OPTICAL METHODS IN QUANTUM DOT QUANTUM COMPUTATION

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Outline:

- Basic concepts
- QC with Optical Driven Excitens
- Spin-based QDQC with Optical Methods
- Conclusions

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Quantum Computation and Information

Do things in quantum ways: superposition and entanglement:

$$\varphi_1 = |1\rangle + |0\rangle \qquad \varphi_2 = |11\rangle + |00\rangle$$

Quantum Algorithms:

- Integer factorization: Quantum Fourier Transform
- Grover's algorithm: Quantum search
- Quantum system simulation

…no more in the past ten years…

Quantum Information:

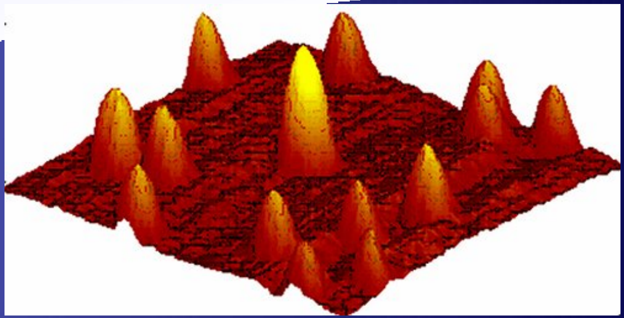
- Quantum Key Distribution

Questions on Quantum Computation

- Is it possible to build a general QC like the one running this ppt?
- Will this general QC run all or most of the algorithms faster than the current computers?

Quantum Dots

- Semiconductor structures
- Using potentials to confine particles or quasi-particles (electrons, holes or exciton pairs)
- Integer and finite number of charge elementary particles (1~100)
- Discrete energy spectrum



Quantum Dot Structures

- Core-shell structure: small material buried in another with larger band gap.

- Confined two dimensional electron or hole gases.

- Self-assembled quantum dots: a material is grown on a substrate with a different lattice. Islands are formed by the strain and buried to QD.

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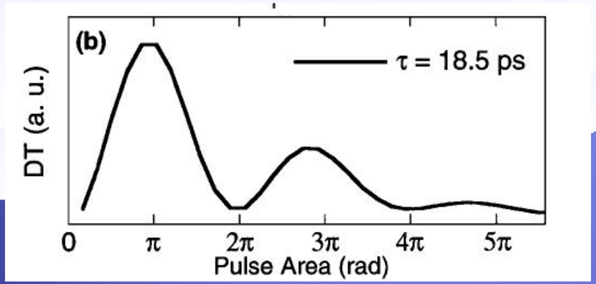
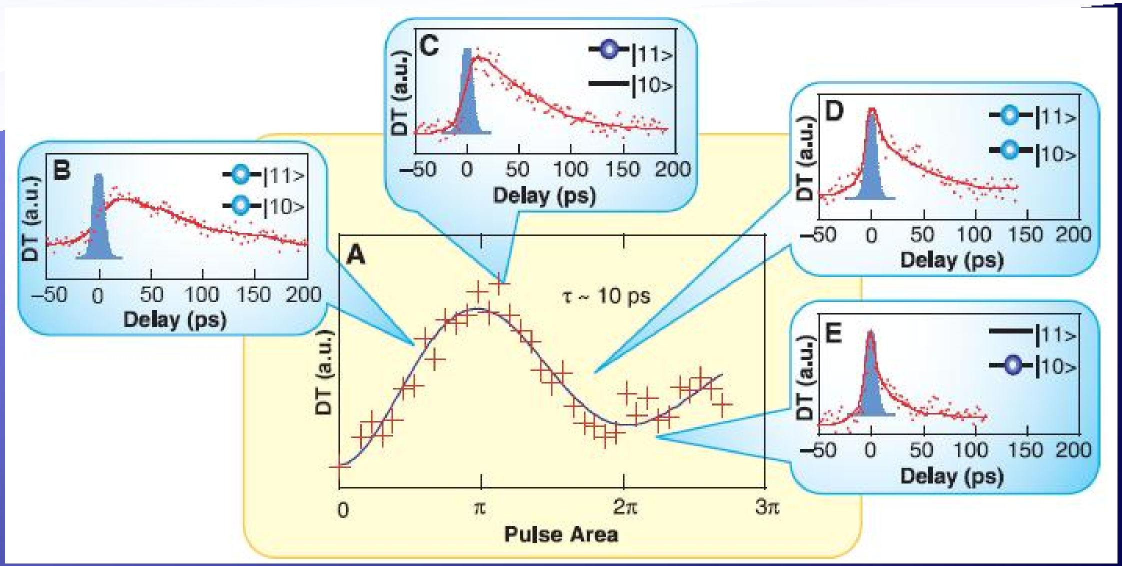
Rabi Oscillations of Excitons:



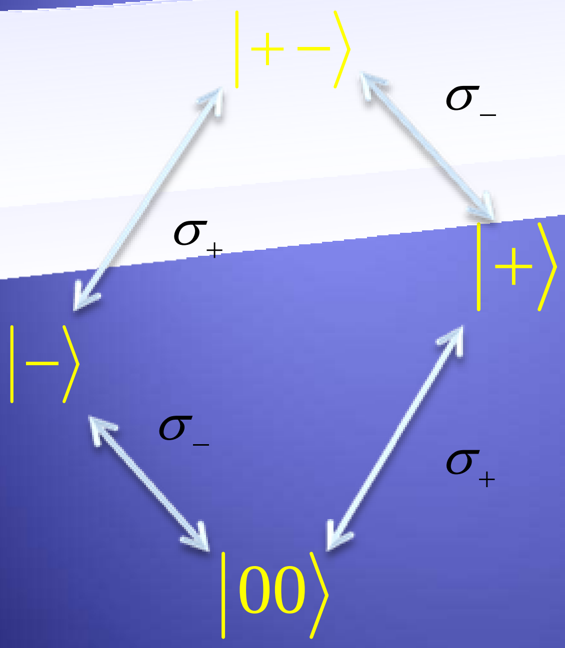


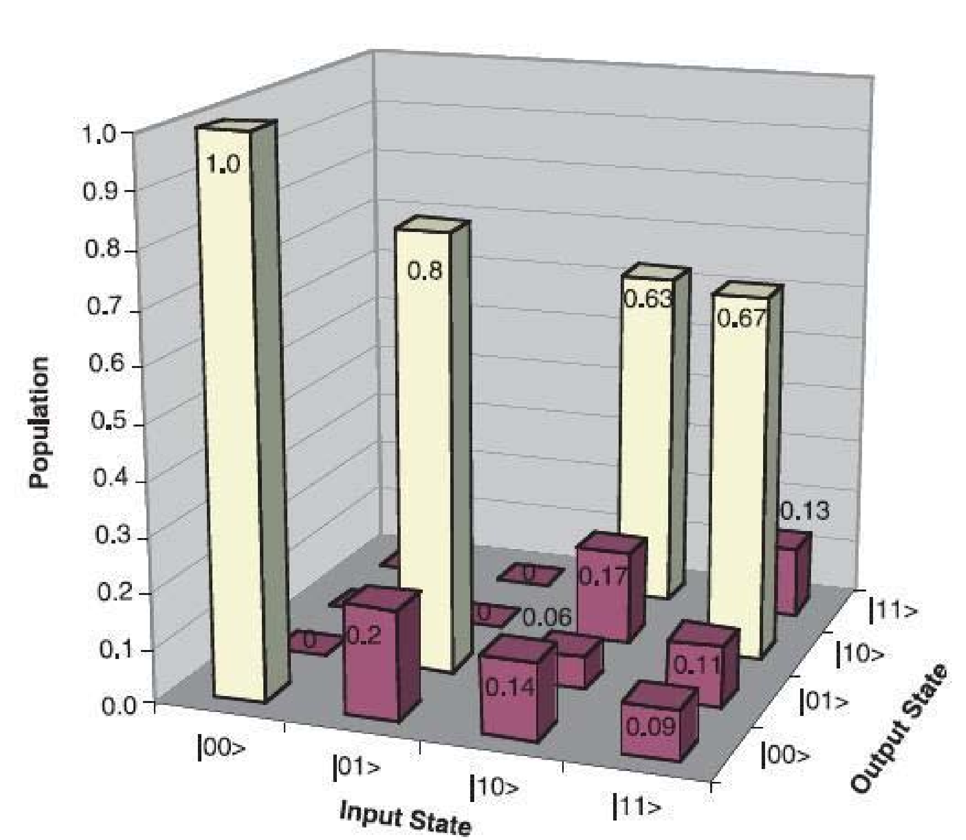
$$\hbar / \Delta\varepsilon < T < 1/\gamma$$

This is essential for single qubit operations

Xiaoqin Li, *et al. Science* ***301, 809***

Two Excitons transitions in a single dot:





This implements the CNOT(CROT) two-qubit gate.

exciton quantum dots can be used to demonstrate simple quantum algorithms such as the Deutsch–Jozsa algorithm

but very difficult to scale up.

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Spin-based QD QC, Non Optical Method:

- Control the electron number by voltage (Coulomb blockade)
- The qubit is defined as spin states of the electron: $|1\rangle = |\downarrow\rangle, |0\rangle = |\uparrow\rangle$

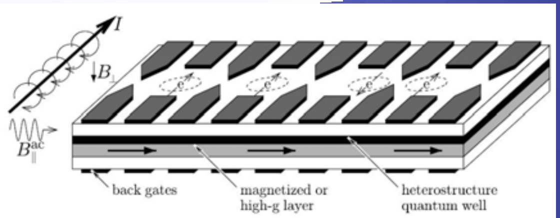
  $g\mu_B B \gg kT$
- Initialized by large magnetic field:

  or by injecting polarized electrons.
- Single qubit gates realized by controlled B
- Two-qubit gate (CNOT or CROT) realized with controlled spin-spin interactions: $H_s(t) = J(t)\vec{S}_1 \cdot \vec{S}_2$

$$\int_0^{\tau_S} J(t)dt/\hbar = \pi \Rightarrow U(t) = T\exp(i\int_0^t H_s(\tau)d\tau/\hbar = U_{swap}$$

Spin-based QD QC, Non Optical Method:

- Readout: transfer the information form spin to charge: Spin filter + auxiliary QC with a known spin direction as reference.

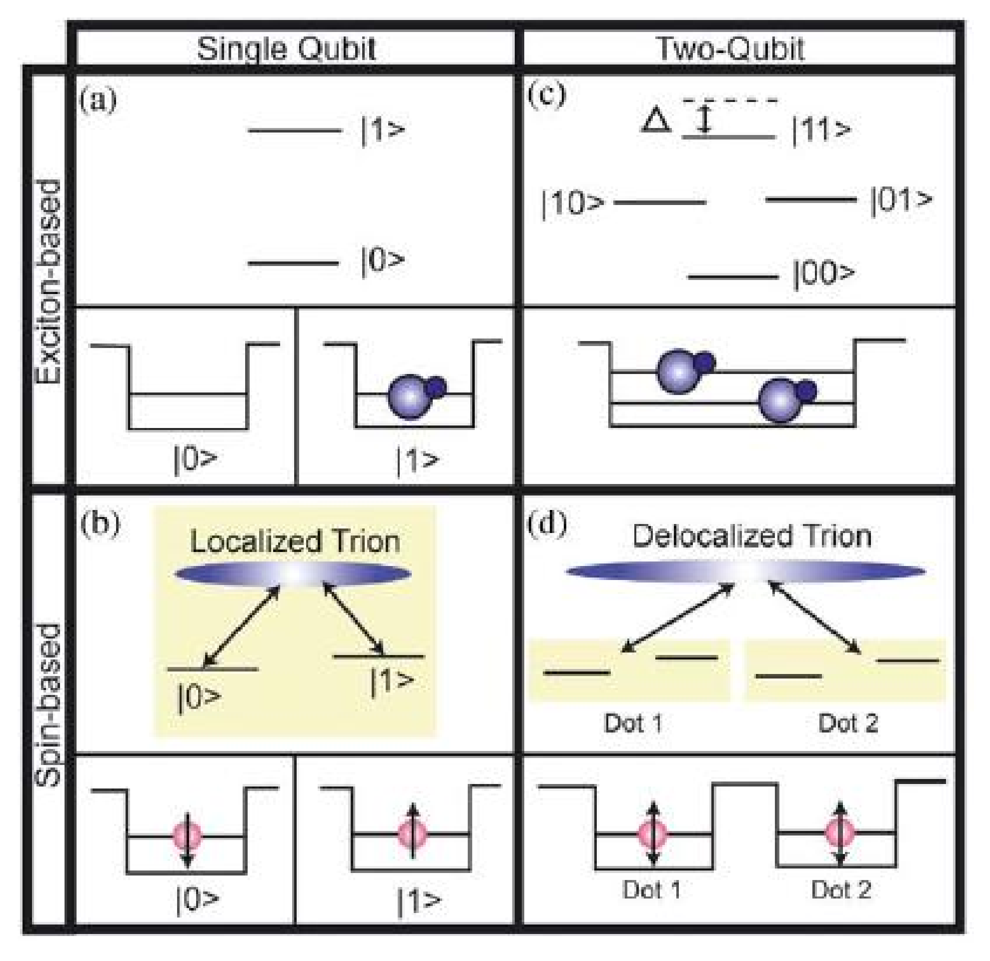


Nice point:

short gate operation time: sub nanosecond while long decoherent time(~1ms)

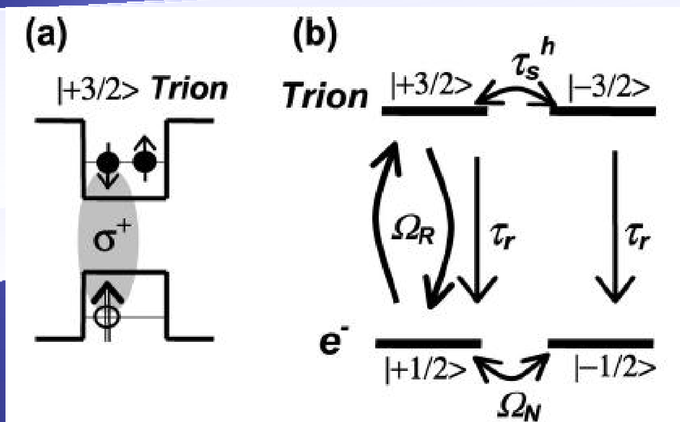
Spin-based QD QC, Optical Method

- Initialized with a single electron.
- The spin polorization serves as a qubit
- Polarized photons exciting an extra electron to form a trion state
- Single qubit rotated by Raman process



Y. Wu et al. / Physica E 25 (2004) 242–248

Optical initialization and readout



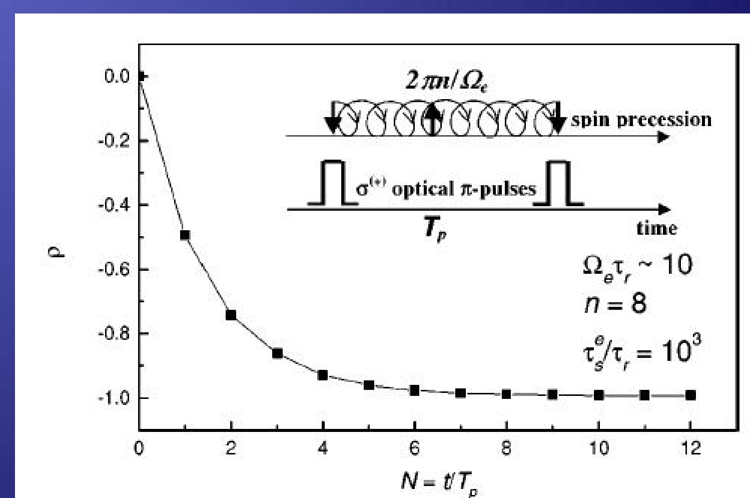
Readout:

Florescence from the dot in laser with matched polarization

$$\Omega_R = 2dE/\hbar$$

Initialization:

A transverse B field with a series of Optical Pi pulses



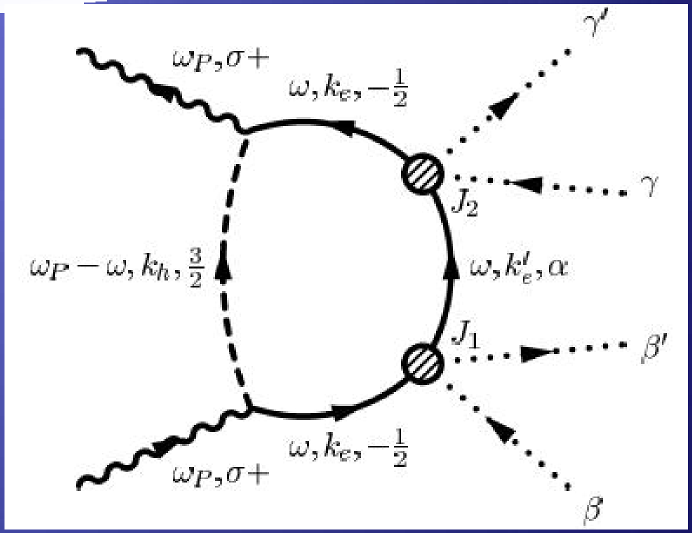
A.Shabaev etc. Phys Rev B 68,201305

Scale up: Optical RKKY effect

Two electrons in different dots interact with each other through optical excited virtual excitons in the host material. The effective interaction is controlled by the external laser.

$$H_X = -\frac{1}{V}\sum_{\substack{l,\alpha,\alpha',\\ k,k'}} J_l(k,k') S^l \cdot s_{\alpha,\alpha'} c^{\dagger}_{k,\alpha} c_{k',\alpha'}$$

$$H_S = -2J_{12} S^1 \cdot S^2$$



The effective H is a spin-spin interaction which couples two electrons in different dots!

C.Piermarocchi, etc. PRL 89,167402

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Quantum dots' Advantages

- Reliable, easy to make and control
- Potential of large scale manufacture
- Long dephasing time with short operation time

Optical methods' Advantages

- use well controlled pulse laser
- potential of scale up and long distance
  (Cavity QED + Optical driven QD)
- All advantages of QD