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# Nuclear spin decoherence of neutral $^{31}$P donors in silicon: Effect of environmental $^{29}$Si nuclei

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Spectral diffusion arising from $^{29}$Si nuclear spin flip-flops, known to be a primary source of electron spin decoherence in silicon, is also predicted to limit the coherence times of neutral donor nuclear spins in silicon. Here, the impact of this mechanism on $^{31}$P nuclear spin coherence is measured as a function of $^{29}$Si concentration using *X*-band pulsed electron nuclear double resonance. The $^{31}$P nuclear spin echo decays show that decoherence is controlled by $^{29}$Si flip-flops resulting in both fast (exponential) and slow (nonexponential) spectral diffusion processes. The decay times span a range from 100 ms in crystals containing 50% $^{29}$Si to 3 s in crystals containing 1% $^{29}$Si. These nuclear spin echo decay times for donors are orders of magnitude longer than those reported for donors in natural silicon. The electron spin of the neutral donors "protects" the donor nuclear spins by suppressing $^{29}$Si flip-flops within a 7frozen core," a-230(flip-7.ar)]TJ-8.067Tulti of

exponential and nonexponential components are present in the decays.

The $^{31}$P nuclear spin coherence time in natural silicon presented here is longer than measured earlier for ionized donors or donors in degenerately doped silicon. NMR measurements of $^{31}$P nuclear spin decoherence in degenerately doped silicon have found times about two orders of magnitude shorter [14,15]. Ionized donors measured with EDMR had a coherence time of 18 ms [16], and single donors measured with an SET had a coherence time of 60 ms [17]. These measurements of ionized donors are in agreement with cluster correlation expansion simulations by Witzel . ($\sim$ 30 ms) [32]. The longer coherence time for our isolated neutral $^{31}$P donors supports the "frozen core" picture [19–21] where most $^{29}$Si pairs near a central spin are too detuned by the donor electron spin to flip-flop.

In conclusion, we have experimentally studied the effect of environmental $^{29}$Si nuclear spins on neutral donor nuclear spin decoherence in silicon. Two contributors have been resolved arising from fast and slow flip-flopping $^{29}$Si nuclear spin pairs. We find that both contributions exhibit a linear dependence on $^{29}$Si concentration. Our results demonstrate long coherence times for neutral donor nuclear spins, ranging from 100 ms in crystals containing 50% $^{29}$Si to 3 s in crystals containing 1% $^{29}$Si, and are in agreement with the picture that an electron