Spin/Carrier Dynamics in Narrow Gap Semiconductors

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Supported by NSF and AFOSR

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InSb Based Structures:

Prof. J. K. Furdyna, InMnSb
Department of Physics, University of Notre Dame

Prof. M. B. Santos , InSb QWs
Department of Physics & Astronomy, University of Oklahoma

- **Intel and Qinetiq researchers have recently demonstrated prototype InSb quantum well transistors**

- **InSb QW has the lowest energy dissipation and gate delay which is an important metric for logic microprocessors**

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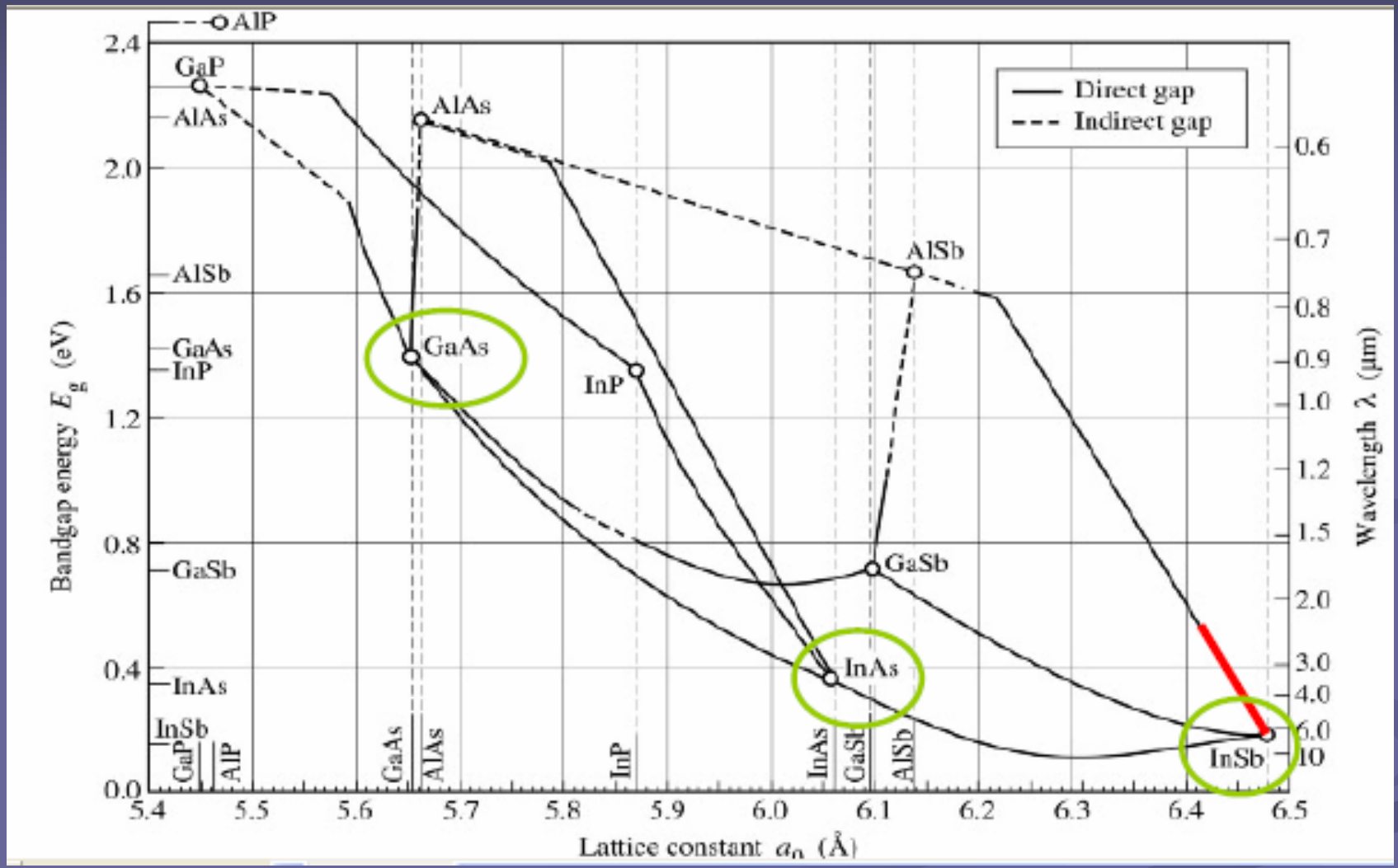
III-V Semiconductors



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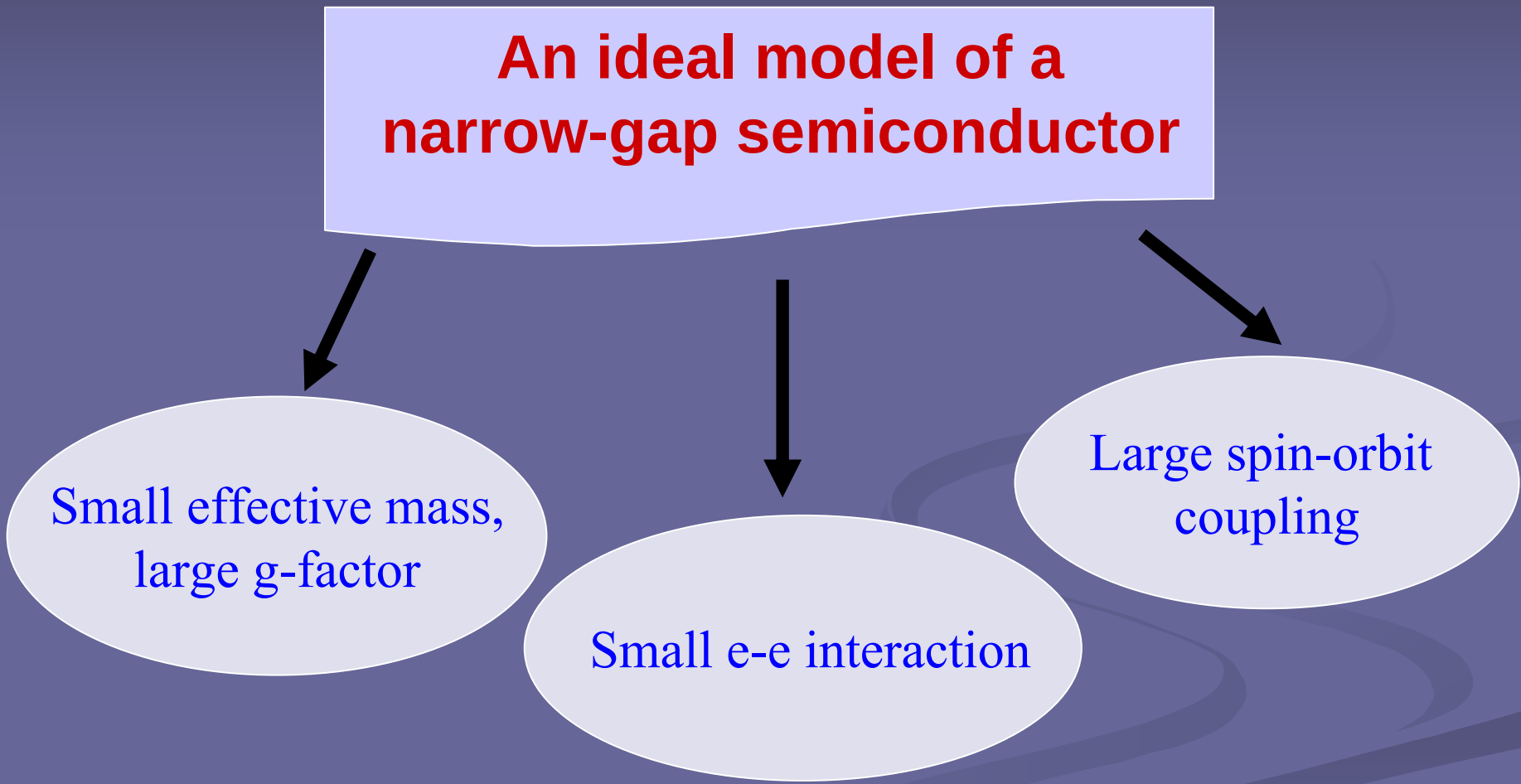
InSb Based Heterostructures



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Narrow Gap : Revisited

Spin Orbit Interaction

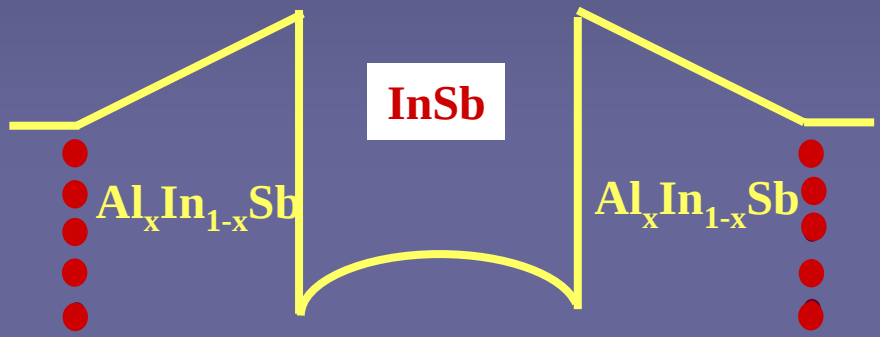
Rashba Effect

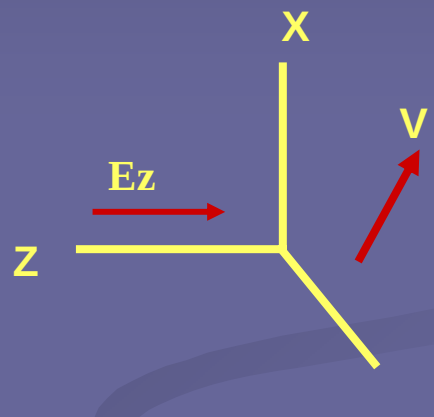
Electronic systems with finite spin splitting in the absence of external magnetic field!!!

InSb Quantum Well Structures

Prof. M. B. Santos
Department of Physics & Astronomy,
University of Oklahoma

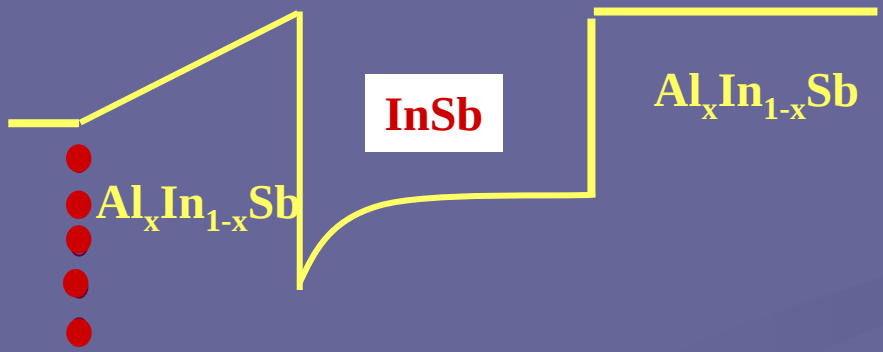
Symmetric quantum well





$B_{eff} = E \times V/c$

Asymmetric quantum well



Density: 1-4x10^{11} cm^{-2}
Mobility: 100,000-200,000 cm^2/Vs
Alloy concentration: 9%, 15%

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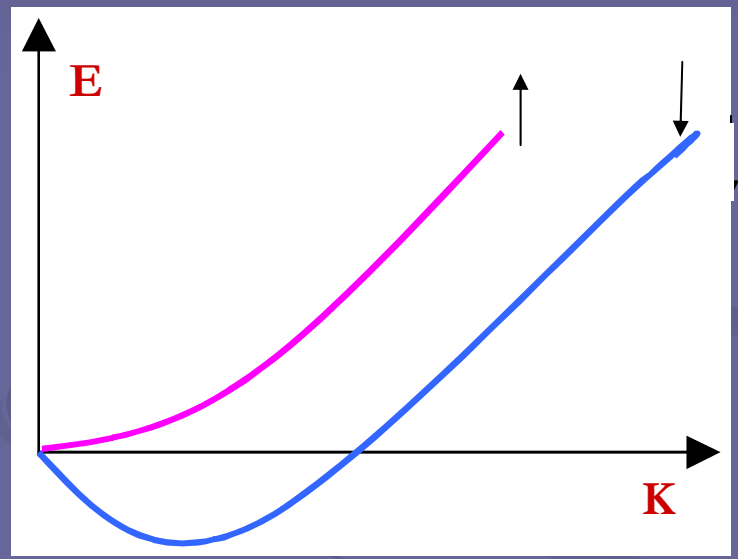
Rashba Effect

Asymmetry of the confining potential in a QW remove the degeneracy of band structure → Rashba effect:

$$E = E_z^{sub} + \frac{\hbar^2 k_t^2}{2m^*} \pm \alpha |k_t|$$



Electronic systems with finite spin splitting in the absence of external magnetic field!!!

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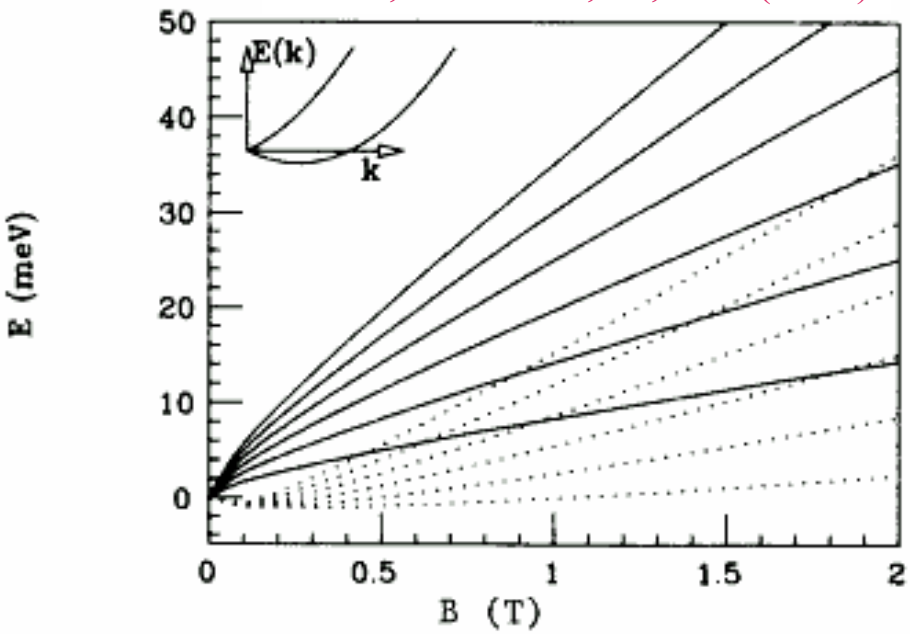
Rashba Splitting at B>0

J. Luo, *et al.* PRB, **41**,7685 (1990)



In addition to:

$E(k)=\hbar^2k^2/2m \pm \alpha k$

Y.A. Bychkov and E.I. Rashba, J. Phys. C **17**, 6039 (1984);
Y.A. Bychkov and E.E. Rashba, [JETP Lett. **39**, 78 (1984)]

Change in g* at low magnetic field
G. A. Khodaparast, *et al.* Phys. Rev. B **70**, 155322 (2004)

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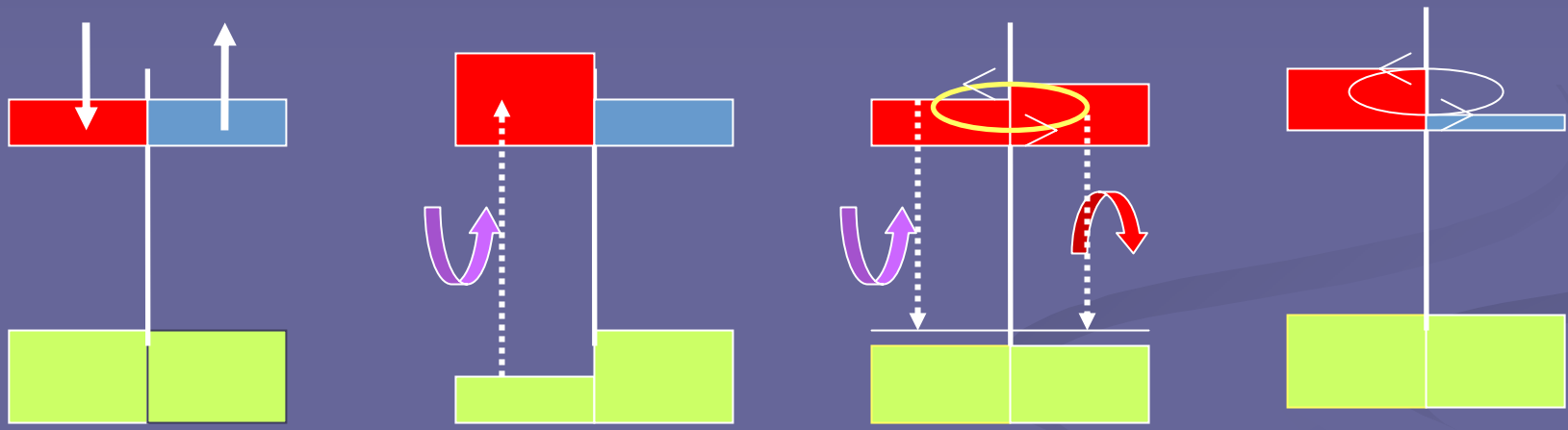
Spin Relaxation



Equilibrium Excitation Recombination Non-equilibrium

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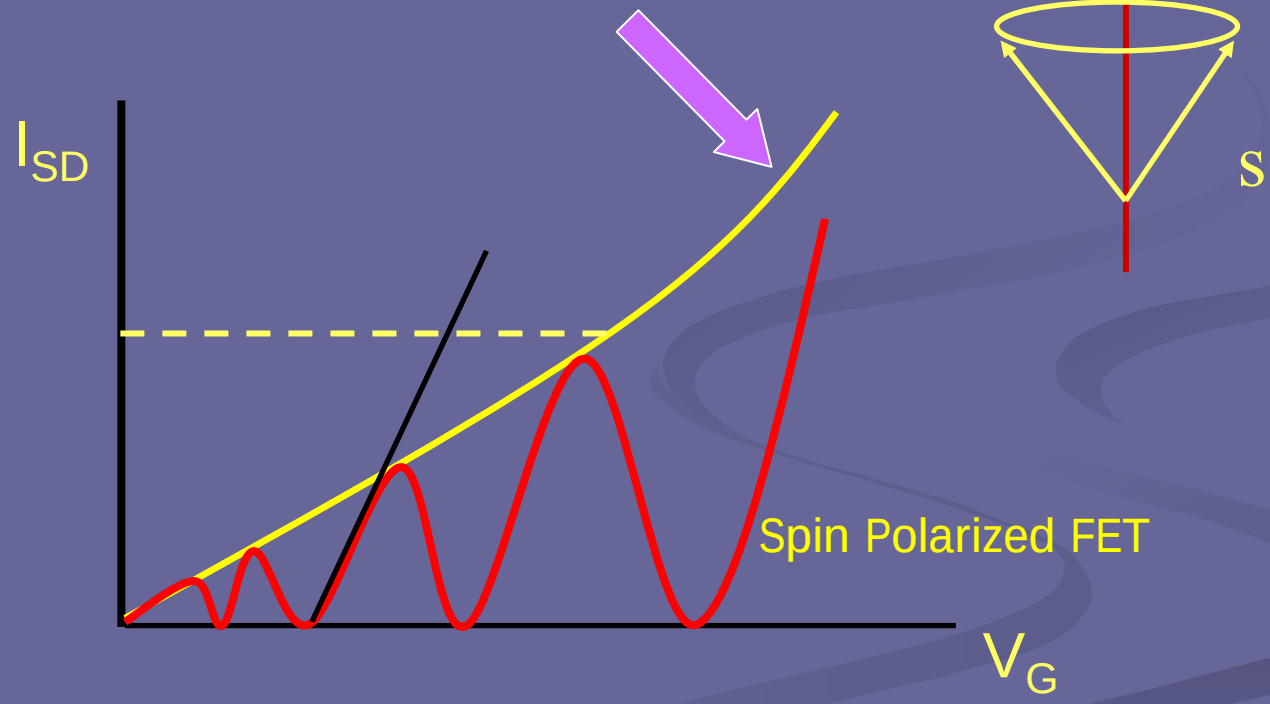
Why Spintronic?

Efficiency!!

$\langle S_x \rangle \propto \cos\omega t$

$\omega \propto E_{\uparrow} - E_{\downarrow}$

Normal Field Effective Transistor (FET)



Spin Field Effective Transistor: Datta and Das, 1990, APL. Phys. Lett., 56, 665

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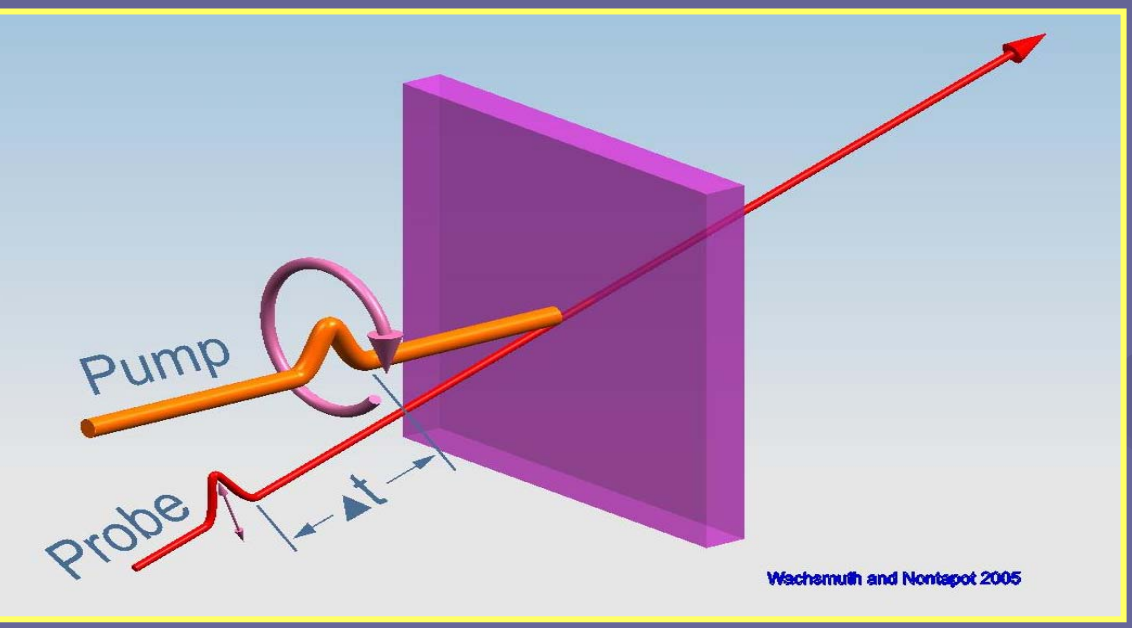
Our Motivation

- Understand charge/spin dynamics in narrow gap structures
- Study phenomena such as interband and intraband photo-galvanic effects, in order to generate spin polarized current

  We will need FEL!!
- Probe the effect of magnetic impurities on the spin/charge dynamics: Poster by Matt Frazier today

Carrier dynamics:

Pump-Probe Spectroscopy



- Ti-Sapphire laser – 800nm Carrier density ~10^{17} cm^{-3}
- Optical Parametric Amplifier – 1.1μm – 2.4 μm, Carrier density ~10^{19} cm^{-3}

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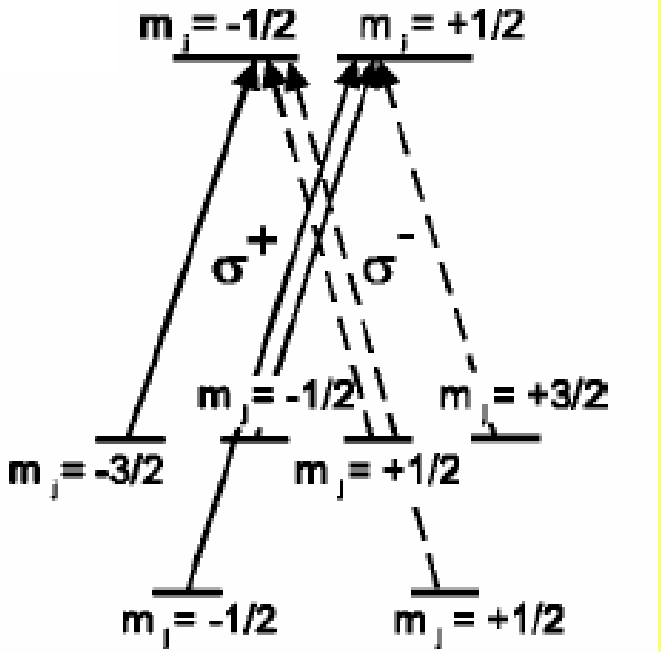
Optical Induced Magneto Optical Kerr Effect (MOKE)



- Selection rules for inter-band transitions, Spin-polarized carriers using circularly polarized beams

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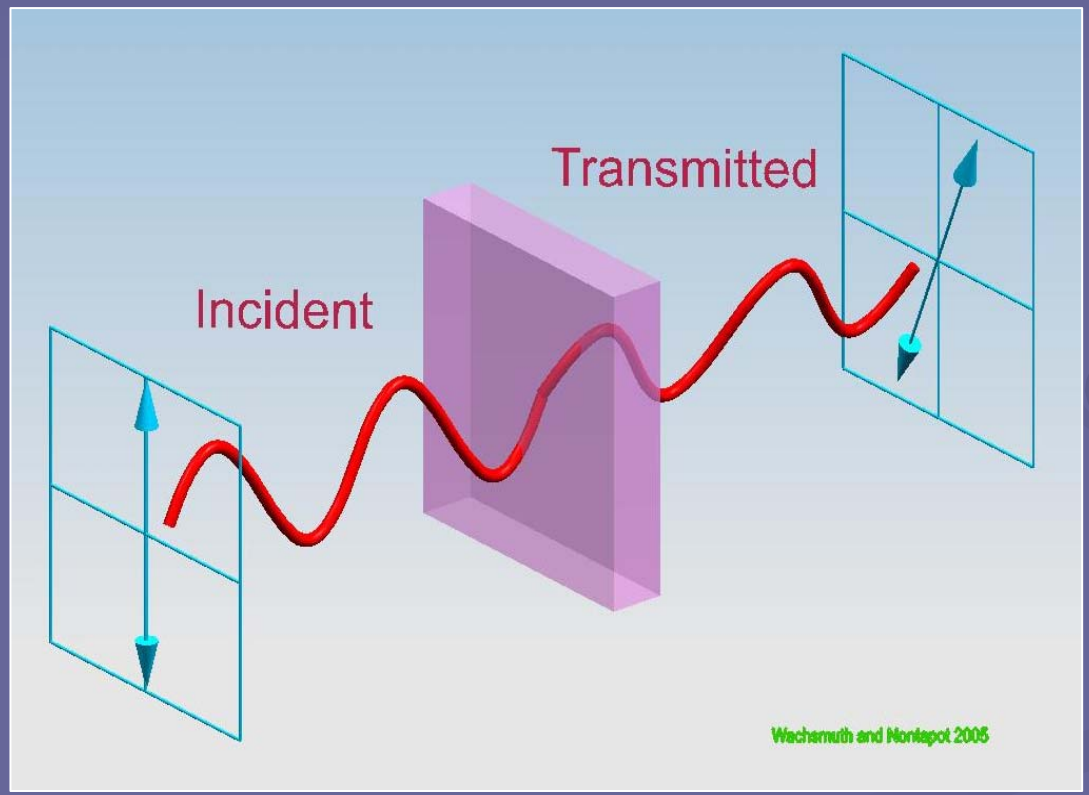
Spin Dynamics:

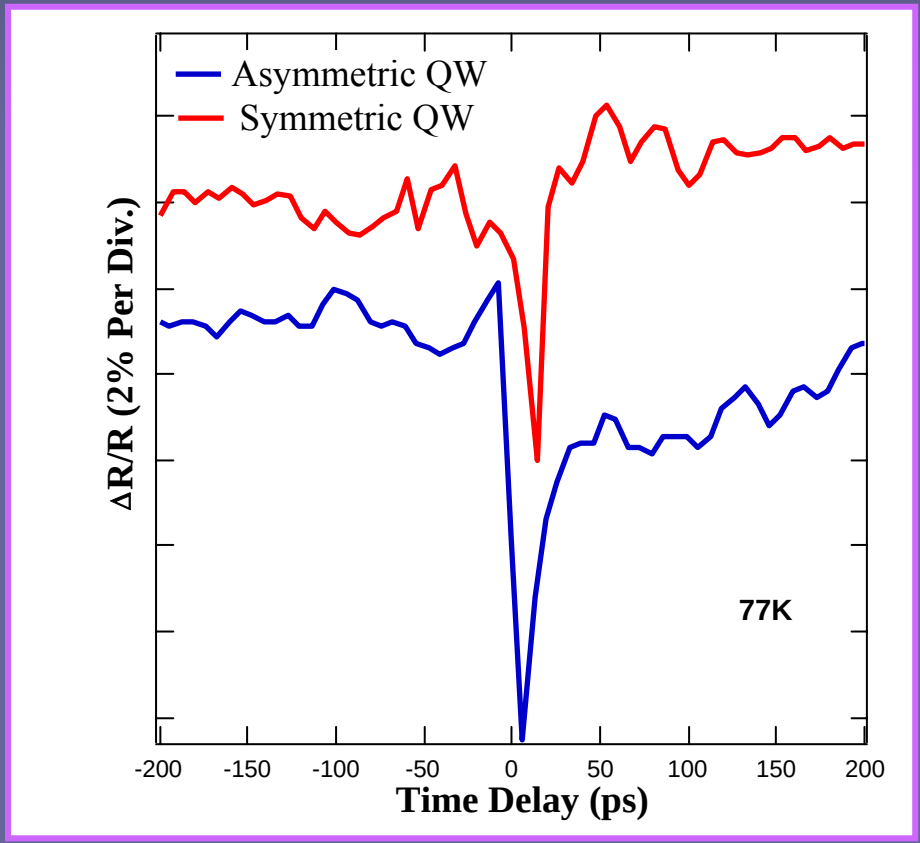
Magneto-Optical Kerr (reflectivity)
Magneto-Optical Faraday (Transmission)



- Optical MOKE signal arises from the difference between the optical coefficients of a material for left and right circularly polarized light.

The rotation of the polarization plane is proportional to the magnetization

Carrier Relaxation



- Pump – 800 nm
- Carrier density ~10^{17} cm^{-3}
- Sharp decrease, followed by an exponential recovery
- Carrier lifetime ~ 40ps

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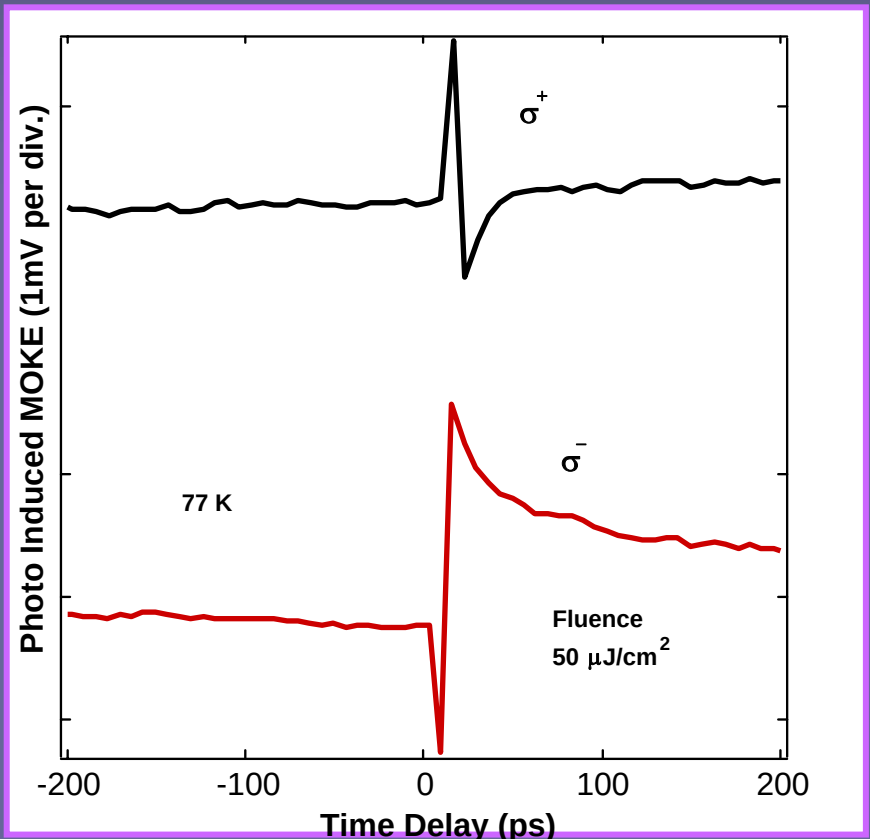
Spin relaxation



- Spin relaxation for left and right circularly polarized pump.
- Relaxation time ~ 40ps

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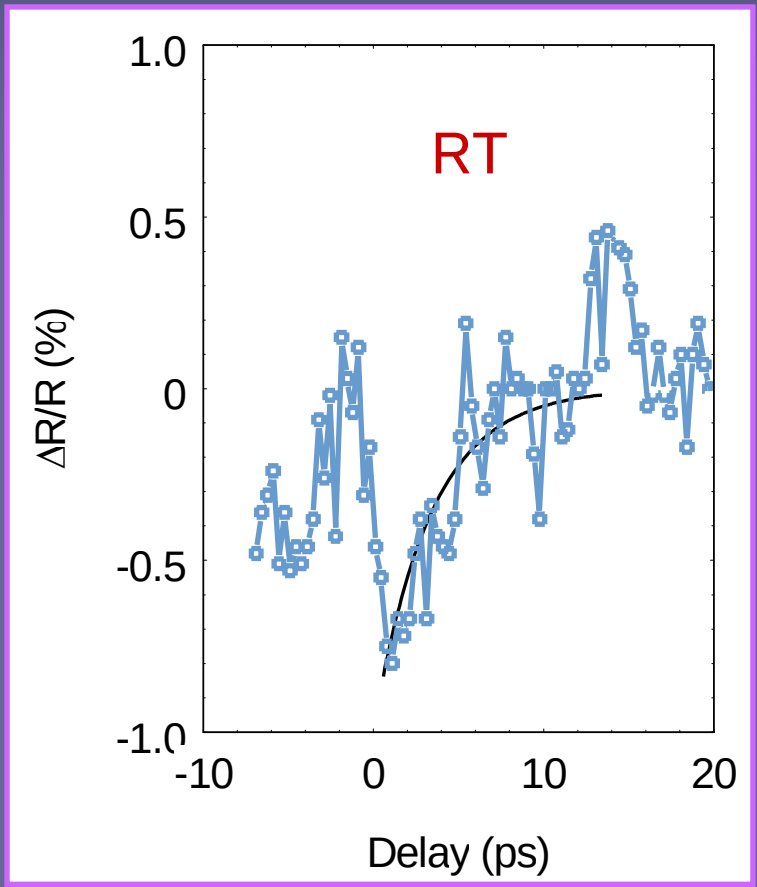
Asymmetric Quantum Well

Carrier relaxation at 2μm



- Pump – 2 μm, Probe 800 nm
- Carrier density ~10^{19} cm^{-3}
- Sharp decrease, followed by an exponential recovery.
- Carrier lifetime ~ 8ps

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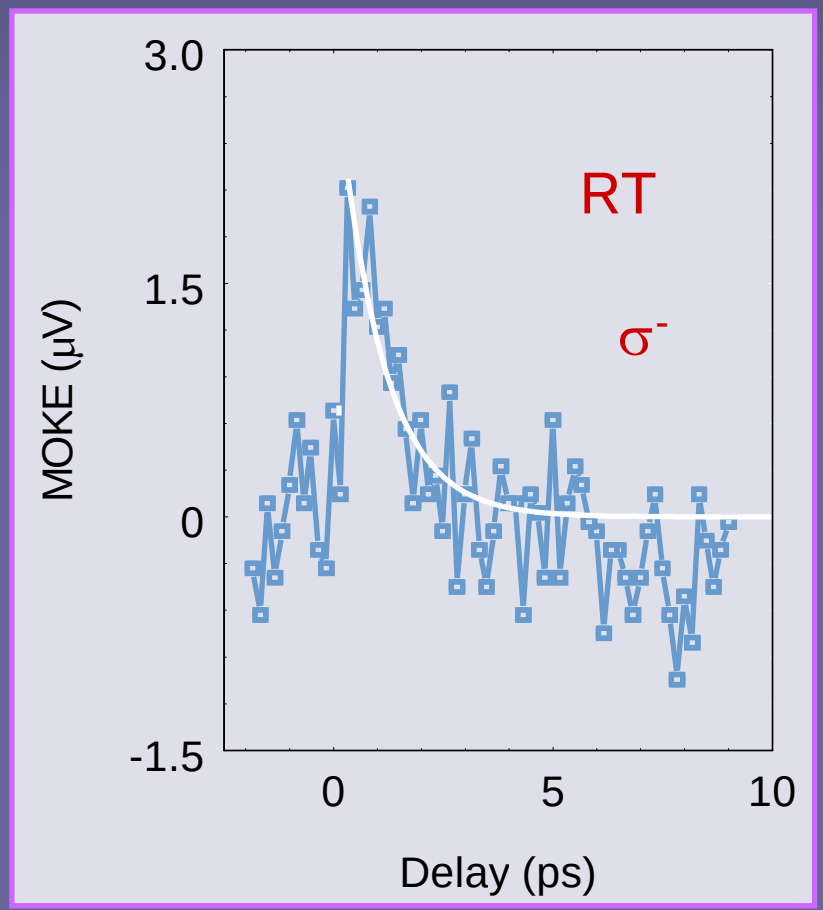
Asymmetric Quantum Well
Spin relaxation at 2μm



- Spin polarized carriers excited using circular polarized light
- Spin lifetime ~ 4 ps

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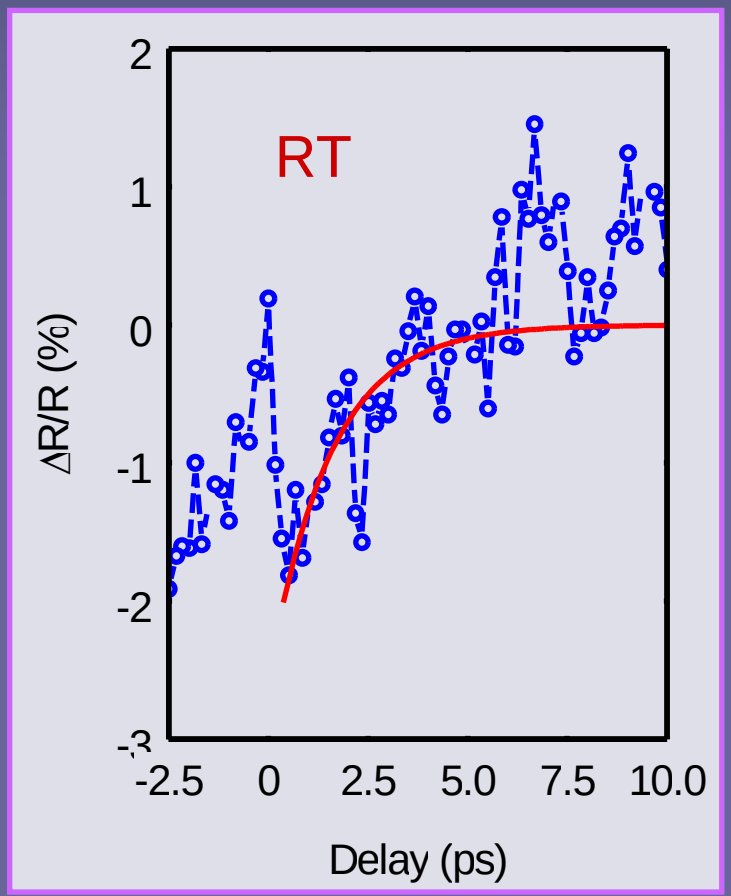
Symmetric Quantum Well

Carrier relaxation at 2μm



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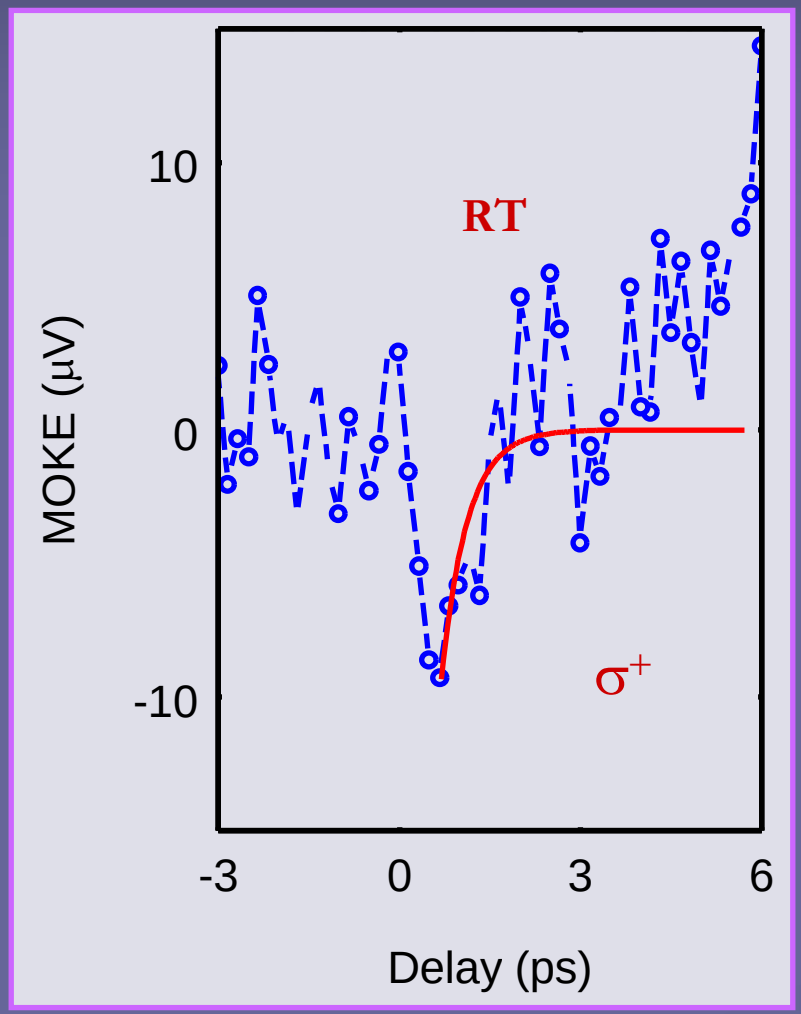
Symmetric Quantum Well

Spin relaxation at 2μm



- Spin polarized carriers excited using circular polarized light
- Spin lifetime ~ 2 ps

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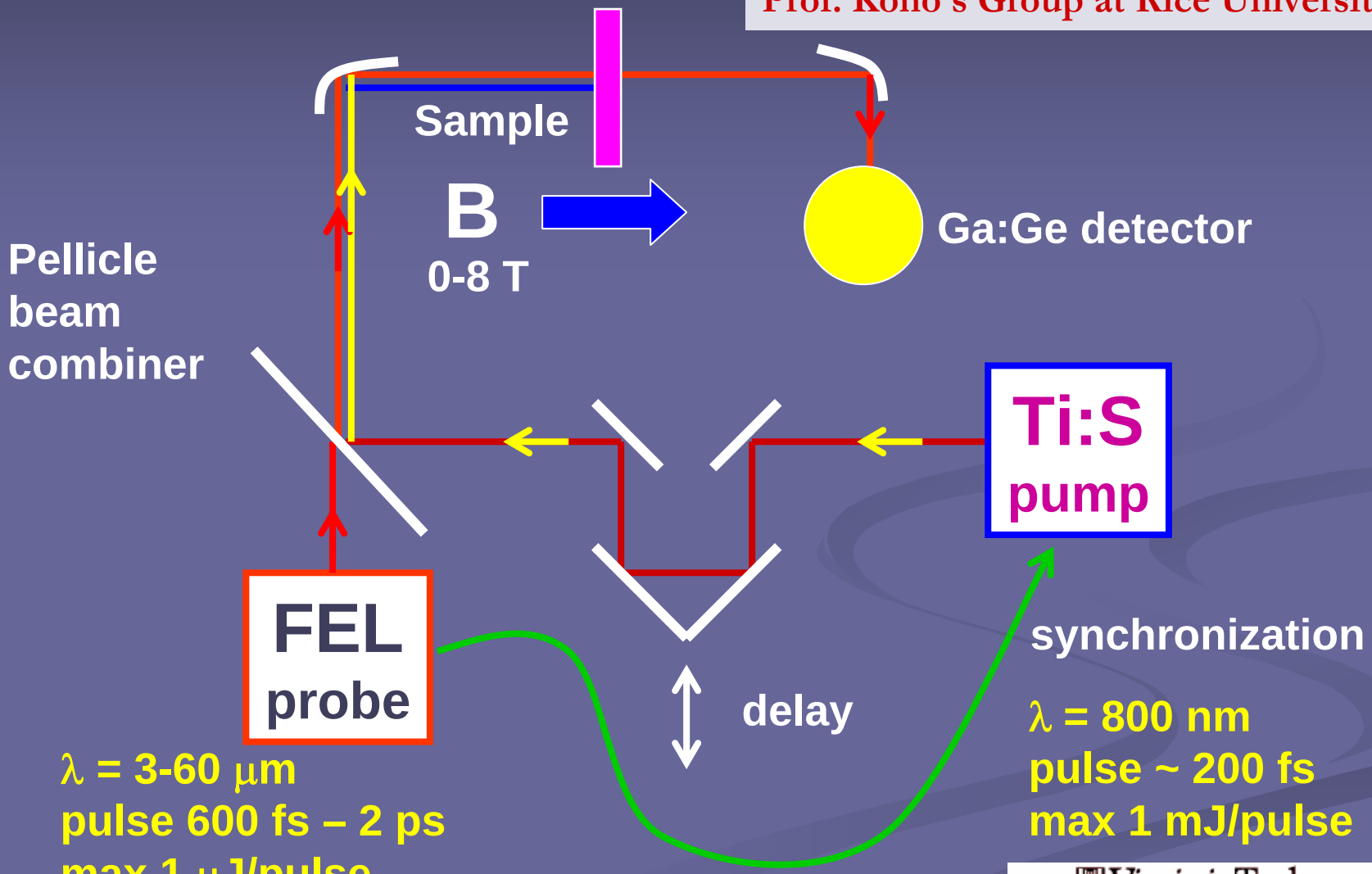
Time Resolved Cyclotron Resonance Measurements, Stanford FEL

Prof. Kono's Group at Rice University



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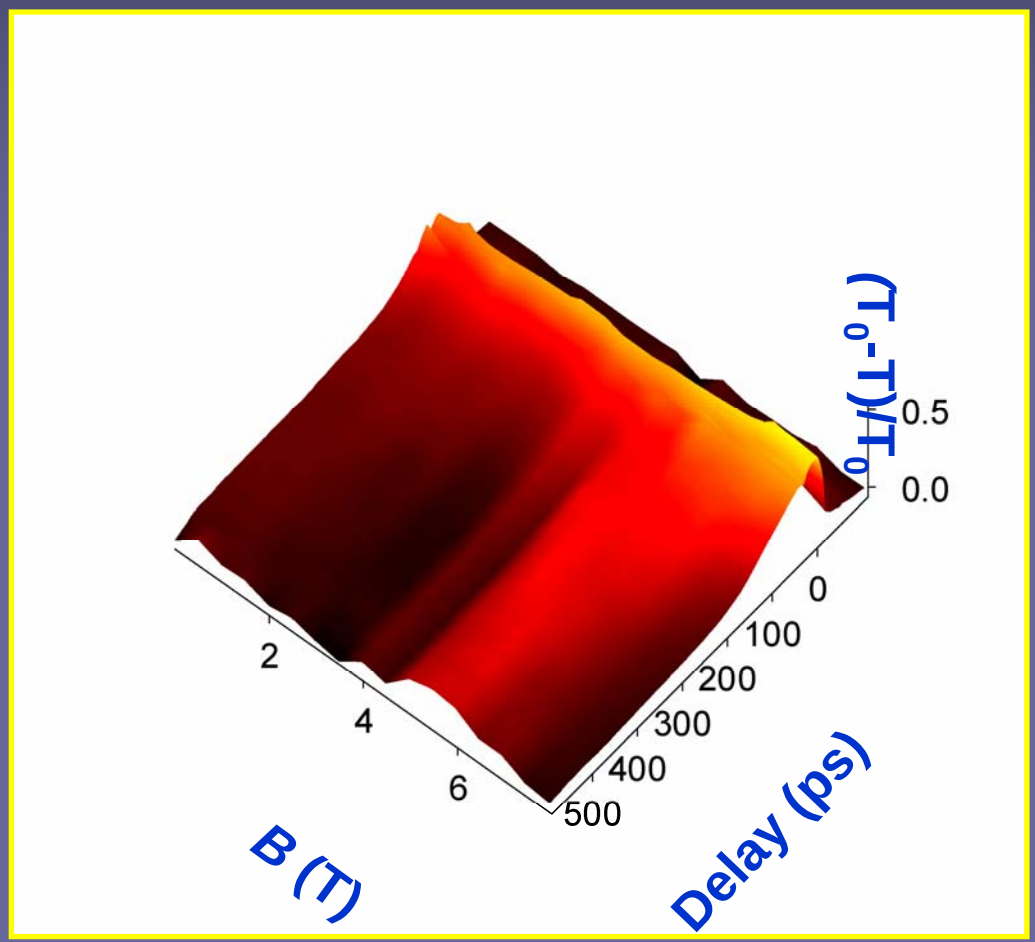
Time Resolved Cyclotron Measurements



Interband pump + Intraband probe

Monitor dynamics of relaxing carriers in conduction band directly in time:

Effective mass	m*(t)
Density	n(t)
Scattering time	τ(t)

G. A. Khodaparast *et al*, PRB 67 035307 (2003)

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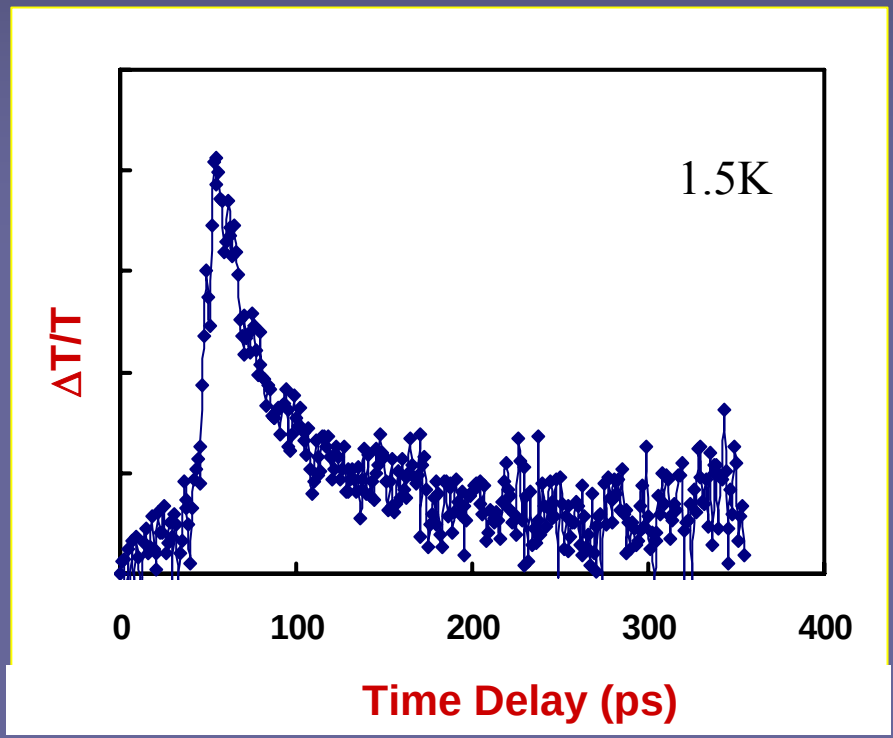
Carrier Dynamics in InSb QWs



Differential Transmission

Interband Pumping (800 nm)

Probe Beam (42 μm)

Undoped InSb MQW containing 25 periods of 35 nm InSb wells

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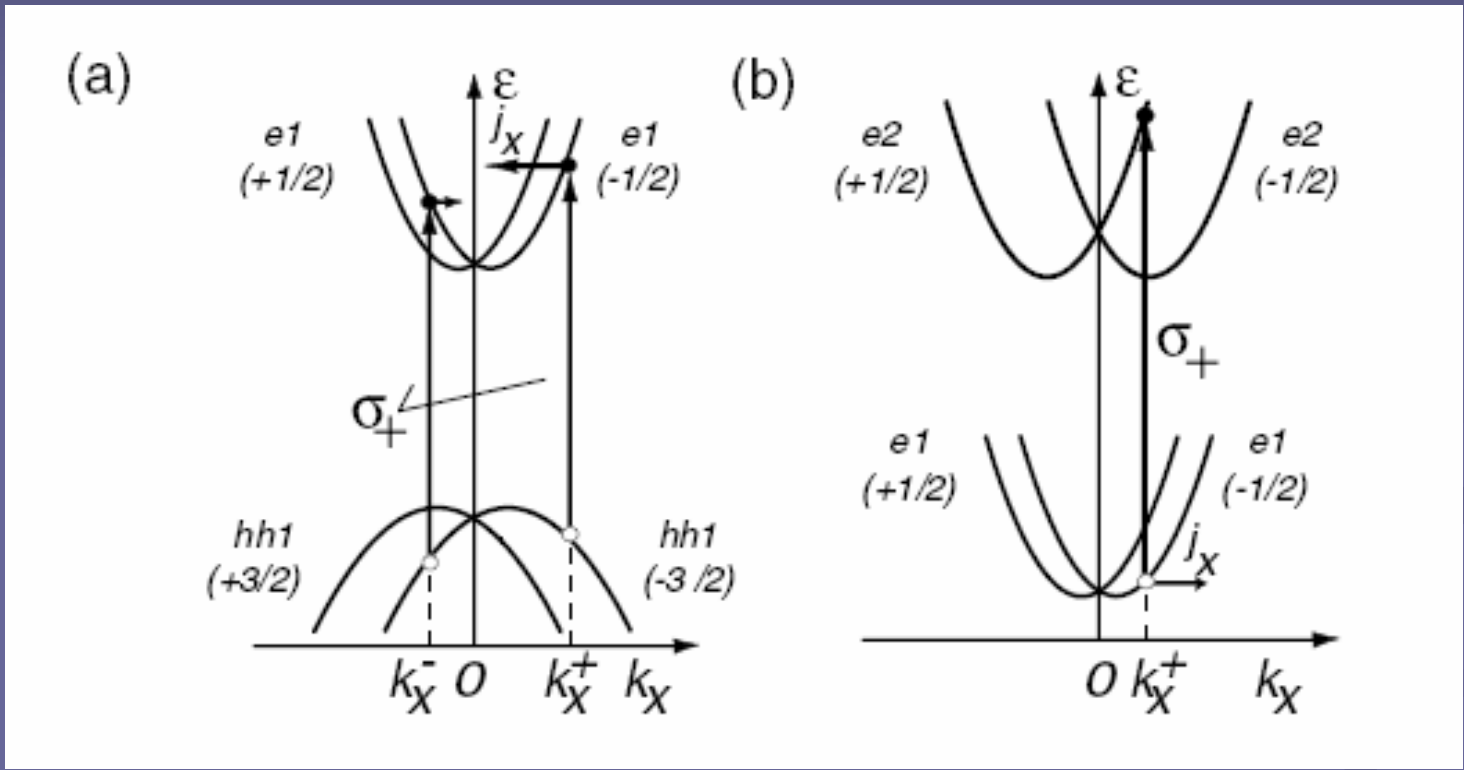
Spin Polarized Current



S. D. Ganichev and W. Prettl, J. Phys: Condens. Matter 15 (2003) R935-R983

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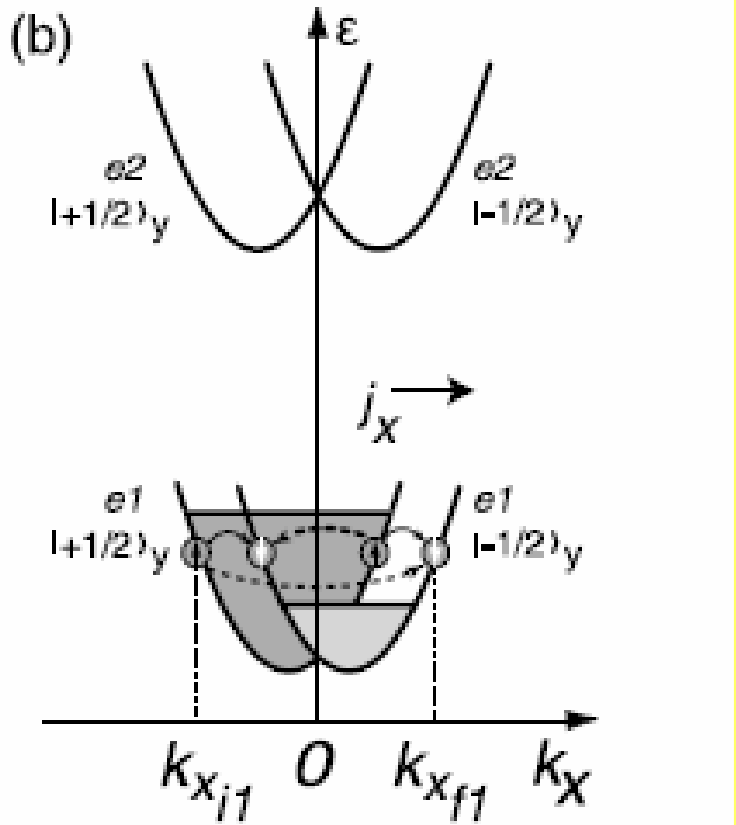
Spin Polarized Current Using FEL



- Spin Current as a result of spin flip scattering
- Both inter-band and inter-subband has been observed in GaAs based QWs

S. D. Ganichev and W. Prettl, J. Phys: Condens. Matter 15 (2003) R935-R983

C. L. Yang *et al.* , PRL, 96, 186605 (2006)

Summary/ Future Work

- InSb based structures important: fundamental physics and applications

  High carrier mobility, large Rashba effect,….

-We have some understanding of carrier/spin relaxations in this system

- We can take advantage of FEL to probe spin polarized current in this structure

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Thank you for your attention

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