The optical-Hall effect

UNIVERSITY OF NEBRASKA-LINCOLN

ThP.25

T. Hofmann and M. Schubert

Department of Electrical Engineering and Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln, U.S.A.

ellipsometry.unl.edu
thofmann@engr.unl.edu

Our message

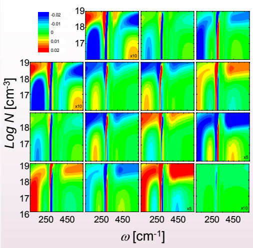
Interaction between long wavelength electromagnetic radiation and bound and unbound electrical charge carriers subjected to an external magnetic field causes optical birefringence precisely measurable using generalized ellipsometry and termed optical-Hall effect.

The optical-Hall effect ….

- allows determination of the free charge carrier properties (density, type, effective mass, and mobility – including their anisotropy) in solid state materials and is demonstrated here for sample systems ranging from simple bulk-like to complex semiconductor hetero-structures and semimetals – even for cases inaccessible for contact based electrical mea-surements so far!
- is an essential new tool for contact-less investigation of optical and electrical properties of next generation nanoelectronic building blocks.

Why optical-Hall effect?

layered structures



Mueller matrix spectra from a typical AlGaAs *p-n* heterostructure as a function of the *n*-type layer density at 3 Tesla.

Free-charge-carrier contribution

$$\varepsilon(\omega,\mathbf{H}) = -\langle\omega_p^{*2}\rangle\left[(\omega^2\mathbf{I}+i\omega\boldsymbol{\gamma}) - i\begin{pmatrix}0 & -h_3 & h_2\\ h_3 & 0 & -h_1\\ -h_2 & h_1 & 0\end{pmatrix}\langle\omega_c\rangle\right]^{-1}$$

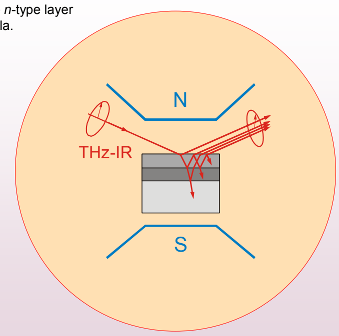
$$\langle\omega_c\rangle = q\left(\frac{H}{m_e}\right)\mathbf{m}^{-1}$$

Cyclotron (frequency) tensor

$$\langle\omega_p^{*2}\rangle = N\frac{e^2}{m_e}\mathbf{m}^{-1}$$

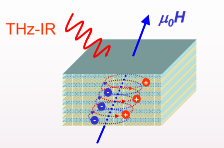
Plasma (frequency) tensor

quantum confinement-effects in low dimensional systems

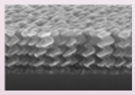


new detector structures:
quantum opto-mechanical couplers
with Eigenresonances in the THz-IR domain

2D – 1D Semiconductors



Complex metamaterials



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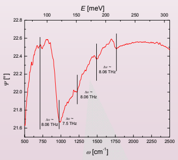
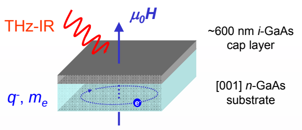
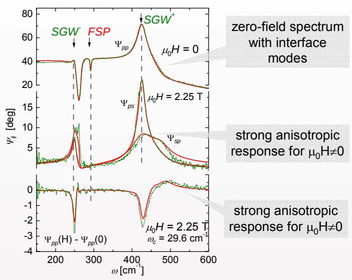


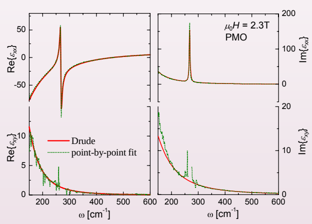
resonances in a sculptured Al thin Film on Si substrate

Bulk-like



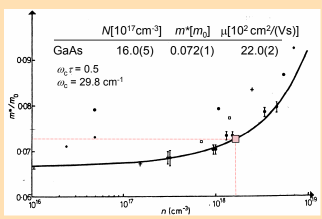


Schubert, Hofmann, and Herzinger, J. Opt. Soc. Am. A 20, 347 - 356 (2003)



Drude dielectric Tensor in comparison with data obtained by point-by-point analysis

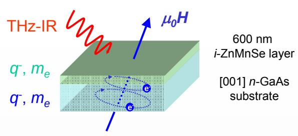
$$\varepsilon_{xy}^{(FC-MO)} = \frac{-\omega_p^2\omega_c}{\omega\left((\omega+i\gamma_p)^2-\omega_c^2\right)} \qquad \varepsilon_{xx}^{(FC-MO)} = \frac{-\omega_p^2(\omega+i\gamma_p)}{\omega\left((\omega+i\gamma_p)^2-\omega_c^2\right)}$$

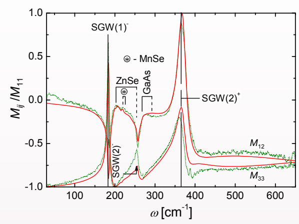


	N[10^{17}cm^{-3}]	m^*[m_0]	µ[10^2 cm^2/(Vs)]
GaAs	16.0(5)	0.072(1)	22.0(2)

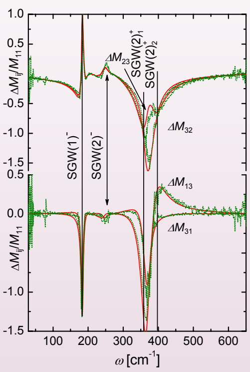
Raymond, Robert, Bernard, J. Phys. C 12, 2289 (1979)

Heterostructure





sharp interface modes (surface guided waves) at the substrate film interface



off-diagonal Mueller matrix difference spectra show sharp resonances at interface mode frequencies

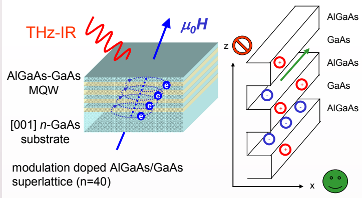
	N[10^{17}cm^{-3}]	m^*[m_0]	µ[10^2 cm^2/(Vs)]	
GaAs	10.5(1)	0.071(1)	20.5(1)	**substrate**
ZnMnSe	4.9(2)	0.086(2)	3.0(2)	**thin film**

Optical-Hall effect allows determination of free charge carrier contributions from substrate and thin film

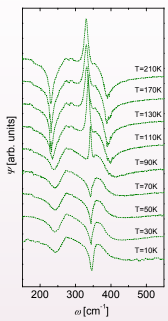
Results for ZnMnSe correspond to kp-calculations of the Γ-Point CB effective mass for $Zn_{0.87}Mn_{0.13}Se$

T. Hofmann et al. Appl. Phys. Lett. 77, 63902 (2006)

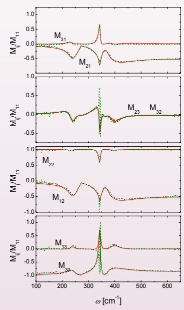
2D spatial confinement



modulation doped AlGaAs/GaAs superlattice (n=40)

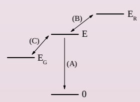


drastic changes of the SGW mode resonances with decreasing temperature



Optical-Hall data:

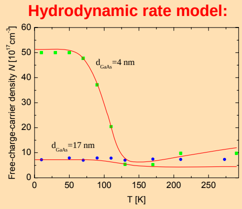
- changes due to an increase of the fcc concentration.
- are not related to mass and mobility changes



number of activated interface states depends on the quantum-well filling!

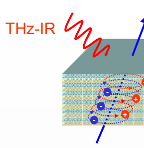
(A) irreversible loss
(B) reversible quantum-well-reservoir interaction
(C) reversible Coulomb activation of surface states

Hydrodynamic rate model:



simple hydrondynamic rate model explains the temperature dependence of carrier density

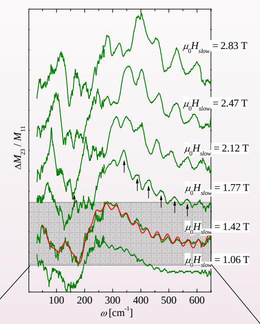
Complex materials

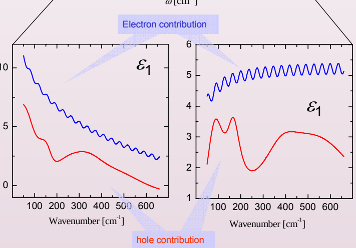


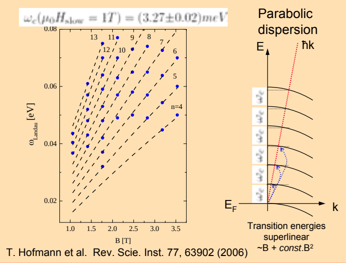
Highly oriented pyrolytic graphite

Defect-induced FM
QHE-like behavior observation
SC observation
field-induced metal-insulator trans.

Landau Level transitions in HOPG at 10K







T. Hofmann et al. Rev. Scie. Inst. 77, 63902 (2006)

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