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Ultrafast optical coherent control of individual electron and hole spins in a semiconductor quantum dot

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We report on the complete optical coherent control of individual electron and hole spin qubits in InAs quantum dots. With a magnetic field in Voigt geometry, broadband, detuned optical pulses couple the spin-split ground states, resulting in Rabi flopping. In combination with the Larmor precession around the external magnetic field, this allows an arbitrary single-qubit operation to be realized in less than 20 picoseconds [1,2]. Slow fluctuations in the spin's environment lead to shot-to-shot variations in the Larmor precession frequency. In a time-ensemble measurement, these would prevent a measurement of the true decoherence of the qubit, and instead give rise to ensemble dephasing. This effect was overcome by implementing a spin echo measurement scheme for both electron and hole spins, where an optical π-pulse refocuses the spin coherence and filters out the slow variations in Larmor precession frequency. We measured coherence times up to 3 microseconds [2,3]. Finally, our optical pulse manipulation scheme allows us to probe the hyperfine interaction between the single spin and the nuclei in the quantum dot. Interesting non-Markovian dynamics could be observed in the free-induction decay of a single electron spin, whereas the complete absence of such effects illustrates the reduction of the hyperfine interaction for hole spin qubits. We measured and modeled these effects, and explain the non-Markovian electron spin dynamics as involving a feedback effect resulting from both the strong Overhauser shift of the electron spin and spin dependent nuclear relaxation [2,4].

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