Microsecond dynamics of electron and hole spin qubits in self-assembled quantum dots.

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It is by now well established that the hyperfine coupling with nuclear spin bath governs spin dynamics and loss of coherence in III-V quantum dots (QDs) [1-4]. However, the mechanisms by which coherence is ultimately lost, for *both* electron and holes, remain subject to active investigation. We present optical studies of the dynamics of electron and hole spins in individual dots over time-scales up to $\geq 100\mu s$ [5]. For *electron* spin qubits at zero magnetic field, our results show that relaxation proceeds over several distinct regimes; a first stage over the first few nanoseconds arising from coherent spin dynamics in the randomly orientated quasi-static Overhauser field, a second stage occurring over several hundred nanoseconds reflecting the quadrupolar evolution of the nuclear spin bath and third stage in which the spin decays very towards to the longest timescales investigated ($\sim 100\mu s$). Traditional approaches to probe spin-coherence involve coherent control using e.g. spin-echo pulse sequences. At $B = 4$ T we observe an exponential decay of the spin-echo signal corresponding to $T_2^{echo} \sim 1.4\mu$s that gives way to a pronounced oscillatory dependence at lower field, a signature of hyperfine dynamics of the nuclear spin bath. Measurement of higher order spin temporal correlators such as $g^3({}_1, {}_2)$, is shown to facilitate the direct determination of $T_2 \sim 1.5\mu$s and $T_2^* \sim 2$ ns for the electron, without coherent spin control [6,7]. Hole spin qubits in III-V QDs have a fundamentally different hyperfine interaction than electrons. The valence states have p-like character with vanishing amplitude at the position of the nuclei. The Fermi *contact* hyperfine interaction is, therefore, strongly suppressed [8-10], while the dipolar part of the hyperfine interaction remains [11,12]. This is expected to lead to much *slower* hole-spin dynamics in an anisotropic effective nuclear field, an expectation supported by recent CPT experiments [10]. We have probed the dynamics of single hole at $B = 0$T over timescales extending up to ~ 0.1 ms. After preparing the hole $\langle S_z \rangle = 1$, we observe no dynamics up to $\sim 50ns$, followed by an exponential decay before saturating at $\langle S_z \rangle \sim 0.3$ for timescales $\geq 50\mu s$. We will discuss the implications of this result for hole spin qubits in optically active quantum dots.

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