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Control of electron spin decoherence in nuclear spin baths[1]

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Nuclear spin baths are a main mechanism of decoherence of spin qubits in solid-state systems, such as quantum dots and nitrogen-vacancy (NV) centers of diamond. The decoherence results from entanglement between the electron and nuclear spins, established by quantum evolution of the bath conditioned on the electron spin state. When the electron spin is flipped, the conditional bath evolution is manipulated. Such manipulation of bath through control of the electron spin not only leads to preservation of the center spin coherence but also demonstrates quantum nature of the bath. In an NV center system, the electron spin effectively interacts with hundreds of ^{13}C nuclear spins. Under repeated flip control (dynamical decoupling), the electron spin coherence can be preserved for a long time (>1 ms). Therefore some characteristic oscillations, due to coupling to a bonded ^{13}C nuclear spin pair (a dimer), are imprinted on the electron spin coherence profile, which are very sensitive to the position and orientation of the dimer. With such finger-print oscillations, a dimer can be uniquely identified. Thus, we propose magnetometry with single-nucleus sensitivity and atomic resolution, using NV center spin coherence to identify single molecules. Through the center spin coherence, we could also explore the many-body physics in an interacting spin bath. The information of elementary excitations and many-body correlations can be extracted from the center spin coherence under many-pulse dynamical decoupling control. Another application of the preserved spin coherence is identifying quantumness of a spin bath through the back-action of the electron spin to the bath. We show that the multiple transition of an NV center in a nuclear spin bath can have longer coherence time than the single transition does, when the classical noises due to inhomogeneous broadening is removed by spin echo. This counter-intuitive result unambiguously demonstrates the quantumness of the nuclear spin bath.

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