Magnetooptic birefringence and bandgap anisotropy in ZnMnSe at Room Temperature

UNIVERSITY OF NEBRASKA-LINCOLN

M. Saenger[1,2,*], X. Liu[3], J. C. Furdyna[3], M. Hetterich[4], D. J. Sellmyer[2], R. D. Kirby[2], R. Skomski[2], T. Hofmann[1,2], and M. Schubert[1,2]

[1] *Department of Electrical Engineering, University of Nebraska-Lincoln, 68588, U.S.A.*
[2] *Nebraska Center for Materials and Nanoscience, University of Nebraska, Lincoln, Nebraska 68588, U.S.A.*
[3] *Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556, U.S.A.*
[4] *Institut für Angewandte Physik, Universität Karlsruhe (TH), Karlsruhe, Germany*

ellipsometry.unl.edu
*saenger@engr.unl.edu

Introduction

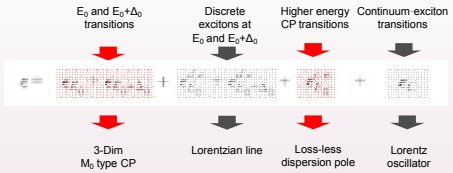
Interaction between long wavelength electromagnetic radiation and bound and unbound electrical charge carriers subjected to an external magnetic field causes optical birefringence precisely measurable using generalized ellipsometry. *ZnSe* is an important II-VI semiconductor with a variety of applications in optoelectronic devices.

$Zn_{1-x}Mn_xSe$ ...

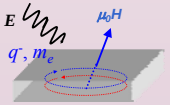
possesses a temperature dependent magnetic moment as well as remarkable magnetooptic (MO) properties, which in conjunction with the electronic properties suggest future applications for MO and spintronic devices.

Dielectric tensor model

$$\varepsilon(E)=\frac{1}{2}\begin{pmatrix}(\rho_+^{\perp}+\rho_-^{\perp}) & i(\rho_+ - \rho_-) & 0\\ -i(\rho_+ - \rho_-) & (\rho_+^{\perp}+\rho_-^{\perp}) & 0\\ 0 & 0 & (\rho_+^{//}+\rho_-^{//})\end{pmatrix}$$



$$E_i(m_J^v \rightarrow m_J^c) = E_i + \underbrace{(m^c g_J - m^v g_J)\mu_0 H}_{\text{Zeeman}} + \underbrace{\left[E_J^c(m_J^c) - E(m_J^v)\right]}_{\text{sp-d exchange or GFE}}$$



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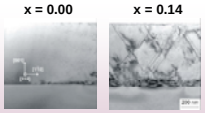
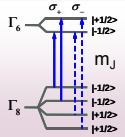
Generalized ellipsometry and magnetism results at Room Temperature

Formation of wurtzite planes normal to the [111] direction causes dielectric birefringence in dependance of the Mn concentration x. At x = 0.3 a phase transformation from the sphalerite to the wurtzite structure occurs.

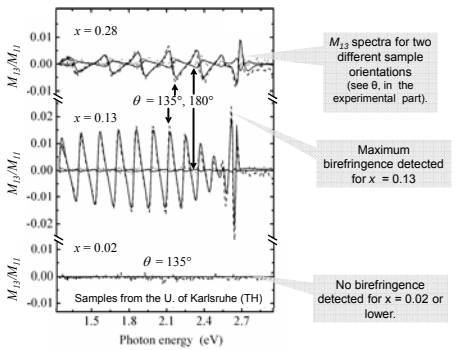


Litvinov 2006

The underlying mechanism of the giant Faraday effect is the interaction between the spin of the localized $3d^5$-electrons of the Mn ions and the band electrons. When $\mu_0 H \neq 0$, the conduction and valence bands split, which is known as *sp-d* exchange.



Intrinsic anisotropy in dependence of Mn concentration

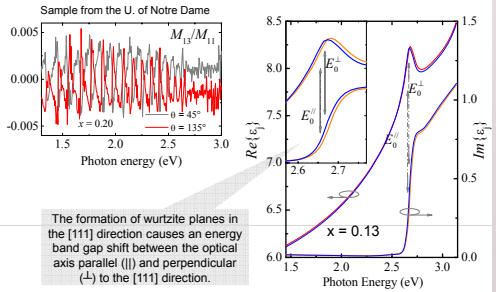


M_{13} spectra for two different sample orientations (see θ, in the experimental part).

Maximum birefringence detected for x = 0.13

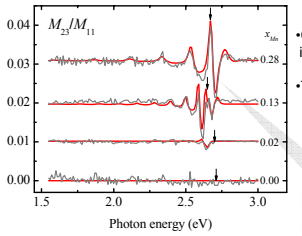
No birefringence detected for x = 0.02 or lower.

Sample from the U. of Notre Dame



The formation of wurtzite planes in the [111] direction causes an energy band gap shift between the optical axis parallel (||) and perpendicular (⊥) to the [111] direction.

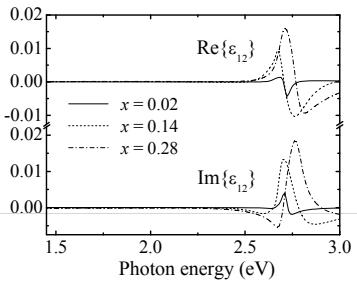
Giant Faraday effect and MO birefringence at RT



- Change due to the *sp-d* interaction.
- The dielectric anisotropy is taken into account when modeling the MO effect.

The oscillations depend on the layer thickness and the dielectric tensor.

With the appropriate model the diagonal elements of the dielectric tensor can be obtained. The sample with highest magnetic birefringence is also the sample with highest Mn concentration.

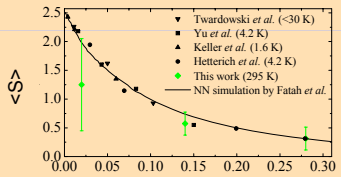


The dielectric anisotropy can be measured in terms of the energy band gap shift.

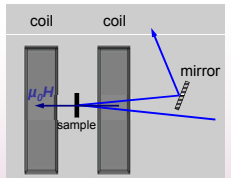
x_{Mn}	$E_0^{//}$ eV	$E_0^{\perp}$ eV	$E_0^{\perp}$ - $E_0^{//}$ meV
0.13	2.6491 (7)	2.6549 (5)	5.8 (9)
0.28	2.6743 (5)	2.6784 (6)	4.1 (8)

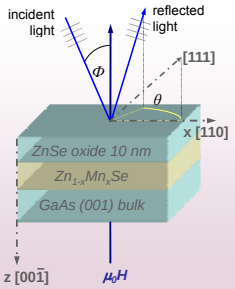
The anisotropy is not proportional to the Mn concentration x. The effect is universal since it is observed in samples from different laboratories.

The ellipsometric model allows us to measure the thermally averaged net moment per Mn atom at RT.



Experiment





Mueller matrix

Generalized Ellipsometry measures the general optical polarization response of samples in terms of *Mueller matrix* elements, and allows for reconstruction of the permittivity, permeability, and magneto-electric response tensors.

The Mueller matrix elements M_{ij} connect incident and emergent real-valued Stokes vector components:

$$S_0 = I_p + I_s$$
$$S_1 = I_p - I_s$$
$$S_2 = I_{45} - I_{-45}$$
$$S_3 = I_{\sigma+} - I_{\sigma-}$$

$$\begin{pmatrix}S_0\\S_1\\S_2\\S_3\end{pmatrix}_{output} = \begin{pmatrix}M_{11} & M_{12} & M_{13} & M_{14}\\ M_{21} & M_{22} & M_{23} & M_{24}\\ M_{31} & M_{32} & M_{33} & M_{34}\\ M_{41} & M_{42} & M_{43} & M_{44}\end{pmatrix}\begin{pmatrix}S_0\\S_1\\S_2\\S_3\end{pmatrix}_{input}$$

Sensitive to chiral anisotropy (magnetic birefringence)

Highly sensitive to dielectric birefringence.

Our message

We studied the dielectric and magnetic-field induced anisotropic optical properties of $Zn_{1-x}Mn_xSe$ thin films. The dielectric and the magnetic field induced anisotropies in $Zn_{1-x}Mn_xSe$ were treated separately into the diagonal and off-diagonal components of the dielectric tensor.

We found an intrinsic anisotropy upon Mn inclusion in ZnSe which induces a relative shift of the band gap energy between the ordinary and extraordinary optical axis. The anisotropy effect is apparently common for MBE grown samples.

The induced magnetooptic birefringence is used to determine the thermally averaged spin moment per Mn atom <S>, which is consistent with the predominance of antiferromagnetic exchange interactions between close manganese neighbors.

References

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