Opto-spintronics

Open theoretical issues

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Large, and tunable coupling strengths in spin-orbit interaction is a mechanism for coupling to optics. Large optical matrix elements in quantum dots enable tunable properties - composition, structure, gates (DC Stark effect). Very large parameter space constructed from a very small number of building blocks. Significant and long-lived final-state interactions like excitons, plasmons result in very large nonlinear optical effects such as AC Stark shifts and strong-field splittings. Carrier-mediated magnetism offers another handle to manipulate magnetism, through ultrafast manipulation of carriers. Optospintronic features of semiconductors...
Quantum information issues with spins and photons

Fidelity of transfer of quantum information between systems

Multiple spins acting as spin-1/2? single spins?

Entangled photons as probe of condensed matter systems

Spin-dependent phenomena in higher order optical effects, and

The role of many-body interactions

Radiation-renormalized electronic energies and couplings

Relationship between spin coherence and orbital coherence

Plasmons versus single-particle transitions

Carriers delocalized or localized in initial and final states?

Devices is an ideal semiconductor

Spintronics technology better?

For what?

A small selection of theoretical issues …
Pump-probe

\[ T = 5K - 300K \]

\[ p u m p \]

100 fs
(~76 MHz)

\[ p r o b e \]

\[ ! t \]

\[ z x \]

Faraday Rotation

Spin state of excess electron in quantum dot of origin:

Incoming photon is linearly polarized in, e.g. x direction:

After interaction of photon with quantum dot:

Process involving heavy/light hole:

Conditional phase shift for maximum entanglement:

Faraday rotation of photon polarization:

Faraday rotation angle:

Measurement of spin in x direction

$\text{photon projected onto}$

$\text{optospintronic link between photons and electron spins}$

Single-photon Faraday Rotation
Accumulated phase shift during interaction time $T$ is controlled by active Q-switching with 1 ps resolution. Phase error 1 ps/1 ns = 0.1%.

Escape probability affects maximum entanglement. Microcavity to control interaction time.
Single-spin detection at origin in x direction (possible with a single photon)

Knowledge of detection outcome and correction

Teleportation complete

Measurement of linear polarization of photon:

or

or

or

Single-particle measurement of spin at origin and photon

% collapse of GHZ state

Teleportation via spin-photon-spin state

Prepare destination spin along -x direction, entangle with photon, send photon to origin

Entangle photon with origin spin - generates GHZ state
Incoming photon is linearly polarized in, e.g. x direction:
After interaction of photon with quantum dot:
Process involving heavy/light hole:
Conditional phase shift for maximum entanglement:
$\text{Faraday rotation of photon polarization:}
\text{Faraday rotation angle:}$
Measurement of photon polarization in 45 degree basis
$\text{Provides direct measurement of spin orientation}$
Single-spin Measurement
Exchange splitting and Moss-Burstein shift
Experimental magnetooptical absorption

J. S z c z y t k o et al., PRB 59, 12935 (1999)

B. Beschoten et al., PRL 83, 3073 (1999)

Experimental magnetooptical absorption
$M_n \sim 3\%$

$T = 0 \text{ K}$

Magnetic circular dichroism
Power Dissipation (CMOS from ITRS 2003)

Low Threshold Voltage: 100 mV

Low Source-Drain Leakage Current: ~16 pA/µm

Low Standby Power

Small Capacitance: 0.05 fF/µm

Switching energy 500 times smaller than 2018 LSTP CMOS
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