Hole Spin-Photon Coupling in Silicon and Germanium Double Quantum Dots

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In recent years, there has been tremendous progress in systems capable of probing and harnessing spin degrees of freedom in solid-state environments. Notably, hybrid architectures have experimentally demonstrated the potential to strongly couple single photons confined in superconducting resonators with the spin of single electrons or holes in quantum dots. These experiments provide significant opportunities for the development of novel hybrid circuit Quantum Electrodynamics (cQED) architectures, wherein photons can probe, entangle, and control the states of multiple spins.

Here we model cQED systems comprising a silicon or germanium double quantum dot hosting a single hole and a resonator coupled to one of the dots, and assess the strength of spin-photon coupling. For that purpose, we devise a methodology to extract the relevant parameters of the double dot from numerical finite difference calculations (g-tensors, detuning, spin-conserving and spin-flipping tunnel couplings), and to tune the device to a suitable sweet spot. We analyze the physics of the spin-photon interactions in both materials. In planar germanium heterostructures, the spin-photon coupling is dominated by the difference between the g-tensors of the two dots due to the asymmetries and to the inhomogeneous cool-down strains in the system. Significant spin-photon couplings ($>$ 100 MHz) can be achieved for in-plane magnetic fields with a proper engineering of the devices. In silicon MOS devices, linear Rashba spin-orbit interactions may dominate spin-photon coupling for strongly squeezed dots, as shown experimentally[1].

References

[1] C. Yu et al., Nature Nanotechnology 18, 741(2023)