Dielectric and magnetic birefringence in $Zn_{1-x}Mn_xSe$

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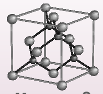
Introduction

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.

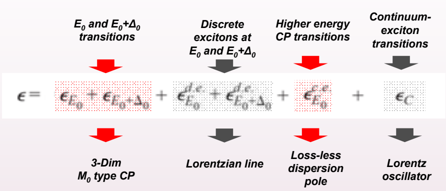
$Zn_{1-x}Mn_xSe$ ...



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

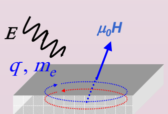
$$\varepsilon(E) = \frac{1}{2}\begin{pmatrix} (\rho_+^\perp + \rho_-^\perp) & i(\rho_+ - \rho_-) & 0 \\ i(\rho_+ - \rho_-) & (\rho_+^\perp + \rho_-^\perp) & 0 \\ 0 & 0 & (\rho_+^{//} + \rho_-^{//}) \end{pmatrix}$$



$$E_i(m_J^v \rightarrow m_J^c) = E_i + \frac{\hbar}{2}(\omega_0^c + \omega_0^v)$$ Landau

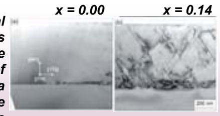
$$+(m^c g_J - m^v g_J)\mu_0 H$$ Zeeman

$$+\left[E_J^c(m_J^c) - E(m_J^v)\right]$$ sp-d exchange



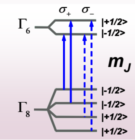
Results

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.

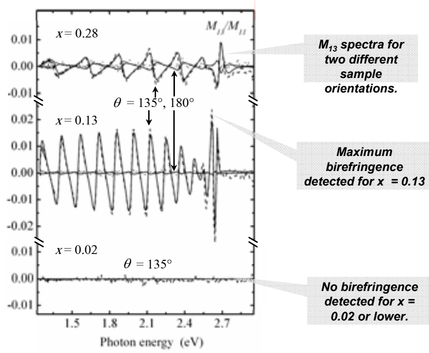


Litvinov 2007

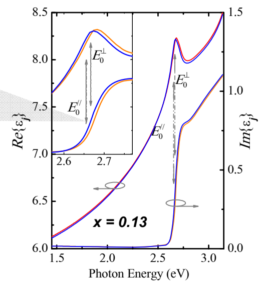
The underlying mechanism of the giant Faraday effect is the interaction between the spin of the localized $3d^5$-electrons of the Mn ions and the band electrons. When $\mu_0 H \neq 0$, the conduction and valence bands split, which is known as sp-d exchange.

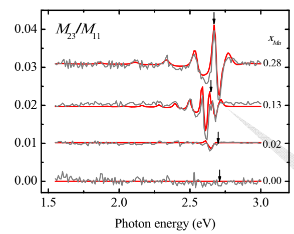


Optical detection and quantification of anisotropy



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.

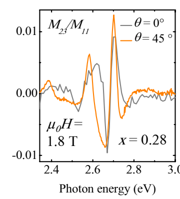




MO birefringence

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

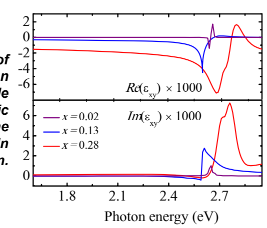
The oscillations depend on the layer thickness.



The dielectric anisotropy influences the MO birefringence

The MO birefringence depends also on the orientation of the sample. Therefore it is necessary to have a model which takes this effect properly into account.

The diagonal elements of the dielectric tensor can be obtined. 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)

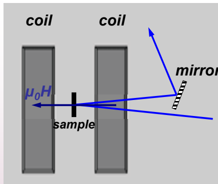
The anisotropy is not proportional to the Mn concentration x. For x closer to 0.13 the anisotropy reaches at least one maximum.

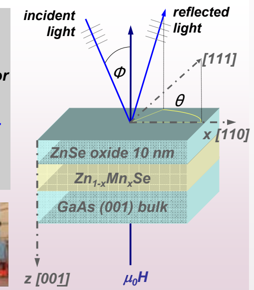
The ellipsometric model allows us to measure the spd-exchange energy and Landau shift.

x_{Mn}	$\lvert E_c(\pm 3/2) - E_v(\pm 1/2)\rvert$ 1×10^{-4} eV	E_L 1×10^{-4} eV
0.02	2 (1)	1.1 (3)
0.13	8 (3)	1.2 (5)
0.28	12 (3)	1.0 (4)

Loop measurements in dependance of the magnetic field can also be modeled.

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:

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

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

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 with generalized spectroscopic ellipsometry in the VIS-UV spectral range for Mn concentrations of x = 0.00, 0.02,0.13 and 0.28. The dielectric and 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 are able to quantify the shift of the band gap energy between the DF parallel and perpendicular to the optical axis caused by the formation of wurtzite domains with increasing x.

The optical anisotropy occurs in the direction [111], which is in good concordance with previous TEM investigations. The dielectric anisotropy results in a red shift of the energy band gap parallel to the optical axis with a maximum for x = 0.13.

Measurements of the sp-d exchange energy at room temperature are presented and found a maximum value for the sample with maximum Mn concentration x = 0.28.

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