Dynamic nuclear polarization in InGaAs/GaAs and GaAs/AlGaAs quantum dots under non-resonant ultra-low power optical excitation

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We study experimentally the dependence of dynamic nuclear spin polarization on the power of non-resonant optical excitation in two types of individual neutral semiconductor quantum dots: InGaAs/GaAs and GaAs/AlGaAs. We show that the mechanism of nuclear spin pumping via second order recombination of optically forbidden ("dark") exciton states recently reported in InP/GaInP quantum dots [Phys. Rev. B 83, 125318 (2011)] is relevant for material systems considered in this work. In the InGaAs/GaAs dots this nuclear spin polarization mechanism is particularly pronounced, resulting in Overhauser shifts up to ~80 micro-eV achieved at optical excitation power ~1000 times smaller than the power required to saturate ground state excitons. The Overhauser shifts observed at low-power optical pumping in the interface GaAs/AlGaAs dots are generally found to be smaller (up to ~40 micro-eV). Furthermore in GaAs/AlGaAs we observe dot-to-dot variation and even sign reversal of the Overhauser shift which is attributed to dark-bright exciton mixing originating from electron-hole exchange interaction in dots with reduced symmetry. Nuclear spin polarization degrees reported in this work under ultra-low power optical pumping are comparable to those achieved by techniques such as resonant optical pumping or above-gap pumping with high power circularly polarized light. Dynamic nuclear polarization via second-order recombination of "dark" excitons may become a useful tool in single quantum dot applications, where manipulation of the nuclear spin environment or electron spin is required.

Circuit QED with Hole-Spin Qubits in Ge/Si Nanowire Quantum Dots

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We propose a setup for universal and electrically controlled quantum information processing with hole spins in Ge/Si core/shell nanowire quantum dots (NW QDs). Single-qubit gates can be driven through electric-dipole-induced spin resonance, with spin-flip times shorter than 100 ps. Long-distance qubit-qubit coupling can be mediated by the cavity electric field of a superconducting transmission line resonator, where we show that operation times below 20 ns seem feasible for the entangling square-root-of-iSWAP gate. The absence of Dresselhaus spin-orbit interaction (SOI) and the presence of an unusually strong Rashba-type SOI enable precise control over the transverse qubit coupling via an externally applied, perpendicular electric field. The latter serves as an on-off switch for quantum gates and also provides control over the g factor, so that single- and two-qubit gates can be operated independently. Remarkably, we find that idle states are insensitive to charge noise and phonons, and we discuss strategies for enhancing noise-limited gate fidelities.

A phonon laser utilizing quantum-dot spin states

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We propose a nano-scale realization of a phonon laser utilizing phonon-assisted spin flips in quantum dots to amplify sound. Owing to a long spin relaxation time, the device can be operated in a strong pumping regime, in which the population inversion is close to its maximal value allowed under Fermi statistics. In this regime, the threshold for stimulated emission is unaffected by spontaneous spin flips. Considering a nanowire with quantum dots defined along its length, we show that a further improvement arises from confining the phonons to one dimension, and thus reducing the number of phonon modes available for spontaneous emission. Our work calls for the development of nanowire-based, high-finesse phonon resonators.

Decay dynamics and exciton localization in large GaAs quantum dots grown by droplet epitaxy

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(Submitted on 28 Jun 2013)

We investigate the optical emission and decay dynamics of excitons confined in large strain-free GaAs quantum dots grown by droplet epitaxy. From time-resolved measurements combined with a theoretical model we show that droplet-epitaxy quantum dots have a quantum efficiency of about 75% and an oscillator strength between 8 and 10. The quantum dots are found to be fully described by a model for strongly-confined excitons, in contrast to the theoretical prediction that excitons in large quantum dots exhibit the so-called giant oscillator strength. We attribute these findings to localized ground-state excitons in potential minima created by material intermixing during growth. We provide further evidence for the strong-confinement regime of excitons by extracting the size of electron and hole wavefunctions from the phonon-broadened photoluminescence spectra. Furthermore, we explore the temperature dependence of the decay dynamics and, for some quantum dots, observe a pronounced reduction in the effective transition strength with temperature. We quantify

and explain these effects as being an intrinsic property of large quantum dots owing to thermal excitation of the ground-state exciton. Our results provide a detailed understanding of the optical properties of large quantum dots in general, and of quantum dots grown by droplet epitaxy in particular.

Observation of the SU(4) Kondo state in a double quantum dot

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Central to condensed matter physics are quantum impurity models, which describe how a local degree of freedom interacts with a continuum. Surprisingly, these models are often universal in that they can quantitatively describe many outwardly unrelated physical systems. Here we develop a double quantum dot-based experimental realization of the SU(4) Kondo model, which describes the maximally symmetric screening of a local four-fold degeneracy. As demonstrated through transport measurements and detailed numerical renormalization group calculations, our device affords exquisite control over orbital and spin physics. Because the two quantum dots are coupled only capacitively, we can achieve orbital state- or "pseudospin"-resolved bias spectroscopy, providing intimate access to the interplay of spin and orbital Kondo effects. This cannot be achieved in the few other systems realizing the SU(4) Kondo state.

Dynamical spin-spin coupling of quantum dots

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(Submitted on 25 Jun 2013)

We carried out a nested Schrieffer-Wolff transformation of an Anderson two-impurity Hamiltonian to study the spin-spin coupling between two dynamical quantum dots under the influence of rotating transverse magnetic field. As a result of the rotating field, we predict a novel Ising type spin-spin coupling mechanism between quantum dots, whose strength is tunable via the magnitude of the rotating field. Due to its dynamical origin, this new coupling mechanism is qualitatively different from the all existing static couplings such as RKKY, while the strength could be comparable to the strength of the RKKY coupling.

Tomography of a spin qubit in a double quantum dot

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(Submitted on 5 Jun 2013)

We investigate a range of methods to perform tomography in a solid-state qubit device, for which a priori initialization and measurement of the qubit is restricted to a single basis of the Bloch sphere. We explore and compare several methods to acquire precise descriptions of additional states and measurements, quantifying both stochastic and systematic errors, ultimately leading to a tomographically-complete set that can be subsequently used in process tomography. We focus in detail on the example of a spin qubit formed by the singlet-triplet subspace of two electron spins in a GaAs double quantum dot, although our approach is quite general.

Stimulated Phonon Emission in a Driven Double Quantum Dot

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(Submitted on 26 May 2013)

The compound semiconductor gallium arsenide (GaAs) provides an ultra-clean platform for storing and manipulating quantum information, encoded in the charge or spin states of electrons confined in nanostructures. The absence of inversion symmetry in the zinc-blende crystal structure of GaAs however, results in strong piezoelectric coupling between lattice acoustic phonons and electrons, a potential hindrance for quantum computing architectures that can be charge-sensitive during certain operations. Here we examine phonon generation in a GaAs double dot, configured as a single- or two-electron charge qubit, and driven by the application of microwaves via surface gates. In a process that is a microwave analog of the Raman effect, stimulated phonon emission is shown to produce population inversion of a two-level system and provides spectroscopic signatures of the phononic environment created by the nanoscale device geometry.