Hybrid magnonics as a unique platform for spin center-based quantum technologies (in-depth report)

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Recently, spin centers in solids have attracted significant attention due to their applications to quantum information science. However, to be able to create entanglement between NVs one requires having NVs coupled to each other. Unfortunately, the bare interaction between two NV centers is week for separations > 20 nm. This creates a key challenge once NV centers cannot be optically resolvable at these distances. Therefore, providing alternative schemes to couple two NV centers over long distances became crucial to enable their use in quantum computation.

Here, we first propose hybrid quantum systems [Fig. 1(a)] that couple and entangle spin centers over micron length scales through the quantized spin-wave excitations (magnons) of a magnetic material [1,2]. These magnons serve as a quantum bus that transfers the information between different NV-qubits. We predict strong long-distance (μm) NV-NV coupling via magnon modes with cooperativities exceeding unity in ferromagnetic bar, waveguide and cylindrical structures [1, 2]. Moreover, we explore and compare on-resonant transduction and off-resonant virtual-magnon exchange protocols [Fig. 1(b)], and discuss their suitability for generating or manipulating entangled states under realistic experimental conditions [2]. Due to the absence of magnon occupation decay of the off-resonant protocol, our results show this protocol is robust at temperatures up to T≈150mK [2]. Conversely, at lower temperatures the on-resonant protocol shows a faster gate operation, and can even outperform the off-resonance protocol for small magnon damping parameters [2]. Secondly, we experimentally determine the NV-NV coupling mediated by magnons for a diamond slab on top of a YIG bar [3]. This is obtained through the magnon-induced self-energy of the NV center, obtained by combining room-temperature longitudinal relaxometry [Fig. 1(d)] and an analysis using the fluctuation-dissipation and Kramers-Kronig relations [3]. We show our results are quantitatively consistent with the model [1,2] where NV centers are coupled to magnons by the dipole interaction. This work is supported by the U.S. Department of Energy, Office of Basic Energy Sciences under Award Number DE-SC0019250, the U.S. Department of Energy, Office of Science, National Quantum Information Science Research Centers and the Vannevar Bush Faculty Fellowship ONR N00014-17-1-3026. ; the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division with additional support from Q-NEXT, a U.S. Department of Energy Office of Science National Quantum Information Science Research Centers and

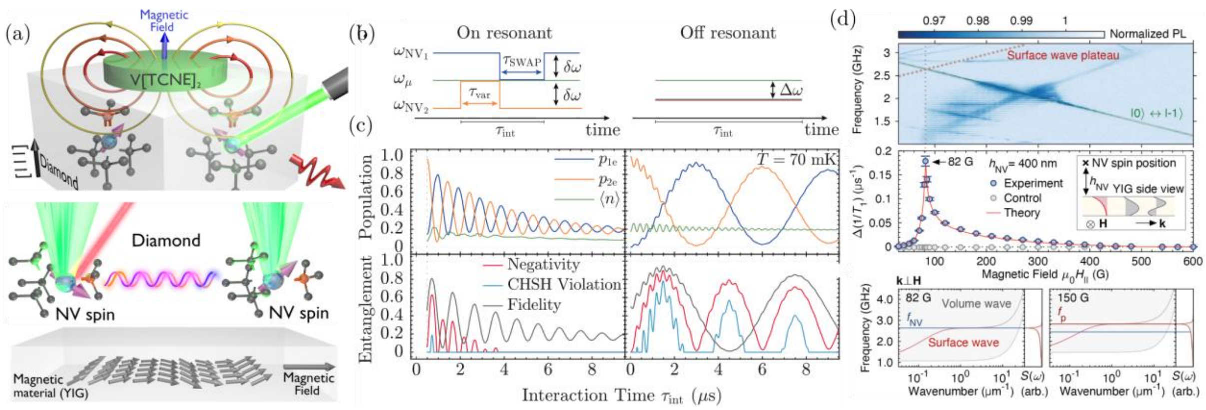

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Figure 1: (a) Quantum-coherent coupling between different NV-center spins through magnon mode. (b) On and off-resonant entanglement protocols. (c) Comparison of the two protocols at T = 70 mK for entanglement negativity scaled by the fidelity, Bell's negativity, the degree of the Bell inequality violation. (d)

Comparison between theory and experimental data on the surface-magnon induced longitudinal relaxation.

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