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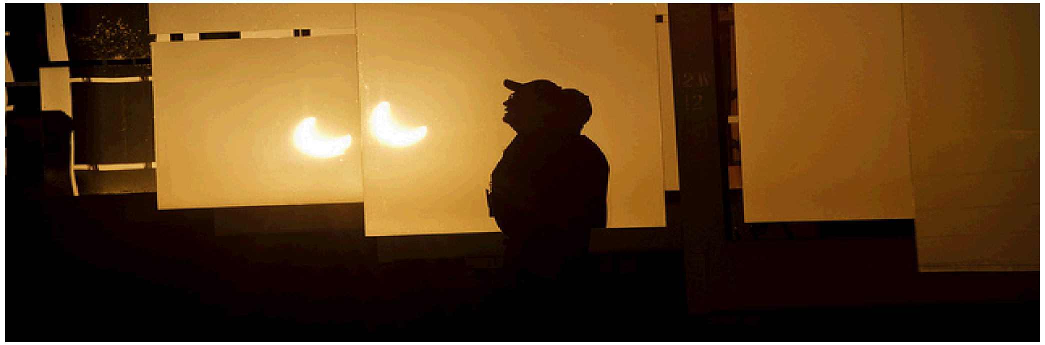

Optically-Controlled, Electrically-Gated Quantum Dots for Quantum Information

Susan Clark

New Laser Scientists Meeting, Tuscon AZ
10/24/2014

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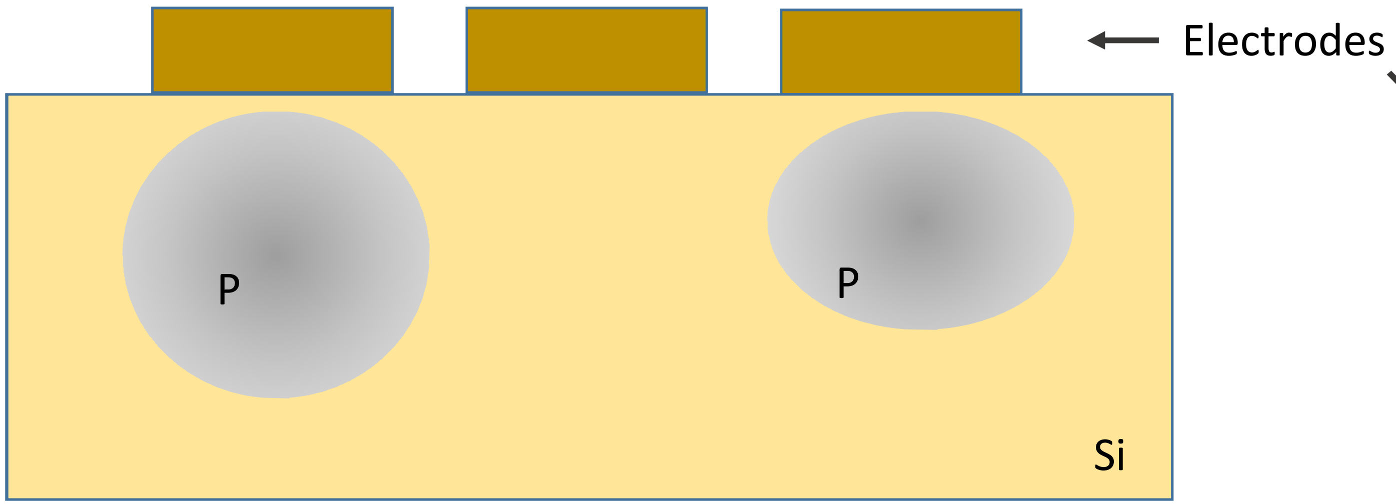
A New Type of Qubit

Proposal: A semiconductor qubit that combines fast optical control for gates with electrical control for placement and homogeneity

Addresses current concerns of semiconductor community

Semiconductor Quantum Computing Perspective

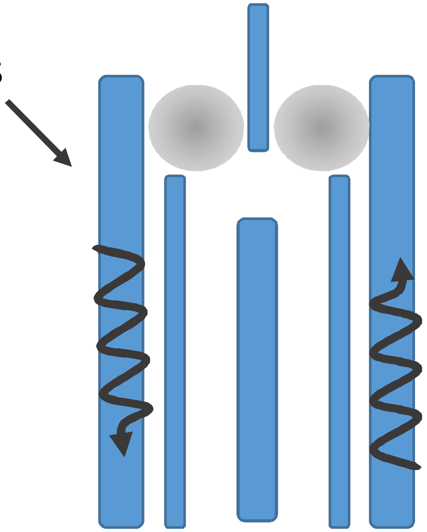
Kane Quantum Computer: Phosphorus in Silicon



Kane, *Nature* **393** 133 (1998)

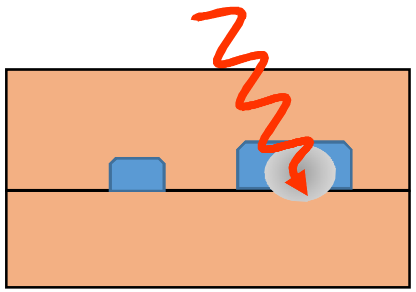
Quantum Dots

Electrically Gated



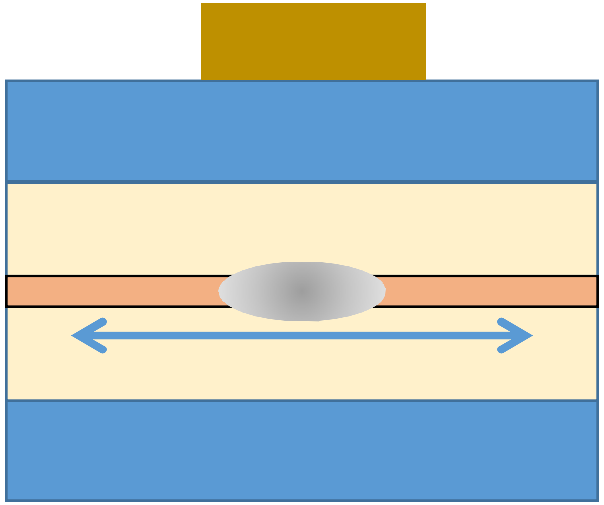
Top View

Self-Assembled



Loss and DiVincenzo, *Phys. Rev. A,* **57** 120 (1998)

Optically-Controlled, Electrically Gated Quantum Dots



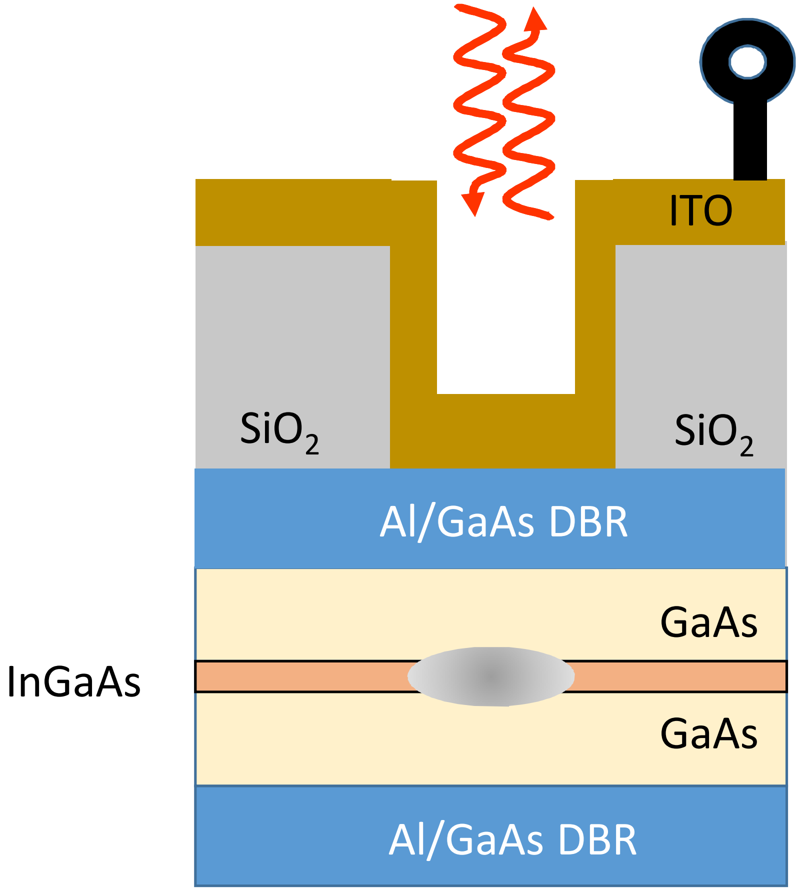
Electrodes to provide lateral confinement

Distributed Bragg Reflectors provide optical enhancement

Quantum Well ~ 10 nm

Optically-Controlled, Electrically Gated Quantum Dots

To actually fab the device, need some extra layers:



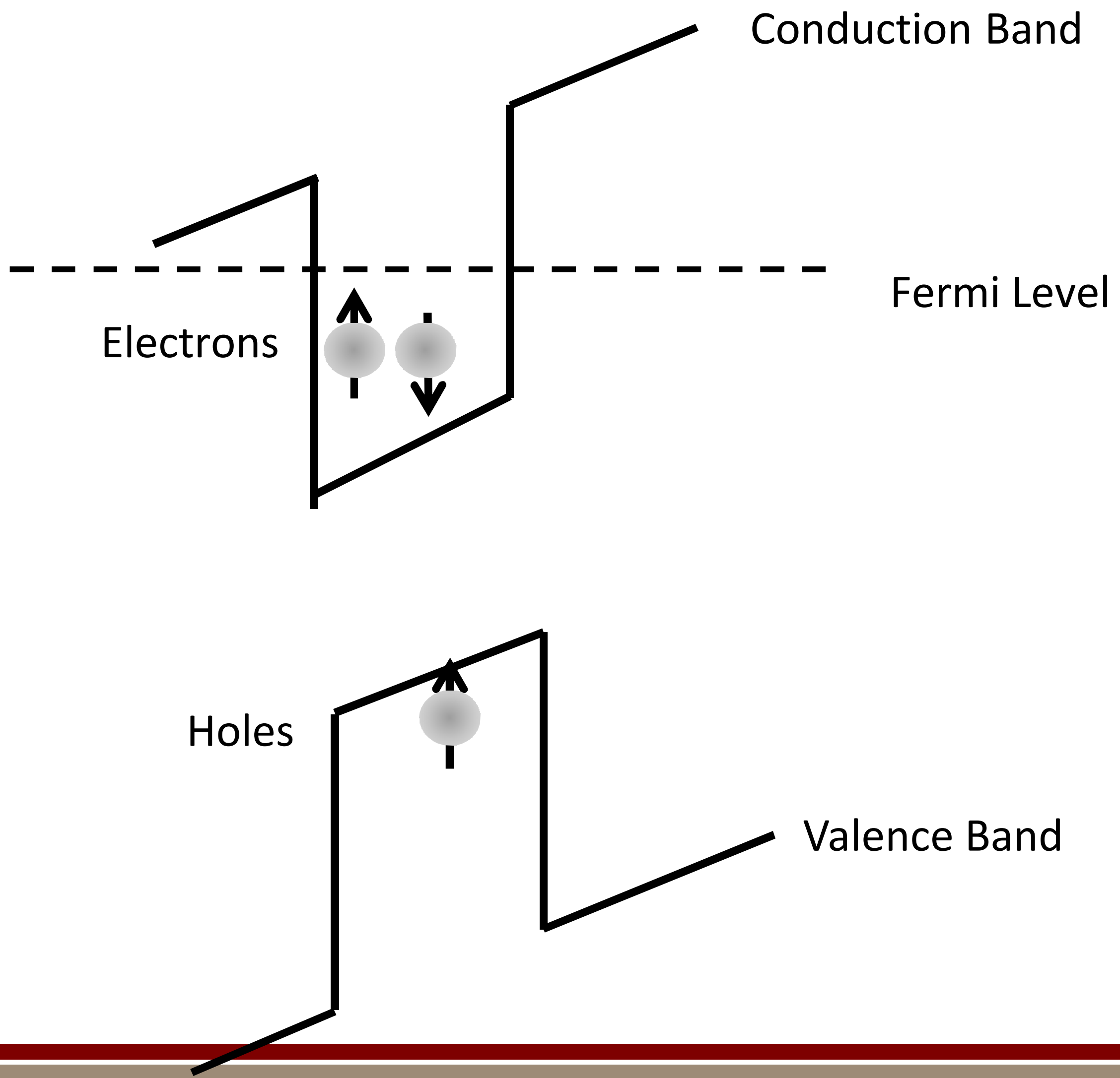
Ohmic contact

Electrodes to provide lateral confinement

Distributed Bragg Reflectors provide optical enhancement

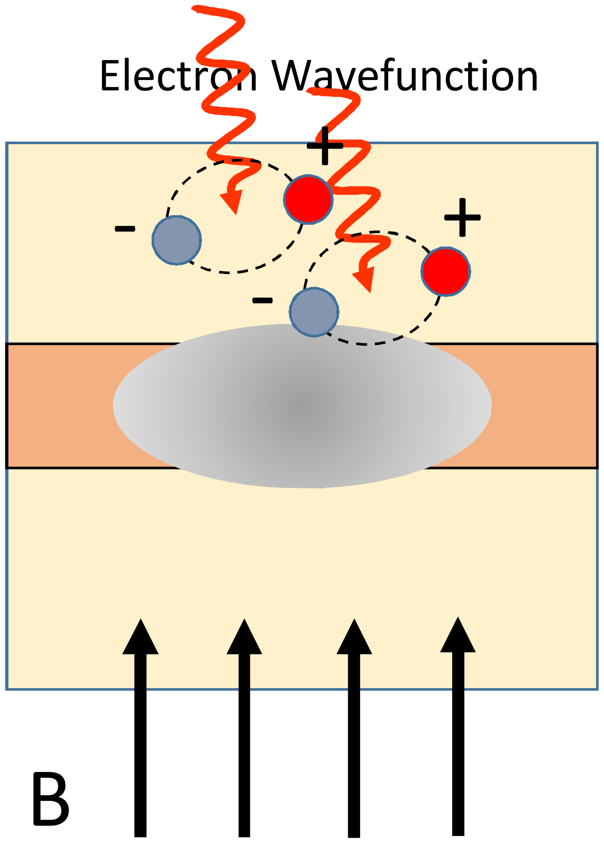
Quantum Well ~ 10 nm

Fermi-Level Engineering



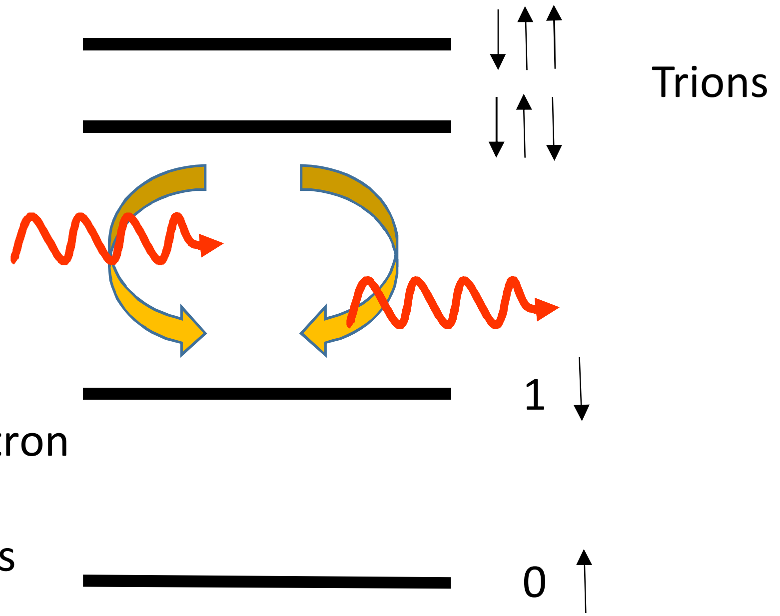
-With applied voltages, band levels tilt
-Doping determines Fermi level
-Adjust doping and applied voltage to trap single electron and electron + exciton

A Closer Look at the Qubit

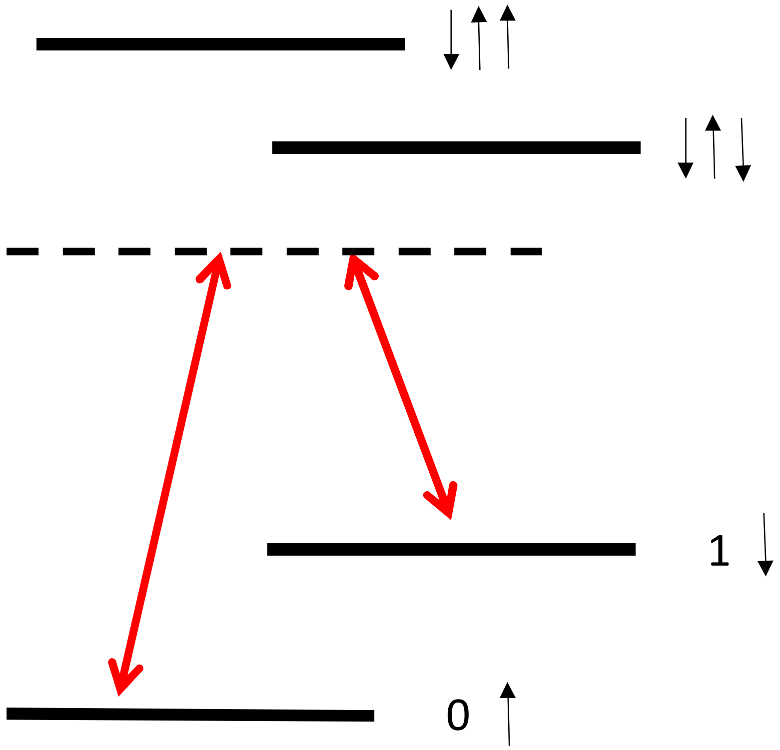


Photons create excitons (electron-hole pairs)

Spin of electron creates two energy levels



Quantum Control of Λ-Systems



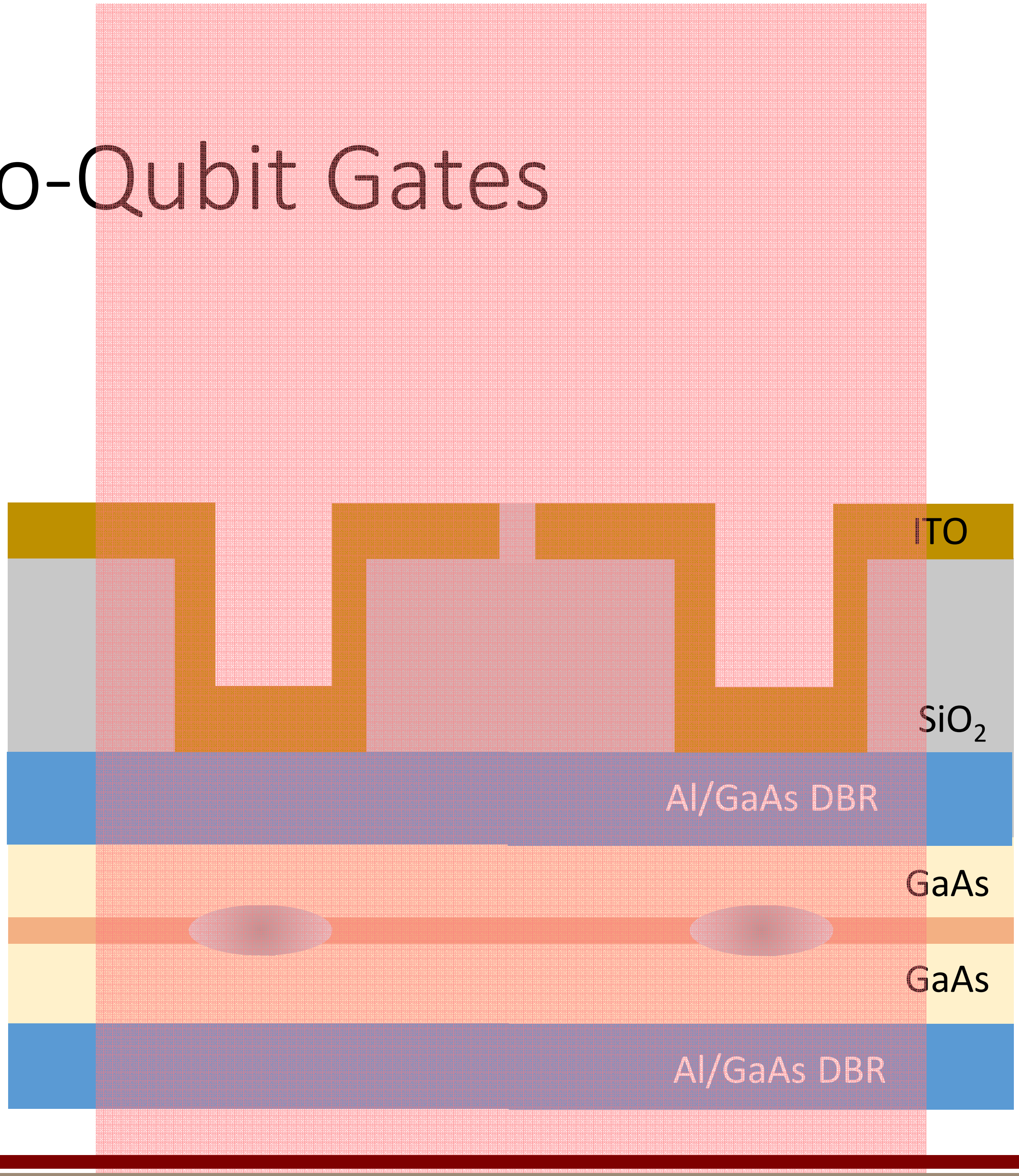
-Optically pump to ground state

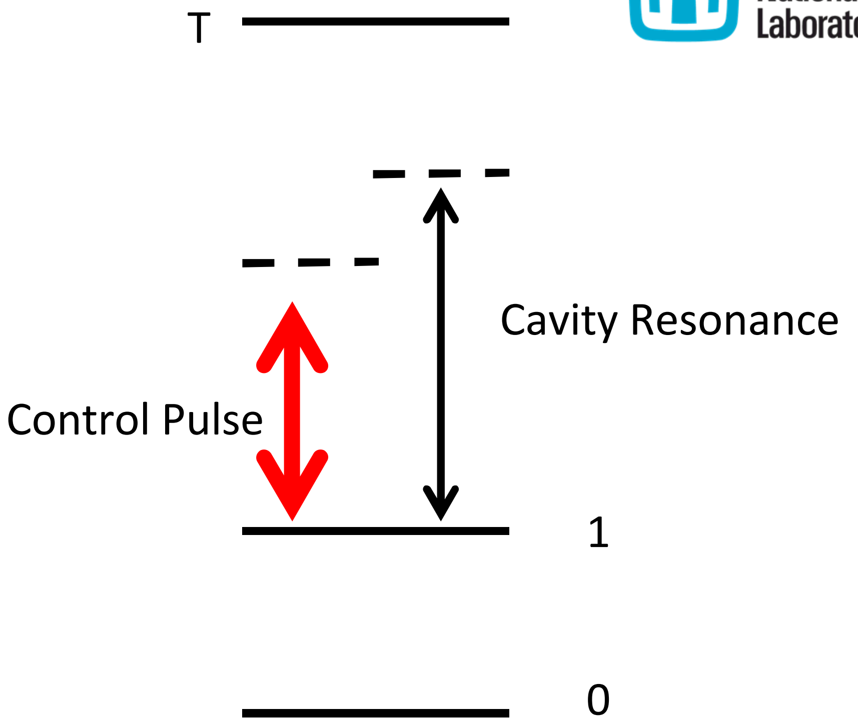
-Stimulated Raman transitions to coherently move between the spin states

-Detection via resonant excitation

Press, et al. *Nature* **458** 218 (2008)

Two-Qubit Gates





During the pulse, the spins acquire a spin dependent geometric phase, which can leave them in a maximally entangled state

Ladd and Yamamoto, ArXiv 0910.4988 (2009)

Anticipated Challenges and Mitigation

- Device Fabrication, Trapping electrons
- Rely on demonstrated techniques, learning benefits community
- Decoherence due to GaAs nuclear matrix
- Dynamical decoupling
- Investigate other materials, i.e. ZnSe

Conclusions

- These types of dots address many of the challenges in current semiconductor quantum computing
  - Fast interactions (optical: picoseconds)
  - Homogeneity (tuned with electrodes)
  - Simple design (electrodes only for placement and tuning)
  - Precision placement of dots
- Device has potential to be testbed for optical control techniques
- Advancement of fabrication techniques and materials testing

Conclusions

Proposing a new type of qubit that leverages semiconductor fabrication techniques, but avoids many of the common pitfalls of semiconductor qubits