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Dynamics Noise Behaviors on Magneto-Optical Kerr Effect Measurement System

Djati Handoko[1*], Dong-Hyun Kim[2]
[1]*Department of Physics, Faculty of Mathematics and Sciences, Universitas Indonesia*
[2]*Department of Physics, Chungbuk National University, Cheongju 361-763, South Korea*

Corresponding Authors E-mail: djati.handoko@ui.ac.id

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Abstract

Nowadays, computer and data processing industry are moving to nanomagnetic devices technology. One of the common measurement systems to observe nanomagnetic device are magneto optical Kerr effect and Faraday effects. The magneto-optical Kerr effect measurement system has been fabricated and precision noise measurement configuration was observed. A light intensity, which was reflected by thin film nanomagnetic surface, was measured accompany with its noise level. The lock-in amplifier was attached to pick up hysteresis signal and low noise level. Different frequency of lock-in amplifier was carried out to observe dynamics noise level behavior. Interestingly, we found butterfly shape noise corresponding to hysteresis loop shape. Furthermore, $1/f$ *noise behavior with 0.94 scaling exponent, was found with respect to lock-in amplifier frequencies suggested that measuring in low frequency became more challenging.*

Introduction

In today's computer and data processing industry, the development of micro-electronics is very rapid. Especially related to the capacity and speed of data processing, one alternative is to use spintronic-based technology. In general, the meaning of spin refers to the spin of a single electron s which has a magnetic moment –gμBs. This magnetic moment, which has up and down directions, will be detected into digital information on its use. For a group of electrons that has a large number of magnetic moments, the average spin can be expressed as a magnetization which is relatively easy to detect. Compared to conventional electronics, spintronic in its use in digital information has advantages such as lower energy consumption and being able to overcome the speed limit of electric charges because it utilizes the nature of spin currents [1]. Currently, it is possible to do spin injection of metallic materials into semiconductors, with short pulses of the order of picosecond, so that the speed of spintronic devices is up to 1000 times faster than conventional electronic devices [2]. It becomes very important to understand the dynamic nature and magnetization behavior of spintronic in order to obtain spintronic warfare in the future.

Magneto-optical Kerr effect (MOKE) is a very frequently used option to explore the magnetization behavior of a ferromagnetic material. The MOKE system is very sensitive to changes in magnetic properties on the surface of the material and is able to capture signals originating from the sub-monatomic layer, so it is often used in the observation of thin-layer ferromagnetic materials. The dynamic properties of the magnetization of the thin film can be observed from the shape of the hysteresis curve, relaxation time and other magnetization parameters such as coercivity and magnetic saturation [3], [4]. With a simple system, MOKE can also be modified into MOKE microscopy to observe magnetic domains and the dynamic properties of magnetic nanomaterials[5]. In a MOKE-based measurement system, overcoming signal interference is one of the parameters that must be carried out, but until now there is still little research that discusses the interference that exists in the MOKE system. There are lots of noise type could be found in optical-based measurement system, two of them are butterfly noise and 1/f noise [6–10].

In this work, we describe very basically Kerr experiment setup. By using simple setup, the noise properties of the system have been explored, which is produced by the instrumentation setup, depend on frequency and power of laser. Two different type of noise was observed, butterfly and 1/f noise, implying became significant to know the noise behavior before the experiment setup is completed.

Experimental Method

Kerr Effect Noise Measurement Setup

The perpendicular-MOKE measurement system has been constructed using 532 nm wavelength green laser as light source is shown in Figure 1. Operated at maximum 30 miliWatt power, the light is chopped by SR540 chopper system designed by Stanford Research System and modified its frequency to 4 kHz. To achieved polarization state, the green laser entering high extinction ratio (1000:1) beam splitter and aligned by front surface mirror configuration. The laser beam illuminates thin film sample, then reflected to analyzer and captured its intensity by photodiode. S5870 Hamamatsu photodiode, which has maximum 10nA dark current, was used as a photodiode sensor. Transimpedance amplifier was applied to convert current from photodiode to voltage and then logged by lock-in amplifier SR810 by Stanford Research System. In this work, hysteresis loop (magnetization-applied field, M-H loop) were constructed accompaniment by noise level with respect to chopper frequency.

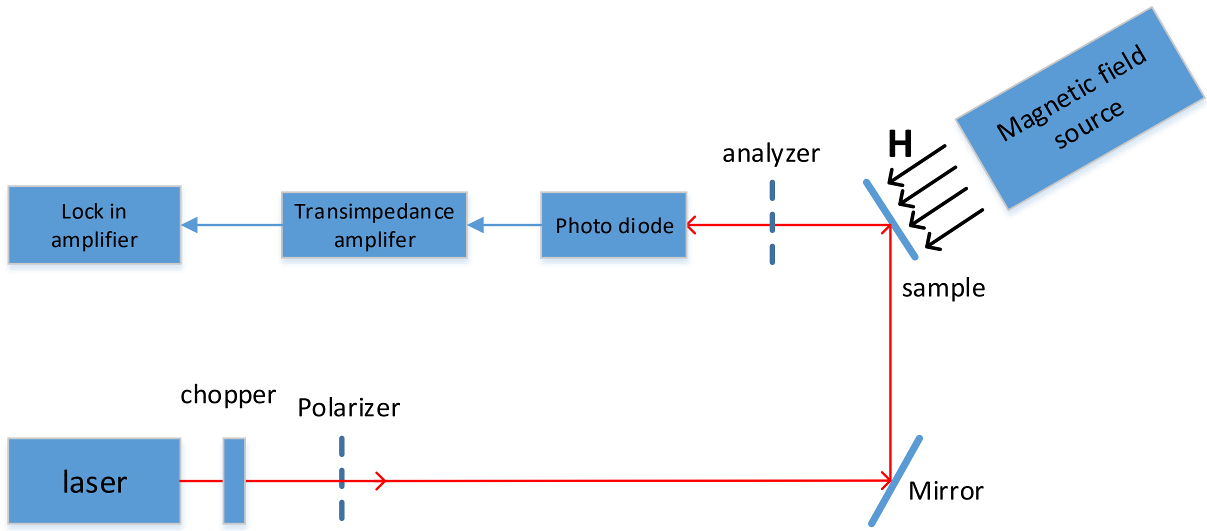

Figure 1. Kerr effect noise measurement setup, the red line indicating laser beam direction and the blue line indicating electronics signal.

Transimpedance Amplifier

In this work, optics signals reflected from sample are convert to electronics signal by using photodiode. After that, it is conditioned by using transimpedance amplifier. It configured as a negative feedback amplifier circuit, while R_f and C_f as a feedback component as shown in Figure 2. The circuit measured signal which are consist of two different signal, noise current and Kerr signal. The amplifier was tuned to ensure that Kerr signal obtained at the output is dominant than noise spectral.

The photodiode worked in reverse bias scheme, which transimpedance amplifier through feedback resistor provided its reverse bias current. By considering terminal capacitance of photodiode and stray capacitance from circuit as a total capacitance on the input port, C_f was chosen to compensate it. In this work, we assumed that the feedback resistor noise is demonstrated as thermal noise. Its spectral density depends on absolute temperature T, feedback resistor R_f, bandwidth Δf and Boltzmann's constant k, and formulated as

$$V_{noise}(rms) = \left(4kTR_f\Delta f\right)^{1/2} \quad (1)$$

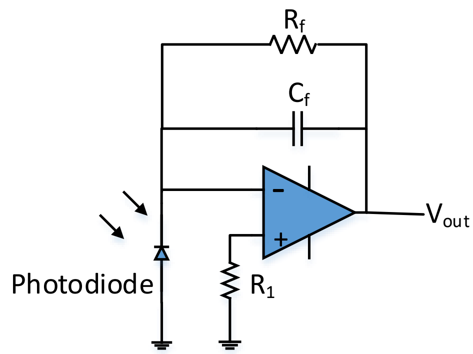

Figure 2. Transimpedance amplifier circuit.

Result and Discussion

The hysteresis loop, as output of this measurement system, has been tested and found to be reproducible. As shown in Figure 3, for different loop shape with respect to sweep rate, showed consistency results. The loop shape changes from square-like with very clear sign of saturation to be rounded corner at the saturation state. The evolution loop shape, evidently suggesting the presence of the response delay of the magnetization with relative phase to the sweeping applied magnetic field. Reproducibility of the hysteresis loop have been tested within the error range. The loop shape was found to be major loop that is dissimilar from previous work[11], [12], which is a set of minor loops for sequential hysteresis loop measurement have been informed.

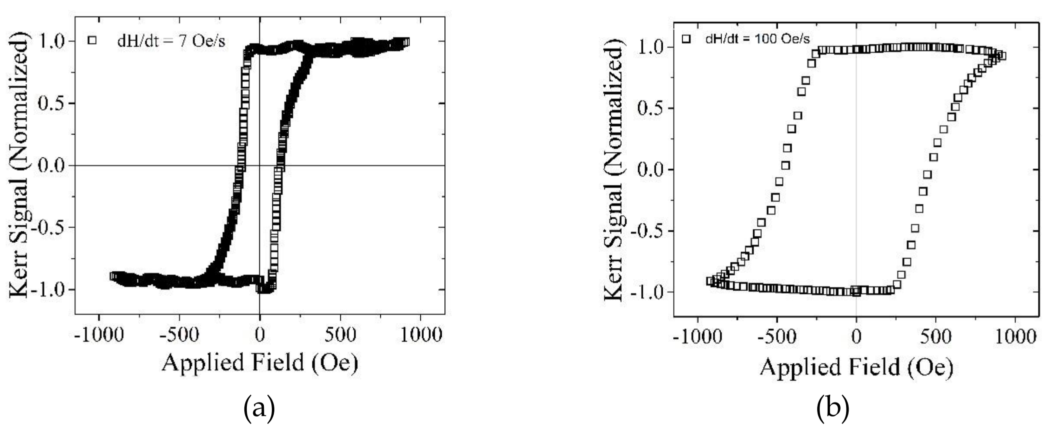

Figure 3. Hysteresis loop obtained by MOKE measurement system for different sweep rate, 7 Oe/s (a) and 100 Oe/s (b).

By using lock-in amplifier, noise properties of MOKE measurement system have been observed. Comparing to Kerr signal, the noise level has been found very small. Interestingly, it shows unique profile as depicted in Figure 4. The noise level showing a butterfly loop shape which is corresponding to the hysteresis loop shape change. As the square-like hysteresis loop transform to rounded corner loop, the noise level profile also transforms from very clear butterfly shape, as shown in Figure 4(a) to rounded broaden shape, as shown in Figure 4(b). The noise level has two minima and obviously related to coercivity state in the hysteresis loop, which are ± 129 Oe and ± 447 Oe for two different sweep rate 7 Oe/s and 100 Oe/s respectively. We believe, at that point, capability to resist an applied field without losing its magnetism has a significant role to perform these two minima and butterfly shape comprehensively[7].

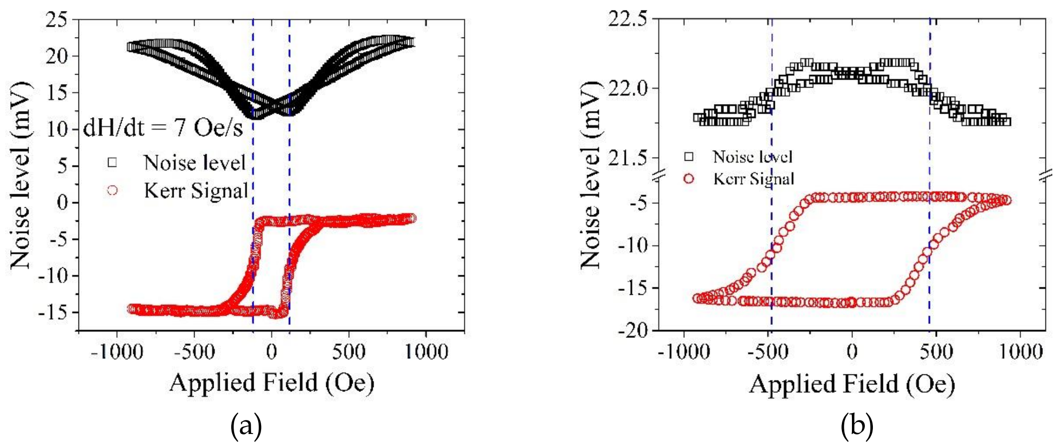

Figure 4. Butterfly shape noise level related to hysteresis loop shape for different sweep rate, 7 Oe/s (a) and 100 Oe/s (b).

Furthermore, the noise level of MOKE measurement system was measured with respect to frequency chopper. In the low frequency regime, 45 – 200 Hz, several alignments for low frequency reference in the lock in amplifier was configured such as: appropriately time constant and synchronous filter slope applied for low pass filter. 5f chopper configuration also applied as a frequency reference. In this regime, as shown in Figure 5(a) on a log-log scale, the noise response decreases linearly as a frequency increase and became stable as approaching high frequency. In the high frequency regime, 400 – 3600 Hz chopper frequency, the lock in amplifier configuration was modified, like 6 dB/oct slope of low pass filter and 3 ms time constant. The noise level, as plotted in Figure 5(b), decrease as a frequency increase and start to be stable at frequency 1000 Hz and completely stable over 2400 Hz.

According to all noise level response, it varies linearly and suggestion the probability of the 1/f noise characterized by the power-law distribution[6]. The power fitting function $f^{-\alpha}$ with scaling exponent α was found to be about 0.94 ± 0.08 as dotted line shown in Figure 4. We also found the effective maximum signal to noise ratio is about 6.8×10^3. The $1/f$ noise in MOKE measurement system considered to be originated from photo-diode conductivity fluctuation occur in photo diode however an electron-proton scattering for most of $1/f$ noise properties[13–15]. The results show that characterized noise level more dominant at low frequency exhibit more difficult measurement in this section.

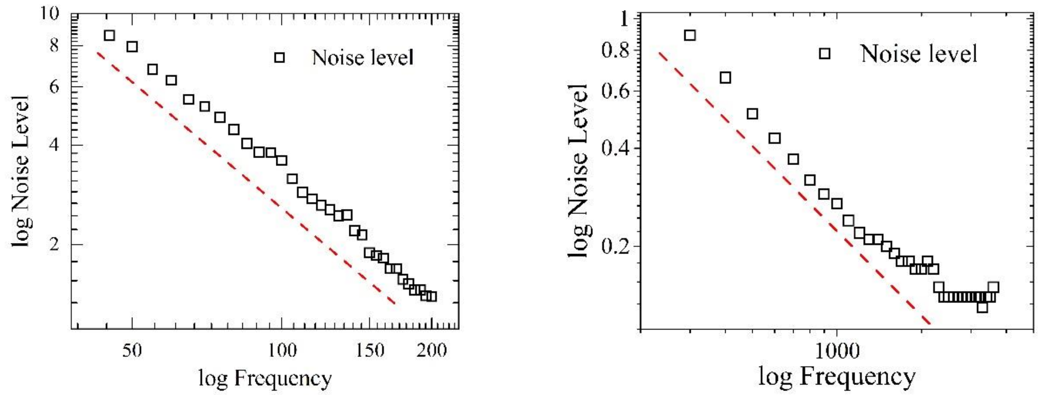

Figure 5. Noise response with respect to frequency, lower 45-200 Hz (a) and higher 400 – 3600 Hz (b).

Conclusion

In the MOKE measurement system, we have found out that the noise characteristics measured at photodiode, exhibit a $1/f$ noise behavior. The noise also shows butterfly shape noise, comparing to hysteresis loop. The 0.94 scaling exponent indicating single universality class of $1/f$ noise. The results suggested that measurement in the low frequency became more difficult considering noise level.

References

[1] Z. An, F. Q. Liu, Y. Lin, and C. Liu, "The universal definition of spin current," *Sci Rep*, vol. 2, 2012, doi: 10.1038/srep00388.

[2] L. Cheng *et al.*, "Far out-of-equilibrium spin populations trigger giant spin injection into atomically thin MoS 2," *Nature Physics*, vol. 15, no. 4. Nature Publishing Group, pp. 347–351, Apr. 01, 2019. doi: 10.1038/s41567-018-0406-3.

[3] D. Handoko, S. H. Lee, K. Min Lee, J. R. Jeong, and D. H. Kim, "Comparison of hysteresis loop area scaling behavior of Co/Pt multilayers: Discrete and continuous field sweeping," *J Magn Magn Mater*, vol. 351, pp. 82–86, 2014, doi: 10.1016/j.jmmm.2013.09.053.

[4] D. Handoko *et al.*, "Dynamic Scaling Behavior of Nucleation and Saturation Field during Magnetization Reversal of Co/Pt Multilayers," *IEEE Trans Magn*, vol. 52, no. 2, Feb. 2016, doi: 10.1109/TMAG.2015.2483581.

[5] D. T. Quach *et al.*, "Analysis of Magnetic Relaxation with Pre-Existing Nucleation Sites Based on the Fatuzzo-Labrune Model," *IEEE Trans Magn*, vol. 51, no. 11, Nov. 2015, doi: 10.1109/TMAG.2015.2443855.

[6] E. Milotti, "noise: a pedagogical review." [E-book] Available: ResearchGate.

[7] B. Drinčić, X. Tan, and D. S. Bernstein, "Why are some hysteresis loops shaped like a butterfly?," in *Automatica*, Dec. 2011, vol. 47, no. 12, pp. 2658–2664. doi: 10.1016/j.automatica.2011.08.027.

[8] Y. Hou, D. F. Wang, and T. Itoh, "Maximizing modulation efficiency to minimize 1/f noise in magnetoresistance," *Measurement (Lond)*, vol. 207, Feb. 2023, doi: 10.1016/j.measurement.2022.112396.

[9] S. Chander, S. K. Sinha, and R. Chaudhary, "Comprehensive review on electrical noise analysis of TFET structures," *Superlattices and Microstructures*, vol. 161. Academic Press, Jan. 01, 2022. doi: 10.1016/j.spmi.2021.107101.

[10] A. Rehman *et al.*, "Nature of the 1/f noise in graphene—direct evidence for the mobility fluctuation mechanism," *Nanoscale*, vol. 14, no. 19, pp. 7242–7249, Apr. 2022, doi: 10.1039/d2nr00207h.

[11] Y. W. Windsor, A. Gerber, M. Karpovski Raymond, and B. Sackler, "Dynamics of Successive Minor Hysteresis Loops."

[12] E. Z. Meilikhov and R. M. Farzetdinova, "Creeping of minor hysteresis loops in Co thin films," *J Appl Phys*, vol. 112, no. 6, Sep. 2012, doi: 10.1063/1.4754560.

[13] T. C. Fung, G. Baek, and J. Kanicki, "Low frequency noise in long channel amorphous In-Ga-Zn-O thin film transistors," *J Appl Phys*, vol. 108, no. 7, Oct. 2010, doi: 10.1063/1.3490193.

[14] C. Y. Jeong, J. I. Kim, J. H. Lee, J. G. Um, J. Jang, and H. I. Kwon, "Low-Frequency Noise Properties in Double-Gate Amorphous InGaZnO Thin-Film Transistors Fabricated by Back-Channel-Etch Method," *IEEE Electron Device Letters*, vol. 36, no. 12, pp. 1332–1335, Dec. 2015, doi: 10.1109/LED.2015.2489223.

[15] L. K. J. Vandamme, X. Li, and D. Rigaud, "1/f Noise in MOS Devices, Mobility or Number Fluctuations?," *IEEE Trans Electron Devices*, vol. 41, no. 11, pp. 1936–1945, 1994, doi: 10.1109/16.333809.