Fluorine-doped ZnSe for Applications in Quantum Information Processing

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Quantum information technology promises revolutionary new capabilities in efficient computation and absolutely secure communication. However, the development of large-scale quantum computers and quantum communication networks requires new technologies in which scalable devices exhibit pronounced quantum interference effects, long quantum coherence times, and compatibility with optical networks.

Impurities in appropriately engineered II-VI semiconductors show strong promise for providing the needed elements for quantum information processing. The direct bandgap in these materials offers high oscillator strengths for optical transitions related to impurity-bound-excitons, and the larger binding energies in contrast to III-V-based devices allow single impurity isolation by nanofabrication. Impurity-related emission shows far less inhomogeneous broadening than quantum-dot-related emission, which enables scalability to many optically connected devices. Critically, the nuclear spins of II-VI materials may be isotopically depleted, which has led to long spin coherence times in optically-dark silicon but is impossible in III-V devices. Finally, the ability to alloy different II-VI materials and lattice-match to GaAs substrates allows a degree of engineering unavailable in other materials under consideration for quantum computers, such as diamond or rare-earth crystals.

We present several experiments indicating the viability of fluorine donors in ZnSe/ZnMgSe quantum wells for quantum information devices. First, we show that single emitters may be isolated in nanometer-scale structures and that they may efficiently emit one photon at a time; such a single-photon source is a critical ingredient of secure quantum communication protocols and quantum computers based on photonic qubits. Then, we show that two independent \textsuperscript{19}F:ZnSe devices emit photons that bunch on a beam-splitter, a quantum interference effect which enables photonic quantum computation schemes and allows the entanglement of distant electron spins bound to fluorine donors. Further, we characterize these single photon-sources via single-impurity optical spectroscopy in high magnetic field, revealing the needed spin structure for quantum information processing protocols. Finally, we show progress in coupling these same impurities to high-$Q$ microdisk optical resonators, demonstrating low-threshold lasing on the donor-bound-exciton transitions \cite{1}. Such cavities will also be critical for providing efficient photonic wiring in potential quantum computers. Finally, we present ongoing experiments on the measurement of electron and nuclear spin coherence times for this important impurity.