CAPEM

Department of Physics
University at Buffalo The State University of New York

Spin polarization measurements of InAs based LED’s

C.J. Meining, K.A. Korolev and B.D. McCombe
Department of Physics and CAPEM, University at Buffalo, SUNY, Buffalo, NY 14260, USA
P. Grabs, I. Chado, G. Schmidt and L.W. Molenkamp
Physikalisches Institut (EP3), Universität Würzburg, 97074 Würzburg, Germany

This work was supported in part by

DARPA

OFFICE OF NAVAL RESEARCH

SpinS

N00014-00-1-0951

And by the
Center for Advanced Photonic and Electronic Materials

Outline:

- Motivation/Samples
- Experiment
- Results
- Discussion

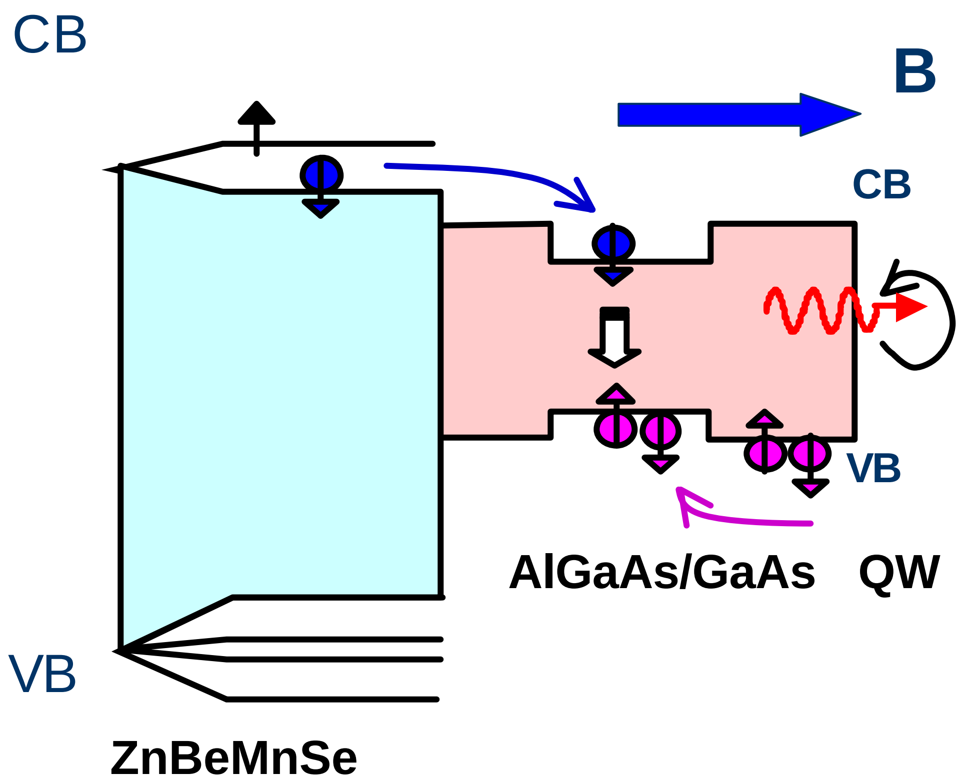
CAPEM

Motivation

Department of Physics
University at Buffalo The State University of New York

C.J. Meining, APS 2004

Würzburg Group, Nature **402**, 787 (1999) and NRL/UB PRB (2000)



- Spin-injection into GaAs QW's by studying circular polarization of recombination
- Unique band alignment of NGS ⇒ Novel device structures (Spinphotonics)

Investigate spin-injection efficiency by means of optical polarization degree of photoluminescence

BUT: III-V NGS have large Zeeman splittings and enhanced non-parabolicity effects

⇒ Is spin-injection into NGS InAs measurable?

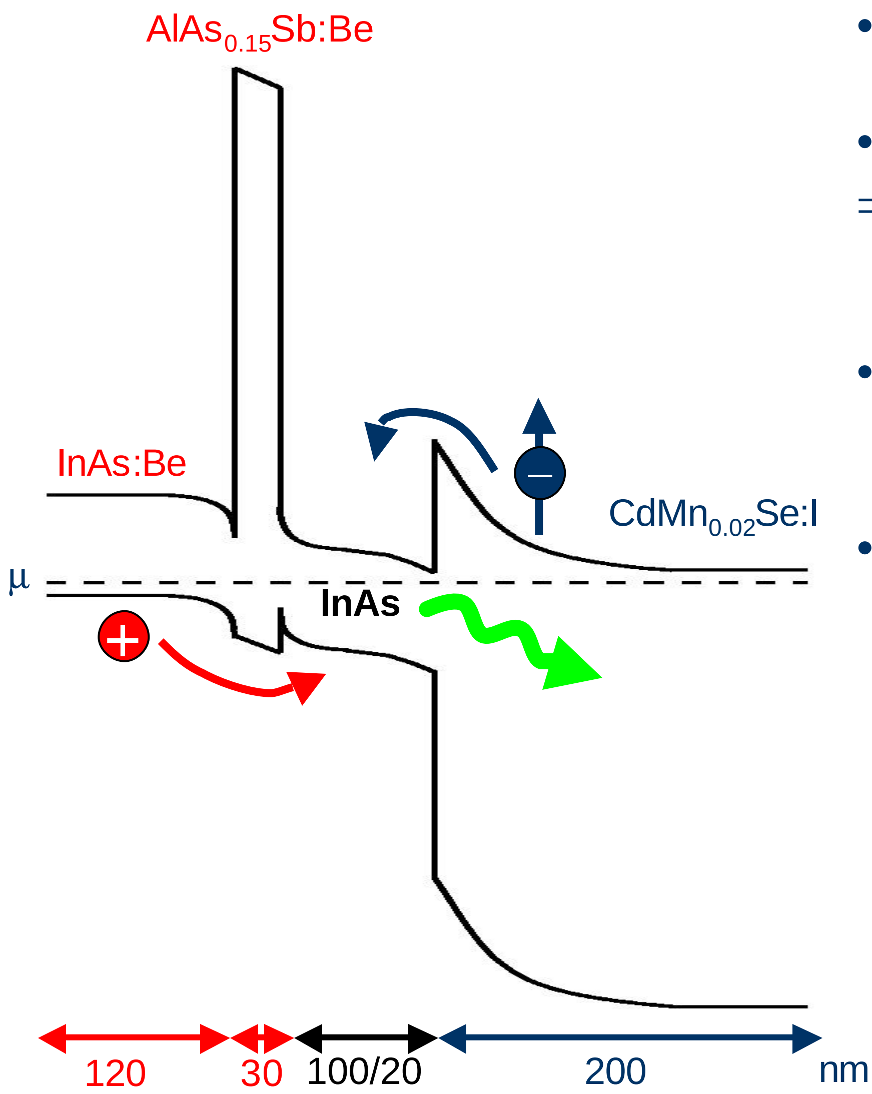
CAPEM

Samples

(University of Würzburg, Germany)

Department of Physics
University at Buffalo The State University of New York

C.J. Meining, APS 2004



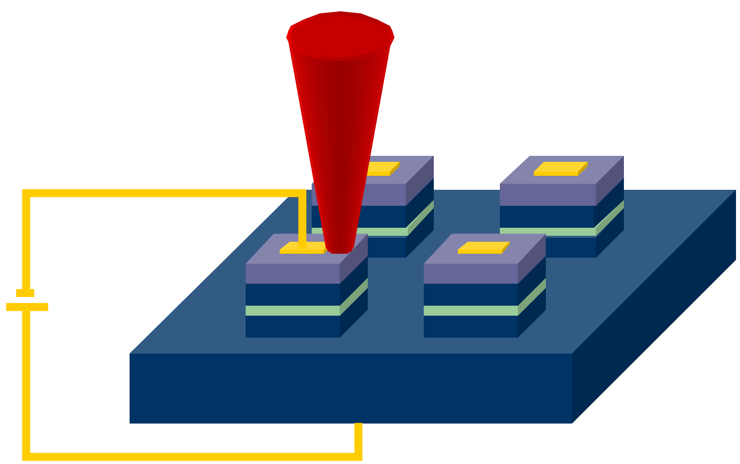
- Hybrid III-V/II-V p-i-n LED's

- asymmetric QW

$\Rightarrow$ high barriers for electrons (~ 1.8eV) and holes (~ 0.86eV)

- magnetic and nonmagnetic reference structures (CdMnSe:I $\Leftrightarrow$ CdSe:I)

- processed into (200 – 500) μm mesas with Au contacts

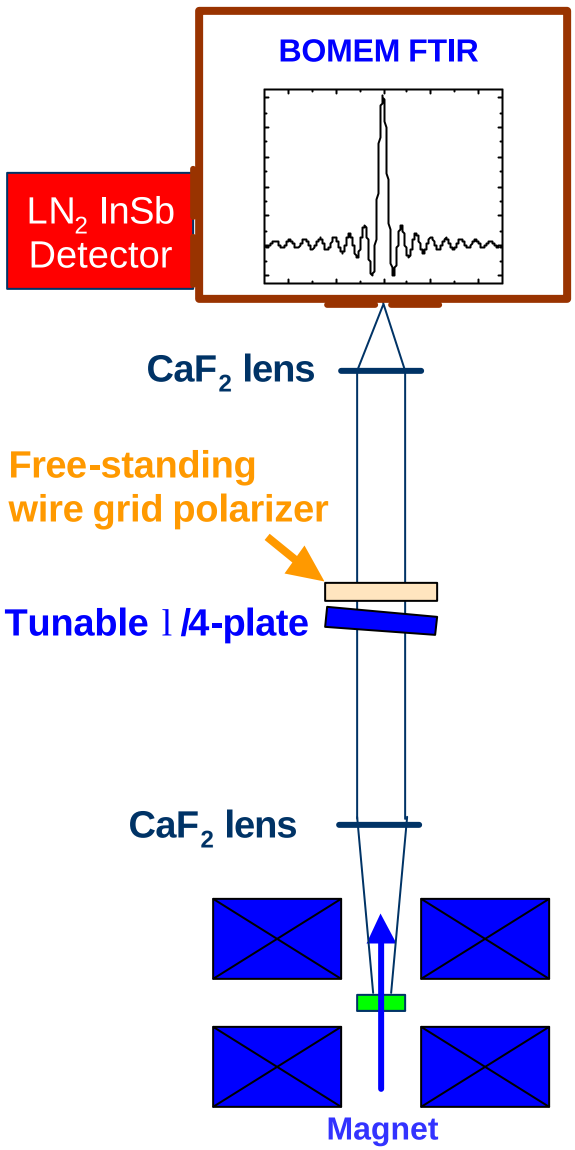


CAPEM

Department of Physics
University at Buffalo The State University of New York

C.J. Meining, APS 2004

Experimental Setup

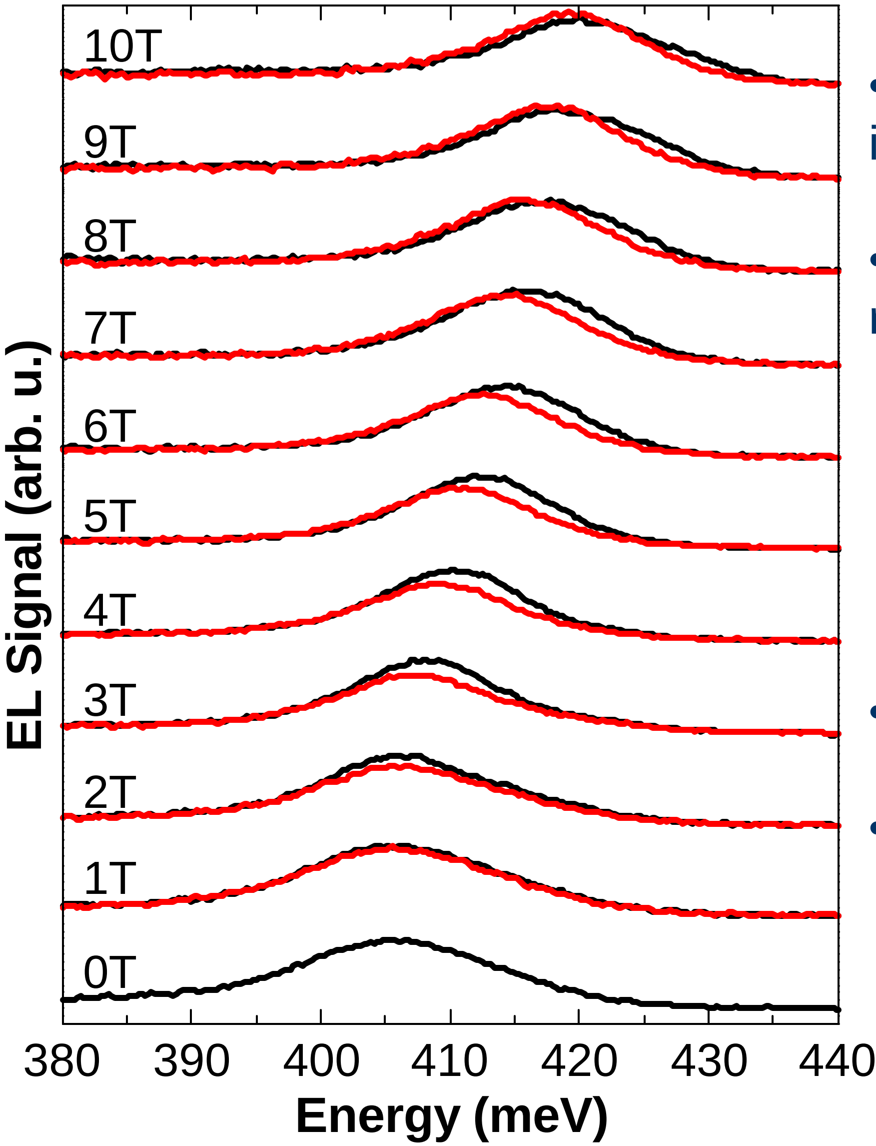


- 10T superconducting split coil magnet with sample immersed in liquid Helium
- CaF_2 lenses for collimation and focusing of EL
- Freestanding wire grids as linear polarizers
- Savart plate as tunable $\lambda/4$-plate
  $\Rightarrow$ wavelength of $\pi/2$ shift depends on angle of incident light
- **F**ourier **T**ransform **I**nfra**R**ed Spectrometer
- LN_2 cooled photovoltaic InSb detector
- AC operation of LED's at f = 104kHz, 50% duty cycle
  $\Rightarrow$ no RT blackbody background

CAPEM

Polarized EL

C.J. Meining, APS 2004



- polarized EL with I_{peak} = 60mA immersed in LHe (j_{av}< 20 W/cm^2)
- access opposite polarization by reversal of magnetic field

black lines: s^-
red lines: s^+

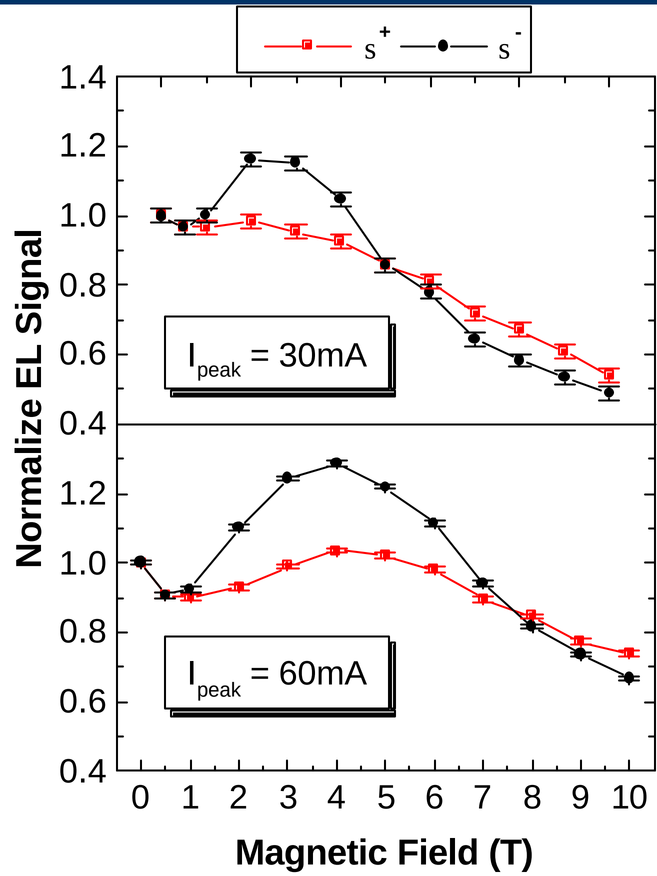
- Low fields: *High energy* σ^- component dominates
- High fields: *Low energy* s^+ component gets stronger and wins

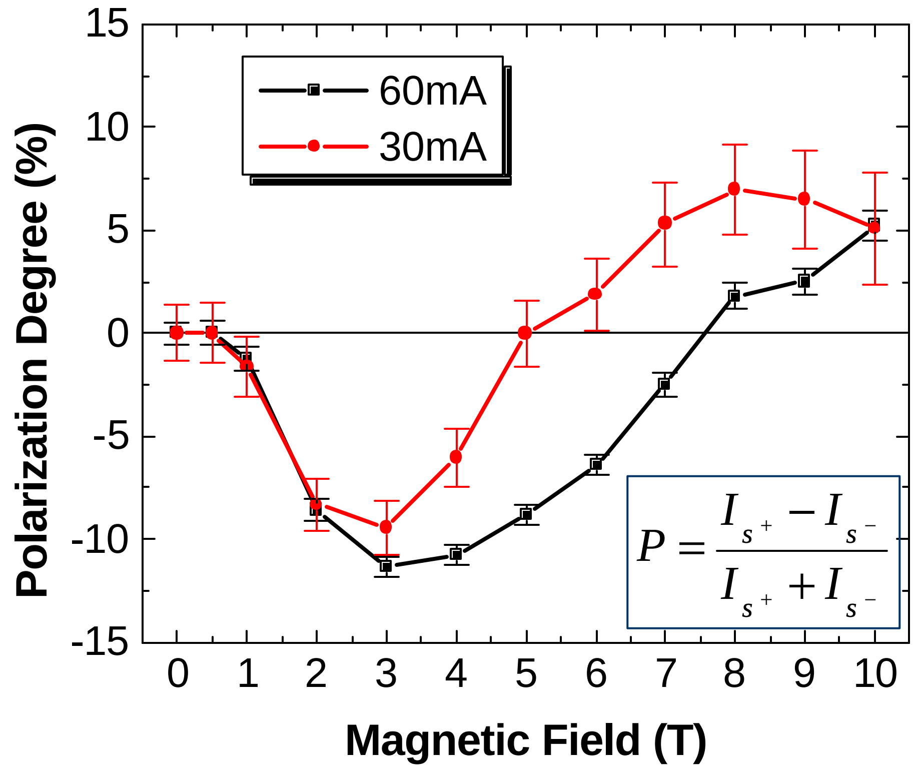
CAPEM

EL intensities and polarization degree

Department of Physics
University at Buffalo The State University of New York

C.J. Meining, APS 2004





- Measured from peak amplitude of dominant line
- Initial increase with B
- Peak, followed by decrease to ~ 60%
- Different injection currents lead to different values of field at peak

- Polarization degree increases with B
- Peaks at about 3T (about 9 – 12 % depending on injection current)
- Peak followed by sharp decrease and change in sign
- crossover at lower fields for lower current

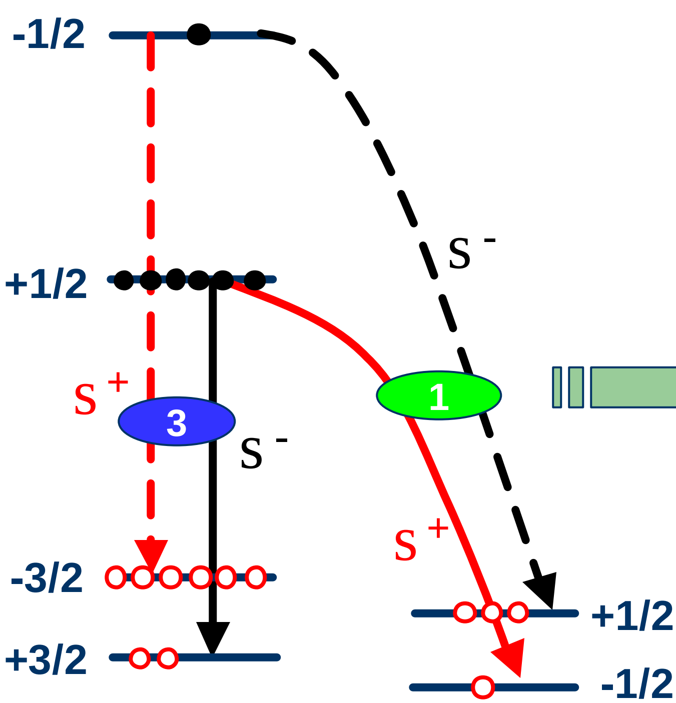
CAPEM

Zeeman splitting in InAs

Department of Physics
University at Buffalo The State University of New York

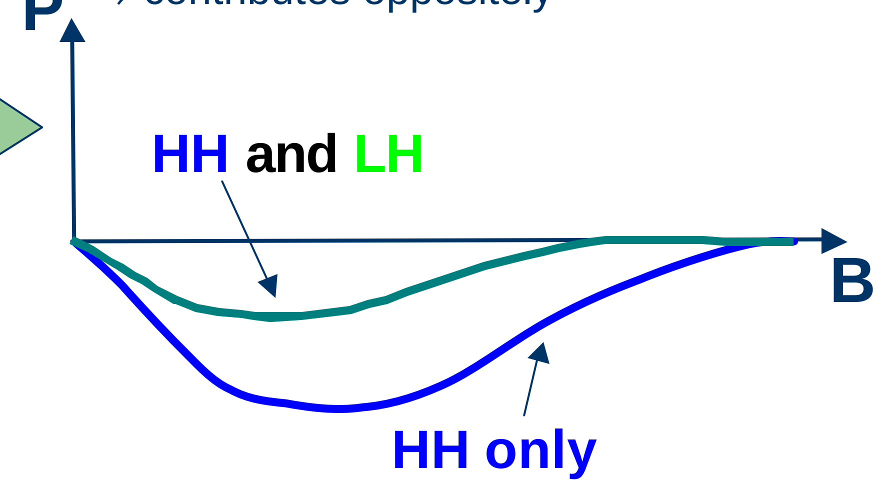
C.J. Meining, APS 2004

- 1000Å InAs "well" ⇒ bulk InAs
  - ⇒ $g_e = -15$
  - ⇒ $\Delta E_{hh\text{-}lh} < 1\text{meV}$
  - ⇒ $|g_{h}| < |g_e|$
- adopt hole level ordering from J.R. Meyer and I. Vurgaftman @ NRL



Steady State (single carrier T):

- P = 0 at B = 0 (negligible zero field splitting)
- HH contribution > LH contribution
  ⇒ transition matrix elements HH:LH = 3:1
- HH σ^- transition strongest low T and low B
- P → 0 as B → ∞, since transitions between ground state conduction and valence band levels are forbidden and excited states are depopulated
- Including LH will decrease and shift minimum
  ⇒ contributes oppositely



CAPEM

Injection from CdSe

Department of Physics
University at Buffalo The State University of New York

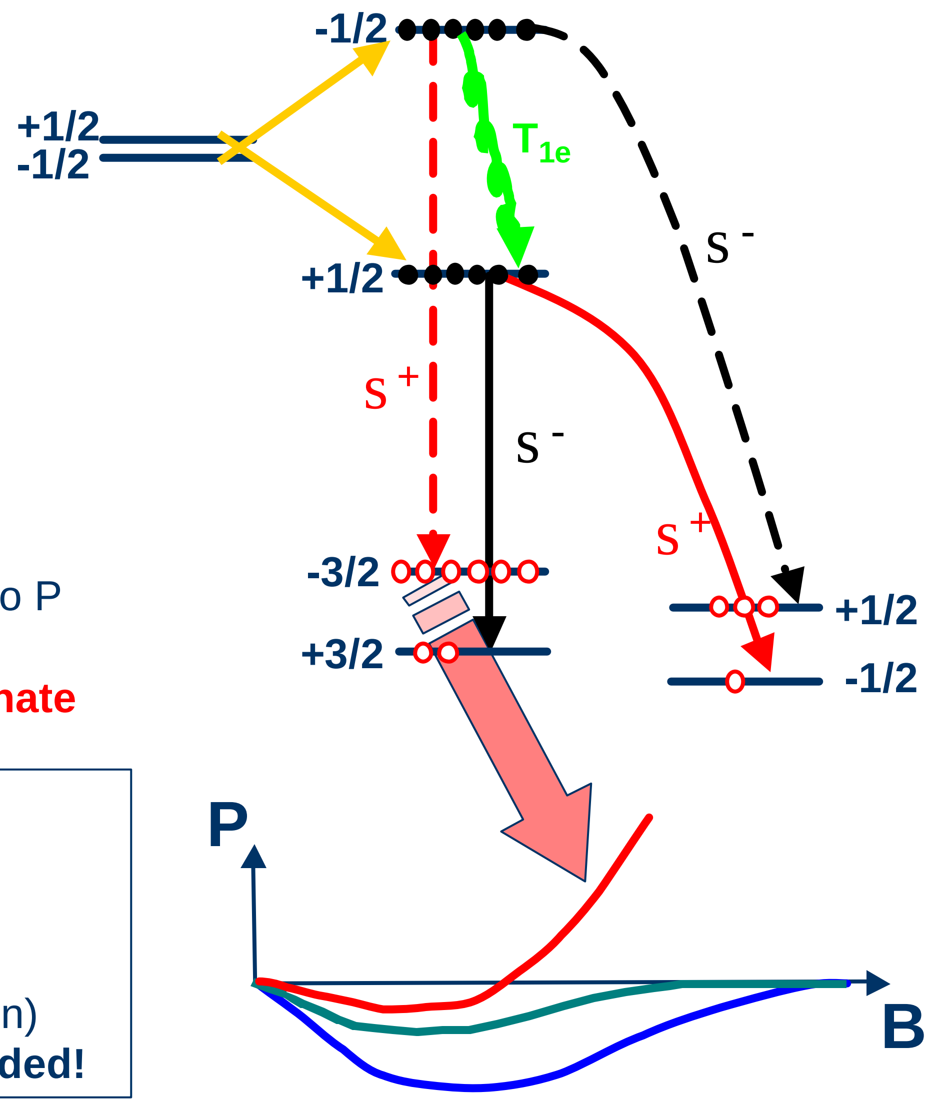
C.J. Meining, APS 2004

• cubic CdSe g_e = + 0.46 negligible (Karimov et al. PRB **62**, 2000)
⇒ equal injection into +1/2 and –1/2 states of InAs

• holes are unpolarized and quickly thermalize ($T_{1h} << \tau_R$)

• Polarization degree will depend on spin relaxation time T_{1e}:

1. $T_{1e} << t_R$
⇒ system thermalizes, no change to P
2. $T_{1e} >> t_R$
⇒ **s^+ transition will start to dominate**



Bulk InAs @ low temperatures:
T_{1e} ~ 1 – 10 ns
(Song and Kim, PRB **66**, 2002)
τ_R ~ 1 – 10 ns
(J.R. Meyer, private communication)
Þ **Detailed quantitative analysis needed!**

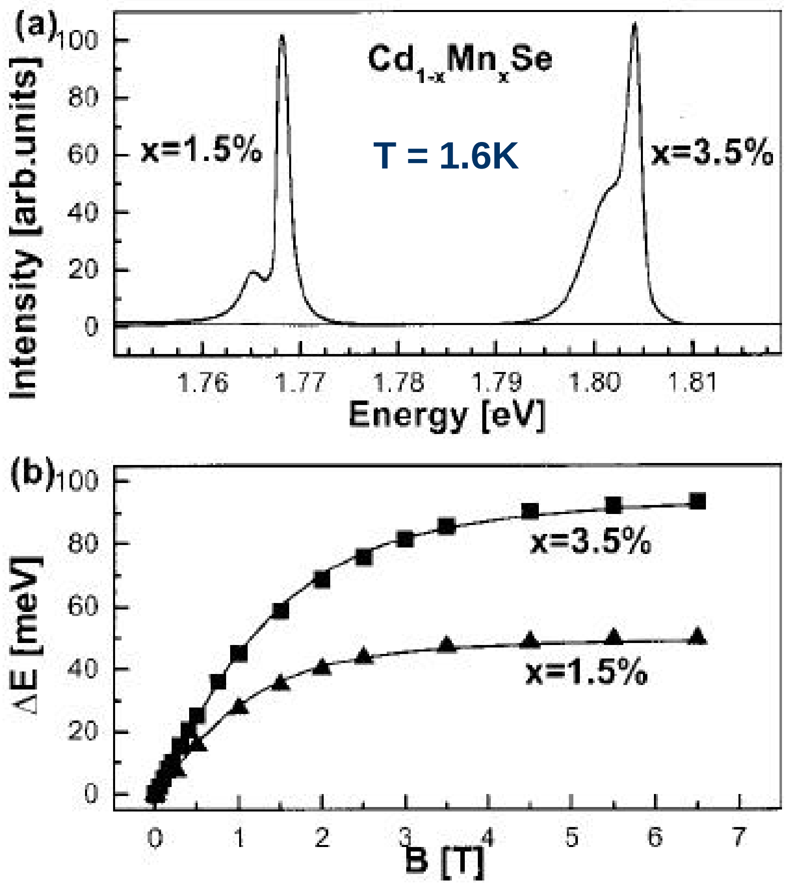
CAPEM

Magnetic CdMnSe

Department of Physics
University at Buffalo The State University of New York

C.J. Meining, APS 2004

P. Grabs et al., APL **80**, 2002



- Paramagnetic DMS CdMnSe: $g_e > 0$
  - ⇒ exclusive injection into upper –1/2 InAs state
  - ⇒ spin splitting decreases with increasing temperature

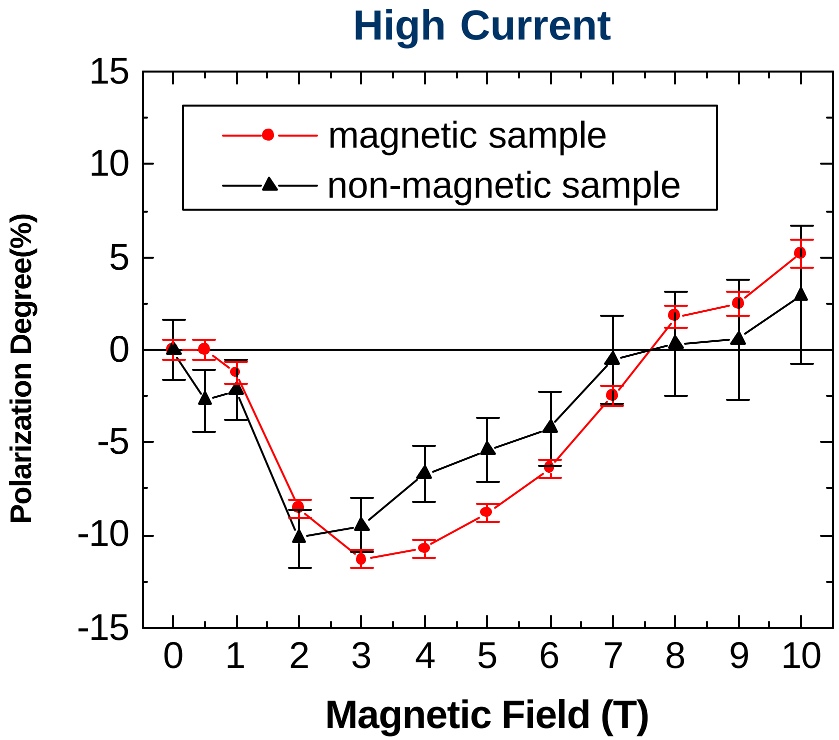
- Polarization degree should change sign faster than for non-magnetic CdSe injector

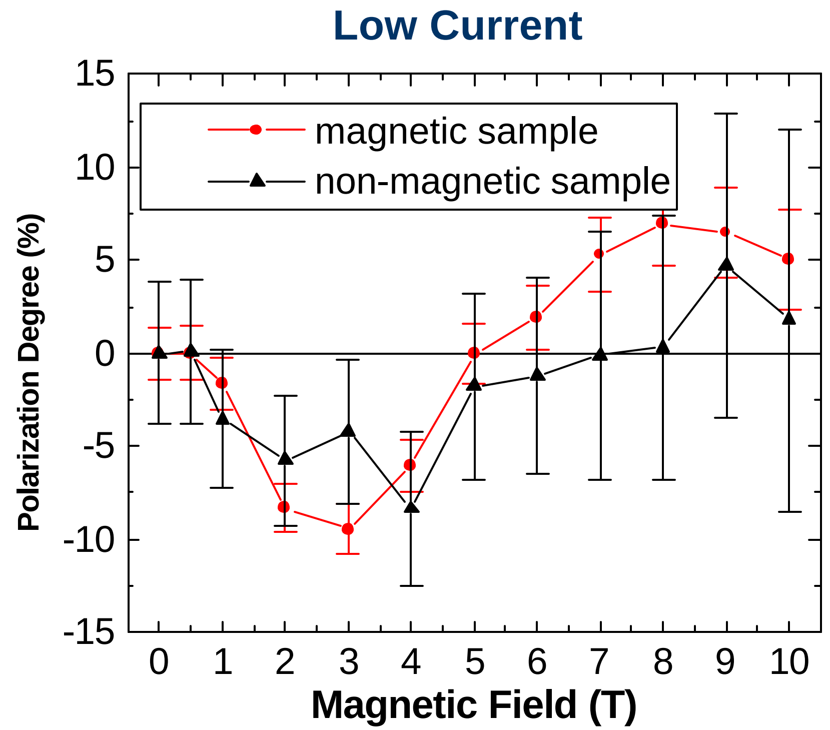
- Crossover field will depend on:
  - **spin-lattice relaxation time T_{1e}**
  - **recombination life time τ_R**
  - g_e in InAs
  - g_{hh} and g_{lh} in InAs
  - carrier density in n-type InAs

CAPEM

Magnetic and Non-Magnetic Sample

C.J. Meining, APS 2004



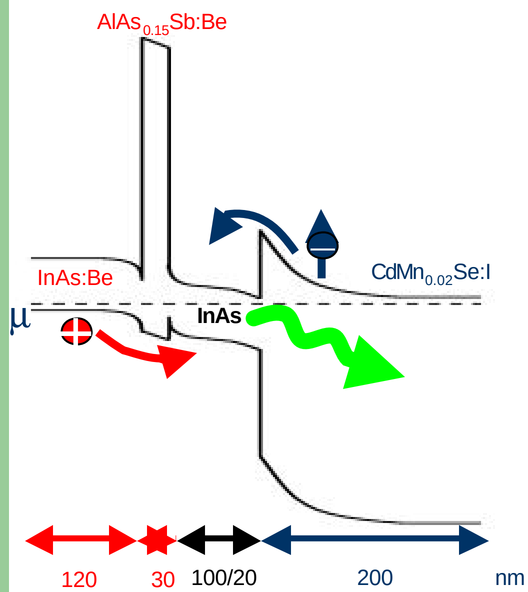


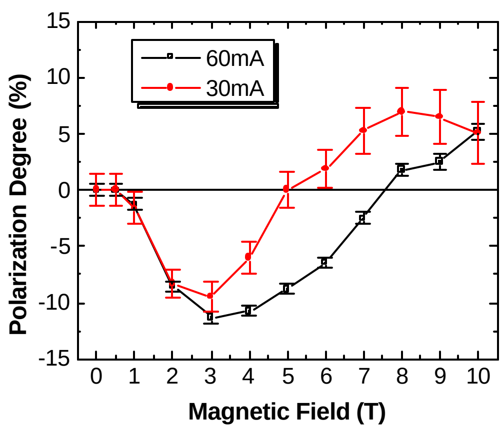
- Overall signal lower for non-magnetic $\Rightarrow$ significant increase in errors
- Similar qualitative behavior of magnetic and non-magnetic sample
- *Low current:* difference in polarization degree masked by noise
- *High current:* small difference in polarization degree only at intermediate fields

CAPEM

Summary/Plans

C.J. Meining, APS 2004





Thanks to J.R. Meyer and I. Vurgaftman

- Circularly polarized EL in MIR from AlAsSb/InAs/CdMnSe Spin-LED's and non-magnetic reference sample
- Difference in P masked by noise but may show some evidence of spin injection at high magnetic fields
- Comparable spin-lattice relaxation time and recombination time render spin-injection difficult
  - ⇒ Large intensity for σ^- and σ^{-+} at 10T
  - ⇒ Crossover from σ^- and σ^{-+} at high B
- Possible carrier heating due to high injection currents
- Detailed knowledge of bandstructure including band bending effects and modeling (rate equation) needed for quantitative interpretation
- Sample improvement
  - ⇒ minimize barriers for electrons and holes
  - ⇒ narrower InAs wells

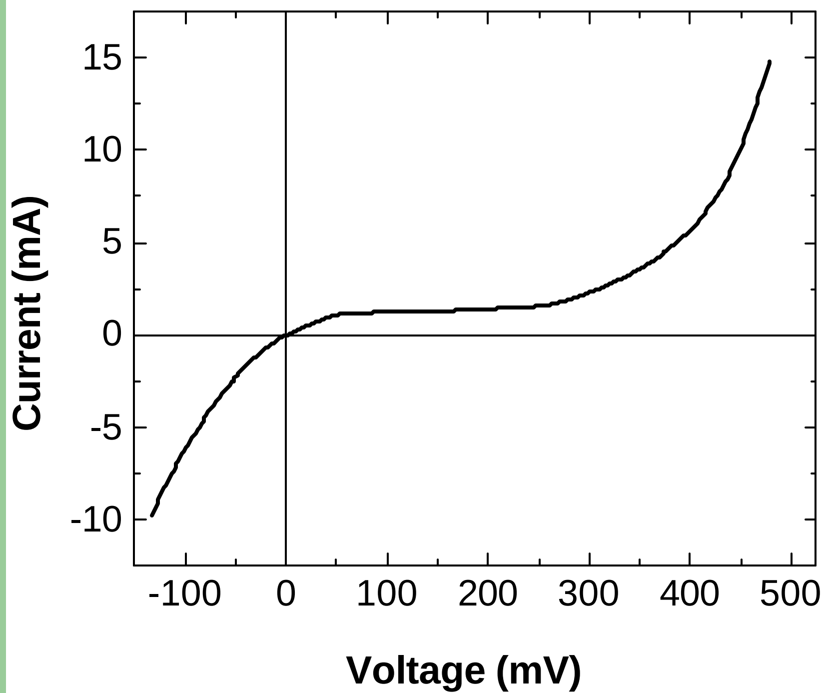
  (minimize LH competition, reduce τ_R)

CAPEM

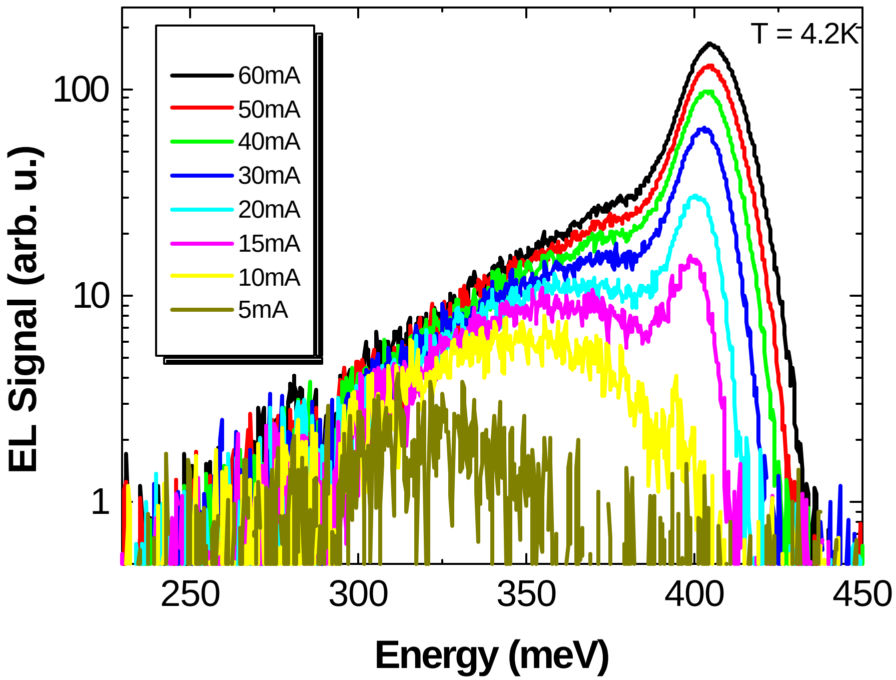
IV and EL of magnetic sample

Department of Physics
University at Buffalo The State University of New York
C.J. Meining, APS 2004

DC – IV @ 4.2K



EL in forward bias for different peak currents

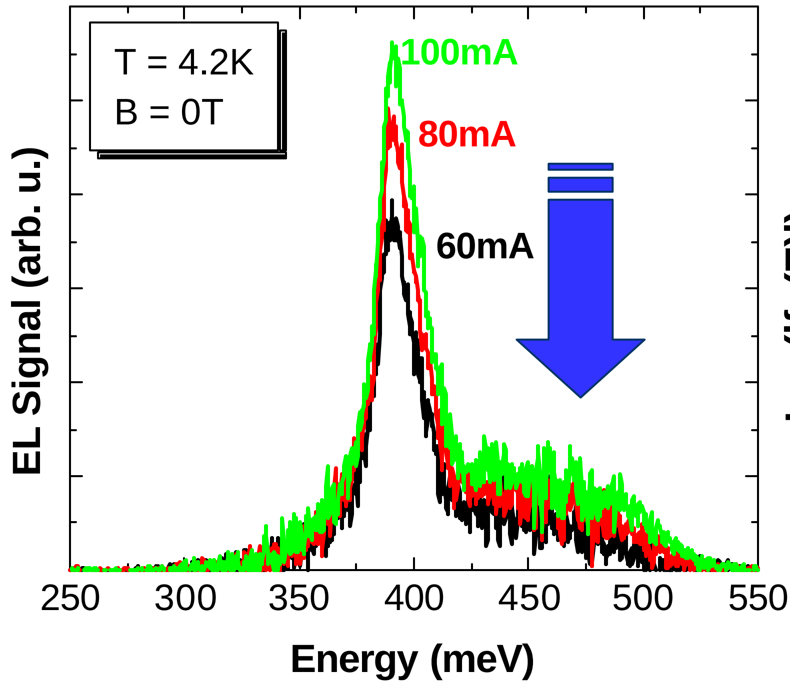


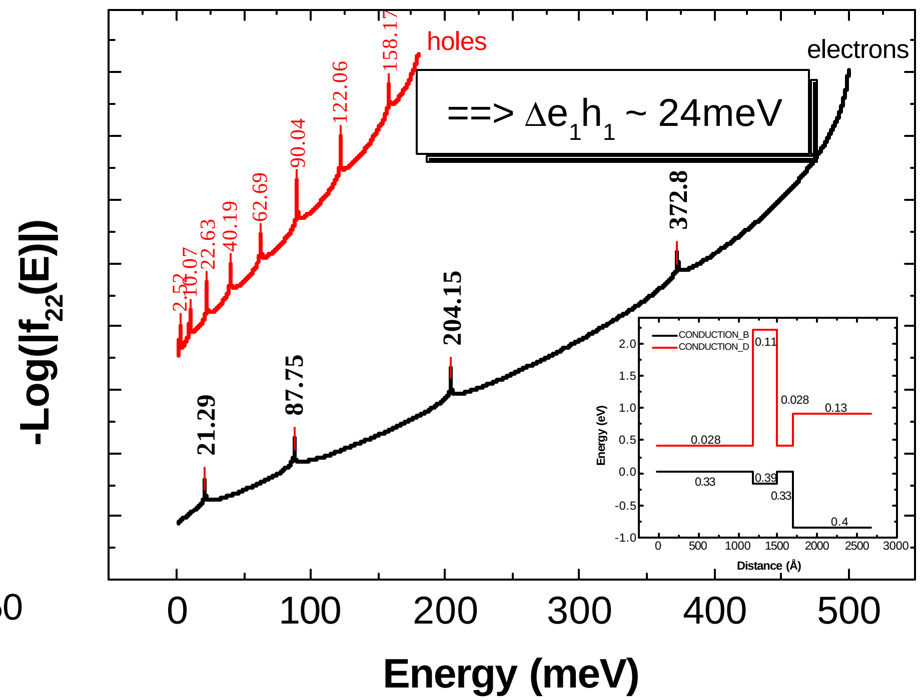
- IV's dominated by tunneling, no clear diode behavior observed
- EL shows two features ("sharp" line near InAs gap; broad band below gap)
- IV and EL data for non-magnetic samples very similar
- some contacts show negative differential resistance

CAPEM

200Å InAs well

Department of Physics
University at Buffalo The State University of New York
C.J. Meining, APS 2004





- EL of 200Å InAs well
- additional feature above 417 meV due to confinement in well

- Transfer-matrix calculation

$\Rightarrow e_1h_1 \sim 24meV$

- LT-E_{gap} (InAs) = 417meV