Designing nanoscale solid state systems for quantum information processing

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Quantum processing of information requires the development of quantum systems that are at the same time coherent and quantum in nature, and yet easily manipulated to process and extract classical information. To meet this challenge we have embarked on the development of technologies which would allow us to design and build nano-scale scalable and coherent solid state systems[1] using elementary building blocks such as single electron spins, single excitons, and single photons using semiconductor quantum dots. We show how gated quantum dots allow to localize individual electrons, control their spin properties by their number, form of confinement, and the magnetic field, enabling nano-spintronics.[2] The spin can be probed and exploited by connecting quantum dots to spin polarized reservoirs. The resulting spectroscopic tool, the spin blockade spectroscopy, will be described as well as a prototype nano-spintronic device, the "single spin transistor".[2] By combining the single spin transistors into coherently coupled devices we are attempting to build an electron spin-based quantum computer.

I will describe double and triple quantum dots and extrapolate to the exciting physics such new capabilities enable. In order to combine the control over spin with the control over photons we need to confine both electrons and valence holes. This is done by transferring the gated technology to self-assembled quantum dots. I will review progress in our understanding of the electronic and optical properties of InAs-based self-assembled quantum dots[3] emitting at 1.5 μm. By combining lithography with self-assembly, single InAs dots can be positioned on InP nanotemplates. This control allows integration of quantum dots with photonic cavities and opens up possibility of "manufacturing" a single photon gun for quantum cryptography and communication. Finally, building on the newly acquired capabilities with quantum dots, we will venture into combining information processing and storage using quantum dots containing both electrons and magnetic ions, a step toward control of magnetism on nanoscale.[4]

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