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Quantum coherent interface of an electron and a nuclear ensemble

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Abstract

We implement an all-optical access to the quantized electronic-nuclear spin transitions in a semiconductor quantum dot, and we perform coherent rotations of a collective nuclear spin excitation corresponding to a spin-wave called a nuclear magnon.

Collective excitations of isolated many-body systems generate useful entanglement and offer the opportunity to control complex quantum dynamics. A simple quantum system, such as a central spin[1], can act as a probe and a control over a larger and more complex quantum system in ways otherwise inaccessible, and can help us perform spectroscopy and engineering over its quantum dynamics[2]. Driving the central spin can stimulate exchange of energy with its surrounding spins, and thus modify the mean-field state of its own environment. In this work, we engineer this very interaction between an InGaAs quantum dot electron spin and its isolated ensemble of nuclear spins in a driven-dissipative regime to remove entropic heat from the ensemble, and so vastly reduce the mean-field state uncertainty tied to its thermal fluctuations[3, 4]. Having cooled the system, we reveal an absorption spectrum of transitions between many-body states that are collectively-enhanced by the creation of single spin-wave excitations – nuclear magnons. Resonantly driving such a transition, we stimulate a coherent interaction between the electron and the nuclear spin ensemble, which is consistent with the controlled creation of entanglement among all constituent particles[4]. These results constitute the building blocks of a local dedicated memory for a quantum-dot spin qubit and inaugurate a new solid-state venue for quantum-state engineering of isolated many-body systems.

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