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Optical control and coherence of electron or hole spins in coupled quantum dots

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The spin of an electron or hole in an InAs quantum dot is an attractive qubit because it combines the advantages of a semiconductor platform with the power of ultrafast optical coherent control techniques. In the last few years, basic quantum operations such as initialization, rotation, and readout have become possible using single spins, but now improvements in spin coherence and demonstrations of multi-qubit systems are needed. In this work, we combine advances in the design and growth of coupled quantum dots with optical coherent control techniques to demonstrate ultrafast manipulation and coherence improvements for one or two interacting electron [1] or hole [2] spins in a coupled pair of InAs dots. For each of these spin systems, we use a sequence of picosecond and nanosecond pulses to initialize, manipulate, and measure the coherent spin dynamics. These dynamics include precession about a magnetic field and also entangling dynamics from the exchange interaction for coupled spins. For a single electron spin, precession dephases after only a few nanoseconds due to the hyperfine interaction with nuclear spins. For hole spins, we measure a dephasing time an order of magnitude longer due to a weaker hyperfine interaction. Coupled electron and hole spins are essential for multi-qubit systems, and they can also be used to decrease sensitivity to the environment. In these systems, we typically measure the coherent dynamics of the singlet-triplet states ($m_s = 0$), which are much less sensitive to the nuclear environment. At present, dephasing is due to fluctuations in the electrical environment. With careful sample design, we can make these systems much less sensitive to electrical fluctuations, giving a powerful combination of long coherence times and ultrafast gates. Finally, we demonstrate that these spin qubits can be incorporated into a photonic crystal cavity and manipulated with optical pulses, a major step toward a quantum interface between photons and these spin qubits.

[1] D. Kim *et al.*, Nature Phys. **7**, 223 (2011).
[2] A. Greilich *et al.*, Nature Photon. **5**, 702 (2011).