Magnetooptic birefringence and bandgap anisotropy in $Zn_{1-x}Mn_xSe$ at room temperature

UNIVERSITY OF NEBRASKA-LINCOLN

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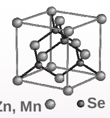
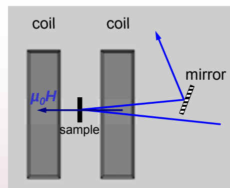
Introduction

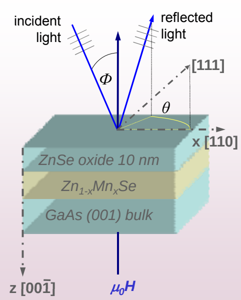
$Zn_{1-x}Mn_xSe$ possesses a temperature dependent magnetic moment as well as remarkable magnetooptic (MO) properties.



Due to the strong temperature dependence, the MO effects and thus, the net effective spin moment per Mn atom <S> are very small to measure with typical magneto photoluminiscence techniques at room temperature. Using advanced measurement methods we are able to measure the <S> value at room temperature. Furthermore, we find an intrinsic optical anisotropy in dependance of the Mn concentration characterized by a bandgap splitting.

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.

Stokes vector Components:

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

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

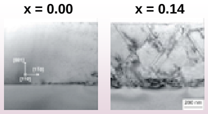
Sensitive to chiral anisotropy (magnetic birefringence)

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

Highly sensitive to dielectric birefringence.

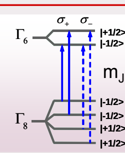
Generalized ellipsometry and magnetism results at room temperature

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.

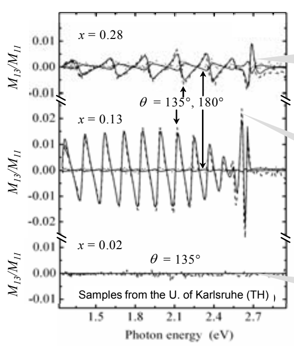


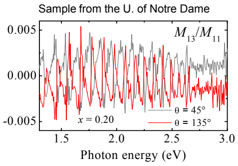
Litvinov 2006

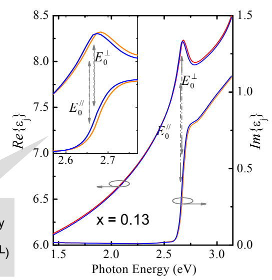
The underlying mechanism of the giant Faraday effect is the interaction between the spin of the localized $3d^5$-electrons of the Mn ions and the band electrons. When $\mu_0 H \neq 0$, the conduction and valence bands split, which is known as *sp-d* exchange.



Intrinsic anisotropy in dependence of Mn concentration

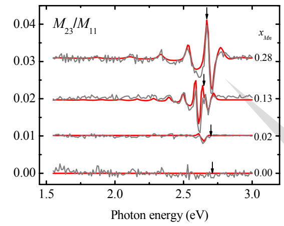






The formation of wurtzite planes in the [111] direction causes an energy band gap shift between the optical axis parallel (||) and perpendicular (⊥) to the [111] direction.

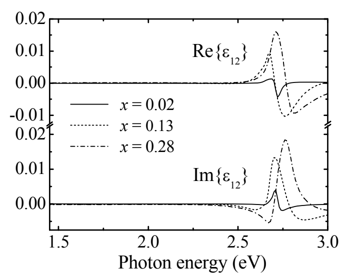
Magnetooptic birefringence measurements at room temperature



- 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.

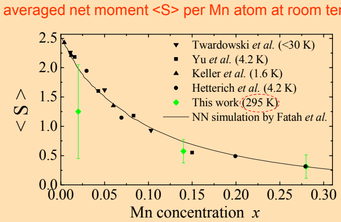


The dielectric anisotropy can be measured in terms of the energy band gap shift.

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)

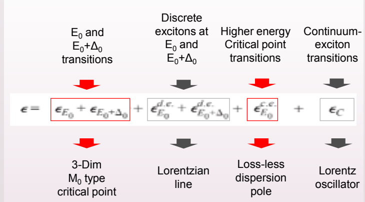
The anisotropy is not proportional to the Mn concentration x. The effect is universal since it is observed in samples from different laboratories.

The ellipsometric model allows us to measure the thermally averaged net moment <S> per Mn atom at room temp.



Model Dielectric Function

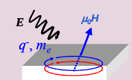
$$\varepsilon(E) = \frac{1}{2}\begin{pmatrix} (\rho_+^{\perp} + \rho_-^{\perp}) & i(\rho_+ - \rho_-) & 0 \\ -i(\rho_+ - \rho_-) & (\rho_+^{\perp} + \rho_-^{\perp}) & 0 \\ 0 & 0 & (\rho_+^{//} + \rho_-^{//}) \end{pmatrix}$$



$$E_i(m_J^v \rightarrow m_J^c) =$$
$$E_i + (m^c g_J - m^v g_J)\mu_0 H + [E_J^c(m_J^c) - E(m_J^v)]$$

Zeeman splitting

sp-d exchange (cause of the giant Faraday effect)



Our message

We determined the thermally averaged spin moment per Mn atom <S> at room temperature in dependence of the Mn concentration x for the first time.

The measured <S> values are consistent with the predominance of antiferromagnetic exchange interaction between close Mn neighbours according to previous calculations [Fatah94].

We found an intrinsic optical anisotropy upon Mn inclusion in ZnSe which is apparently common in MBE grown ZnMnSe films.

We determine the bandgap splitting energy value characteristic for the uniaxial anisotropy.

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Meet us at: Ellipsometry Topical Meeting at 56th AVS Conference, San Jose, Nov. 8-13, 2009.