Journal of Magnetism and Magnetic Materials 386 (2015) 150–154

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Influence of the light incidence angle on the precision of generalized magneto-optical ellipsometry

C. Gonzalez-Fuentes [a,b,*], J.B. Gonzalez-Diaz [a,1], L. Fallarino [a], J.A. Arregi [a], A. Berger [a]

[a] CIC nanoGUNE Consolider, E-20018 Donostia-San Sebastián, Spain
[b] Departamento de Física, Universidad Técnica Federico Santa María, Avenida España 1680, Valparaíso, Chile

ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form
24 March 2015
Accepted 25 March 2015
Available online 26 March 2015

Keywords:
Generalized magneto-optical ellipsometry
Ellipsometry
Kerr magnetometry
Magneto-optics

ABSTRACT

We study theoretically and experimentally the influence of the light incidence angle φ_0 on the precision of generalized magneto-optical ellipsometry (GME). A brief review of the GME methodology is presented together with a study of the error propagation from measurement uncertainties to the precision of the resulting complex index of refraction N and magneto-optical constant Q. The results are compared with longitudinal GME measurements on bulk polycrystalline cobalt. We observe a strong increase of the resulting relative error as φ_0 decreases below 45°. We tested our theoretical estimates by performing GME measurements for polycrystalline cobalt ($N = 2.20 + 3.42i$; $Q = (2.25 - 0.80i) \times 10^{-2}$)) and found GME measurements to clearly exhibit improved reliability for $\varphi_0 > 30°$.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Generalized magneto-optical ellipsometry (GME) [1] is a powerful, nondestructive technique that combines in a single experimental setup and sequence magneto-optical Kerr effect (MOKE) magnetometry and ellipsometry. It is therefore capable of determining by means of a single measurement sequence the complex index of refraction $N = n + ik$, the magneto-optical coupling constant $Q = Q_r + iQ_i$, as well as the magnetization orientation of a ferromagnetic material [2,3].

It was also demonstrated that GME can be extended to variable wavelength and temperature dependent measurement types [4,5]. Some recent works have furthermore improved the efficiency of data acquisition [6] and used GME to characterize purely optical anisotropy effects [7].

It is known that the sensitivity of a conventional, non-magneto-optical ellipsometer is in general better for higher incidence angles [8] (as measured from the sample normal), with recommended angles being typically larger than 40°. Until now, no significant attention has been given to the incidence angle of the light in GME experiments, which could affect the precision and accuracy of results in a significant way.

In this work we present a thorough study of error propagation for N and Q at different incidence angles of the light φ_0 and we compare these theoretical results with GME measurements on polycrystalline cobalt films for different values of φ_0.

2. Theory

For simplicity, we restrict our analysis here to the assumption of a bulk material that is optically isotropic and has isotropic magneto-optical response in that it can be described by a single magneto-optical coupling constant Q. The light used in the GME experiment is assumed to be a fully polarized plane wave. The electric field of such a light wave can be expressed as the superposition of components that are perpendicular and parallel to the plane of incidence, as shown in Fig. 1:

$$\mathbf{E} = \begin{pmatrix} \mathbf{E}_s \\ \mathbf{E}_p \end{pmatrix}. \tag{1}$$

The surface acts as a transformation matrix

$$\mathbf{R} = \begin{pmatrix} r_{ss} & r_{sp} \\ r_{ps} & r_{pp} \end{pmatrix} \tag{2}$$

for the incoming beam. The diagonal components of $\mathbf{R}$, r_{ss} and r_{pp} are the conventional, nonmagnetic reflection coefficients of the

---

[*] Corresponding author.
E-mail address: claudio.gonzalez@postgrado.usm.cl (C. Gonzalez-Fuentes).
[1] Current address: IK4-LORTEK S. Coop, E-20240 Ordizia, Spain.

http://dx.doi.org/10.1016/j.jmmm.2015.03.077
0304-8853/© 2015 Elsevier B.V. All rights reserved.

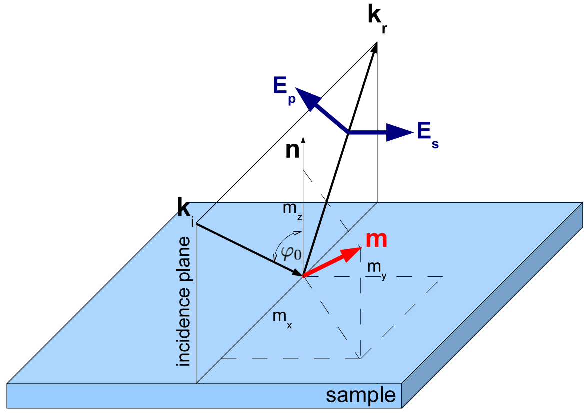

Fig. 1. Reflection of light at the surface of a magnetized medium with arbitrary direction of the magnetization. **m** represents the unit vector of the magnetization. **n** is the vector normal to plane and lies in POI. m_x, m_y, m_z are the longitudinal, longitudinal and polar components of **m** respectively.

perpendicular and parallel components, respectively, i.e. the Fresnel reflection coefficients, which are known to follow [9]

$$\tilde{r}_s = \frac{r_{ss}}{r_{pp}} = -\frac{\cos(\varphi_0 - \varphi_1)}{\cos(\varphi_0 + \varphi_1)}, \tag{3}$$

with

$$\tan(\varphi_1) = \cot(\varphi_0)\left(\frac{\tilde{r}_s + 1}{\tilde{r}_s - 1}\right), \tag{4}$$

where φ_1 is the complex angle of refraction. The non-diagonal components of matrix **R** are terms that appear if the sample material is magnetized. In the case studied here, we restrict ourselves to magnetization orientations along the longitudinal axis only, so that

$$\mathbf{R} = r_{pp}\begin{pmatrix} \tilde{r}_s & \tilde{\alpha} \\ -\tilde{\alpha} & 1 \end{pmatrix} \tag{5}$$

with [3]

$$\tilde{\alpha} = -\frac{ibQ\ \sin\left(2\varphi_0\right)\sin^2\left(\varphi_1\right)}{\sin\left(\varphi_0 + \varphi_1\right)\cos\left(\varphi_1\right)\left[\sin\left(2\varphi_0\right) - \sin\left(2\varphi_1\right)\right]} \tag{6}$$

for a bulk like sample, where Q is defined via the dielectric tensor

$$\boldsymbol{\varepsilon} = \varepsilon_r\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + iQ\varepsilon_r\begin{pmatrix} 0 & m_z & -m_y \\ -m_z & 0 & m_x \\ m_y & -m_x & 0 \end{pmatrix}, \tag{7}$$

with ϵ_r being the permittivity of the medium in the absence of magnetization.

For a GME set-up like the one shown [6] in Fig. 2, the polarizers are described by the transformation matrix

$$\mathbf{P} = \begin{pmatrix} \cos^2(\theta) & \sin(\theta)\cos(\theta) \\ \sin(\theta)\cos(\theta) & \sin^2(\theta) \end{pmatrix} \tag{8}$$

acting upon the incoming electric field vector. Hereby, θ is the angle between the polarizer transmission axis and the s-polarization orientation. The electric field vector $\mathbf{E}_D$ arriving at the photodetector is then given by

$$\mathbf{E}_D = \mathbf{P}(\theta_2)\cdot\mathbf{R}\cdot\mathbf{P}(\theta_1)\cdot\mathbf{E}_0, \tag{9}$$

with $\mathbf{E}_0$ being the electric light field produced by the laser. Correspondingly, the intensity of the light at the photodetector is

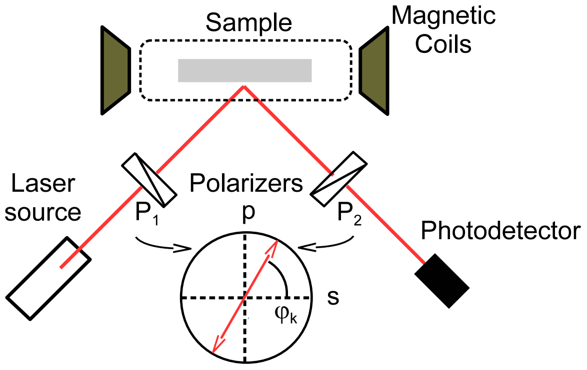

Fig. 2. Scheme of the GME setup.

$$I_D = \mathbf{E}_D\cdot\mathbf{E}_D^*. \tag{10}$$

The analysis of light intensity changes at the detector upon magnetization state inversion, while varying the angles of the polarizers θ_1 and θ_2, enables now the determination of **R**, which in turn allows for the extraction of N and Q, in both their real and imaginary parts. We define here the fractional intensity change:

$$\frac{\delta I}{I}(\theta_1, \theta_2) = 2\frac{I_\uparrow - I_\downarrow}{I_\uparrow + I_\downarrow}, \tag{11}$$

where $I_\uparrow$ and $I_\downarrow$ are the light intensities for inverted magnetization states of the sample. It has been shown [1] that

$$\frac{\delta I}{I} = \frac{B_1 f_1 + B_2 f_2}{B_5 f_5 + 2B_6 f_4 + f_3} \tag{12}$$

with

$$\begin{aligned} B_1 &= \Re\left(\tilde{\alpha}\right), \\ B_2 &= \Re\left(\tilde{r}_s\alpha^*\right), \\ B_5 &= \left|\tilde{r}_s\right|^2, \\ B_6 &= \Re\left(\tilde{r}_s\right) \end{aligned} \tag{13}$$

and[1]

$$\begin{aligned} f_1 &= \sin\ \theta_2\ \cos\ \theta_2\ \sin^2\ \theta_1 - \sin\ \theta_1 \cos\ \theta_1\ \sin^2\ \theta_2, \\ f_2 &= \sin\ \theta_1\ \cos\ \theta_1\ \cos^2\ \theta_2 - \sin\ \theta_2 \cos\ \theta_2\ \sin^2\ \theta_1, \\ f_3 &= \sin^2\ \theta_1\ \sin^2\ \theta_2, \\ f_4 &= \sin\ \theta_1\ \cos\ \theta_1\ \sin\ \theta_2 \cos\ \theta_2, \\ f_5 &= \cos^2 \theta_1\ \cos^2\ \theta_2. \end{aligned} \tag{14}$$

From Eq. (13) we obtain

$$\tilde{r}_s = B_6 + i\sqrt{B_5 - B_6^2} \tag{15}$$

The relation between r_s and the index of refraction is given by [9]

$$\tilde{r}_s = \frac{\sin^2\left(\varphi_0\right) + \cos\left(\varphi_0\right)\sqrt{N^2 - \sin^2\left(\varphi_0\right)}}{\sin^2\left(\varphi_0\right) - \cos\left(\varphi_0\right)\sqrt{N^2 - \sin^2\left(\varphi_0\right)}}. \tag{16}$$

Thus we obtain

---

[1] If the orientation of magnetization is arbitrary, the numerator in right part of Eq. (12) will have four additional terms describing the transversal and polar components of magnetization [5].

Download English Version:

https://daneshyari.com/en/article/1799207

Download Persian Version:

https://daneshyari.com/article/1799207

Daneshyari.com