hybrid architecture for quantum information

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The field of cavity quantum electrodynamics (QED) studies the interaction of photons in resonant cavities with either natural or "artificial" atoms, such as quantum dots and superconducting qubits, having a nonlinear and discrete energy level spectrum [1]. For applications in spectroscopy and especially quantum information processing, a major goal is to maximize the coupling strength g1 of the atom to either electric or magnetic cavity fields, making it larger than the decoherence rates of both the cavity and the atom (strong coupling regime). Attaining this regime for individual spin qubits would open the possibility of developing an all-magnetic quantum processor [2]. This goal remains, however, very challenging because the interaction of each spin with the photon's magnetic field is much weaker than the typical decoherence rates of the resonator and of most magnetic qubits. For this reason, strong coupling has been observed only in the case of macroscopic spin ensembles, containing N > 10^12 spins, for which the effective collective coupling gN is enhanced by a factor N^(1/2) with respect to that of a single spin [3,4]. We have recently shown that the microwave magnetic field of a coplanar superconducting resonator can be enhanced locally via the fabrication of nanoscopic constrictions at its central line [5]. In this communication, we report the results of experiments performed on small spin ensembles directly deposited onto such constrictions.

1.5 GHz superconducting resonators were fabricated by optical lithography on Nb layers grown onto crystalline sapphire substrates. A typical design is shown in Fig. 1A. The width w of the central line can be reduced from the original 14 microns down to less than 50 nm by using a focused beam of Ga+ ions, without appreciably altering the resonator characteristics (Figs. 1B and 1C) [5]. Experiments were also performed using a w = 400 microns wide central line resonator. The magnetic samples consist of ensembles of DPPH free radicals, each having a spin s = 1/2 with a fully isotropic gyromagnetic factor g = 2 and a negligibly small inhomogeneous broadening.6 Molecules were deposited onto the devices from a saturated solution in DMSO. For large ensembles on standard resonators, the deposition was made using a micropipette and the size of the spin ensemble varied by controlling the droplet volume. Smaller spin ensembles were deposited using dip-pen nanolithography.7 The tip of an atomic force microscope (AFM) is used to write small dots (between 5 and 60 microns wide) with a very high spatial resolution. The number of spins N lying inside the area of the constriction was accurately determined from Scanning Electron Microscopy and AFM experiments (Fig 1D). The transmission S21 of microwave radiation trough the resonators was measured at T = 4.2 K as a function of magnetic field and frequency omega. The maximum transmission, near the ground mode at omega/2pi = 1.5 GHz, and the effective Q factor decrease sharply when the field brings the spins into resonance with the circuit. From these experiments, the collective coupling constant has been determined for samples with N varying between 10^8 and 10^16 spins. The results (Fig. 1 E) show that gN is proportional to N^(1/2) both for the original resonators and for the constrictions. However, the average coupling to each spin g1 = gN/N^(1/2), is enhanced by more than two orders of magnitude (from 0.25 Hz up to 50 Hz) in the latter case. As a result, magnetic ensembles, e.g. a 30 microns drop, that are completely undetectable with a conventional resonator become visible when they are deposited near a superconducting nano-bridge. Furthermore, the dependence of g1 on the width of the central line agrees quantitatively with theoretical predictions (Fig. 1 F) [8].
These results show that the coupling of spin qubits to quantum superconducting circuits can be enhanced via a combination of top-down and bottom up nanolithography techniques. In the present experiments, the spin-photon coupling remains in the weak coupling regime because DPPH shows decoherence rates 1/T2

> 12 MHz. The strong coupling regime might, however, be attained for especially designed molecular spin qubits that can show 1/T2 values as small as 1 kHz [9]. Furthermore, reaching this limit for individual spins, a pre-requisite for the development of a magnetic quantum processor, will then also be feasible provided that nanofabrication techniques are pushed down to w < 10 nm.

References
[1] R. J. Schoelkopf and S. M. Girvin, Nature 451 (2008) 669
[2] M. D. Jenkins, D. Zueco, O. Roubeau, G. Aromí, J. Majer and F. Luis, Dalton Trans. 45 (2016) 16682.
[3] D. I. Schuster et al, Phys. Rev. Lett. 105 (2010) 140501
[4] R. Amsüss et al, Phys. Rev. Lett. 107 (2011) 060502
[5] M. D. Jenkins et al, Applied Physics Letters 105 (2014) 162601
[6] N. D. Yordanov, Appl. Magn. Res. 10 (1996) 339
[7] M. J. Martínez-Pérez, E. Bellido, R. de Miguel, J. Sesé, A. Lostao, C. Gómez-Moreno, D. Drung, T. Schurig, D. Ruiz-Molina, and F. Luis, Applied Physics Letters 99 (2011) 032504
[8] M. D. Jenkins, T. Hümmer, M. J. Martínez-Pérez, J. J. García-Ripoll, D. Zueco and F. Luis, NJP 15 (2013) 095007
[9] J. M. Zadrozny, J. Niklas, O. G. Poluektov and D. E. Freedman, ACS Cent. Sci. 1 (2015) 488

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