Spin/Carrier Dynamics in Narrow Gap Semiconductors

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Supported by NSF and AFOSR
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- 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
III-V Semiconductors
InSb Based Heterostructures

An ideal model of a narrow-gap semiconductor

- Small effective mass, large g-factor
- Large spin-orbit coupling
- Small e-e interaction
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

Symmetric quantum well

Al_{x}In_{1-x}Sb

Al_{x}In_{1-x}Sb

Asymmetric quantum well

Al_{x}In_{1-x}Sb

InSb

B_{eff} = E \times \frac{V}{c}

Density: 1-4 \times 10^{11} \text{ cm}^{-2}

Mobility: 100,000-200,000 \text{ cm}^{2}/\text{Vs}

Alloy concentration: 9\%, 15\%
Asymmetry of the confining potential in a QW remove the degeneracy of band structure → Rashba effect:

\[ E = E_{z}^{\text{sub}} + \frac{\hbar^2 k^2}{2m^*} \pm \alpha|k_t| \]

Electronic systems with finite spin splitting in the absence of external magnetic field!!!
Rashba Splitting at $B>0$

\[ E(k) = \frac{\hbar^2 k^2}{2m} \pm \alpha k \]

In addition to:

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

Spin Relaxation

Equilibrium  Excitation  Recombination  Non-equilibrium
Why Spintronic?

Efficiency!!

\[
\langle S_x \rangle \propto \cos \omega t
\]

\[
\omega \propto E^\uparrow - E^\downarrow
\]

Normal Field Effective Transistor (FET)

Our Motivation

- Understand charge/spin dynamics in narrow gap structures
- Study phenomena such as interband and intraband photogalvanic 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 $\sim 10^{17} \text{ cm}^{-3}$

- Optical Parametric Amplifier – 1.1μm – 2.4 μm, Carrier density $\sim 10^{19} \text{ cm}^{-3}$
Optical Induced Magneto Optical Kerr Effect (MOKE)

- Selection rules for inter-band transitions, Spin-polarized carriers using circularly polarized beams
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 $\sim 10^{17}$ cm$^{-3}$
- Sharp decrease, followed by an exponential recovery
- Carrier lifetime $\sim 40$ ps
• Spin relaxation for left and right circularly polarized pump.
• Relaxation time ~ 40ps
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
Asymmetric Quantum Well
Spin relaxation at 2μm

- Spin polarized carriers excited using circular polarized light
- Spin lifetime ~ 4 ps
Symmetric Quantum Well
Carrier relaxation at 2μm

- Pump – 2 μm, Probe 800 nm
- Carrier density - \( \sim 10^{19} \text{ cm}^{-3} \)
- Sharp decrease, followed by an exponential recovery.
- Carrier lifetime \( \sim 4 \text{ ps} \)
Symmetric Quantum Well

Spin relaxation at 2μm

- Spin polarized carriers excited using circular polarized light
- Spin lifetime ~ 2 ps
**Time Resolved Cyclotron Resonance Measurements, Stanford FEL**

Sample

**B**

0-8 T

Ga:Ge detector

**Ti:S pump**

Pellicle beam combiner

**FEL probe**

\( \lambda = 3-60 \, \mu \text{m} \)

pulse 600 fs – 2 ps

max 1 \( \mu \text{J/pulse} \)

Prof. Kono’s Group at Rice University
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 $\tau(t)$

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
Spin Polarized Current

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

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
Thank you for your attention