Hole hyperfine interaction: valence band orbital composition and its effect on hole spin dephasing

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Decoherence caused by nuclear field fluctuations is a fundamental obstacle to the realization of quantum information processing using single electron spins. Alternative proposals have been made to use spin qubits based on valence band holes having weaker hyperfine coupling. However, it was demonstrated recently both theoretically [1, 2] and experimentally [3, 4] that the hole hyperfine interaction is not negligible, although a consistent picture of the mechanism controlling the magnitude of the hole-nuclear coupling is still lacking. We address this problem by performing element selective measurement of the valence band hyperfine coupling in InGaAs/GaAs, InP/GaInP and GaAs/AlGaAs quantum dots [5], enabled by recent progress in nuclear magnetic resonance in semiconductor nanostructures [6,7]. Contrary to existing models [1, 2] we find that the hole hyperfine constant along the growth direction of the structure (normalized by the electron hyperfine constant) has opposite signs for different isotopes - positive for anions (phosphoros, arsenic) and negative for cation (gallium, indium) - and ranges from −15% to +15%. We attribute such changes in hole hyperfine constants to the competing positive contributions of *p*-symmetry atomic orbitals and the negative contributions of *d*-orbitals. Furthermore, we find that the *d*-symmetry contribution leads to a new mechanism for hole-nuclear spin flips which may play an important role in hole spin decoherence. In addition the measured hyperfine constants enable a fundamentally new approach for verification of the computed Bloch wavefunctions in the vicinity of nuclei in semiconductor nanostructures.

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