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Semiconductor Spin-Qubit Arrays for Axion Dark Matter Search

Axions and axion-like particles are compelling dark-matter candidates whose derivative couplings to fermion spins generate an oscillatory, spin-dependent effective field, often referred to as the axion wind. This talk explores semiconductor quantum-dot spin qubits as frequency-resolved quantum sensors for axion-induced spin dynamics and, more broadly, as a platform for weak-field detection at the nanoscale. By mapping the axion–spin interaction or other weak effective-field perturbations onto controlled phase accumulation in coherent spin-qubit protocols, semiconductor devices provide a tunable architecture in which coherence time, control bandwidth, sensor filter functions, and readout fidelity can be engineered for narrowband sensing. I will discuss how spectral engineering of spin-qubit control sequences can enhance sensitivity within targeted axion-mass windows while suppressing charge noise, magnetic noise, and control-induced backgrounds. Particular emphasis will be placed on realistic noise spectra, quantum-control filter functions, weak field sensitivity limits, and the resulting coupling reach. Beyond sensitivity optimization, I will show how the motion of the terrestrial laboratory through the Galactic dark-matter halo produces characteristic sidereal and annual modulation signatures, leading to structured sideband responses that provide a robust discriminator against stationary instrumental backgrounds. Finally, I will outline prospects for hybrid electronic–nuclear spin architectures, where long-lived nuclear coherence can be combined with fast electronic-spin initialization and readout through hyperfine-mediated transduction, offering a scalable and CMOS-compatible route toward chip-integrated weak field sensing, axion searches, and broader quantum-enabled dark-matter detection.

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