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Coherent control over diamond nitrogen-vacancy center spins with a mechanical resonator[1]

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We demonstrate coherent Rabi oscillations of diamond nitrogen-vacancy (NV) center spins driven directly by a mechanical resonator without mediation by a magnetic driving field. Using a bulk-mode acoustic resonator fabricated from single crystal diamond, we exert non-axial ac stress on NV centers positioned at an antinode of a gigahertz frequency mechanical mode. When the $\Delta m_s = -1$ to $+1$ spin state splitting energy is tuned into resonance with a driven mechanical mode, we observe $\Delta m_s = \pm 2$ spin transitions, which are forbidden by the magnetic dipole selection rule. To rule out stray electric and magnetic fields as the origin of these spin transitions, we study the spin signal as a function depth within the diamond resonator. We find that the spin signal reproduces the periodicity of the acoustic standing wave, confirming the mechanical origin of the observed spin resonance [1]. Using single-crystal diamond mechanical resonators with fQ products of 2×10^{12}, we observe coherent mechanically driven Rabi oscillations up to 4 MHz [2]. For ensembles of NV centers coupled to the resonator, we analyze Rabi oscillations and their dephasing with a combination of spatially inhomogeneous mechanical driving and fluctuating magnetic fields from a noisy spin environment. Additionally, we examine the coherence of mechanically controlled NV center qubits and compare it to the coherence of magnetically controlled spin qubits in the NV center ground state spin manifold. This work demonstrates direct and coherent coupling between NV center spins and resonator phonons, which has potential for NV-based metrology using hybrid spin-mechanical sensors, fundamental research into spin-phonon interactions at the nanoscale, and as a platform for hybrid spin-mechanical quantum systems. [1] E. R. MacQuarrie *et al.*, Phys. Rev. Lett. **111**, 227602 (2013). [2] E. R. MacQuarrie *et al.*, arXiv:1411.5325 (2014).

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