MOKE: Principles and Measurement

Corbyn Mellinger
Dr. Xu Group
June 10, 2016
Common Magneto-optical Effects

• Faraday Effect: magnetization of material affects transmission of polarized light

• Kerr Effect: magnetization of material affects reflection of polarized light

• Reflectance magneto-circular dichroism: magnetization of material causes difference in reflectivity of right- and left-hand circularly polarized light
Polarized Light in Terms of Circular Polarization

Two rotations of polarizations cancel in y-direction but add in x-direction.

General linear polarization: equal field strengths and phase velocities, different phases.

Elliptical polarization: different field strengths and phases, same phase velocities.
Faraday Effect

• First of the magneto-optical effects to be discovered (1845)
• Easiest to explain phenomenologically

• Propagation speeds of left- and right-hand polarized light change under application of magnetic field (tilts polarization plane)
• Absorption of left- and right-hand polarized light can be different (elliptically polarizes light)
Reflectance Magneto-Circular Dichroism (RMCD)

- Difference in reflectivity between right- and left-handed circularly polarized light
  - Takes linearly polarized light to elliptically polarized light, with semimajor axis aligning with original polarization axis
Magneto-Optical Kerr Effect (MOKE)

- Linearly polarized light incident on magnetized material becomes *elliptically* polarized
  - Takes linearly polarized light to general elliptically polarized light, with semimajor axis at angle $\phi$ to original polarization axis
Kerr Effect: Three Geometries

• Polar MOKE
  • Magnetization direction out of plane; incident light at near normal incidence

• Longitudinal MOKE
  • Magnetization direction in plane of surface and in plane of incidence

• Transversal MOKE
  • Magnetization direction in plane of surface and normal to plane of incidence
Theoretical Treatment of MOKE

• Matrix formulation in late 1980’s-early 1990’s by Zak, Moog, Liu & Bader at Argonne National Labs
  • Matrices describing interface between layers derivable in terms of magneto-optical properties
• Later expanded formulation to multi-layered systems and systems with arbitrary magnetization directions
• Magnetization parameterized by so-called Voigt constant Q
Measurement of Kerr Rotation

• Typical measurements use $\lambda/4$ wave plate to convert elliptically polarized light back to linearly polarized
  • Kerr rotation manifests as new final plane of polarization
  • Insensitive to direction of magnetization (cannot recover hysteresis loop)

• Relationship between Kerr rotation and magnetization not simple to recover
  • Relative magnetization typically reported in literature

- Photoelastic modulator (Mo) introduces phase along x-axis only
- $\delta = \delta_0 \sin(2\pi ft)$, f is modulator frequency (~50 kHz normally)
- Detector (D) measures either at frequency f or 2f 

P at 45° to x-axis, A at general angle $\phi$ to x-axis

\[
\frac{I_2}{I_1} = A \frac{J_1(\delta_0) \Delta R/R}{1 + J_0(\delta_0) \sin (\Delta \theta + 2\phi)}, \quad (13)
\]

\[
\frac{I_3}{I_1} = B \frac{2J_2(\delta_0) \sin (\Delta \theta + 2\phi)}{1 + J_0(\delta_0) \sin (\Delta \theta + 2\phi)}, \quad (14)
\]

- RMDC: measured at lock-in frequency \( f \)
- MOKE: measured at lock-in frequency \( 2f \)
  - \( 2\phi_K = -\Delta \theta \)
Determining $\phi_K$

- Set analyzer to 0°
  - $\frac{I_3}{I_1} \approx 2BJ_2(\delta_0)\Delta \theta$
  - Requires calibration to determine constant $2BJ_2(\delta_0)$

- Set analyzer to $2\phi = -\Delta \theta$
  - $\frac{I_3}{I_1} = 0$
  - Requires ability to precisely measure and control angle of analyzer
Calibration of Kerr Rotation

• Replace sample with highly reflective, nonmagnetic material. Set analyzer angle $\phi = \pm \pi/4$

  - $\left( \frac{I_3}{I_1} \right)_{\pm} = \frac{2BJ_2(\delta_0)}{1 \pm J_0(\delta_0)}$

• Ratio of 2 angles gives $J_0(\delta_0)$, and therefore $2BJ_2(\delta_0)$
Limitations of Sato Paper

• Derivation requires near zero incidence angle
  • Fresnel reflectivities depend on this

• Purely methodological; no link between optical rotation and magnetization of sample