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Investigation of magnetic properties of a CoFeB thinfilm by MOKE

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The magneto optical Kerr effect describes the change of polarization of light while reflected on a magnetic surface. This effect can be used to explore the magnetic properties of a surface. In this work a longitudinal MOKE configuration was used to study a ferromagnetic CoFeB thin film. It is shown that the technique is relative easy to setup and handle and shows the expected properties of this material. On the other hand it was noticed that the setup needs to be improved to reach maximum sensitivity and reliability.

Introduction

The exploration of magneto-optical effects goes back to the middle of the 19th century, when Micheal Faraday found the first magneto-optical effect in paramagnetic glass. This so called Faraday effect describes the change of polarization when light is transmitted through a magnetic medium. An analog effect, the change of polarization of light reflected by a magnetic surface was discovered 1887 by John Kerr, the magneto optical Kerr effect. In general magneto optical effects occurs from optical anisotropy of the material. The source of this optical anisotropy is the magnetization M within surface domains, those can be influenced by external forces like a magnetic field. Since this is a non destructive, sensitive method to study the local magnetic properties of a surface, it's commonly used to obtain the magnetization in dependence of the external magnetic field $M(H)/M_s$. The magneto optical Kerr effect is usually explained macroscopically by the dielectric tensor (1), which contains all information about the optical properties of the material[3].

$$\epsilon = \epsilon_0 \begin{pmatrix} 1 & -iQ_z & iQ_y \\ iQ_z & 1 & -iQ_x \\ -iQ_y & iQ_x & 1 \end{pmatrix} \tag{1}$$

Where ϵ_0 is the dielectric constant and $Q_{x,y,z}$ are the Voigt magneto optic parameters. Microscopically the effects can be explained by a coupling between the electric field of the light and magnetization by spin-orbit interaction[4].

Light is a transverse electromagnetic wave which can be optically manipulated in its polarization into planar, circular and elliptical polarized light. Generally and in the present work, the plane of polarization is spanned by the electric field and the direction of propagation. Polarized Light in the plane of incidence is called p-polarized light, is the polarization perpendicular to the plane of incident it's called s-polarized light. It exists three different Kerr effect classified by the magneto optic geometry. The vector of magnetization is parallel to the plane of incident and in-plane of the sample surface, LMOKE. Is the magnetization out of plane it's the polar MOKE (PMOKE). s-polarized light is then called transversal MOKE 1. In this experiment we use PMOKE to determine the magnetization of our sample.

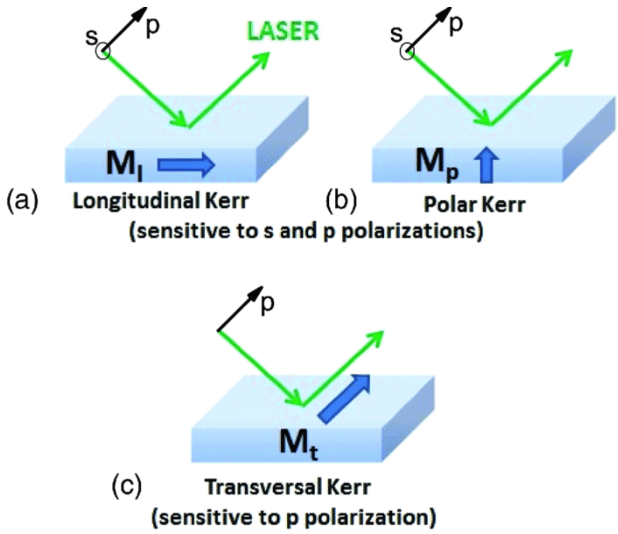

Abb. 1: Schematic illustration of different Kerr effect geometries. (a) Longitudinal, (b) polar, and (c) transversal MOKE.

In-plane vectorial MOKE

A beam of light reflected by a magnetic material has amplitudes corresponding to polarization parallel and perpendicular to the plane of incident, they are related to the incidence p and s amplitudes by the Fresnel coefficients.

$$E_r = R \cdot E_i \tag{2}$$

from this, assuming E_i is polarized in plane of incidence, can be derived the expression [1]

$$E_r = E_i((m_t^2 r_{pp}^t + m_l^2 r_{pp}^l + m_z^2 r_{pp}^p)\hat{p} + (m_l^2 r_{sp}^l + m_z^2 r_{sp}^p)\hat{s}) \tag{3}$$

where $\hat{p}$ and $\hat{s}$ are unit vectors for p- and s-polarization. Then the reflected intensity is given by

$$I_r = |E_i|^2(|m_t^2 r_{pp}^t + m_l^2 r_{pp}^l + m_z^2 r_{pp}^p|^2 + |m_l^2 r_{sp}^l + m_z^2 r_{sp}^p|^2). \tag{4}$$

$r_{\alpha\beta}^c$ are the refection coefficients related to the polar (c=p), longitudinal (c=l) and transversal (c=t) Kerr effects for the field components parallel ($\alpha =$ p and/or $\beta =$p) and perpendicular ($\alpha =$ s and/or $\beta =$ s) to the plane of incidence. m_t, m_l, and mz refer to the relative magnitude and direction of the magnetization components relative to the incidence and sample planes. Calling Δ the difference between I_p and I_s it cam be rewritten as

$$\Delta = |E_r|^2 cos(2\Theta_K) \tag{5}$$

and is proportional to $M(H)$, the magnetization of the sample [1].

Experimental Setup

To perform a MOKE measurement we use a $610nm$, linear polarized laser with $0.4W$. The p-polarized beam hits the target under and angle of about 60°, respectively to the surface normal, to gain maximum reflected intensity with respect to Fresnel equations. The target is placed between two helmholz-coils to change the magnetization of the material. The reflected beam passes a $\lambda/2$-device, to increase the contrast of I_p and I_s. To separate those intensities the beam passes an Wollaston prism, each intensity with respect to the polarization is detected in a Photodiode. A Labview program measures then Δ over B. The setup is illustrated in Fig.2.

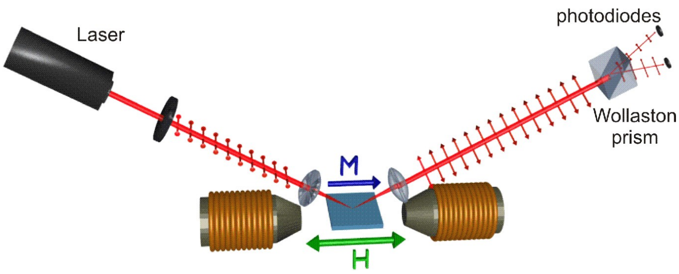

Abb. 2: Schematic experimental setup. The beam of light is reflected at the surface and changes his polarization. The beam get splitted in it's p- and s-components which then are each measured in a photodiod.

Measurement

The measurement was performed with an CoFeB thin film sample made at room temperature in transversal Kerr geometry. A magnetic field of 1.4 Hz and a triangular waveform was applied. The magnetic anisotropy of CoFeB is expected to be an easy axis perpendicular to a hard axis [2]. Before the magnetic field was switched on, the $\lambda/2$ device was adjusted in a way, that the Intensity in both configurations (p- and s-polarized) is the same, so the signal $I_p - I_s = 0$.

CoFeB thin film

The measurement was performed as explained above. Additionally the angle of the sample was changed, so that it's still in PMOKE configuration, but the magnetization of the sample changes through it's magnetic anisotropy and relative direction to the external magnetic field. This allows to measure the magnetic anisotropy. In Fig.3 the hysteresis loop is plotted in dependence of the applied magnetic field for an rotation of 0°. In Fig.3 are two curves plotted.

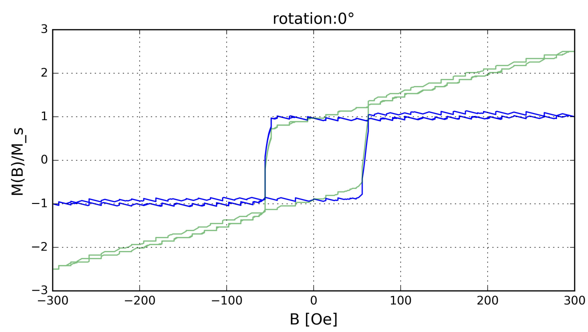

Abb. 3: $M(H)/H$ trace for a rotation of 0°. The green curve is the measured signal without subtracting the offset, the blue curve is subtracted by the offset. The hysteresis shows a H_c of about 60 Oe.

The green curve is the unchanged output of the latex program. Obviously there is a systematical error in the setup, because the material has to converge to an maximum magnetization. The blue curve is plotted with the same data, but subtracted by a linear function $f(B) = a_{offset} \cdot B$, with $a_{offset} = 0.002$. Since this corrected the graphs for 0° and 180° in the same way, this was subtracted at all measurements. It although have to be mentioned that control of the angle is very uncertain, because it was changed with a pair of squeezer without having a reference, so the relative angle is guessed. Besides that the sample surface shows a lot of scratches, what can have a bad influence of the reflection, magnetic domains and in the end of the magnetization measurement. In Fig.4 are curves for rotation between 90° and 180°. On the one hand those curves show that the hysteresis get

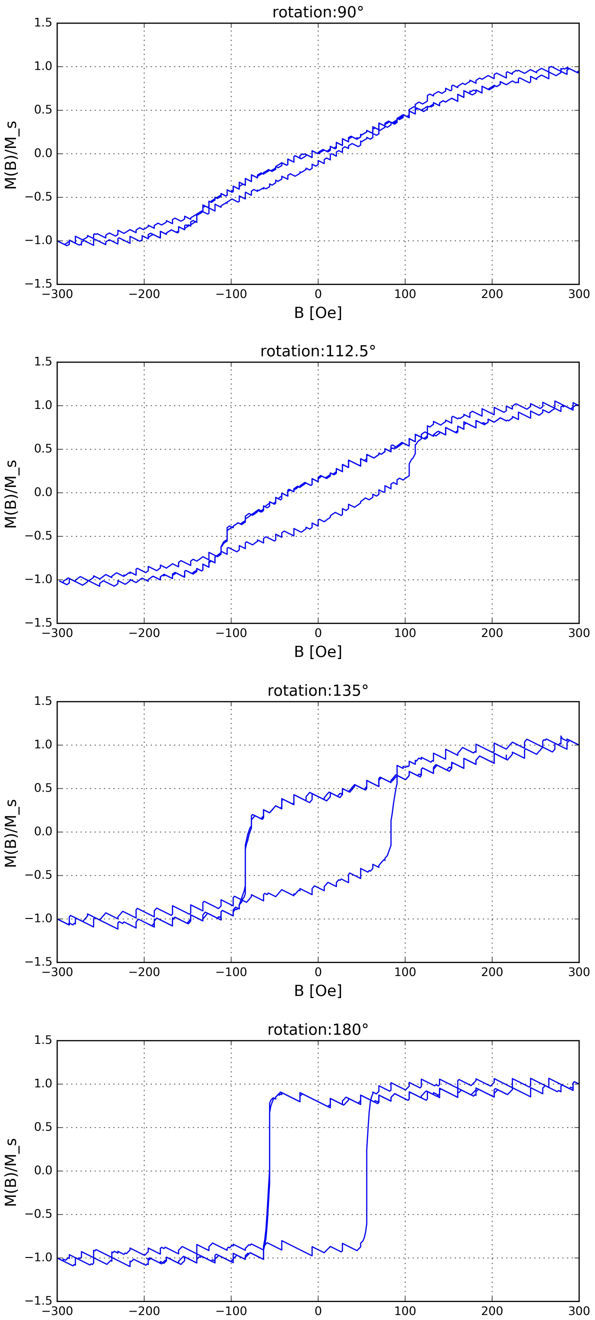

Abb. 4: $M(B)/H$ trace for rotations between $90°$ and $180°$. The change in H_c and shape of the trace in dependence of rotation is illustrated.

smoother the more the direction of magnetization is in the easy axis of the sample. For an angle of $180°$ the switch between M/M_s and $-M/M_s$ is sharp, for $90°$ it's nearly linear in B. On the other hand an increase of the critic magnetic field H_c is indicated in the graphs. In the easy axis ($90°$) $H_c = 0Oe$, the more the sample is rotated in the hard axis ($180°$) H_c increase. This behavior is although shown in Fig.5, here H_c is plotted for different angles over a range from $0°$ to $180°$. Easy and hard axis are easy visible. It's to mention that the highest magnetization is not

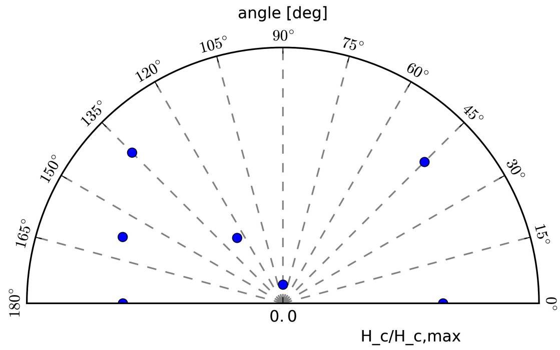

Abb. 5: H_c for diffrent roatations of the sample. A easy and hard axis is visible.

measured at $90°$ relative to the easy axis, but at $45°$. So the cosin-dependence of Δ and the rotation (5), even with an unknown phase, can't be shown in this experiment. But a periodic behavior is seen. This can either be a real property of the sample or coursed by one of the bad influences mentioned above.

Conclusion

The experiment shows that MOKE, in this case PMOKE is an good technique to measure the magnetic properties of surfaces. The setup is relative easy to obtain and provides a range of settings which can be used to obtain other quantities of the sample (like PMOKE and TMOKE). Besides that it's not necessary to do the measurement in an cryogenic environment, like a SQUID measurement.

The measurement of a CoFeB thin film visualized the magnetic anisotropy of the material and shows a behavior in agreement with the theory when changing the direction of magnetization. For a serious study of the CoFeB thin film the setup have to be improved to obtain more sensitive and reliable results.

Literatur

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