Spectroscopic Ellipsometry for Metamaterials by Glancing Angle Deposition

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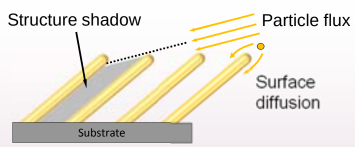
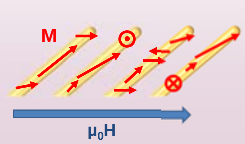
Our Message

- **Glancing angle deposition is utilized to grow achiral and chiral metallic sculptured thin films**
- **Generalized Ellipsometry (GE) is employed to determine optical and geometrical properties; slanted columnar thin films have monoclinic optical properties**
- **Polar Magneto-Optical Kerr Effect measurements are analyzed to determine magneto-optical activity and giant Kerr rotation of low-symmetric ferromagnetic nanostructure thin films was measured**
- **Vector Magneto-Optical Generalized Ellipsometry (VMOGE) allows for determination of the entire dielectric tensor by measuring at arbitrary magnetic field orientations and will give insight into magnetic domain switching of complex nanostructures**

Ferromagnetic Nanostructures





How do magnetic domains align and how do they switch

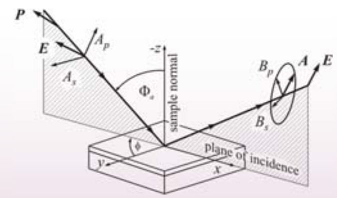
Dielectric tensor of a biaxial material with polar, transversal, and longitudinal magneto-optical elements

Dielectric Tensor

$$\varepsilon = \begin{pmatrix} \varepsilon_{xx} & \varepsilon_{xy}^{P} & -\varepsilon_{xz}^{T} \\ -\varepsilon_{xy}^{P} & \varepsilon_{yy} & \varepsilon_{yz}^{L} \\ \varepsilon_{xz}^{T} & -\varepsilon_{yz}^{L} & \varepsilon_{zz} \end{pmatrix}$$

Off-diagonal parts account for magneto-optical activity

Generalized Ellipsometry



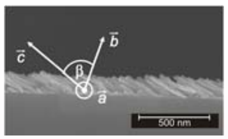
Ellipsometry measures the polarization state change of an electromagnetic wave upon reflection off a sample surface.

If the sample is anisotropic, generalized (Mueller matrix) ellipsometry allows for determination of complete and accurate sets of optical constants.

The 4x4 real-valued Mueller matrix connects the incident and emergent Stokes vector components, which are linear combinations of different polarization states.

$$\begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix}_{out} = \begin{pmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \\ M_{41} & M_{42} & M_{43} & M_{44} \end{pmatrix} \begin{bmatrix} I_p + I_s \\ I_p - I_s \\ I_{45} - I_{-45} \\ I_{RC} - I_{LC} \end{bmatrix}_{in}$$

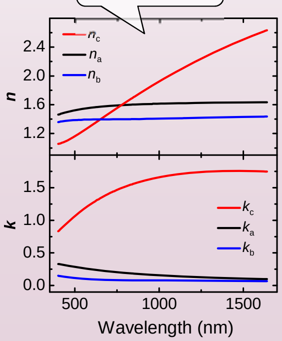
Monoclinic Slanted Columnar Thin Films



	GE	SEM
Thickness d	113.4 nm	125 nm
Inclination θ	55.3°	55°
Angle β	80.6°	---

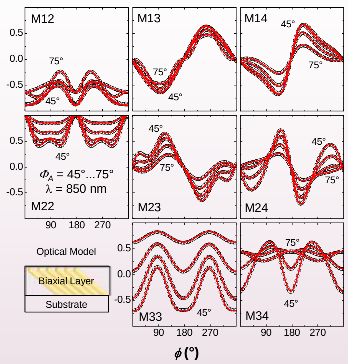
D. Schmidt *et al.*, J. Appl. Phys. **105**, 113508 (2009).
D. Schmidt *et al.*, Opt. Lett. **34**, 992 (2009).
D. Schmidt *et al.*, Appl. Phys. Lett. **94**, 011914 (2009).

large birefringence, extreme dichroism



Mueller Matrix Ellipsometry

Generated and experimental non-redundant Mueller matrix data at different angles of incidence versus sample azimuth

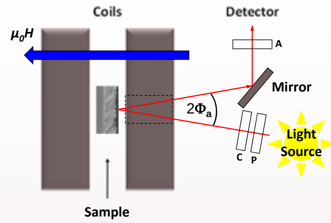


Slanted columnar thin films from metal have monoclinic optical properties

Principal refractive index n_i and extinction coefficient k_i along axes i = **a**, **b**, **c** of cobalt slanted columnar thin film depicted in the SEM.

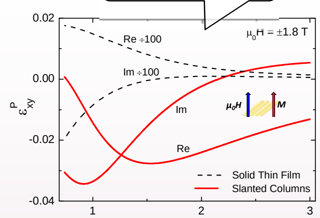
Magneto-Optical Generalized Ellipsometry

Polar Magneto-Optical Kerr Effect



The sample is magnetized in a magnetic field created by an electromagnet. Generalized ellipsometry in the polar configuration (incident light parallel to the magnetic field) can be performed by shining light through a hole in the magnetic pole piece.

large magneto-optical activity, independent of sample azimuth

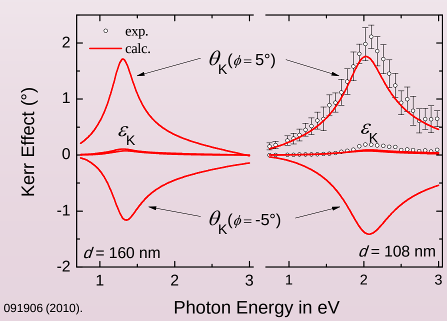


At 1.8 T all domains are parallel to the external magnetic field. Only an azimuthally independent ε^P is necessary to model magneto-optic coupling.

100 nm Co can still be transparent!

Giant Kerr rotation is calculated and observed for certain in-plane orientations.

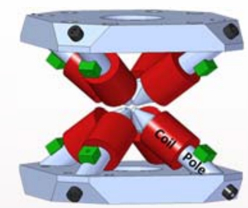
Giant Kerr-Rotation



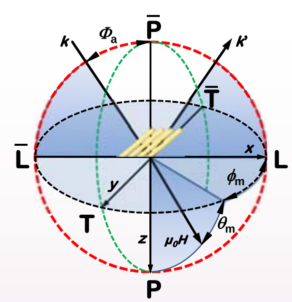
D. Schmidt *et al.*, Appl. Phys. Lett. **96**, 091906 (2010).

Vector Magneto-Optical Generalized Ellipsometry

Octupole Magnet



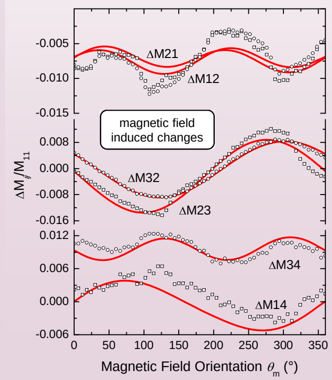
An octupole vector magnet allows for generalized ellipsometry measurements at arbitrary magnetic field orientations.



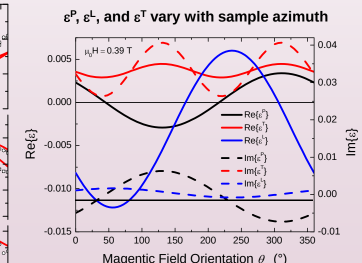
0.4 T is not sufficient to force all domains along the external magnetic field → also ε^T present in present configuration, for example

LP-VMOGE Results

$\varepsilon^P \sim \cos(\theta_m)$
$\varepsilon^L \sim \sin(\theta_m)$
$\varepsilon^T \sim \sin(\theta_m)\cos(\theta_m)$



ε^P, ε^L, and ε^T vary with sample azimuth



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