Manipulating Quantum Information with Semiconductor Spintronics

David D. Awschalom

Department of Physics, University of California, Santa Barbara, CA 93106

ABSTRACT:

There is a growing interest in the use of electronic and nuclear spin in nanostructures as a medium for the manipulation and storage of classical and quantum information. Spin-based electronics offers remarkable opportunities for a new generation of quantum magneto-electronic devices combining standard microelectronics with spin-dependent effects that arise from the interaction between electrons, nuclei, and electric or magnetic fields. Here we provide an overview of recent scientific developments in coherent electronic spin dynamics in semiconductors and quantum structures, including a discussion of the temporally- and spatially-resolved magneto-optical experiments in new classes of hybrid magnetic/semiconductor materials. Femtosecond-resolved experiments reveal a surprising resilience of electronic spin states to environmental decoherence in a variety of bulk semiconductors, heterostructures, and quantum dots [1]. Spin lifetimes can exceed hundreds of nanoseconds, enabling the transport of coherent spin packets over hundreds of microns. Interfaces appear surprisingly permeable over a broad range of temperatures, and the transport of spin information can be controlled with both electric and magnetic fields. To manipulate these states, we have developed techniques with the potential for coherent electrical manipulation [2] or all-optical control [3] over electron spins in nanostructures on femtosecond time scales.

Nuclear spin lifetimes, that are orders of magnitude longer than those of electrons, may ultimately enable long-term storage of quantum information. Local manipulation of nuclei can be achieved by periodic optical excitation of precessing electrons that surround the atomic sites. Changes in the magnetization of resonantly tipped nuclei demonstrate the ability to perform all-optical nuclear magnetic resonance (NMR) [4]. This sensitive and spatially selective NMR technique may serve as a basis for the coherent manipulation of nuclear moments at the atomic level. Finally, the capability to integrate ferromagnetism within semiconductor nanostructures may create new schemes for operating on electron and nuclear spins [5,6]. The results point towards promising opportunities to combine logic, storage, and communication for future multifunctional quantum mechanical electronics that incorporate electronics, magnetics, and photonics.

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1. S.A. Wolf et al., "Spintronics: a spin-based electronics vision for the future", Science 294, 1488 (2001)

2. G. Salis et al., "Optical manipulation of nuclear spin by a two-dimensional electron gas," Phys. Rev. Lett. 86, 2677 (2001)

3. J.A. Gupta et al., "Ultrafast manipulation of electron spin coherence," Science 292, 2458 (2001).

4. G. Salis et al., "Electrical control of spin coherence in semiconductor nanostructures", Nature 414, 619 (2001).

5. R.K. Kawakami et al., "Ferromagnetic imprinting of nuclear spins in semiconductors," Science 294, 131 (2001).

6. R. J. Epstein et al., "Spontaneous Spin Coherence in n-GaAs Produced by Ferromagnetic Proximity Polarization", Phys. Rev. B 65, 121202(R) (2002).