A Kerr magnetometer setup in the kHz regime based on open-hardware architecture.

MA Arroyave, JM Marín Ramírez, G Campillo, JH López, OL Arnache, J Osorio.
1 Grupo de Estado Sólido, Instituto de Física, Universidad de Antioquia, A.A. 1226, Medellín, Colombia.
2 Grupo de Materiales Nanoestructurados y Biomodelación, Facultad de Ciencias Básicas, Universidad de Medellín, Medellín, Colombia.
3 Grupo de Instrumentación Científica y Microelectrónica Instituto de Física. Universidad de Antioquia. A.A. 1226, Medellín, Colombia.
E-mail: matheos.mc2@gmail.com

Abstract. A high sensitivity Kerr magnetometer ($\Delta I/I = 1/30$) is presented, making use of open source hardware and software. By making time resolved measurements (up to $0.15 \text{ s/cycle}$) the signal quality has been greatly improved up to an order of magnitude, enabling us to compare our measurements with commercial vibrating sample magnetometers. We also present an additional setup to amplify the Kerr signal in a 25:1 scale, cleaning a large part of the electronic and trigger noise.

1. Introduction

The physical origin of the magneto-optical Kerr effect (MOKE) is the magnetic circular dichroism, which is characterized by the exchange and spin-orbit coupling in a magnetic material subjected to an external magnetic field leading to different absorption spectra for left and right circularly polarized light [1]. In some cases, dual detection based techniques have shown to improve the signal strength, although the signal-to-noise ratio and information of the magnetization state could be lost in the process [2]. MOKE allows to study the magnetic effects in the nanoscale limit [3], the magnetization dynamics in the femtosecond time scale [4], magnetoplasmonics [5] and spintronics [6,7].

Even though MOKE characterization in low dimensional magnetic systems has been widely used [8–10], we propose a creative way to implement a low cost longitudinal Kerr magnetometer (L-MOKE), where differential [2] and single detection schemes can be built and contrasted. This singular approach is mainly based on the used of modular architecture of open hardware instrumentation and open software data acquisition which can led to a significant increase in the acquisition time and resolution of the measurement. Such unique idea, allows to obtain results which can be compared and relate to those of more sophisticated and broadly studied instrumentation schemes [11,12], which highlights the importance of recovering a more descriptive instrumentation.
A Kerr magnetometer setup in the kHz regime based on open-hardware architecture.

2. Theory

Linearly polarized light is turned into elliptically polarized light with ellipticity $\epsilon_K$ and its major axis rotated by the Kerr angle $\Theta_K$ relative to the polarization axis of the incident beam [13]. By considering a bulk-like medium that is magnetized in the plane of the air/medium interface ($x-y$ plane of incidence, hence $m_z = 0$), the Kerr rotation and ellipticity in the magneto-optically isotropic case is given by [14],

$$\Theta_K + i\epsilon_K = \frac{r_{sp}}{r_p} \propto m_x. \quad (1)$$

Where $r$ represents the Fresnel coefficients of the light reflection which are specifically defined as the complex ratios between the reflected ($r$) and the incident ($i$) electric field amplitudes, i.e. $r_{mn} = \frac{E_{r,m}}{E_{i,n}}$, where $m$ and $n$ represents the orthogonal $\vec{s}$ and $\vec{p}$ polarization states. Thus, $\Theta_K$ and $\epsilon_K$ are proportional to $m_x$, and it is for this reason that the ratio $r_{sp}/r_p$ is commonly termed as the longitudinal magneto-optical Kerr effect. [15, 16].

3. Experimental setup

A linearly polarized, low noise (0.1% rms) and monochromatic ($\lambda = 632.8$ nm) He–Ne laser. To achieve a good polarization degree a Thor Labs LPVIS050 polarizer ($P1$) with 1 : 10$^5$ extinction rate was placed between the laser and sample, thus defining the polarization axis $\vec{s}$ or $\vec{p}$, which led to an improved stability and precision in the polarization state of the incident light. After the light source is carefully aligned in either $\vec{s}$ or $\vec{p}$ polarization through ($P1$), the beam is reflected by the sample which is placed in the center of a pair of Helmholtz coils. An analyzer ($A$) with same reference as ($P1$) is placed in the way of the reflected beam and its rotated until extinction and then is carefully placed at a small angle away from it. The best signal-to-noise ratio was gained from 2° to 6° degrees. Behind the analyzer, the light intensity is acquired by a FDS100 photodiode ($Ph1$) from Thor Labs in photoresistive mode and converted in an op-amp OPA380 transimpedance amplifier. The signal acquisition is done by means of WaveShare High-Precision AD/DA (24 bits) Expansion Board for a Raspberry Pi, which controls the power input to the Helmholtz Coils through an L298N H-Bridge commutator and a voltage source system through a PWM signal, as depicted in Fig 2a. The main control was implemented in C for performance reasons and runs in the Raspberry Pi. The raw data is accessible via ssh using the Raspberry Pi as server. Finally the data is analyzed in python and plotted in gnuplot in a PC.
A Kerr magnetometer setup in the kHz regime based on open-hardware architecture.

A small modification from the original setup was also put to test as seen in Fig. 2b by modifying the detection scheme. Hence, between the laser source and P1, a beam splitter (Bs) was used to intersect and redirect the beam through a second polarizer (P2) with a similar photodetection arrange. This was done to get a reference signal which was subtracted with the one coming from A in a pre-amplified stage. Such scheme, enable a reduction in the electrical and source noise, which allowed an amplification gain of 25:1.

4. Results

A set of ferromagnetic Fe$_{1-x}$C$_x$ ($0.0 \leq x \leq 0.8$ at. %) thin films were used to verify the magnetic response and accuracy of our MOKE setup, for which we make comparison between measurements taken in a vibrating sample magnetometer (VSM Microsense EV 9) and our L-MOKE setup at room temperature under a maximum external magnetic induction of 100 Oe. Single hysteresis loop was taken in longitudinal conventional Kerr, changing the sampling rate. Same kind of measurements were performed for the differential setup. Comparison between different acquisition time of the Kerr signal, are assessed by the fractional intensity change upon magnetization reversal $\Delta I/I$, and the signal to noise ratio (SNR). $\Delta I/I = 1/30$ was reached in the single mode MOKE setup, regardless of the different sampling rate. Full comparison between the L-MOKE methods and VSM is exhibited in Fig. 3.

Furthermore, signal to noise ratio exhibits a valuable difference when using both methods. Thus, when increasing the sampling rate from 100 SPS to 2.5 kSPS, SNR raises. Thereby, while the slow acquisition measurement has a signal fluctuation around 40%, fast resolved measurements are able to cut in half such variations; with a full range Kerr signal $\Delta I$ close to 200 mV. Additionally, the differential arrangement enhances the signal quality by eliminating the shot noise, and electric noise during the pre-amplification stage, yielding to a $\Delta I \approx 400$ mV. Nevertheless, the differential arrangement does not allow a Kerr angle computation, because the main signal reference has been subtracted, while in the single mode is easily obtained by approximations as...
A Kerr magnetometer setup in the kHz regime based on open-hardware architecture, seen in Fig. 4a.

![Graph showing M/\text{Ms} (\text{a.u.}) vs. H (Oe)](image)

Figure 3: Comparison between Fe hysteresis response upon different methods: (a) One cycle on conventional MOKE setup taken in 200 seconds, (b) 100 averaged cycles on conventional MOKE taken in 2 seconds, (c) one cycle on differential MOKE taken in 2 seconds, (d) VSM Microsense EV9, with \( M_s = 15 \text{ emu/cm}^3 \).

Averaged coercive fields values were obtained and compared with the ones reached by VSM. The comparison of this method and VSM demonstrates a great performance of the MOKE setup for the deter of coercive fields. The differences in the values of the coercive fields of both methods, VSM and MOKE, are explained because MOKE technique require smaller fields to magnetize the surface area where the spot is located, while the VSM measurements require a larger field to magnetize the entire volume of the sample as shown in Fig. 4b.

![Graph showing \( \Theta_K \) (deg) vs. carbon at. %] and ![Graph showing \( H_c \) (Oe) vs. carbon at. %](image)

Figure 4: (a) Kerr angle calculation for the different samples, and (b) coercitive values of the set as measured in MOKE vs. VSM.
5. Conclusions

The magnetic response in Fe$_{1-x}$C$_x$ thin films was measured and compared with VSM measurements at room temperature, showing the same sharp transition at the coercive field without any substantial difference in its magnitude, bearing out the high quality of the presented assembly. Time-resolved amplification is crucial for the quality of the Kerr signal, enhancing the signal to noise ratio in comparison to longer measures. To achieve time-resolved magnetometry, a fast photoamplification is mandatory, and therefore, small, low capacitance photodiodes. Big photodiodes have big relaxation times and can lead to wrong coercitive values. The use of open source enhances the velocity of the assembly and the research itself, allowing versatile instrumentation, and furthermore makes a better cost effective equipment, with great quality.

6. Acknowledgments

This work was supported by Solid State Group Sustainability strategy 2018 - 2019. J.M.M. acknowledges Colciencias for his Ph.D. fellowship.

7. Bibliography

[1] Behnam Esmaeilzadeh, Mehrdad Moradi, and Farhad Jahantigh. Journal of Magnetism and Magnetic Materials, 460:207–212, 2018.
[2] Bertúlio de Lima Bernardo. Applied Physics B, 117(4):1099–1105, 2014.
[3] ER Moog and SD Bader. Superlattices and microstructures, 1(6):543–552, 1985.
[4] E Beaurepaire. Phys. Rev. Lett., 76:4250, 1996.
[5] VI Belotelov, DA Bykov, LL Doskolovich, AN Kalish, and AK Zvezdin. JOSA B, 26(8):1594–1598, 2009.
[6] Tomoya Higo, Huiyuan Man, Daniel B Gopman, Liang Wu, Takashi Koretsune, Olaf MJ van’t Erve, Yuri P Kabanov, Dylan Rees, Yufan Li, Michi-To Suzuki, et al. Nature Photonics, 12(2):73, 2018.
[7] Patricia Riego, Satoshi Tomita, Kaoru Murakami, Toshiyuki Kodama, Nobuyoshi Hosoi, Hisao Yanagi, and Andreas Berger. Journal of Physics D: Applied Physics, 50(19):19LT01, 2017.
[8] VH Calle, C Calle, C Marín, E Salazar, A Cortés, W Lopera, D Arias, O Guzmán, P Prieto, A Berger, et al. Revista Colombiana de Física, 38(1), 2006.
[9] J. I. Torres and B. Cruz. Tecnura, 10(20), 2007.
[10] Jorge Iván Ochoa Gómez and Ana María Cárdenas Soto. Revista Politécnica, 9(17):19–25, 2013.
[11] J. Torres, P. Angarita, and B. Cruz. Revista Colombiana de Física, 43(3):675, 2011.
[12] AL Morales, L Reyes, J. Tobón, J. Osorio, J. López, R. Henao, and M. Grimsditch. Revista de la Sociedad Colombiana de Física, 37(2):384–387, 2005.
[13] GY Guo and H Ebert. Physical Review B, 50(14):10377, 1994.
[14] ZQ Qiu and Samuel D Bader. Review of Scientific Instruments, 71(3):1243–1255, 2000.
[15] JA Arregi, JB González-Díaz, O Idigoras, and A Berger. Physical Review B, 92(18):184405, 2015.
[16] E Oblak, P Riego, L Fallarino, A Martínez-de Guerenu, F Arizti, and A Berger. Journal of Physics D: Applied Physics, 50(23):23LT01, 2017.

A Kerr magnetometer setup in the kHz regime based on open-hardware architecture.