Electron Spin Dynamics in Non-Magnetic Narrow Gap Semiconductors

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Spin Dynamics in InSb

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- University of Surrey, Guildford
- Imperial College, London
- QinetiQ, Malvern

Outline

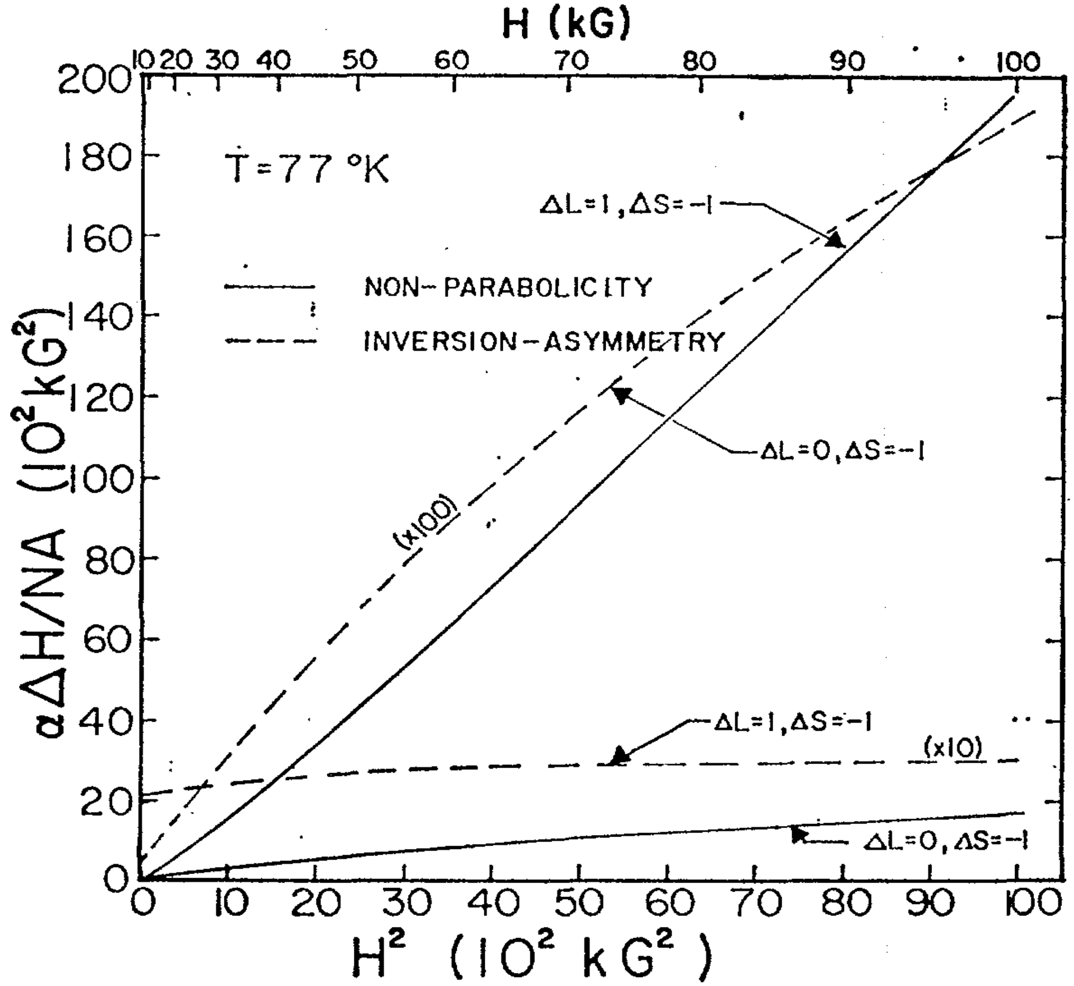
- History – Bruce
- Circularly polarised pump/probe with Voigt **B**
  g*(T) results for InSb – and GaAs (theory)
- Spin relaxation in [100] InSb n-ASQWs
- Spin modulation in [110] GaAs and InAs QWs
- Spin injection in InAs QWs (c.f. Meining et al)
- Conclusion

“Bruce and electric dipole spin res.”

B D McCombe
Phys. Rev. 1969
(non-degenerate)

Rashba, 1961
(Dresselhaus)
Yafet, 1963

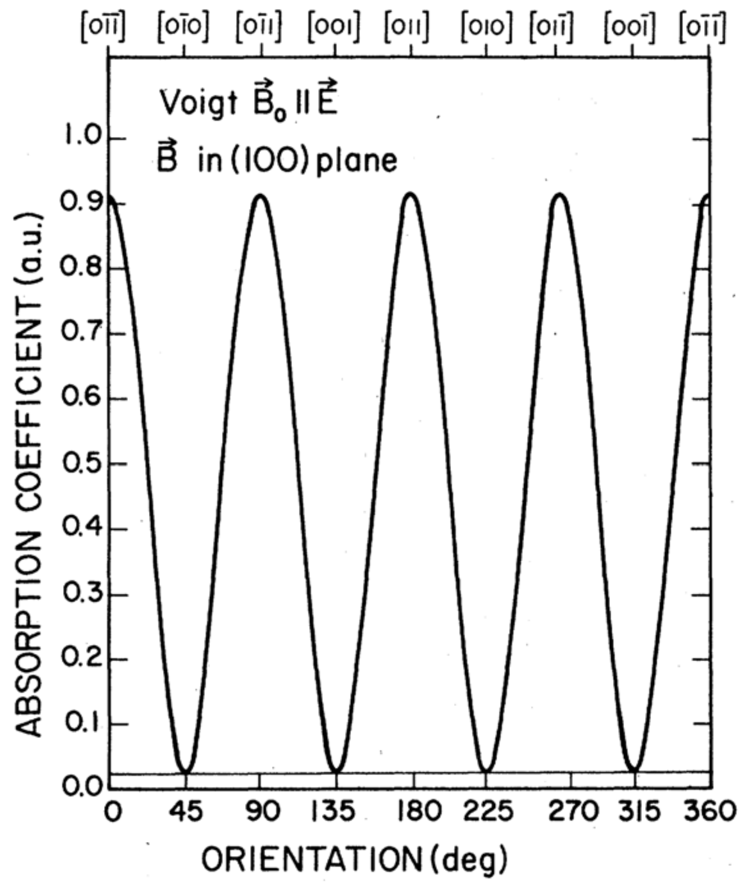
Spin Relaxation
DP; EY



Inversion Asymmetry esr in n-InSb

Dobrowolska, Furdyna et al
early 80s
Voigt config.
Degenerate

Anisotropy (DP) good news for **E**-field modulation in QWs via Rashba effect - spintronics



Pump/Probe (dynamic B-M shift)

$E_L \approx E_G + E_C$, hence g*(E,T)

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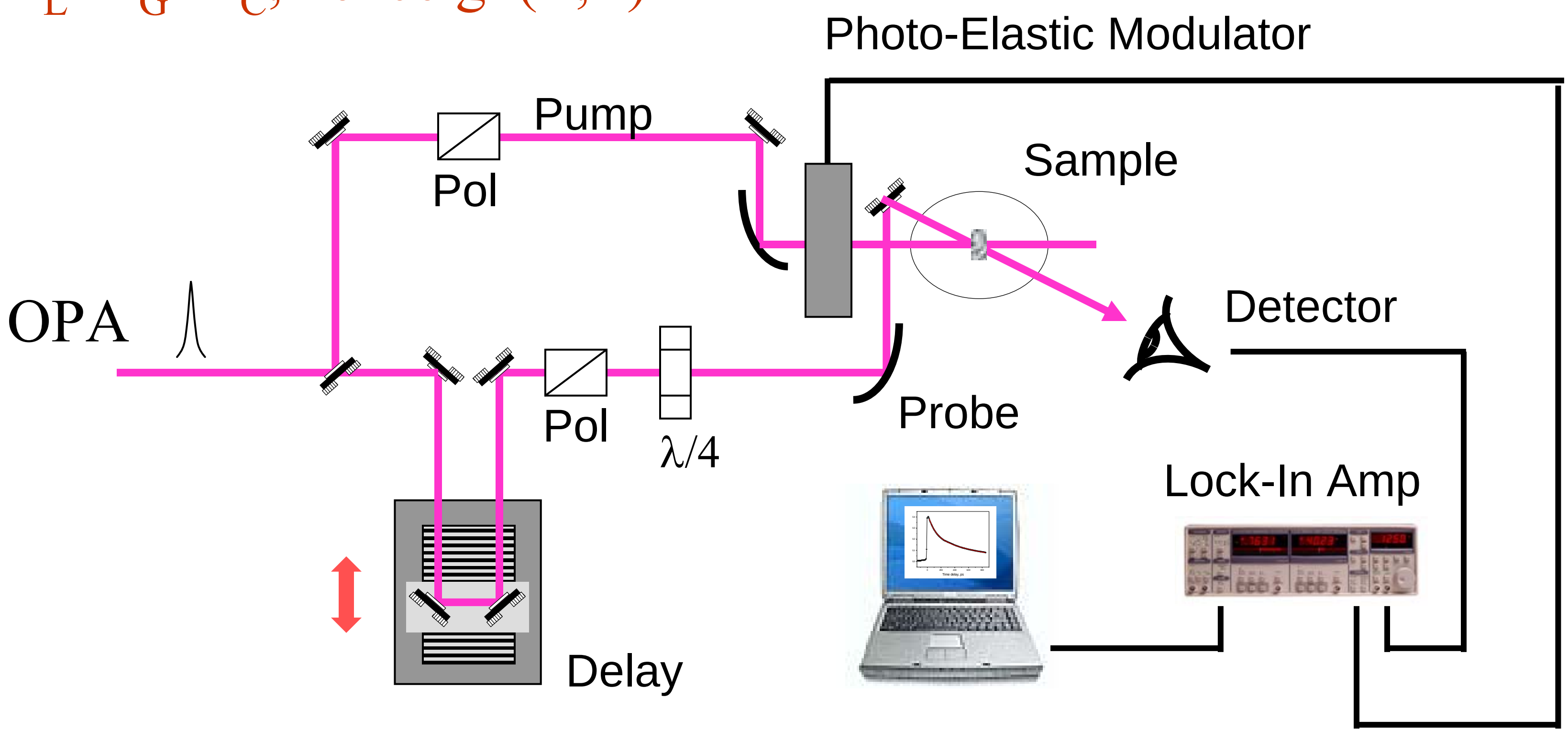


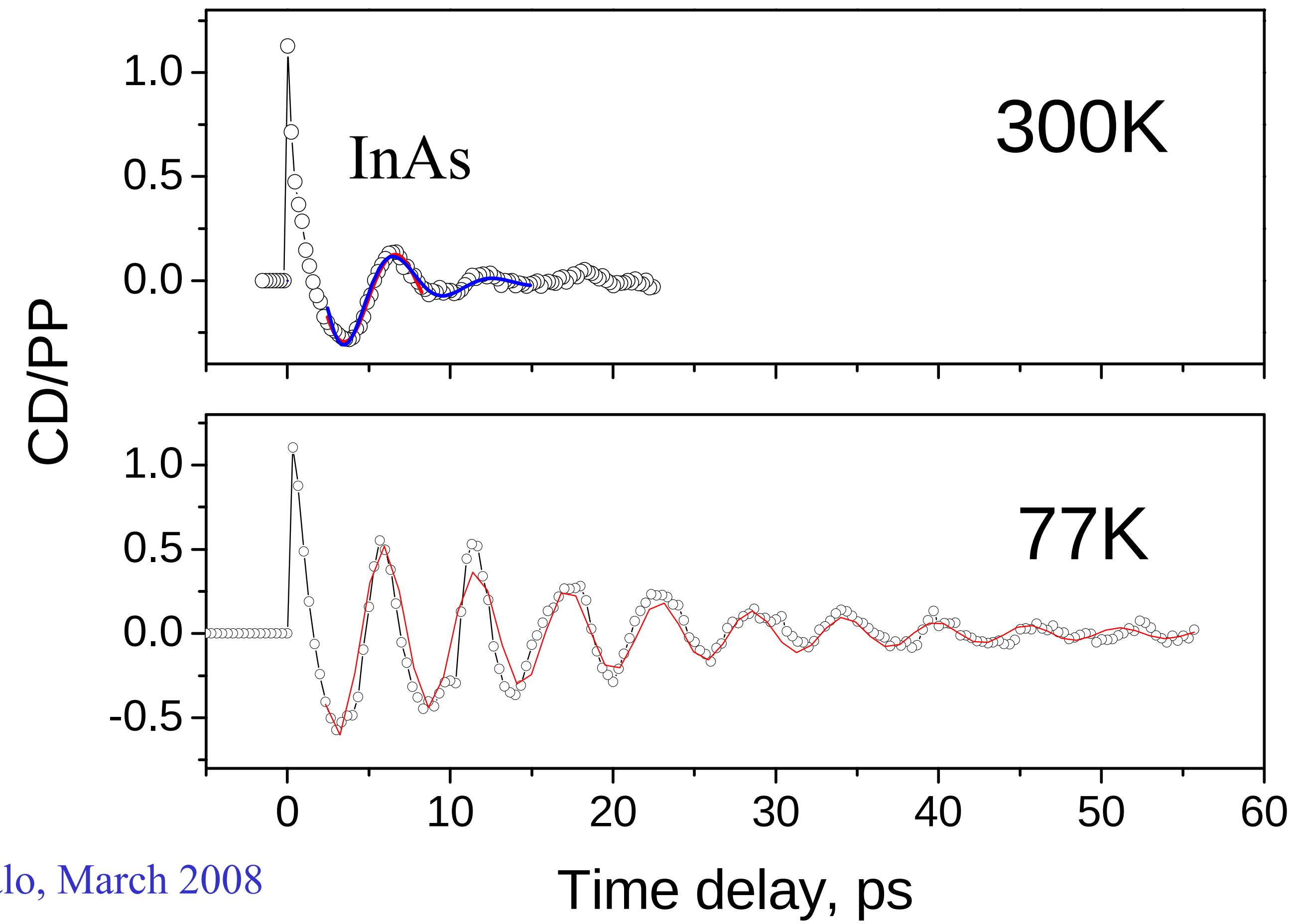
$$P(t) = \frac{\Delta T_{SCP} - \Delta T_{OCP}}{\Delta T_{SCP} + \Delta T_{OCP}} \propto \frac{\Delta T_{CD}}{\Delta T_{LP}}$$

Small Voigt Field

Small trans. B

$$\omega = g^* \beta B / \hbar$$

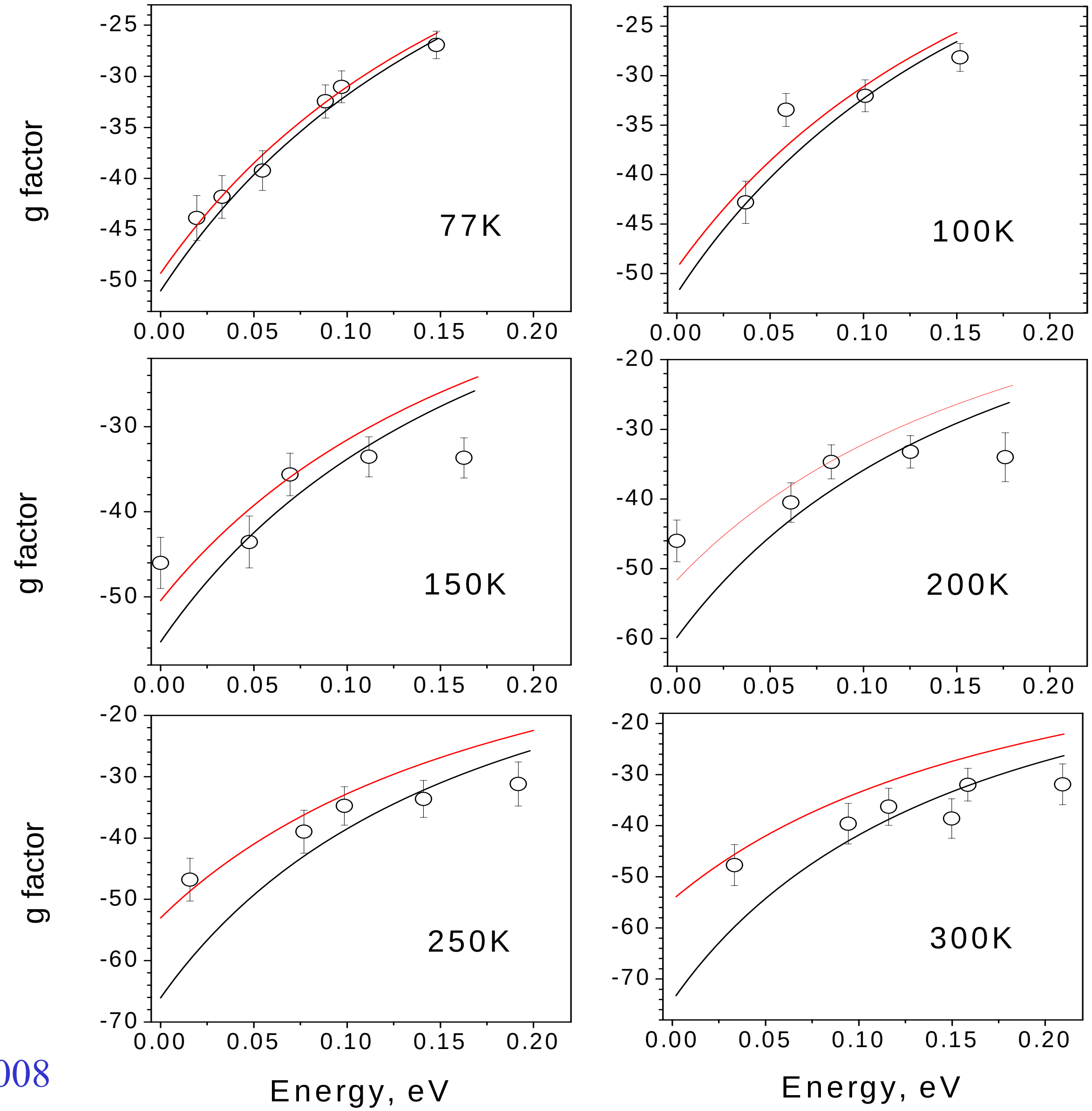
$$P = A\cos\left(\frac{g^* \mu_B B}{\hbar} t\right)\exp\left(-\frac{t}{\tau_s}\right)$$



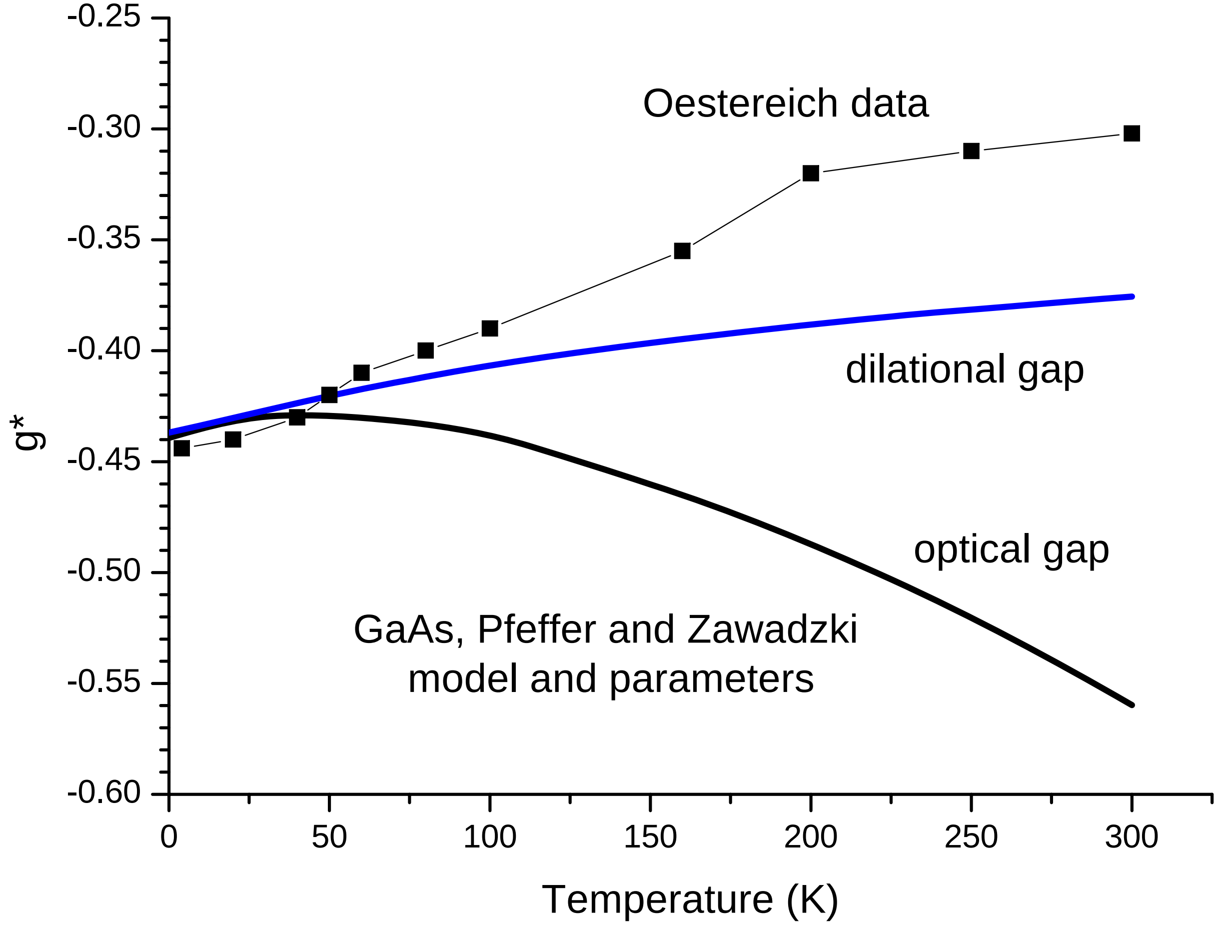
g*(E,T) for InSb

— optical gap

— dilational gap



GaAs: PL results



Spin relaxation in set of InSb n-ASQWs

DP dominates for high μ InSb QWs at T >20K

Zero-field spin splitting:

Pseudo-field drives precession about **Ω**

$$\hbar\boldsymbol{\sigma}\bullet\boldsymbol{\Omega}(\mathbf{k}) = \begin{pmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\end{pmatrix}\bullet\begin{pmatrix}\beta k_x - \alpha k_y - \gamma k_x k_y^2\\ \alpha k_x - \beta k_y + \gamma k_x^2 k_y\\ 0\end{pmatrix}$$

Motional narrowing: $\frac{1}{\tau_s} = \left\langle \left|\boldsymbol{\Omega}_\perp\right|^2 \right\rangle \tau_p$

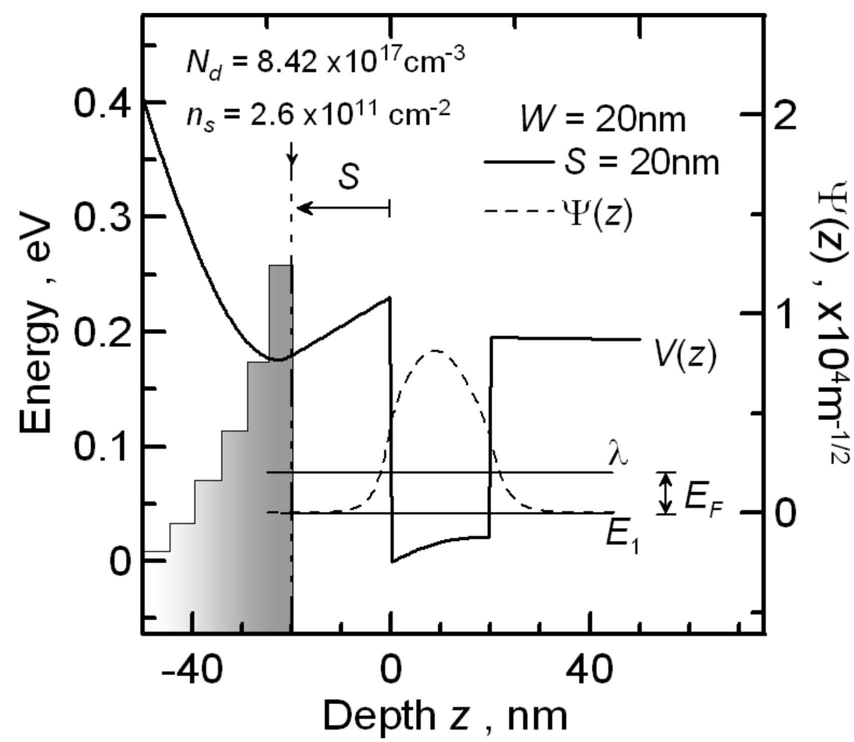
$$\frac{1}{\tau_s^{[0,0,1]}} = \frac{4k_F^2}{\hbar^2}\left\{\left[\alpha^2 + \left(\beta - \frac{1}{4}\gamma k_F^2\right)^2\right] + \frac{1}{16}\gamma^2 k_F^4\right\}\tau_p$$

$$\frac{1}{\tau_s^{[1,\pm1,0]}} = \frac{2k_F^2}{\hbar^2}\left\{\left[\pm\alpha + \beta - \frac{1}{4}\gamma k_F^2\right]^2 + \frac{1}{16}\gamma^2 k_F^4\right\}\tau_p$$

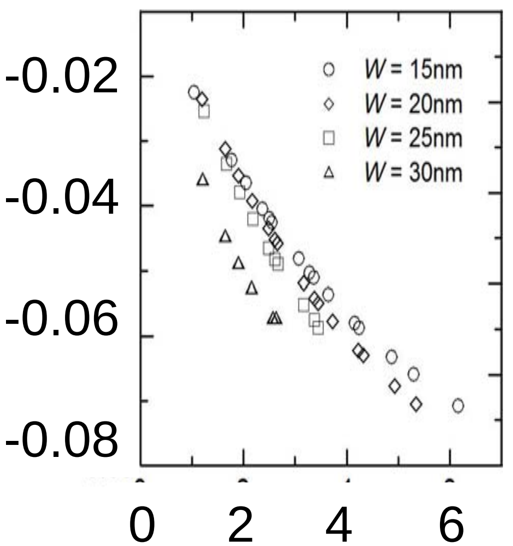
[001] Samples: MBE on GaAs

InSb/$Al_{0.08}In_{0.92}Sb$ quantum wells

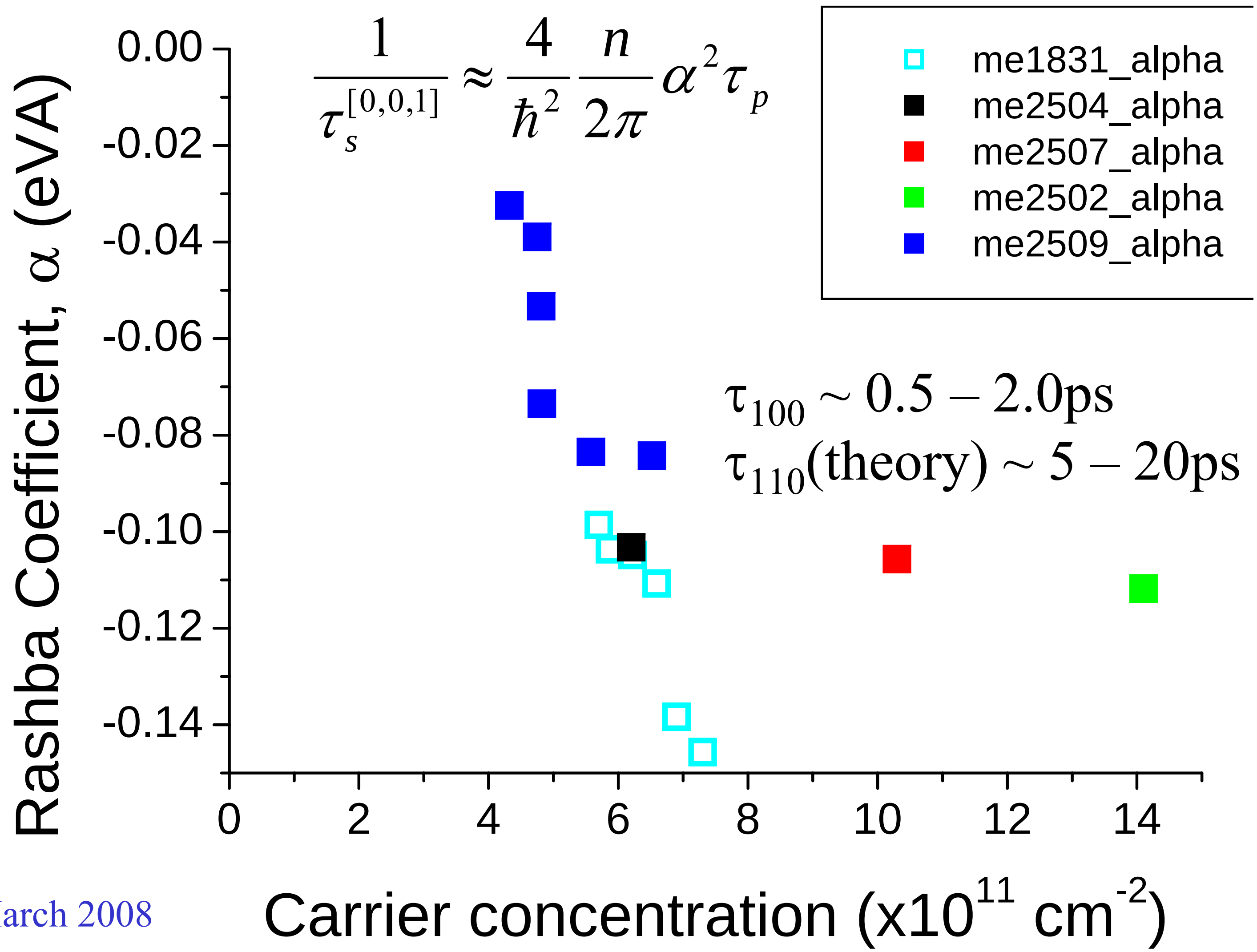
samples	L, nm	Al, %	μ, $m^2V^{-1}s^{-1}$ at 77K (RT)	n, 10^{11} cm^{-2} at 77K (RT)
ADJ1127	10	8	-	-
me1831	20	15	0.9 (1.37)	5.7 (7.3)
me1833	20	15	4.87 (2.1)	3.6 (5.3)
me2501	30	8	- (4.0)	- (1.8)
me2502	30	8	5.27 (2.2)	8.95 (14.1)
me2504	30	8	16 (3.7)	4.24 (6.2)
me2507	30	8	11.9 (2.9)	5.43 (10.3)
me2509	30	8	14.5 (3.5)	2.26 (5.99)
ADJ1129	30	8	-	-
ADJ1126	40	8	-	-



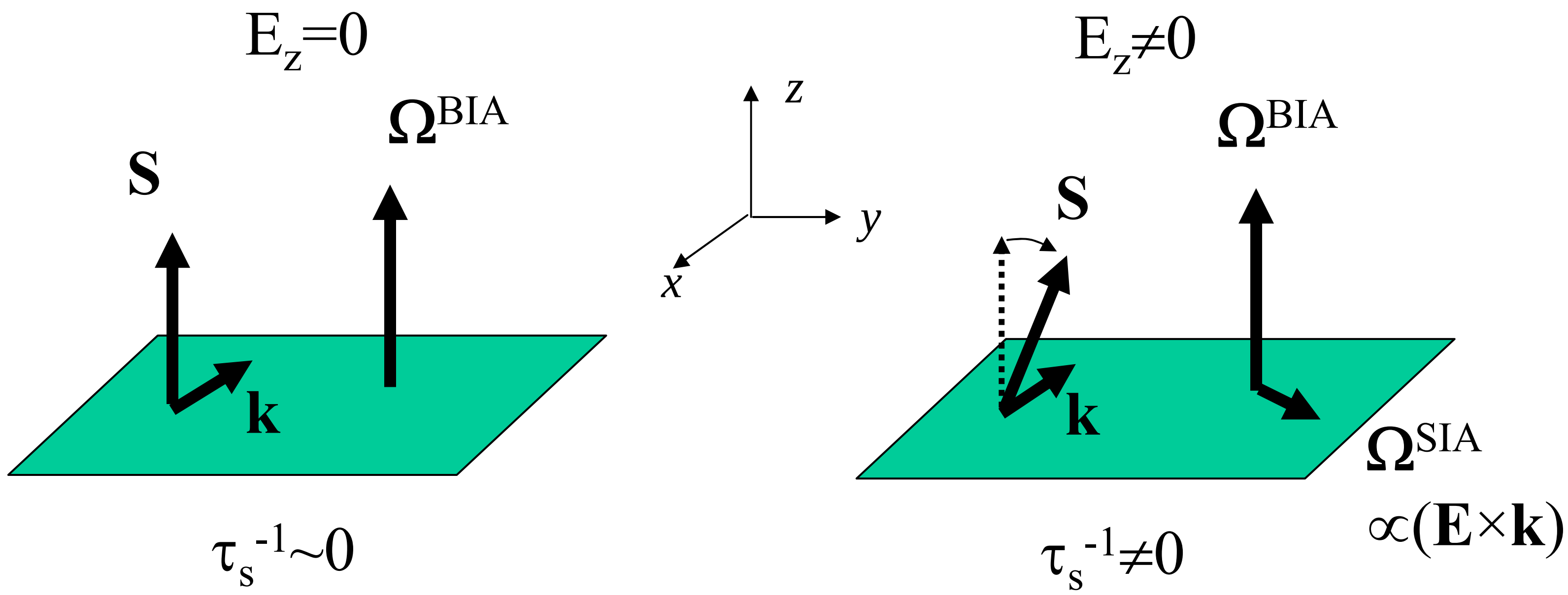
[001] $Al_xIn_{1-x}Sb/InSb/n\text{-}Al_yIn_{1-y}Sb$ AQWs



Theory from IC,
[Gilbertson et al]

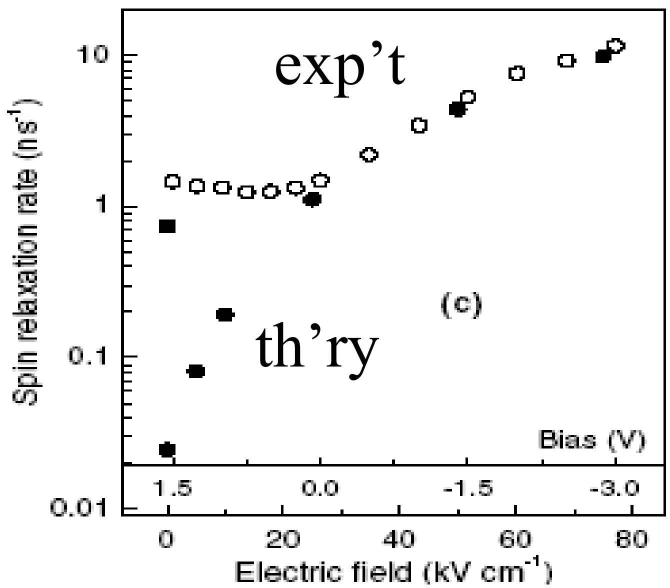


Gate control of [110] QW spin lifetime



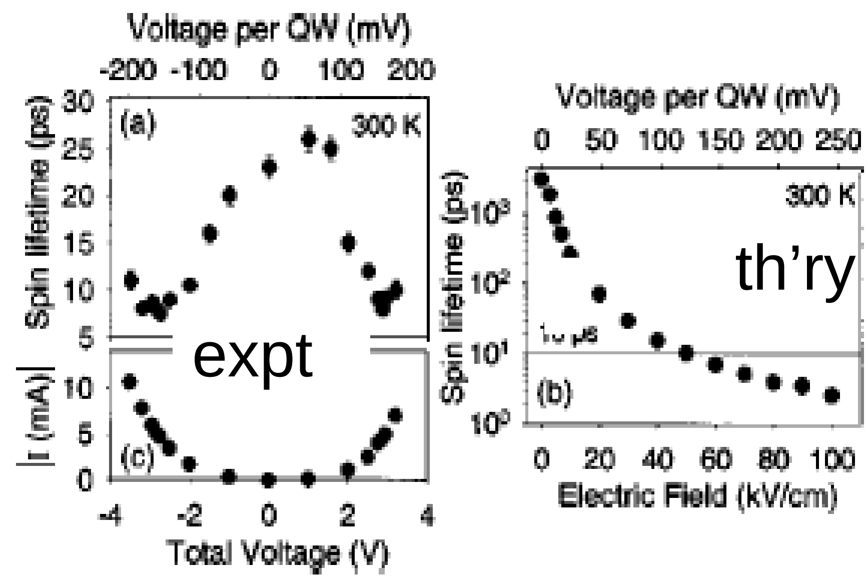
Modulation of τ_s for [110] GaAs and InAs QWs

[110] GaAs/AlGaAs



Karimov et al PRL 2003

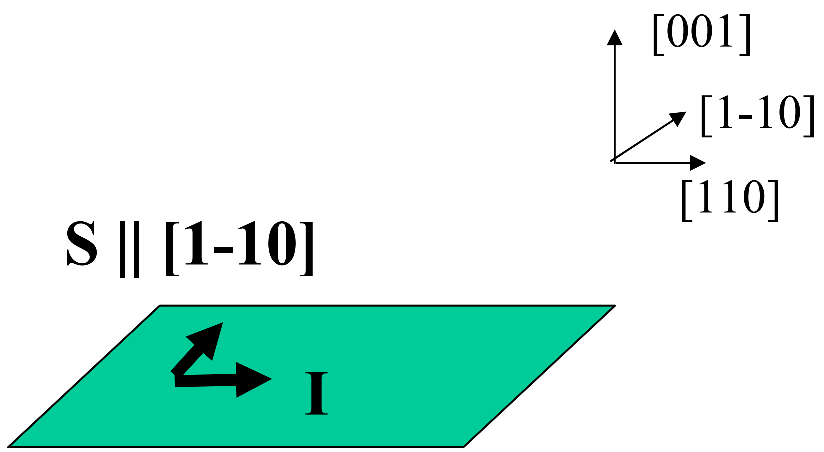
[110] InAs/GaSb

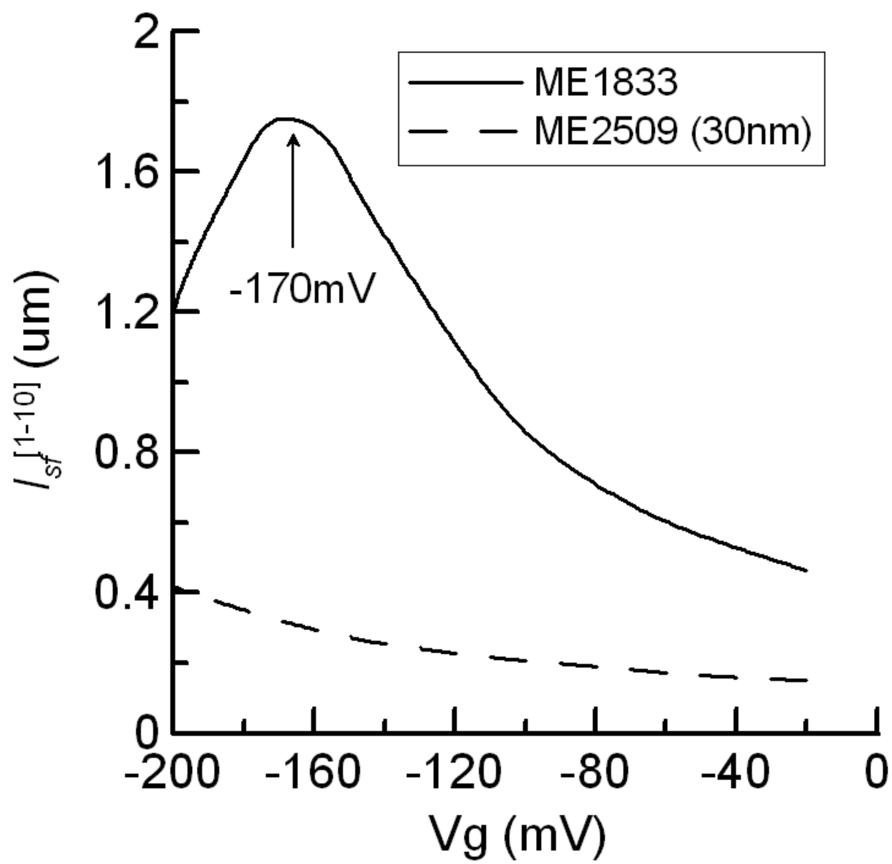


Hall et al APL 2005

~ half the field per well for equiv. decrease in lifetime

FET programme for [001] InSb

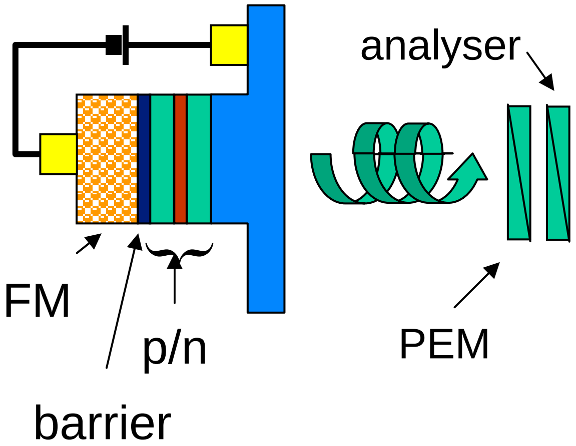




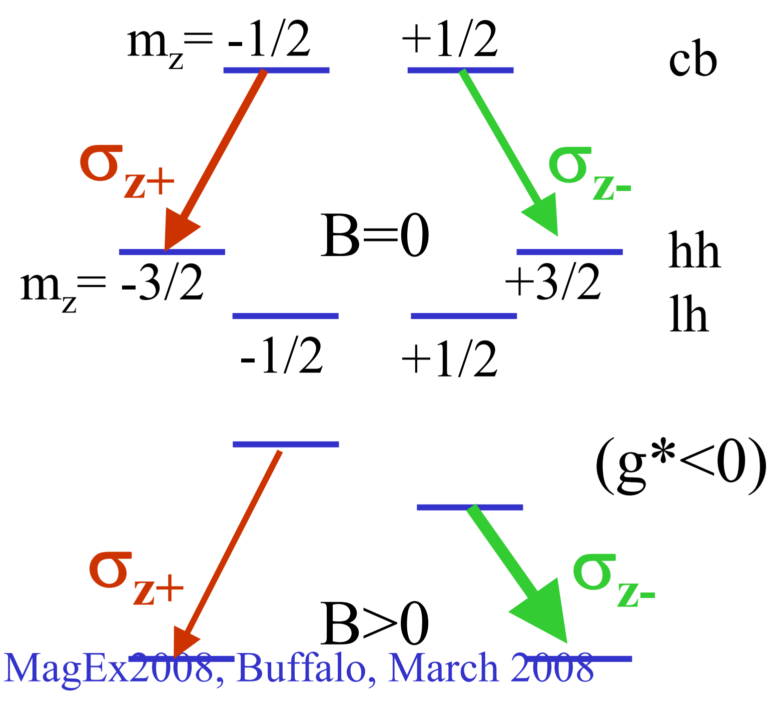
$$\frac{1}{\tau_s^{[1,\pm1,0]}}=\frac{2k_F^2}{\hbar^2}\left\{\left[\pm\alpha+\beta-\frac{1}{4}\gamma k_F^2\right]^2+\frac{1}{16}\gamma^2k_F^4\right\}\tau_p$$

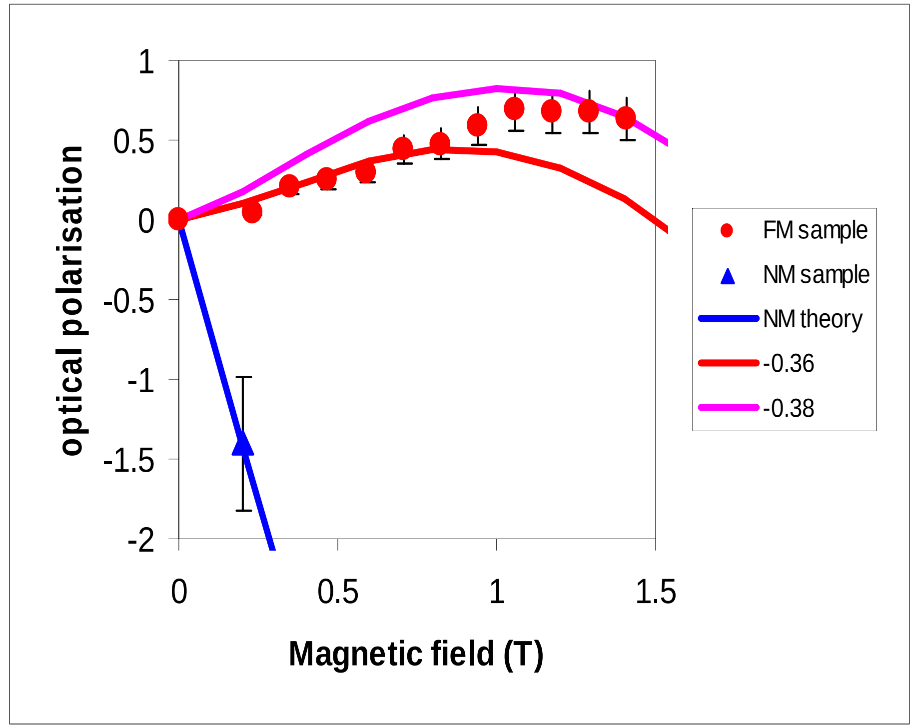
$$l_{sd}=\sqrt{\frac{n\mu\tau_s}{2e\rho}}=\frac{\hbar^2}{4m^*m_0\alpha^*}$$

InAs Spin-LED (c.f. Meining et al)



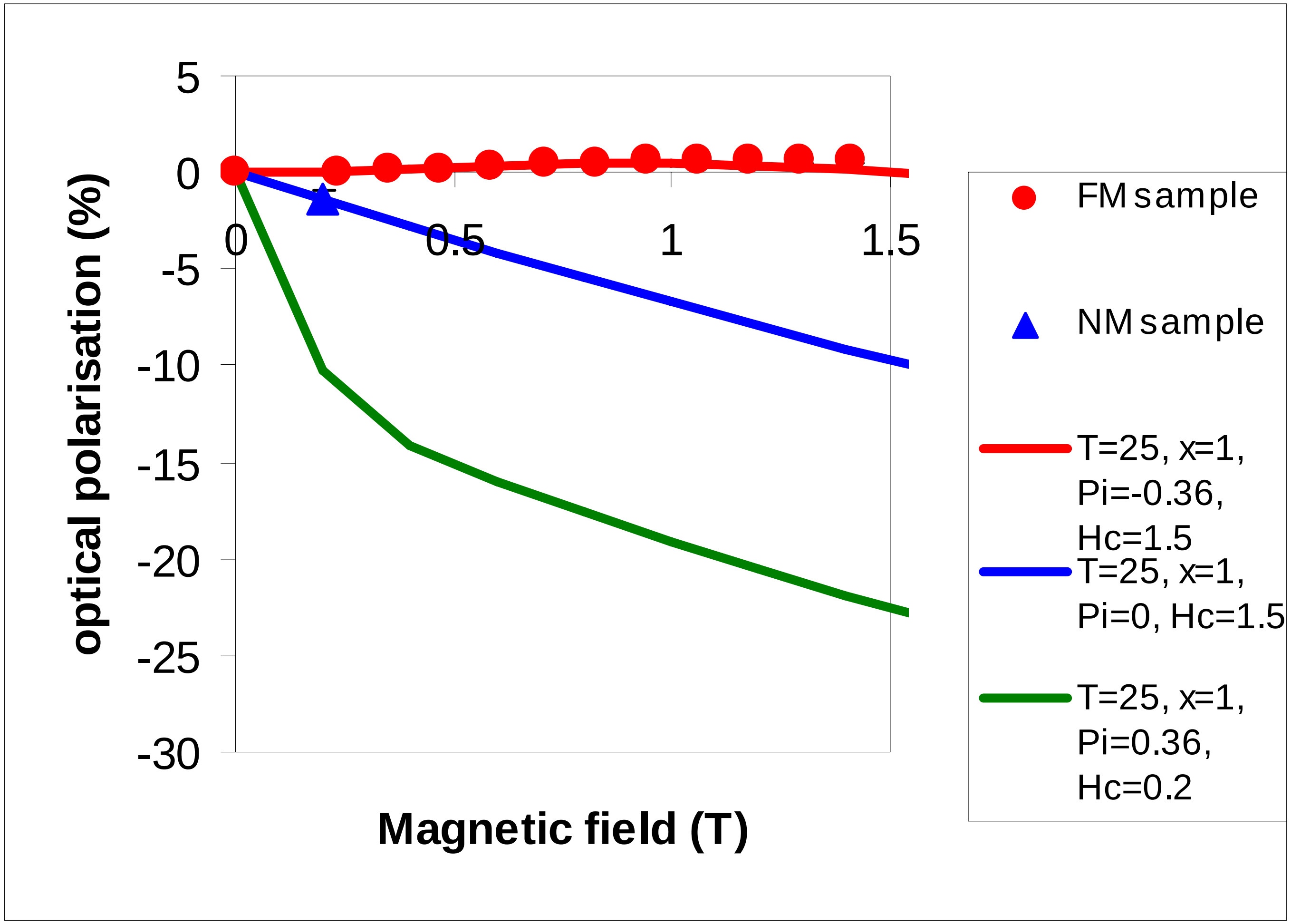
Light emission observed along growth direction





~ 36% efficient injection **minority** spins from a magnetic metal (CoFe) into semiconductor spin LED

InAs spin LED – majority carriers



CoPt multilayers
Hc<200mT

Conclusion

Dependence of g* on E and T: good agreement with **k.p** (8x8) for InSb and (14x14) for GaAs up to 300K

[001] InSb n-ASQWs: good agreement with theory, α dominant

Spin Modulation: InAs more effective than GaAs; expect modulation of the order of 4 in spin diffusion length for [001] InSb

Spin injection: efficiency near maximum (~ 0.4) for CoFe/InAs

Near Future: modulation (spin along [110], either electrically or optically), in InSb; improved spin injection, CoPt/InSb .