Electric-dipole control and coupling of spin qubits

Guido Burkard[1]

[1] *Department of Physics, University of Konstanz, Germany*

Electron spin qubits in dilute nuclear-spin materials now rank among the most coherent systems for quantum information processing. However, a number of challenges remain on the way to a scalable spin-based qubit architecture. Here, we address the need for fast and robust quantum gates between spin qubits, both local and non-local, from a theoretical point of view. Recent progress in realizing electrically driven two-qubit gates for electron spins in adjacent silicon quantum dots in a magnetic-field gradient [1] has motivated several further conceptual advances, such as the synchronized controlled-NOT gate [2].

The placement of a double quantum dot filled with a single electron into a field gradient endows the electron spin with a large and controllable electric dipole. Our theoretical analysis shows that in combination with a superconducting microwave resonator, the induced spin-photon coupling makes the strong-coupling regime of cavity quantum electrodynamics attainable [3], in agreement with a recent experiment demonstrating spin-cavity strong coupling [4].

While electrical control and cavity coupling for spin-1/2 qubits can be achieved using magnetic field gradients [1–4], multi-spin qubits allow for all-electric control purely on the basis of the Pauli exclusion principle, in the form of both local gates and non-local coupling to a superconducting microwave resonator [5,6]. However, the electric controllability of spin qubits is typically accompanied by an increased sensitivity of the spin qubit to electric noise. We have analyzed this effect and have identified suitable points in parameter space, so-called sweet spots, where qubits are optimally shielded from electrical noise [5,6].

We finally highlight the extraordinarily long coherence time of defect spins in diamond and present a method for their electric-dipole control using optical fields [7]. Recently, we have found that the use of geometric phases allows for the implementation of robust all-optical holonomic single-qubit gates [8]. Looking further ahead, we describe a mechanism for electrically controlled non-local quantum gates between defect spins coupled to an optical cavity [9].

[1] D. M. Zajac, A. J. Sigillito, M. Russ, F. Borjans, J. M. Taylor, G. Burkard, and J. R. Petta, arXiv:1708.03530 (2017).
[2] M. Russ, J. M. Taylor, D. M. Zajac, A. J. Sigillito, F. Borjans, J. R. Petta, and G. Burkard, in preparation.
[3] M. Benito, X. Mi, J. M. Taylor, J. R. Petta, and G. Burkard, arXiv:1710.02508 (2017).
[4] X. Mi, M. Benito, S. Putz, D. M. Zajac, J. M. Taylor, G. Burkard, and J. R. Petta, submitted for publication.
[5] M. Russ and G. Burkard, Journal of Physics: Condensed Matter (Topical Review) 29, 393001 (2017).
[6] M. Russ, F. Ginzel, and G. Burkard, Phys. Rev. B 94, 165411 (2016).
[7] C. G. Yale, B. B. Buckley, D. J. Christle, G. Burkard, F. J. Heremans, L. C. Bassett, and D. D. Awschalom, PNAS 110, 7595 (2013).
[8] B. B. Zhou, P.C. Jerger, V. O. Shkolnikov, J. F. Heremans, G. Burkard, and D. D. Awschalom, Phys. Rev. Lett. 119, 140503 (2017).
[9] G. Burkard, V. O. Shkolnikov, and D. D. Awschalom, Phys. Rev. B 95, 205420 (2017).