OPTICAL ORIENTATION AND SPIN DEPHASING IN HIGH-MOBILITY QUANTUM WELLS

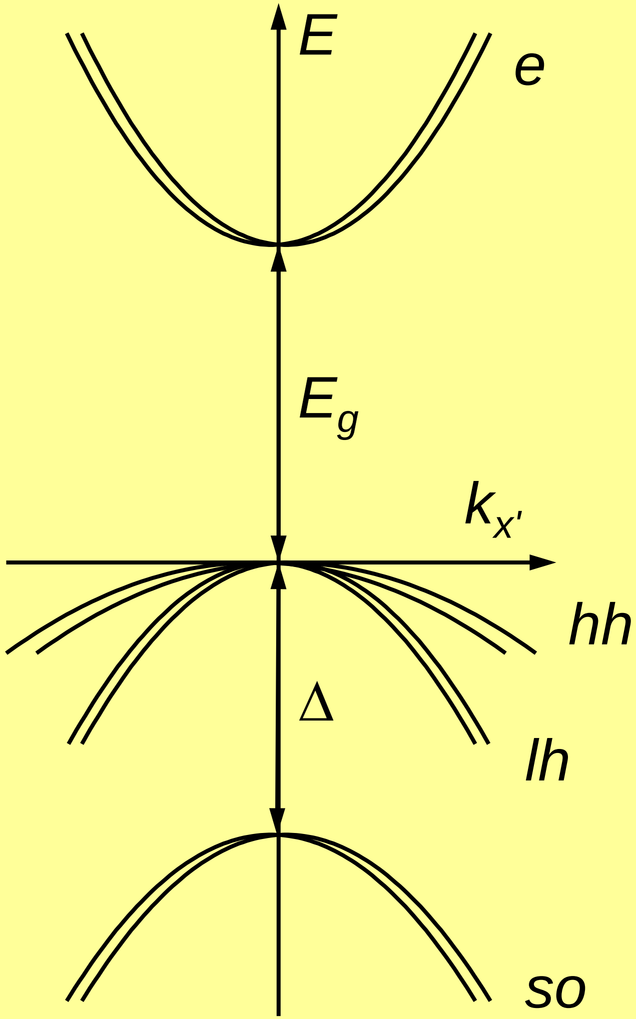
Sergey Tarasenko

Ioffe Physical-Technical Institute, St. Petersburg

- Introduction. Band structure of III-V semiconductors
- Spin dephasing in high-mobility (001)-grown quantum wells
  - Anomalous Hanle effect
  - Spin dephasing in 2D structures with anisotropic scattering
- Spin dephasing in (110)-grown quantum wells
  - Suppression of spin dephasing in symmetric quantum wells
  - Dynamic coupling of the in-plane and out-of-plane spin components
- Optical orientation by linearly polarized pulses
- Concluding remarks

Nordita, Stockholm, September 21, 2012

BAND STRUCTURE OF III-V SEMICONDUCTORS



Γ_6 band
J=1/2 (two states)

Γ_8 band
J=3/2 (four states)

Γ_7 band
J=1/2 (two states)

Spin-orbit coupling gives rise to both optical orientation and spin relaxation

SPIN-ORBIT SPLITTING OF CONDUCTION BAND

Bulk crystal

$$H = \frac{\hbar^2 \mathbf{k}^2}{2m^*} + \gamma\left[\sigma_x k_x (k_y^2 - k_z^2) + \ldots\right] = \frac{\hbar^2 \mathbf{k}^2}{2m^*} + \frac{\hbar}{2}\left(\boldsymbol{\sigma} \cdot \boldsymbol{\Omega}_{\mathbf{k}}\right)$$

$\Omega_{\boldsymbol{k}} \sim 10^{11}$ rad/s

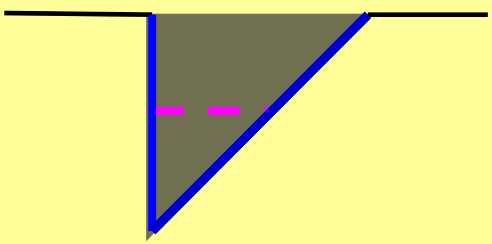
GaAs-based QWs

k-cubic Dresselhaus term

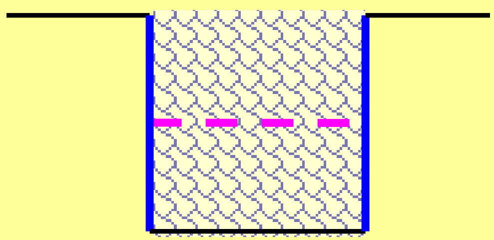
Larmor frequency
of effective magnetic field

2D semiconductor structures without space inversion:

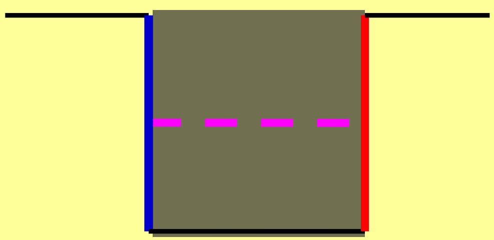
Structure
inversion asymmetry



Bulk inversion asymmetry



Interface
inversion asymmetry



Rashba term

$$H_R = \gamma_R [\boldsymbol{\sigma} \times \boldsymbol{k}]_z$$

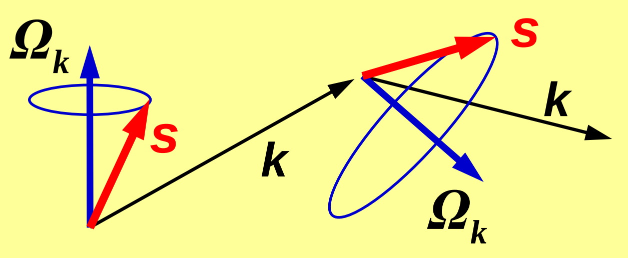
k-linear Dresselhaus term

$$H_D = \sum_{\alpha\beta} \gamma_{\alpha\beta}\, \sigma_\alpha k_\beta$$

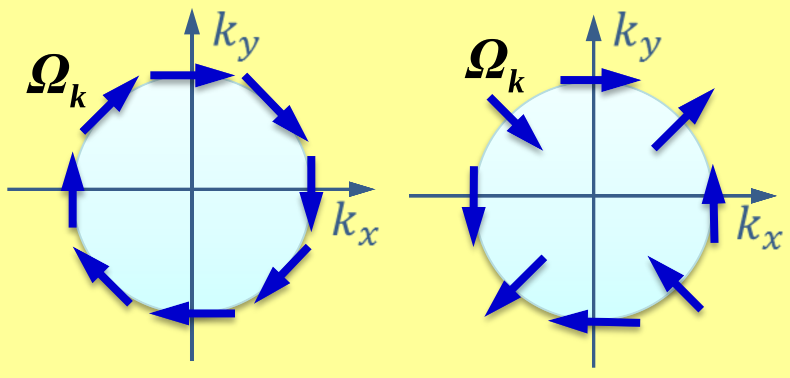
depends on QW crystallographic orientation

D'YAKONOV-PEREL' MECHANISM

Spin precession in the effective field



Effective fields in (001)-grown QWs



Collision-dominated regime, $\Omega_{\boldsymbol{k}}\tau \ll 1$

- exponential decay of electron spin polarization
- spin relaxation time $T_s \sim \left(\Omega_{\boldsymbol{k}}^2 \tau\right)^{-1}$, with τ being the scattering time

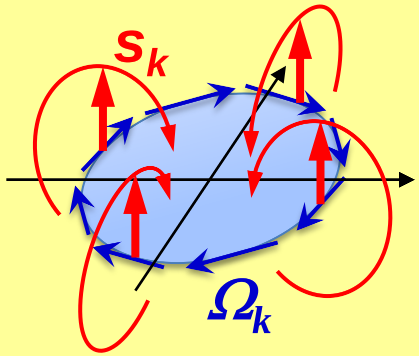
3D: M.I. D'yakonov and V.I. Perel', Sov. Phys. Solid State (1971)
2D: M.I. D'yakonov and V.Yu. Kachorovskii, Sov. Phys. Semicond. (1986)
(001) QWs: N.S. Averkiev and L.E. Golub, Phys. Rev. B (1999)
N.S. Averkiev et al., Phys. Rev. B (2006)
(111) QWs: X. Cartoixà, D.Z.-Y. Ting, Y.-C. Chang, Phys. Rev. B (2005)
A. Balocchi et al., Phys. Rev. Lett. (2011)
(110) QWs: S.A. Tarasenko, Phys. Rev. B. (2009)

OSCILLATORY REGIME OF SPIN DEPHASING, $\Omega_k \tau > 1$

Rashba field

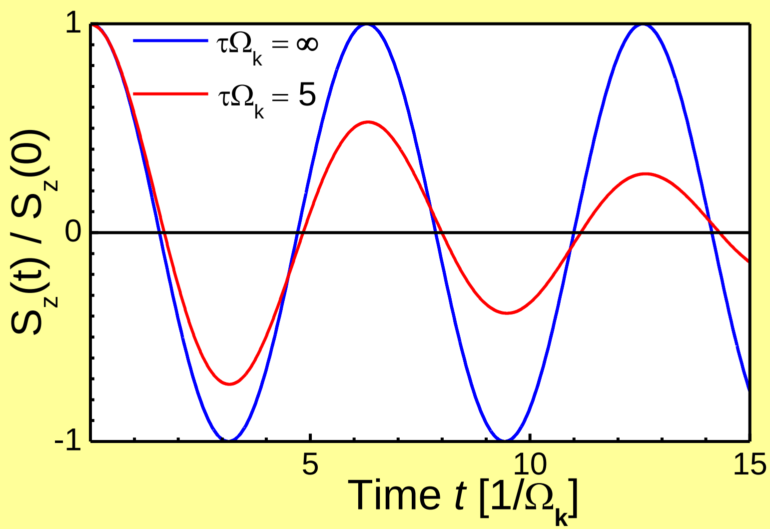
$$S_x = S_y = 0$$

$$S_z = S_z(0)\cos\Omega_k t$$

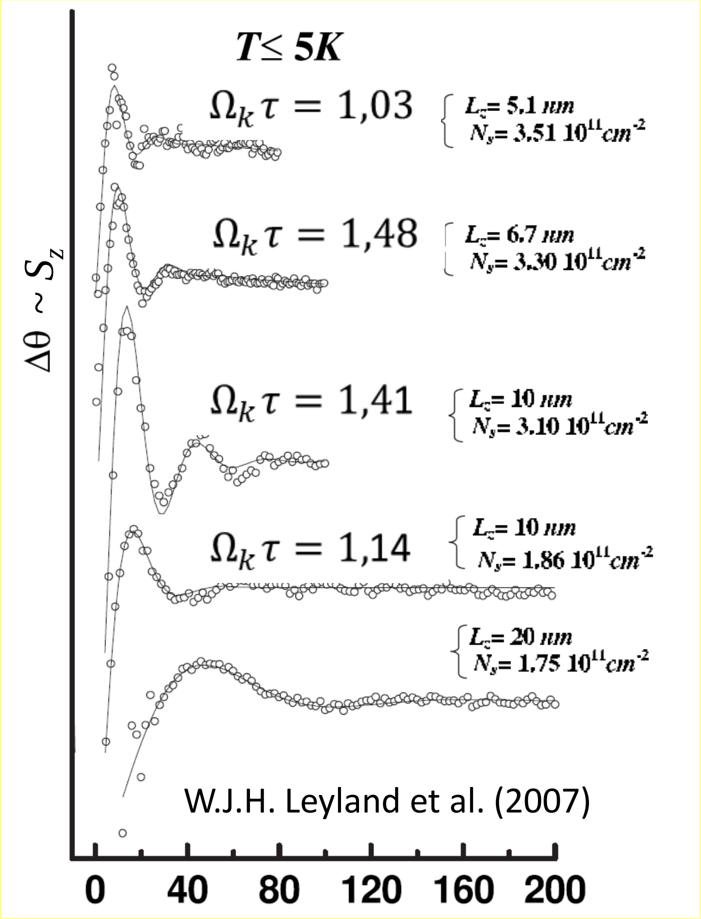


V.N. Gridnev, JETP Lett. (2001)

Spin oscillations in the absence of *B*



Experimental data



M. A. Brand et al., Phys. Rev. Lett. (2002)
W. J. H. Leyland et al., Phys. Rev. B (2007)
M. Griesbeck et al., Phys. Rev. B (2009)

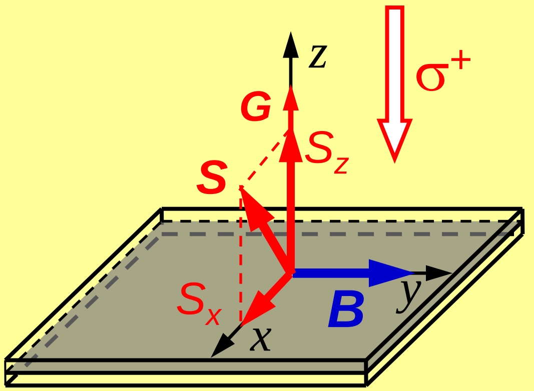
OUTLINE

- Introduction. Band structure of III-V semiconductors
- Spin dephasing in high-mobility (001)-grown quantum wells
  - Anomalous Hanle effect
  - Spin dephasing in 2D structures with anisotropic scattering
- Spin dephasing in (110)-grown quantum wells
  - Suppression of spin dephasing in symmetric quantum wells
  - Dynamic coupling of the in-plane and out-of-plane spin components
- Optical orientation by linearly polarized pulses
- Concluding remarks

HANLE EFFECT

Depolarization of luminescence in transverse magnetic field, W. Hanle, Z. Phys. (1924)

Experimental geometry



Master equation for total spin

$$\frac{d\mathbf{S}}{dt} + \mathbf{S} \times \boldsymbol{\Omega}_L = \mathbf{G} - \frac{\mathbf{S}}{T_s}$$

$\boldsymbol{\Omega}_L = g\mu_B \mathbf{B}/\hbar$ is the Larmor frequency

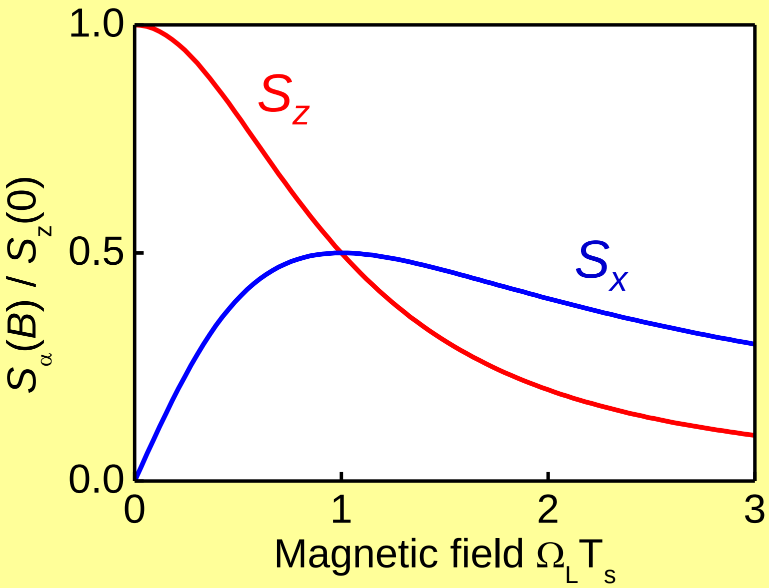
$\mathbf{G}$ is the spin generation rate

T_s is the spin relaxation time

Steady-state spin components

$$S_z(B) = \frac{S_z(0)}{1+\Omega_L^2 T_s^2}$$

$$S_x(B) = \frac{S_z(0)\,\Omega_L T_s}{1+\Omega_L^2 T_s^2}$$



HANLE EFFECT: MICROSCOPIC THEORY

Kinetic equation for the spin density matrix

$$\frac{\partial \rho_{\boldsymbol{k}}}{\partial t} + \frac{i}{\hbar}\left[H_{\text{so}}, \rho_{\boldsymbol{k}}\right] = G_{\boldsymbol{k}} + \text{St}\,\rho_{\boldsymbol{k}}$$

$H_{\text{so}} = \frac{\hbar}{2}\boldsymbol{\sigma}\cdot(\boldsymbol{\Omega}_{\boldsymbol{k}} + \boldsymbol{\Omega}_L)$ is the Hamiltonian of spin-orbit coupling

$\rho_{\boldsymbol{k}} = f_{\boldsymbol{k}} I + \left(\boldsymbol{s}_{\boldsymbol{k}}\cdot\boldsymbol{\sigma}\right)$ is the spin density matrix

$\text{St}\,\rho_{\boldsymbol{k}} = -\frac{\rho_{\boldsymbol{k}} - \langle \rho_{\boldsymbol{k}} \rangle}{\tau}$ is the collision integral (short-range scattering)

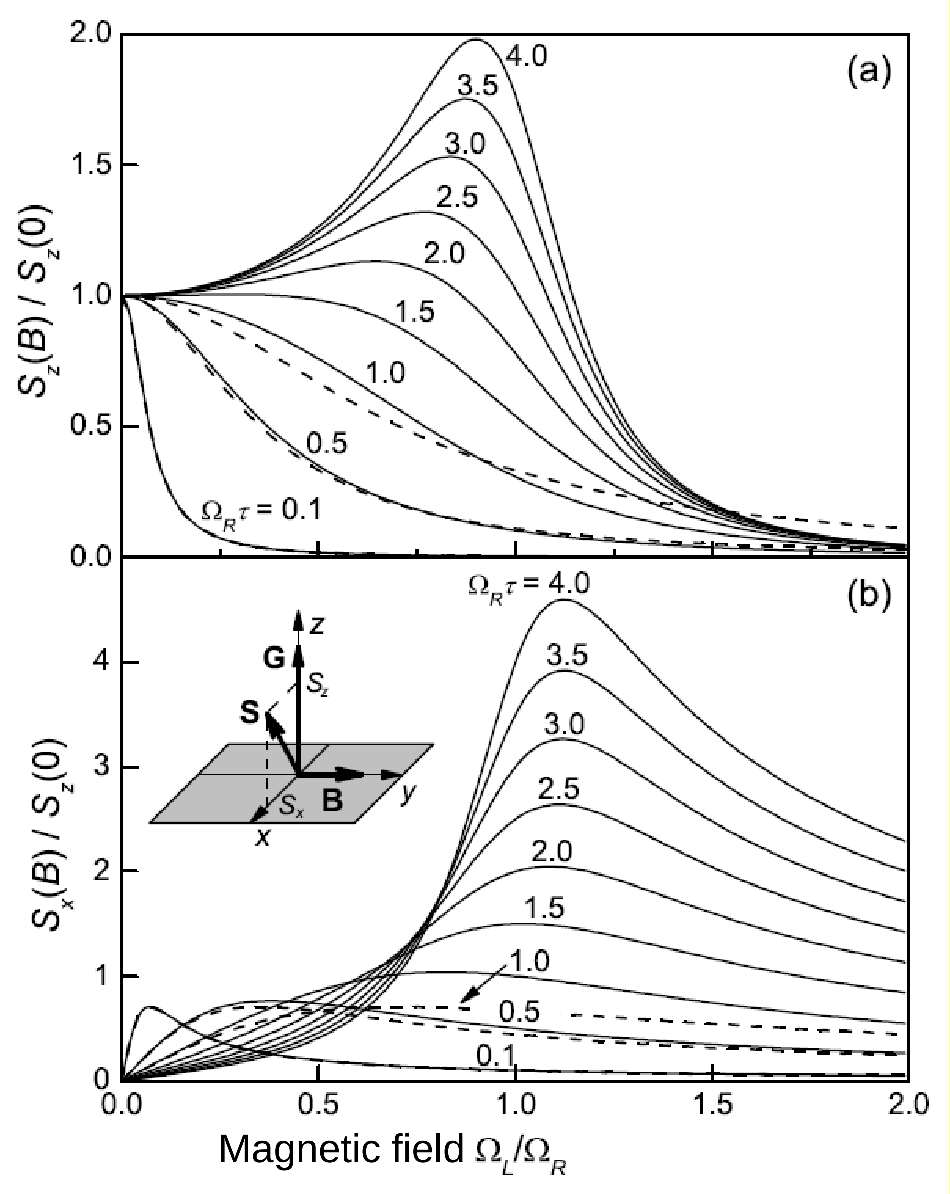
Magnetic field dependence of total electron spin $\boldsymbol{S} = \Sigma_{\boldsymbol{k}}\, \boldsymbol{s}_{\boldsymbol{k}}$

Exact solution for the Rashba splitting, $|\,\boldsymbol{\Omega}_{\boldsymbol{k}}\,| = \Omega_R$

$$S_z = \frac{\Omega_R^2 \tau G_z}{(\Omega_R^2 - \Omega_L^2)^2\tau^2 + \Omega_L^2\left[1 + \sqrt{1 + (\Omega_R + \Omega_L)^2\tau^2}\sqrt{1 + (\Omega_R - \Omega_L)^2\tau^2}\right]}$$

$$\boldsymbol{S}_{\parallel} = \frac{4\boldsymbol{\Omega}_L \times \boldsymbol{G}_z}{4\Omega_L^2 + (\Omega_R^2 - \Omega_L^2)^2\tau^2 + (\Omega_R^2 - \Omega_L^2)\left[\sqrt{1 + (\Omega_R + \Omega_L)^2\tau^2}\sqrt{1 + (\Omega_R - \Omega_L)^2\tau^2} - 1\right]}$$

HANLE CURVES



Collision-dominated regime, $\Omega_R\tau << 1$

$$S_z = \frac{S_z(0)}{1+\Omega_L^2 T_z T_\parallel}, \quad S_x = \frac{S_z(0)\,\Omega_L T_\parallel}{1+\Omega_L^2 T_z T_\parallel}$$

$$T_z = T_\parallel/2 = 1/(\Omega_R^2\tau)$$

spin dephasing times

High-mobility structures, $\Omega_R\tau > 1$

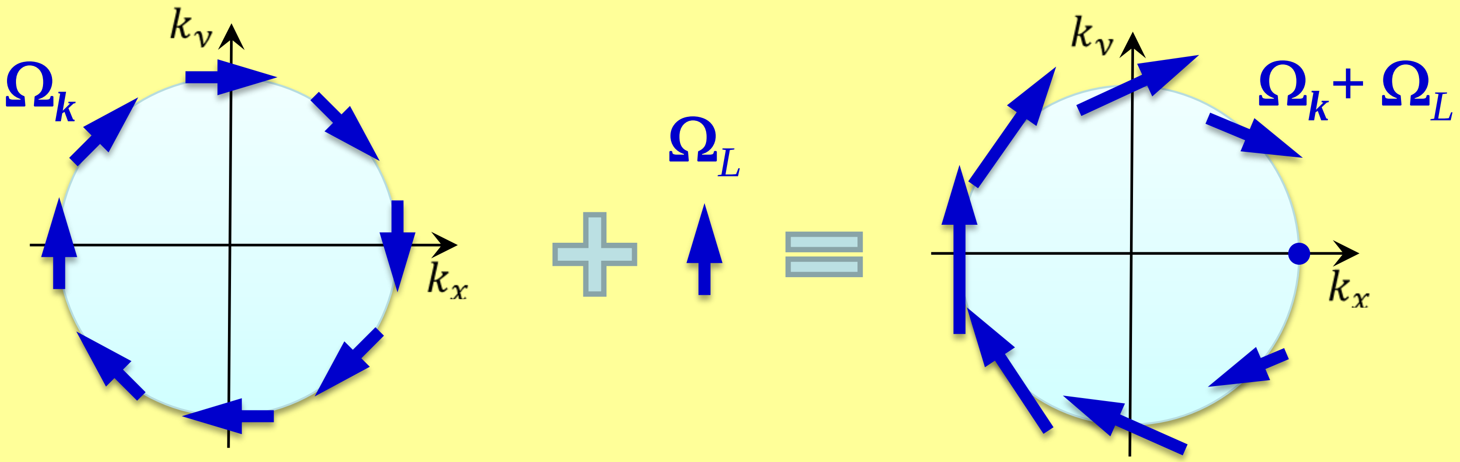
sharp peak at $\Omega_L \approx \Omega_R$

$$S_z(\Omega_R) \approx \frac{G_z}{2\Omega_R} = \frac{\Omega_R\tau}{2} S_z(0) \gg S_z(0)$$

A. V. Poshakinskiy and S. A. T.,
Phys. Rev. B **84**, 073301 (2011)

MICROSCOPIC MODEL OF ANOMALOUS HANLE EFFECT

Spin precession in the total magnetic field (external field + spin-orbit field)



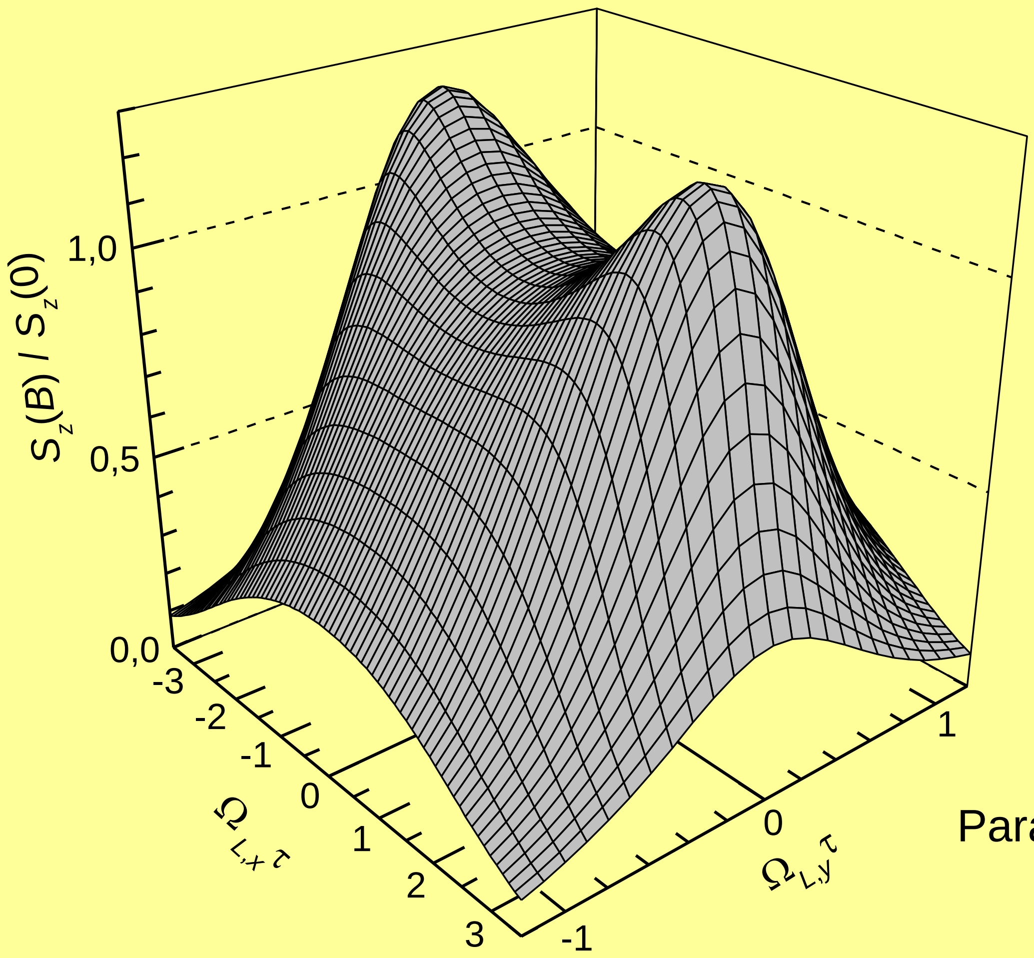
Steady-state spin

Steady-state spin

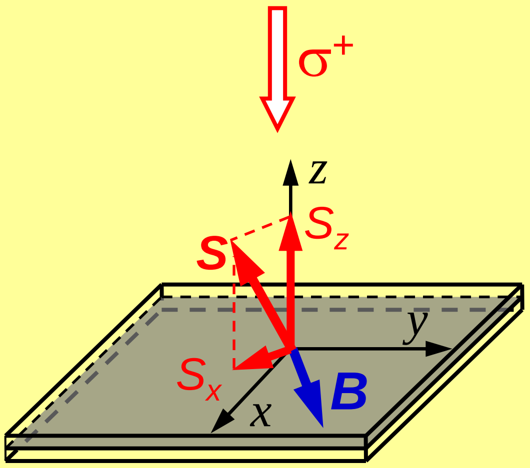
$$S_z(0) = \frac{G_z}{\Omega_{\boldsymbol{k}}^2 \tau} \quad << \quad S_z(\Omega_R) = \frac{G_z}{2\Omega_{\boldsymbol{k}}}$$

HANLE EFFECT ANISOTROPY

Quantum wells with both Rashba and Dresselhaus contributions



Experimental geometry



Parameters used in calculation

$$\Omega_R \tau = 2,\ \Omega_D \tau = 1$$

OUTLINE

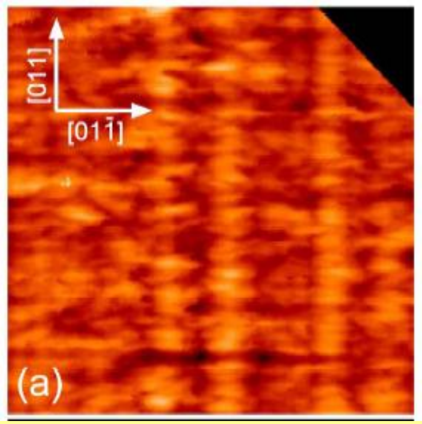
- Introduction. Band structure of III-V semiconductors
- Spin dephasing in high-mobility (001)-grown quantum wells
  - Anomalous Hanle effect
  - Spin dephasing in 2D structures with anisotropic scattering
- Spin dephasing in (110)-grown quantum wells
  - Suppression of spin dephasing in symmetric quantum wells
  - Dynamic coupling of the in-plane and out-of-plane spin components
- Optical orientation by linearly polarized pulses
- Concluding remarks

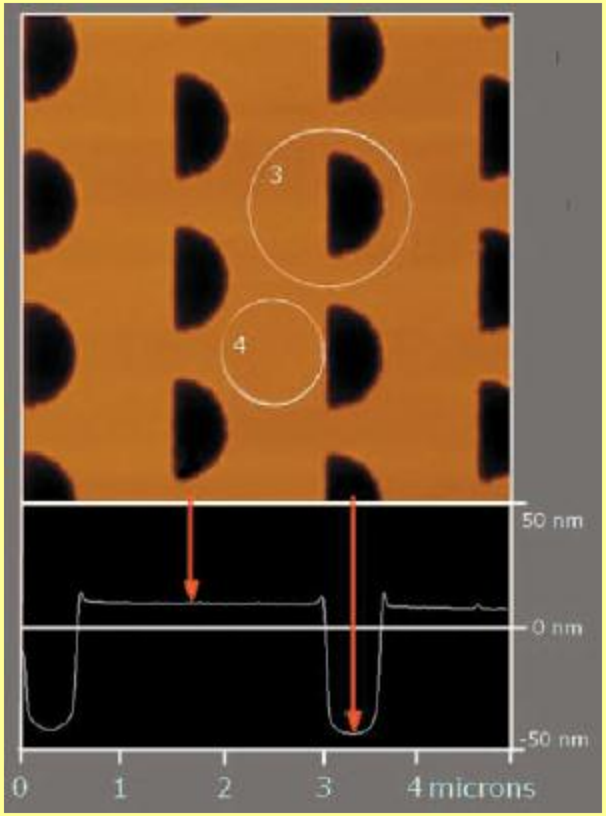
2D STRUCTURES WITH ANISOTROPIC SCATTERERS

In-plane anisotropy of electron mobility in (001)-grown *n*-type quantum wells

S.J. Papadakis et al., PRB **65**, 245312 (2002)
D. Ercolani et al., PRB **77**, 235307 (2008)
M. Akabori et al., Physica E **42**, 1130 (2010)

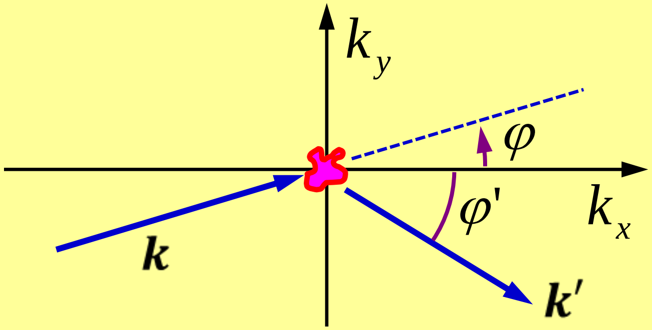
AFM surface topography of (001)-grown *n*-type InGaAs/InAlAs QWs,
from D. Ercolani et al., Phys. Rev. B (2008)





AlGaAs/GaAs HJ with semidisk antidots,
S. Sassine et al., PRB **78**, 045431 (2008)

SCATTERING ASYMMETRY IN 2D SYSTEMS



The integral of collisions

$$St[f] = \frac{1}{2\pi}\int_0^{2\pi}[w(\varphi,\varphi')\,f(\varphi') - w(\varphi',\varphi)f(\varphi)]d\varphi'$$

Expansion of the scattering rate in angular harmonics

$$w(\varphi,\varphi') = \sum_{n,m} w_{n,m} e^{in\varphi+im\varphi'}$$

The properties of elastic scattering

the reality of rate	$w(\varphi,\varphi')$ is real	$w_{m,n} = w^*{}_{-m,-n}$
"optical theorem"	$\int_0^{2\pi} w(\varphi,\varphi')\,d\varphi' = \int_0^{2\pi} w(\varphi,\varphi')d\varphi = const$	$w_{0,n} = w_{n,0} = 0 \quad (n \neq 0)$
time inversion sym.	$w(\varphi,\varphi') = w(\pi+\varphi',\pi+\varphi)$	$w_{m,n} = (-1)^{m+n} w_{n,m}$

SPIN DYNAMICS IN ANYSOTROPIC STRUCTURES

Quantum equation for the spin density matrix

$$\frac{\partial \rho_{\boldsymbol{k}}}{\partial t} + \frac{i}{\hbar}\left[H_{\mathrm{so}}, \rho_{\boldsymbol{k}}\right] = G_{\boldsymbol{k}} + \mathrm{St}\,\rho_{\boldsymbol{k}}$$

spin rotation — spin generation — scattering

Spin density matrix $\rho_{\boldsymbol{k}} = f_{\boldsymbol{k}} I + \left(\boldsymbol{s}_{\boldsymbol{k}} \cdot \boldsymbol{\sigma}\right)$

Hamiltonian of spin-orbit coupling $H_{\mathrm{so}} = \frac{\hbar}{2} \boldsymbol{\sigma} \cdot \boldsymbol{\Omega}_{\boldsymbol{k}}$

Expansion in angular harmonics

$$\boldsymbol{s}_{\boldsymbol{k}} = \sum_n \boldsymbol{s}_n e^{in\varphi}, \quad \boldsymbol{\Omega}_{\boldsymbol{k}} = \boldsymbol{\Omega}_{-1} e^{-i\varphi} + \boldsymbol{\Omega}_1 e^{i\varphi}$$

k-linear splitting in QWs

System of coupled linear equations to be solved

$$\frac{d\boldsymbol{s}_n}{dt} + [\boldsymbol{s}_{n-1} \times \boldsymbol{\Omega}_1] + [\boldsymbol{s}_{n+1} \times \boldsymbol{\Omega}_{-1}] = -w_{0,0}\boldsymbol{s}_n + \sum_m w_{n,-m}\boldsymbol{s}_m + \boldsymbol{g}_n$$

COLLISION-DOMINATED REGIME

- intensive scattering, small rotation angles between collisions, $\tau \boldsymbol{\Omega}_{\boldsymbol{k}} \ll 1$

Spin distribution function $\boldsymbol{s}(\varphi) = \boldsymbol{s}_0 + \delta \boldsymbol{s}(\varphi)$

small correction

Electrical conductivity in two-dimensional structures

Distribution function of electrons in electric field $f(\varphi) = f^{(0)} + \delta f(\varphi)$

small correction

Electric current $$\boldsymbol{j} = \frac{e}{\pi\hbar}\int_0^\infty \langle \delta f\ \boldsymbol{k}\rangle\, d\varepsilon = \frac{e}{\pi\hbar}\int_0^\infty (\delta f_{-1}\boldsymbol{k}_1 + \delta f_1 \boldsymbol{k}_{-1})\, d\varepsilon = \hat{\sigma}\boldsymbol{E}$$

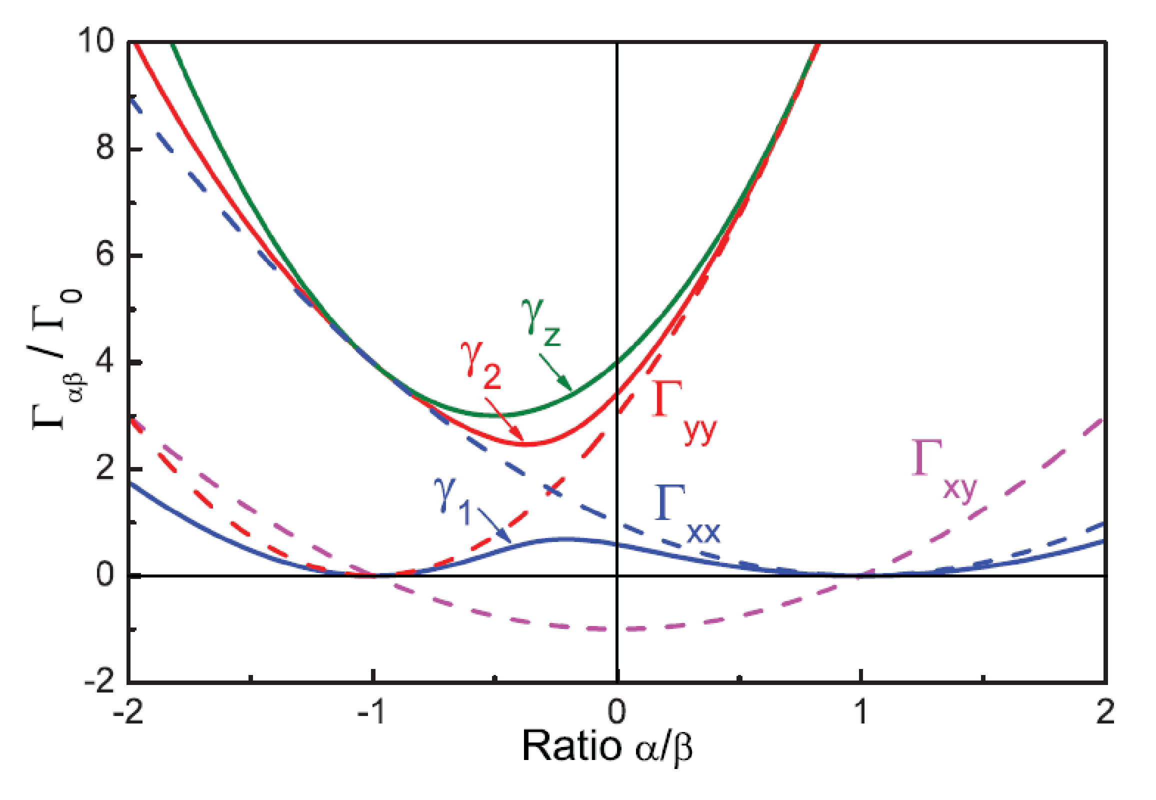
Spin-relaxation-rate tensor

$$\hat{\boldsymbol{\Gamma}} = \frac{\pi m^*}{e^2}\left[\boldsymbol{I}\,\mathrm{Tr}(\Lambda\boldsymbol{\sigma}\Lambda^{\mathrm{T}}) - \Lambda\boldsymbol{\sigma}\Lambda^{\mathrm{T}}\right]$$

$\boldsymbol{\Omega}_k = \Lambda \boldsymbol{k}$ the Larmor frequency of the effective magnetic field

$\boldsymbol{\sigma}$ the conductivity tensor

DEPHASING RATES IN (001) QUANTUM WELLS



Master equation

$$\frac{dS_\alpha(t)}{dt} = -\sum_\beta \Gamma_{\alpha\beta} S_\beta(t)$$

Γ-tensor components

$$\Gamma_{xx} = (\pi m^* / e^2)(\alpha - \beta)^2 \sigma_{xx}$$

$$\Gamma_{yy} = (\pi m^* / e^2)(\alpha + \beta)^2 \sigma_{yy}$$

$$\Gamma_{xy} = (\pi m^* / e^2)(\alpha^2 - \beta^2)\sigma_{xy}$$

$$\Gamma_{zz} = \Gamma_{xx} + \Gamma_{yy}$$

γ_1, γ_2, and $\gamma_z = \Gamma_{zz}$ are the eigen values of $\Gamma_{\alpha\beta}$

Parameters: $\sigma_{xx} / \mathrm{Tr}\,\sigma = \sigma_{xy} / \mathrm{Tr}\,\sigma = 1/4$

$$\Gamma_0 = (\pi m^* / e^2)\,\beta^2\,\mathrm{Tr}\,\sigma$$

α the Rashba constant

β the Dresselhaus constant

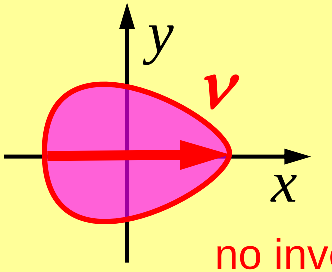
$\sigma_{\sigma\beta}$ the conductivity tensor

OSCILLATORY REGIME

Model of anisotropic scatterers

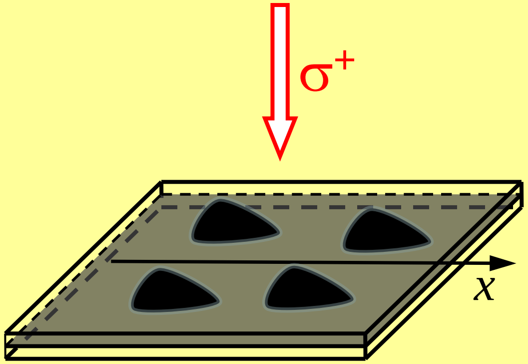
The scattering rate

$$w_{0,0} = 1/\tau\,,\ w_{-2,1} = w_{2,-1} = \nu_x + i\,\nu_y$$

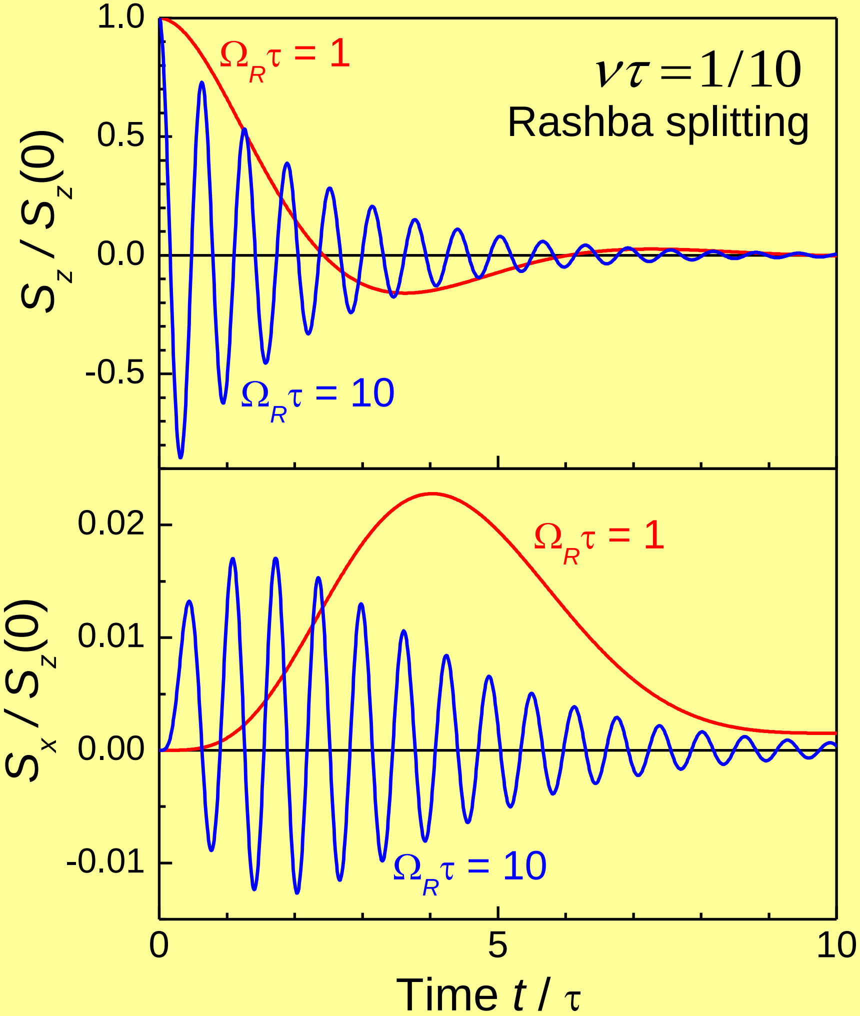


no inversion center

Pulse excitation
(at normal incidence)



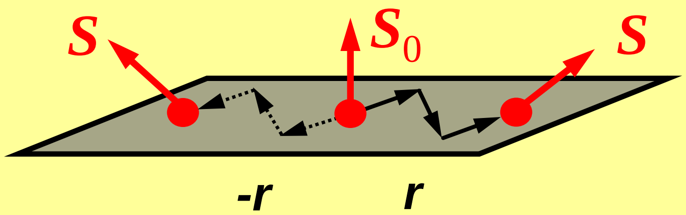
Time dependences of spin components



A. V. Poshakinskiy and S. A. T., Phys. Rev. **84**, 155326 (2011)

KINETIC ANISOTROPY OF SPIN RELAXATION

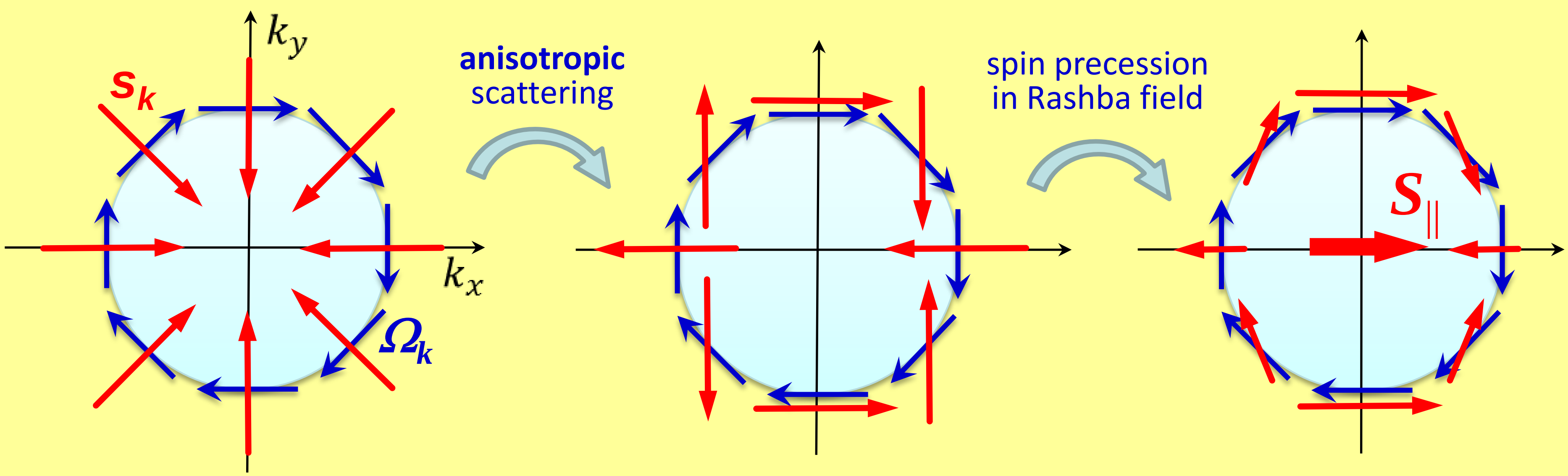
Electron trajectories



Spin components at *cw* excitation

$$S_z = \frac{1+(v\tau)^2}{\Omega_k^2 \tau} G_z\,, \quad \boldsymbol{S}_\parallel = \frac{v\tau}{\Omega_k} G_z$$

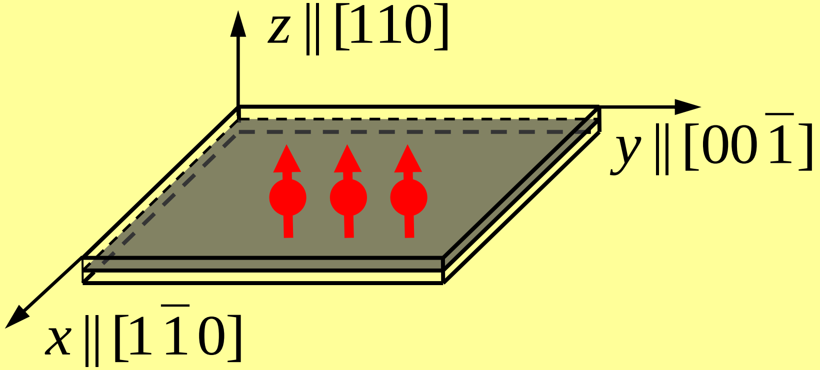
Microscopic model



OUTLINE

- Introduction. Band structure of III-V semiconductors
- Spin dephasing in high-mobility (001)-grown quantum wells
  - Anomalous Hanle effect
  - Spin dephasing in 2D structures with anisotropic scattering
- Spin dephasing in (110)-grown quantum wells
  - Suppression of spin dephasing in symmetric quantum wells
  - Dynamic coupling of the in-plane and out-of-plane spin components
- Optical orientation by linearly polarized pulses
- Concluding remarks

SPIN DEPHASING IN (110) QUANTUM WELLS



Symmetric wells (110)

Effective magnetic field

$$\boldsymbol{\Omega}_D = (0, 0, k_x)$$

⇨ Slow relaxation of electron spin along the growth direction

M.I. D'yakonov, V.Yu. Kachorovskii, Sov. Phys. Semicond. (1986)

Asymmetric wells (110)

Effective magnetic field

$$\boldsymbol{\Omega}_D = (0, 0, k_x)$$

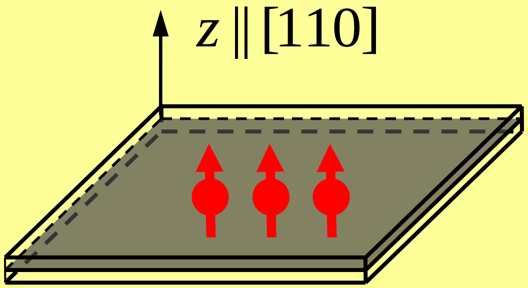
+

$$\boldsymbol{\Omega}_R = (\alpha_1 k_y, -\alpha_2 k_x, 0)$$

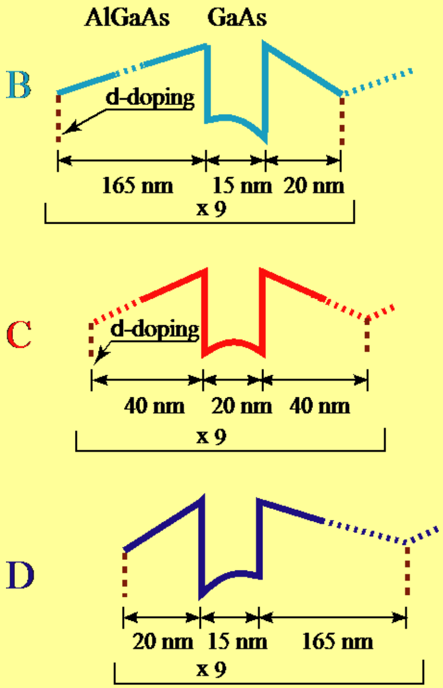
Rashba effect

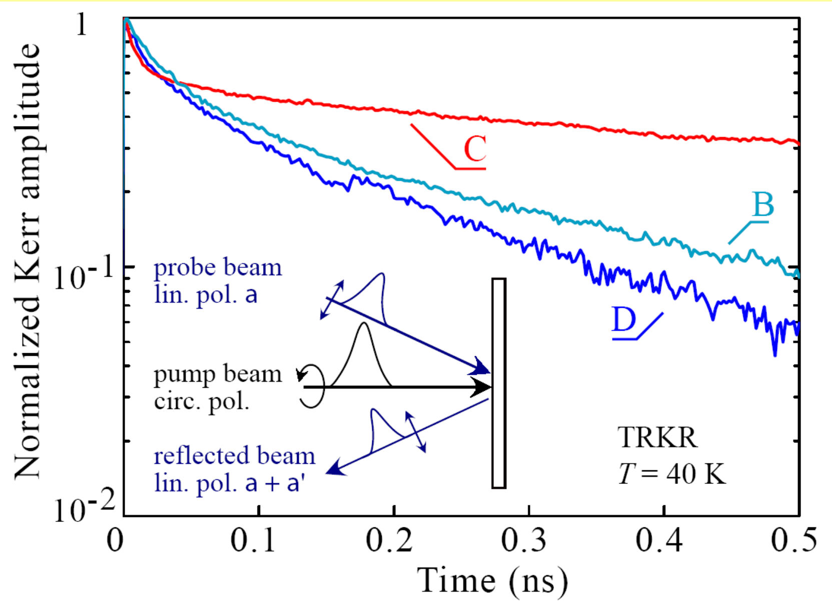
⇨ Fast relaxation of electron spin along the growth direction

SUPPRESSION OF SPIN DEPHASING IN SYMMETRIC QWS



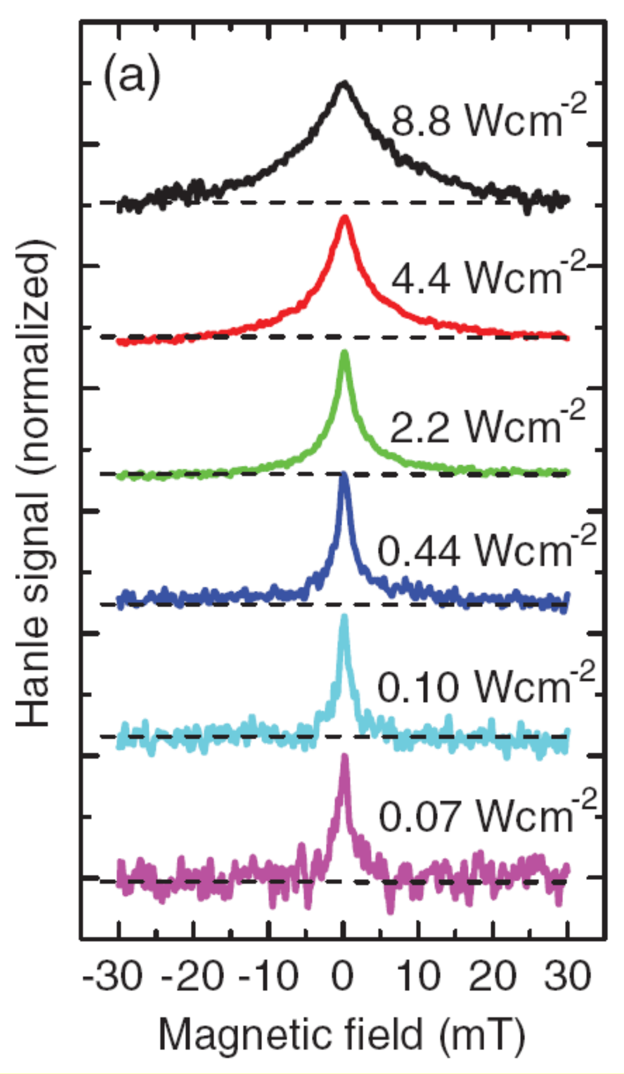
Y. Ohno et al., Phys. Rev. Lett. (1999)
O.Z. Karimov et al., Phys. Rev. Lett. (2003)
S. Döhrmann et al., Phys. Rev. Lett. (2004)
K.C. Hall et al., Appl. Phys. Lett. (2005)
O.D.D. Couto et al., Phys. Rev. Lett. (2007)
V.V. Bel’kov et al., Phys. Rev. Lett. (2008)
G.M. Müller et al., Phys. Rev. Lett. (2008)
S. Iba et al., Appl. Phys. Lett. (2011)
J. Hübner et al., Phys. Rev. B (2011)
R. Völkl et al., Phys. Rev. B (2011)
M. Griesbeck et al., Phys. Rev. B (2012)

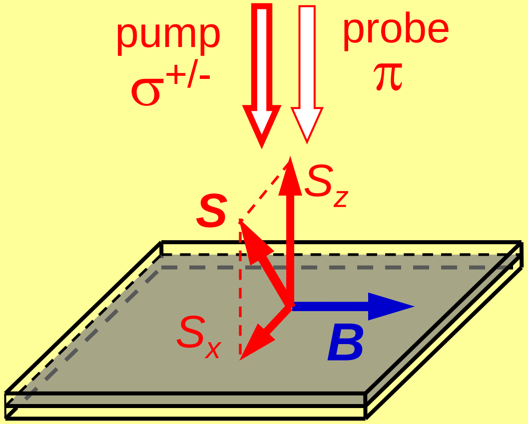




V.V. Bel’kov et al., Phys. Rev. Lett. **100**, 176806 (2008)

LIGHT INTENSITY DEPENDENCE

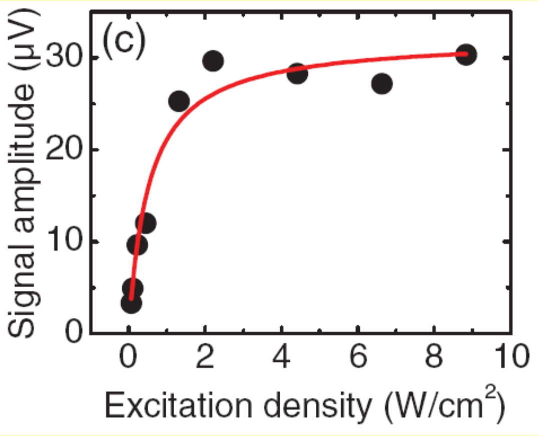




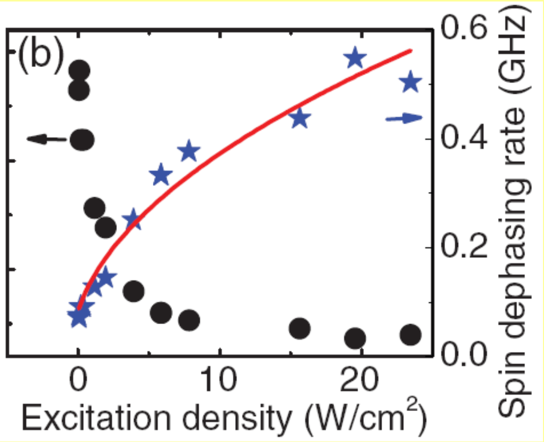
Hanle effect

$$S_z(B) = \frac{S_z(0)}{1+\Omega_L^2 T_s^2}$$

Signal amplitude ~ $S_z(0)$



Dephasing rate $1/T_s$

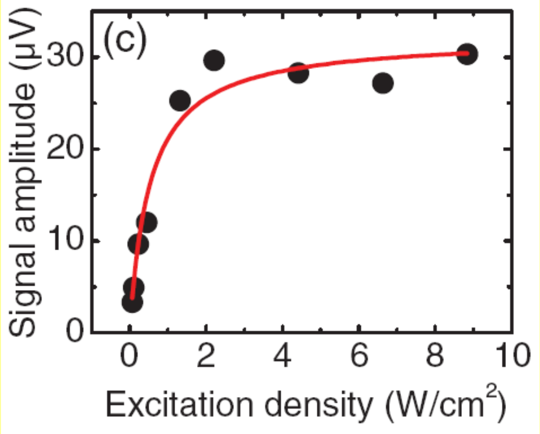


(110) 30nm GaAs/AlGaAs, T = 20K

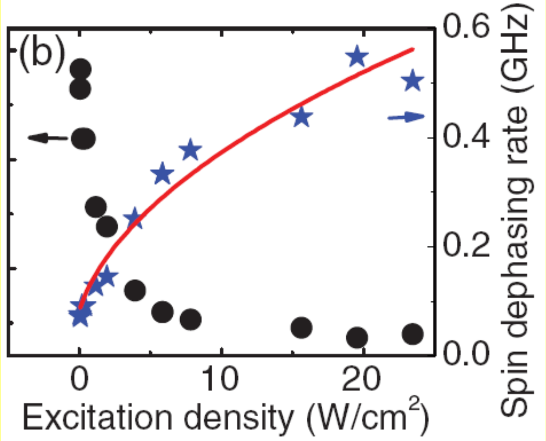
Experiments by T. Korn et al. (Regensburg)

SPIN DEPHASING IN (110) QUANTUM WELLS

Signal amplitude ~ $S_z(0)$



Dephasing rate $1/T_s$



Spin dephasing at zero magnetic field

$$S_z(0) = G_z T_z$$

Optical generation rate $G_z \sim I$

Dephasing rate $1/T_z = 1/T_z^{\lim} + \gamma^{\mathrm{BAP}} N_h$

hole density $N_h \sim I$

Intensity dependence

$$S_z(0) \propto \frac{I}{1 + I/I_0}$$

Dephasing rate from Hanle curves

$$1/T_s = \sqrt{1/T_z}\sqrt{1/T_\parallel} = \sqrt{1/T_z^{\lim} + \gamma^{\mathrm{BAP}} N_h}\sqrt{1/T_\parallel^{\lim}}$$

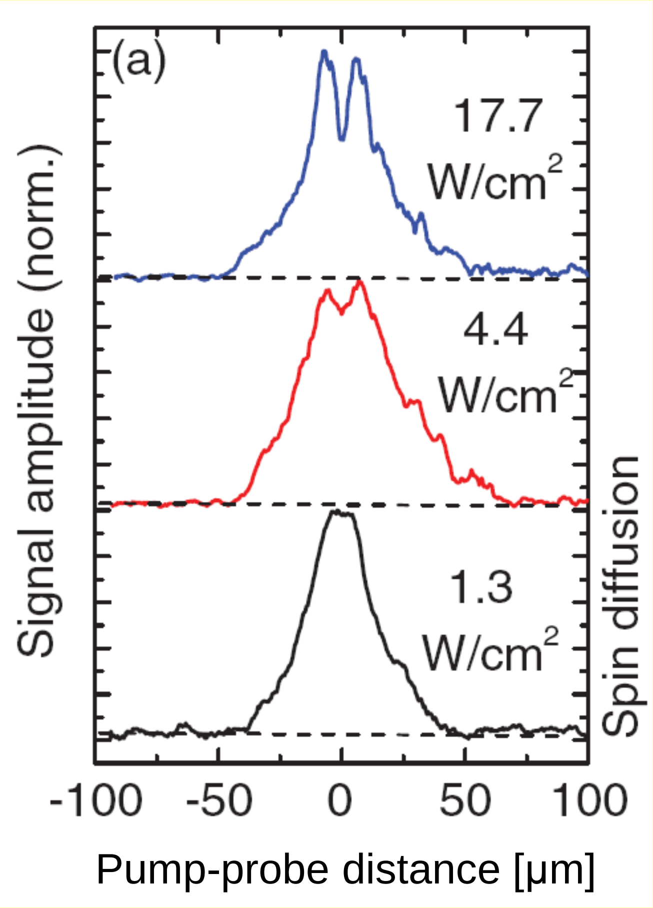
Intensity dependence

$$1/T_s(I) \propto 1/T_s(0)\sqrt{1 + I/I_0}$$

$I_0 \approx 0.5$ W/cm² in the experiment

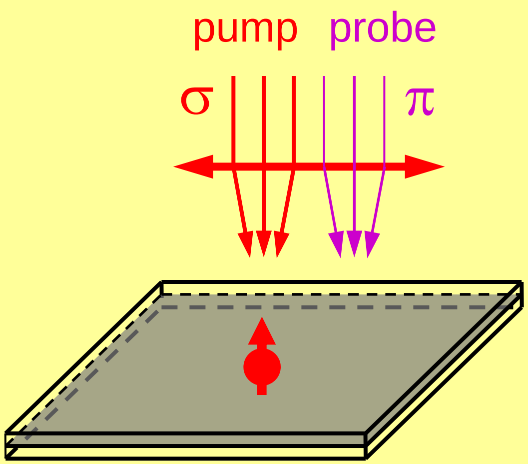
R. Völk, M. Griesbeck, S. A. T. et al., Phys. Rev. B **83**, 241306(R) (2011)

SPIN DIFFUSION IN THE PRESENCE OF HOLES



(110) 30nm-wide GaAs/AlGaAs

MOKE experiment with high space resolution



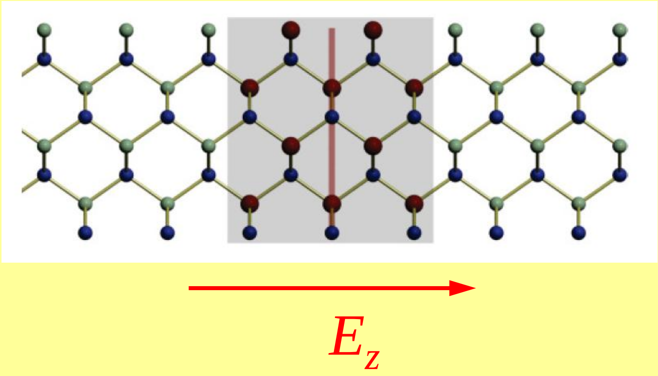
Difference in the diffusion coefficients of electrons and holes results in a non-monotonic dependence of spin polarization on the pump-probe distance

OUTLINE

- Introduction. Band structure of III-V semiconductors
- Spin dephasing in high-mobility (001)-grown quantum wells
  - Anomalous Hanle effect
  - Spin dephasing in 2D structures with anisotropic scattering
- Spin dephasing in (110)-grown quantum wells
  - Suppression of spin dephasing in symmetric quantum wells
  - Dynamic coupling of the in-plane and out-of-plane spin components
- Optical orientation by linearly polarized pulses
- Concluding remarks

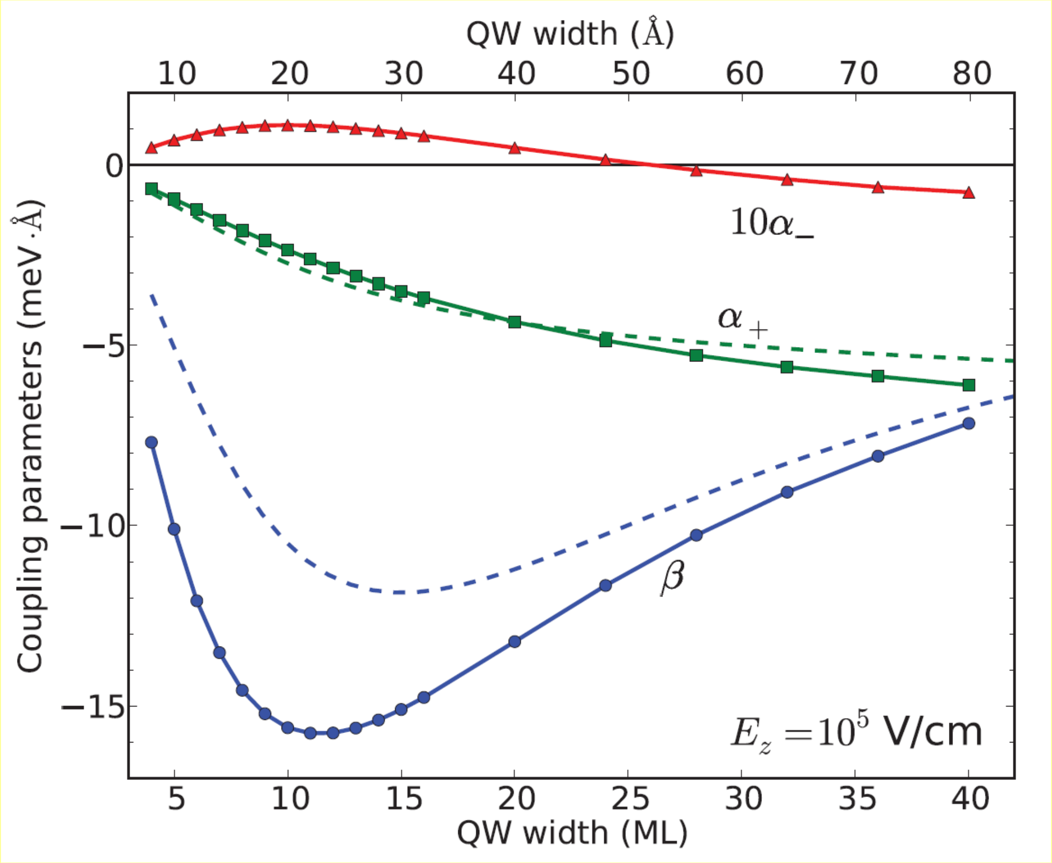
SPIN SPLITTING IN ASYMMETRIC (110) QWS

Crystal structure (C_s group)



Effective Hamiltonian

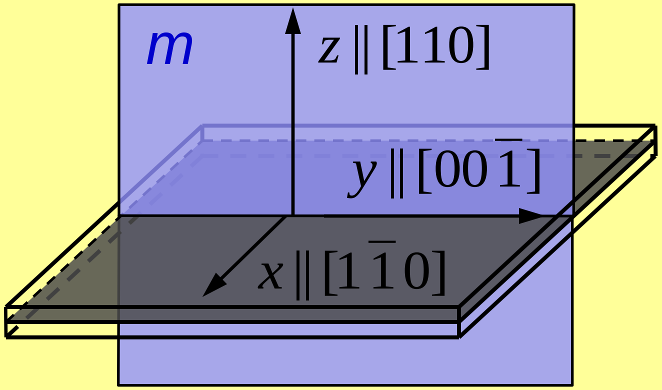
$$H_{so} = \beta\sigma_z k_x + \alpha_+(\sigma_x k_y - \sigma_y k_x) + \alpha_-(\sigma_x k_y + \sigma_y k_x)$$



Spin-orbit coupling parameters as a function of QW width for (110) $GaAs/Ga_{0.7}Al_{0.3}As/GaAs$

M. O. Nestoklon, S.A.T., J.-M. Jancu, and P. Voisin, Phys. Rev. B **85**, 205307 (2012)

SPIN DEPHASING. COLLISION-DOMINATED REGIME



Balance equation for total spin

$$\frac{dS_\alpha(t)}{dt} = G_\alpha - \sum_\beta \Gamma_{\alpha\beta} S_\beta(t)$$

G_α is the spin generation rate

$\Gamma_{\alpha\beta}$ is the tensor of spin relaxation rates

Point group C_s: identity, one mirror plane $m \perp x$

Non-zero components of the second-rank tensor

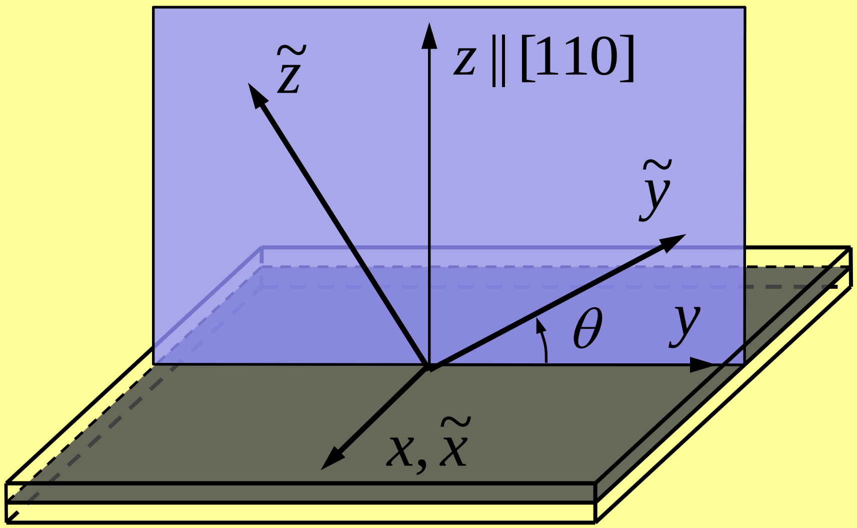
$$\Gamma_{xx},\ \Gamma_{yy},\ \Gamma_{zz},\ \Gamma_{yz} = \Gamma_{zy}$$

DP mechanism: Components of the spin-relaxation-rate tensor

$$\Gamma_{\alpha\beta} = -\int_0^\infty \frac{\tau_1}{f(0)} \frac{df(\varepsilon_{\mathbf{k}})}{d\varepsilon_{\mathbf{k}}} \left[\left\langle \Omega_{\mathbf{k}}^2 \right\rangle \delta_{\alpha\beta} - \left\langle \Omega_{\mathbf{k},\alpha} \Omega_{\mathbf{k},\beta} \right\rangle \right] d\varepsilon_{\mathbf{k}}$$

Larmor frequency of the field $\boldsymbol{B}_{\mathrm{eff}}$

PRINCIPLE AXES OF SPIN-RELAXATION-RATE TENSOR



Equation for eigen values and vectors

$$\det(\Gamma - \gamma \, \mathrm{I}) = 0$$

Principle axes: $\tilde{x}, \tilde{y}, \tilde{z}$

$$\tan\theta = \frac{2\Gamma_{yz}}{\Gamma_{yy} - \Gamma_{zz} + \sqrt{(\Gamma_{yy} - \Gamma_{zz})^2 + 4\Gamma_{yz}^2}}$$

Spin relaxation rates in the principle axes:

$$\gamma_{\tilde{x}} = \Gamma_{xx}$$

$$\gamma_{\tilde{y}} = \left[\Gamma_{yy} + \Gamma_{zz} + \sqrt{(\Gamma_{yy} + \Gamma_{zz})^2 + 4\Gamma_{yz}^2}\right]/2$$

$$\gamma_{\tilde{z}} = \left[\Gamma_{yy} + \Gamma_{zz} - \sqrt{(\Gamma_{yy} + \Gamma_{zz})^2 + 4\Gamma_{yz}^2}\right]/2$$

DP mechanism

$$\gamma_{\tilde{x}} = [(\alpha_+ - \alpha_-)^2 + \beta^2]C$$

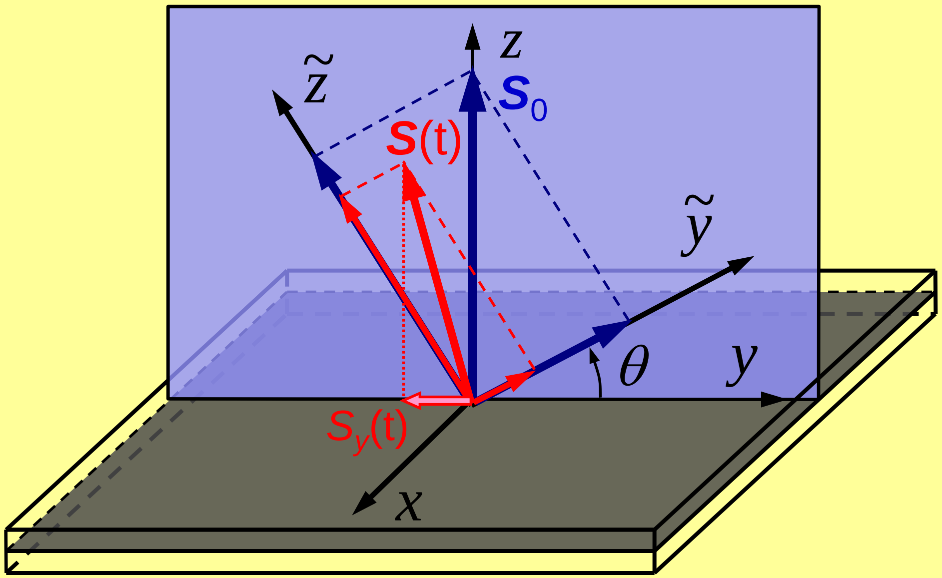
$$\gamma_{\tilde{y}} = (2\alpha_+^2 + 2\alpha_-^2 + \beta^2)C$$

$$\gamma_{\tilde{z}} = (\alpha_+ + \alpha_-)^2 C$$

$$\tan\theta = (\alpha_+ - \alpha_-)/\beta$$

Rashba/Dresselhaus

SPIN DECAY AFTER PULSE EXCITATION



Relaxation of S_z

is described by two lifetimes and leads to the appearance of S_y

Time evolution of spin components

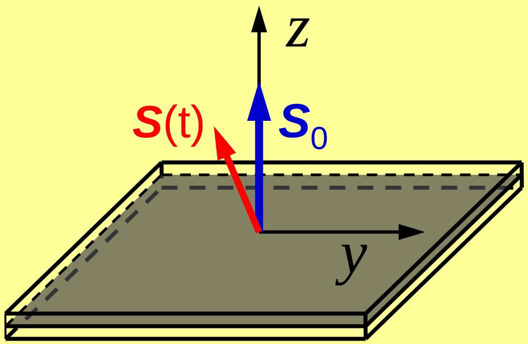
$$S_x(t) = S_{0x} e^{-\gamma_{\tilde{x}} t}$$

$$S_y(t) = S_{0y}(\cos^2\theta \, e^{-\gamma_{\tilde{y}} t} + \cos^2\theta \, e^{-\gamma_{\tilde{z}} t}) + S_{0z}\cos\theta\sin\theta(e^{-\gamma_{\tilde{y}} t} - e^{-\gamma_{\tilde{z}} t})$$

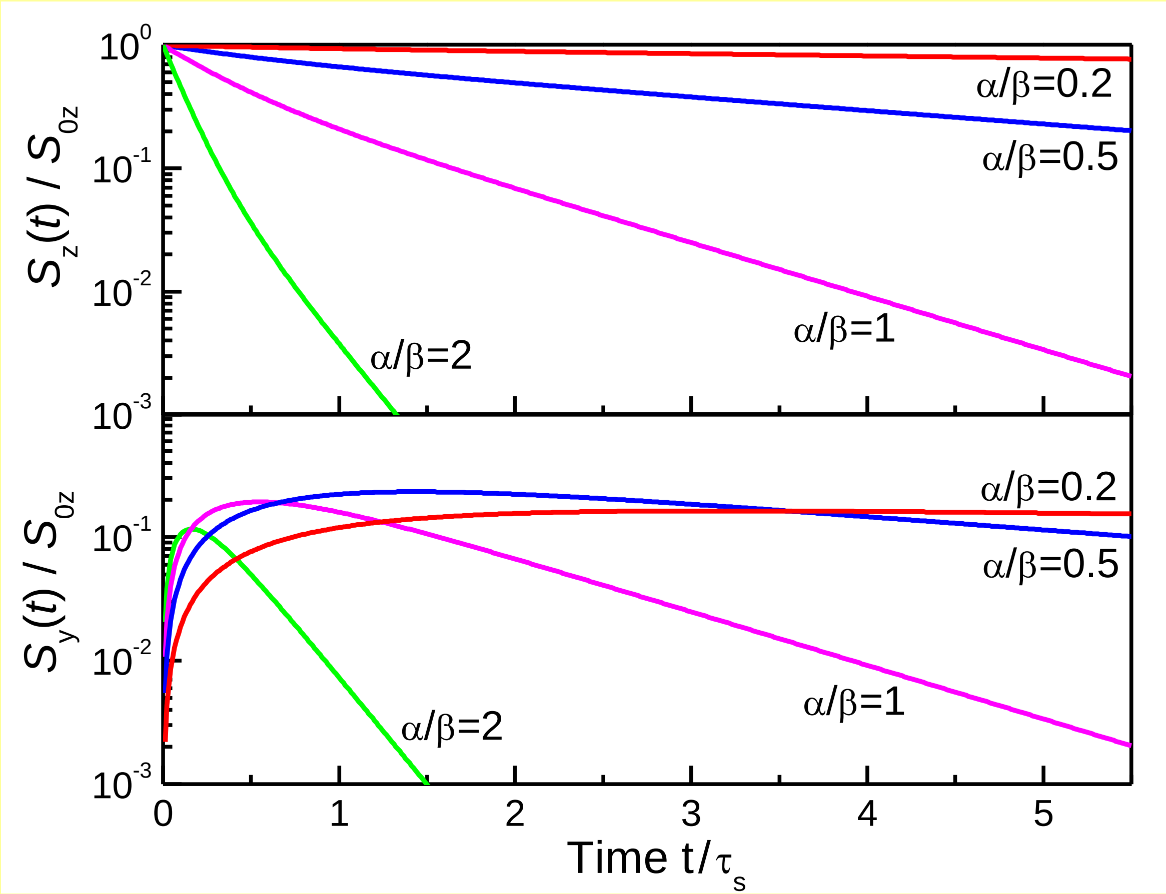
$$S_y(t) = S_{0z}(\cos^2\theta \, e^{-\gamma_{\tilde{z}} t} + \cos^2\theta \, e^{-\gamma_y t}) + S_{0z}\cos\theta\sin\theta(e^{-\gamma_{\tilde{y}} t} - e^{-\gamma_{\tilde{z}} t})$$

RELAXATION OF ELECTRON SPIN INITIALLY ORIENTED ALONG THE GROWTH DIRECTION

Geometry of experiment



Time dependence of the spin components S_z and S_y

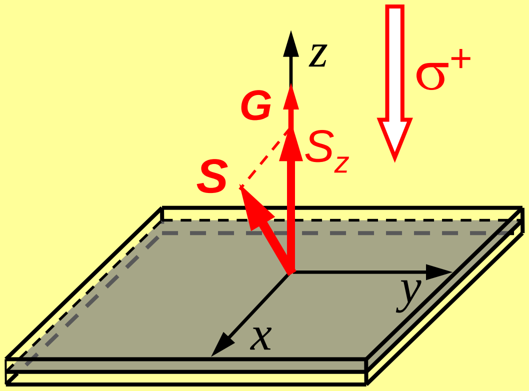


characteristic time $\tau_s = 1/(\beta^2 C)$

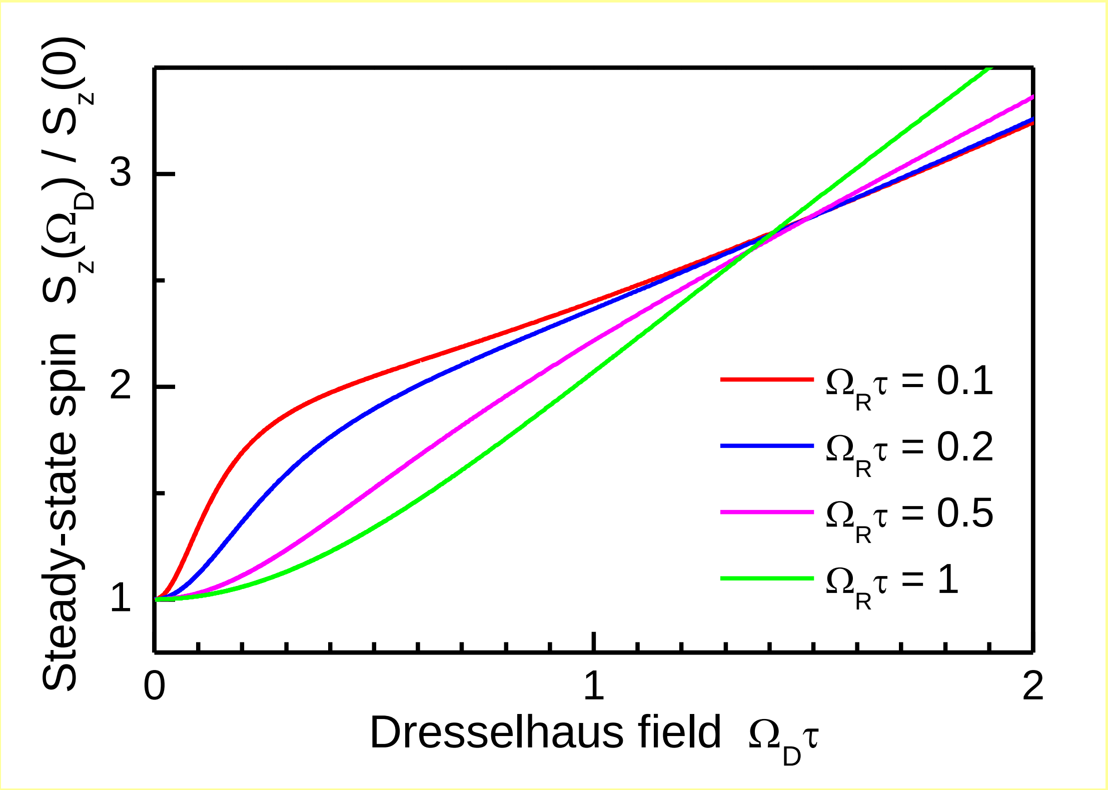
S.A.T., Phys. Rev. B **80**, 165317 (2009)

SUPPRESSION OF SPIN DEPHASING BY DRESSELHAUS FIELD

CW optical pumping



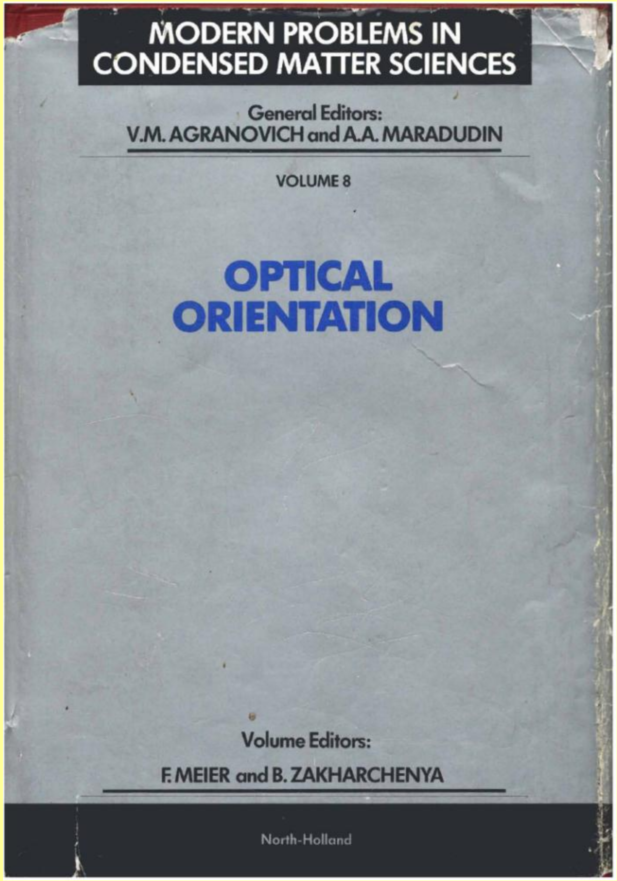
Dependence on the Dresselhaus field

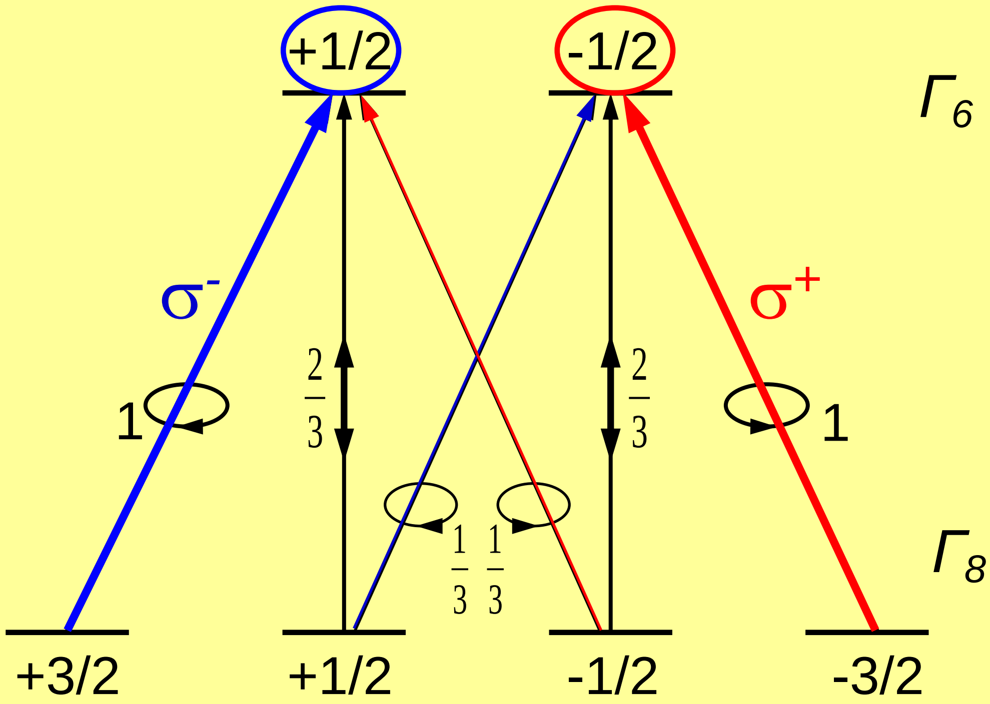


OUTLINE

- Introduction. Band structure of III-V semiconductors
- Spin dephasing in high-mobility (001)-grown quantum wells
  - Anomalous Hanle effect
  - Spin dephasing in 2D structures with anisotropic scattering
- Spin dephasing in (110)-grown quantum wells
  - Suppression of spin dephasing in symmetric quantum wells
  - Dynamic coupling of the in-plane and out-of-plane spin components
- Optical orientation by linearly polarized pulses
- Concluding remarks

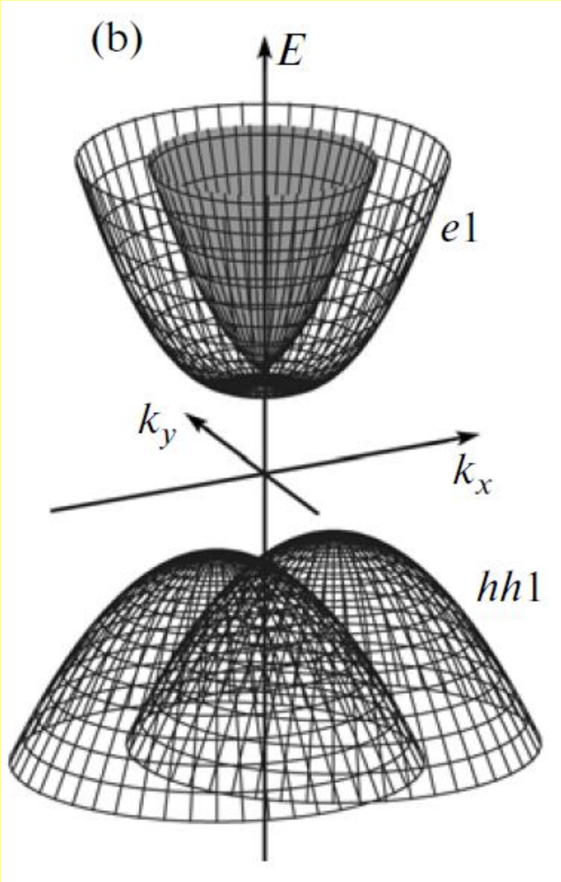
OPTICAL ORIENTATION IN SEMICONDUCTORS



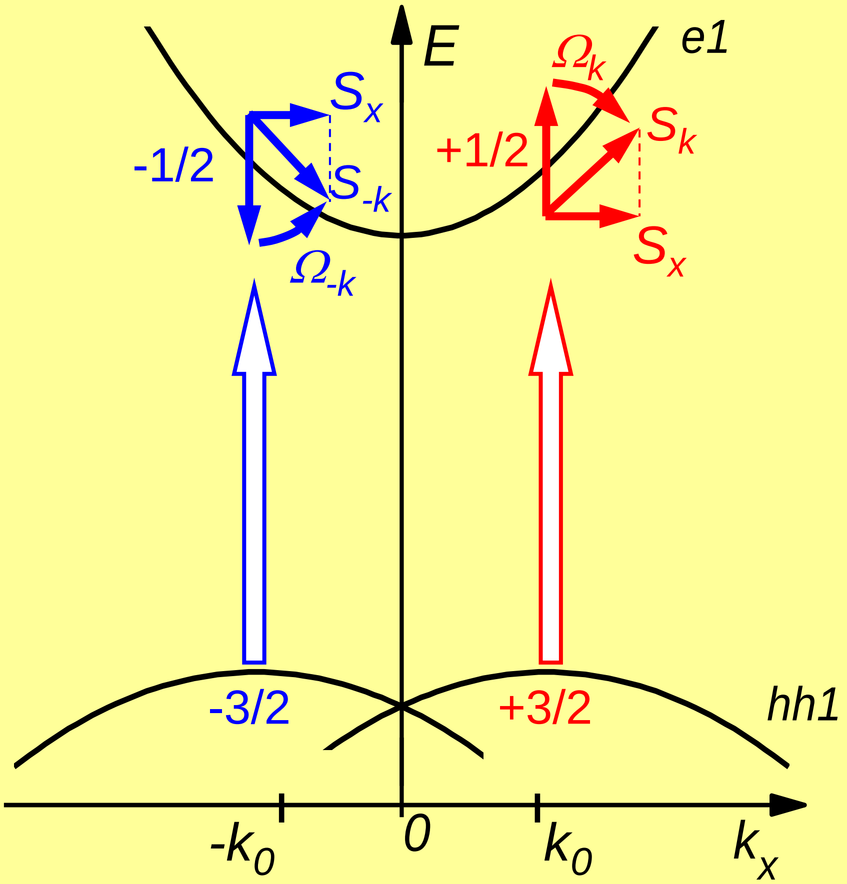


Selection rules for the interband transitions

OPTICAL ORIENTATION BY LINEARLY POLARIZED LIGHT



(110)-quantum wells, C_s

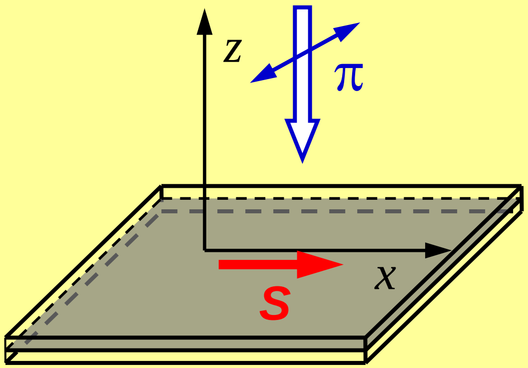


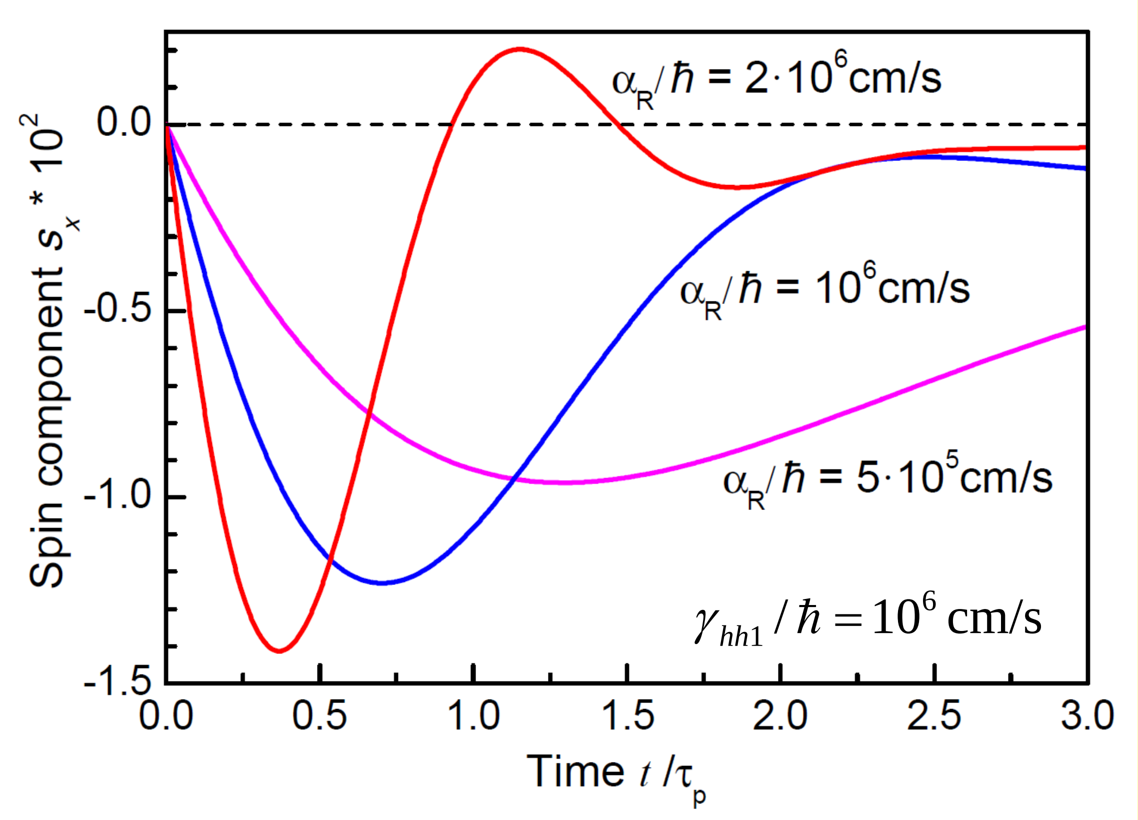
asymmetric photoexcitation followed by
spin precession in the effective magnetic field

S.A.T., Phys. Rev. B **72**, 113302 (2005)

EXCITATION BY LINEARLY POLARIZED PULSE

Pump pulse





Time evolution of average spin of photoelectrons

Numerical calculations for
pulse duration 10^{-13} s, momentum relaxation time $\tau_p = 10^{-12}$ s

V.A. Gorelov, S.A.T., N.S. Averkiev, JETP **113**, 873 (2011)

COLLABORATION / ACKNOWLEDGEMENT

A.V. Poshakinskiy, M.O. Nestoklon, V.A. Gorelov, and N.S. Averkiev

Ioffe Physical-Technical Institute, St. Petersburg

R. Völkl, M. Griesbeck, T. Korn, and C. Schüller
D. Schuh and W. Wegscheider[1]

Universität Regensburg, Regensburg, Germany

[1] Solid State Physics Laboratory, ETH Zurich, Switzerland

J.-M. Jancu[2] and P. Voisin[3]

[2] FOTON-INSA Laboratory, Rennes Cedex, France

[3] CNRS-LPN, Marcoussis, France

OPTICAL ORIENTATION AND SPIN DEPHASING IN HIGH-MOBILITY QUANTUM WELLS

Summary

- Spin dynamics of optically oriented electrons in quantum wells drastically depends on crystallographic orientation of the structure, electron gas mobility, details of scattering, and intensity of optical pumping.
- The absorption of linearly polarized light in quantum wells leads to the spin orientation of photoexcited electrons.