Quantum Point Defects in Wide Band Gap Semiconductors: Donor Properties in ZnO and Charge States of Diamond

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Quantum point defects which exhibit both spin and optically active states are attractive qubit candidates for quantum sensing and network technologies. Here we present progress on two qubit systems: shallow donors in ZnO and deep vacancy-related defects in diamond.

In direct band-gap semiconductors, the bound-electron spin states of shallow donors forming the qubit states can be optically accessed via the donor-bound exciton (D^0X) with high radiative efficiency. We have recently measured the optical and coherence properties of In defects in ZnO, *in situ* doped and formed by implantation and annealing. We observe an inhomogeneous linewidth of several GHz [1], longitudinal spin lifetimes up to 0.5 s [2] and coherence times up to 50 μs which are limited by substrate purity [3]. Two-laser spectroscopy also reveals the large, 100 MHz hyperfine coupling of the In electron spin-1/2 to the In nuclear spin- 9/2 [4]. Thus, there is a path toward deterministic formation of In donors with access to a nuclear spin memory. Further, we have demonstrated isolation of single In donors by probing only a small sample volume [5]. We further investigate the role of substrate purity by studying In donors fabricated in high-purity ZnO grown by molecular beam epitaxy. Finally, we discuss the outlook for new defect centers in an ultra-pure ZnO host.

A fundamental property that must be controlled in any defect-based technology is the charge state. We demonstrate the use of deep-ultraviolet (DUV) radiation to dynamically neutralize nitrogen- (NV) and silicon-vacancy (SiV) centers in diamond [6]. We first examine the conversion between the neutral and negatively charged NV states by correlating the variation of their respective spectra, indicating that more than 99% of the population of NV centers can be initialized into the neutral charge state. We then examine the time dynamics of bleaching and recharging of negatively charged SiV^- centers and observe an 80% reduction in SiV^- photoluminescence within a single 100-μs DUV pulse. Finally, we demonstrate that the bleaching of SiV^- induced by the DUV is accompanied by a dramatic increase in the neutral SiV^0 population; SiV^0 remains robust to extended periods of near-infrared excitation despite being a non-equilibrium state. Our results on two separate color centers at technologically relevant temperatures indicate a potential for above-band-gap excitation as a universal means of generating the neutral charge states of quantum point defects on demand.

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