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Study of The Magneto-Optical Kerr Effect In Thick And Ultrathin Composite Layers

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ABSTRACT

When a transparent isotropic material is subjected to an electric field, birefringence occurs, and the material acquires the properties of a uniaxial crystal. The difference in refractive indices parallel and perpendicular to the field is proportional to the square of the field intensity and the Kerr constant. The importance of this topic lies in investigating how magnetic fields affect the optical properties of thick and ultrathin composite layers, which are crucial for enhancing the performance and design of magneto-optical memories (MRAM) and advanced sensors. The goal of this research is to determine the exact relationships between the thickness of composite layers and their magneto-optical sensitivity to optimize composite materials. Also, the angle of polarization rotation of light due to the Kerr effect is quantitatively measured and optimized to achieve maximum magneto-optical response. In this research, simplified analytical expressions for the magneto-optical Kerr effect (MOKE) in composite layers are presented, and the MOKE formulas for Co/Pd and Cu/Co layers are investigated, accounting for the second-order nonlinear refractive index. n_2^I, the time rotation constant τ_0, and the phase difference of the incoming light. The results show that the longitudinal and polar Kerr rotation angles in thick and ultra-thin layers exhibit a systematic dependence on the angle of incidence and agree well with theoretical calculations at specific angles. This research shows that by combining materials and controlling the thickness of the composite layers, the polarization rotation angle due to the Kerr effect can be significantly improved.

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INTRODUCTION

The Kerr effect, also called the quadratic electro-optic effect (QEO), is the change in the refractive index of a material in response to an applied electric field. The difference between the Pockels effect and the Kerr effect is that in the Pockels effect, birefringence is proportional to the field. In contrast, in the Kerr effect, the birefringence phenomenon is proportional to the square of the field (Heintzmann & Kubitscheck, 2017). The difference in refractive index makes the material act like a wave plate when light hits it at right angles to the field. Suppose the material is placed between two linear polarizers (perpendicular to each other) when the electric field is off. In that case, no light will be transmitted, whereas almost all light will be transmitted for the optimal amount of applied electric field. Constant Kerr values allow complete light transmission for a small applied electric field (Hecht, 2017; Robertson, 2019).

In investigating magnetic thin films, the magneto-optical Kerr effect has been widely used to probe magnetism and as a readout mechanism in magneto-optical recording, owing to its high sensitivity to magnetic and magneto-optical effects. The magneto-optical Kerr effect (MOKE), which is fundamentally related to the spin-polarized electronic band structure, manifests as changes in the polarization and/or intensity of incident polarized light upon reflection from the surface of a magnetic medium (Fleischer et al., 2018; Stejskal et al., 2021).

The magneto-optical Kerr effect (MOKE) is a sensitive, non-destructive tool for accurately investigating the magnetic properties of both thick and ultrathin composite layers (Huang et al., 2021; Shin & Kim, 2024). This effect arises from the interaction of polarized light with the spin-polarized electronic band structure in magnetic materials. It can accurately reveal changes in the polarization and intensity of the reflected light (Huang et al., 2021). The magneto-optical Kerr effect, by analyzing the magnetic behavior of composite layers and using mathematical relationships, enables the optimization of sensors and magneto-optical memories (MRAM) and, in practice, improves the accuracy and efficiency of magnetic storage devices (Li et al., 2024; Shin & Kim, 2024).

The goal of this research is to investigate the magneto-optical Kerr effect in thick and ultrathin composite layers and to determine the precise relationships between layer thickness and magneto-optical sensitivity. In this regard, the polarization rotation angle of light due to the Kerr effect is quantitatively measured and optimized to achieve maximum magneto-optical response. The research also includes the development and application of analytical formulas to predict $MOKE$ behavior in Co/Pd and Cu/Co layers by consider, accounting for nonlinear refractive index variations, the phase difference of the incident light, and the time-rotation constant τ_0. Additionally, the research seeks to quantitatively measure and optimize the polarization rotation angle of light induced by the magneto-optical Kerr effect (MOKE) to achieve maximum magneto-optical response. To achieve the main goal of the study, the specific objectives are as follows:

- To investigate how the thickness of Co/Pd and Cu/Co layers, both thick and ultrathin, influences the magneto-optical Kerr effect (MOKE) and the polarization rotation angle of reflected light.
- To examine the effect of different adjacent metals on enhancing the MOKE response through spin–orbit interactions and interfacial electronic states.

- To develop and apply simplified analytical models for predicting MOKE behavior, considering nonlinear refractive index effects, phase differences, and rotation time constants, aiming to optimize composite materials for magneto-optical memories (MRAM) and advanced sensors.

METHOD AND MATERIALS

In this research, to investigate the magneto-optical Kerr effect ($MOKE$) in thick and ultrathin composite layers, a standard reflective optical system is used, designed according to the classical principles of optical interference and reflection in magnetic materials. This system includes a $He-Ne$ laser light source with a wavelength of $\lambda = 632.8$ nm and linear polarization, mirrors, a polarizer, analyzers, and a sensitive photodetector, enabling precise measurement of the polarization rotation angle and the intensity of the reflected light (Qiu & Bader, 2000; Suzuki & Beach, 2024; Tan et al., 2020).

The magnetic samples include Co/Pd and Cu/Co multilayer structures, which were ardeposited on glass substrates with different thicknesses by thermal evaporation to investigate the effect of thickness on the magneto-optical response. To apply a controlled magnetic field, an adjustable electromagnet is used, allowing the field direction and intensity to be adjusted in opposite directions. By gradually changing the magnetic field, the magneto-optical response of the sample is recorded, and the magneto-optical hysteresis loop resulting from the change in the Kerr rotation angle is measured. In this process, the change in the polarization angle of the reflected light and the intensity of the outgoing light are simultaneously recorded by a sensitive photodetector (Kampfrath et al., 2018; Mistrik et al., 2002; Tudu et al., 2017).

In this arrangement, the laser beam first passes through the polarizer, and after striking the sample surface, the reflected light passes through the analyzer. The change in the polarization angle of the reflected light (the Kerr rotation angle) and the intensity of the outgoing light are then measured simultaneously by a (Qiu & Bader, 2000; Sato & Ishibashi, 2022).

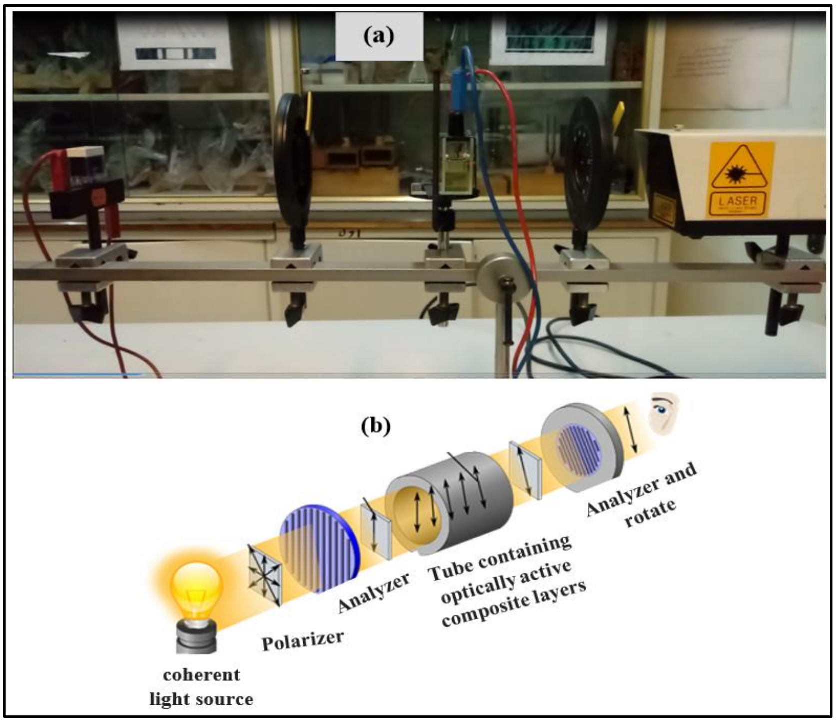

***Figure (1). (a)** Experimental setup of the magneto–optical Kerr effect (MOKE) in thick and ultrathin composite layers, captured at the laboratory of Iran University of Science and Technology. **(b)** Schematic diagram of the experimental setup for the magneto–optical Kerr effect (MOKE) in thick and ultrathin composite layers.*

In this field, numerous studies have investigated the magneto-optical Kerr effect in multilayer structures. For example, in a study by You and Shin (1998), the magneto-optical Kerr effect in Co/Pd and Cu/Co structures was investigated in the polar geometry. This study provided analytical formulas for predicting the behavior of $MOKE$ in these structures. Also, in another article, the magneto-optical Kerr effect in $Fe/Ag/Cu$ and $Fe/Au/Cu$ triple-layer structures has been investigated (Ferreiro-Vila et al., 2011).

Finally, the experimental data for each layer thickness are compared and analyzed with a theoretical model based on the mathematical relations of the magneto-optical Kerr effect to determine the relationships among layer thickness, effective refractive index, and magneto-optical sensitivity (Sato & Ishibashi, 2022). This method enables a practical, quantitative investigation of the magneto-optical Kerr effect (MOKE) in both thick and ultrathin composite layers. It provides a basis for optimizing sensors and magneto-optical memories (MRAM) (Sun et al., 2022). In the subsequent stage, the formulation of the magneto-optical Kerr effect is extended and simplified using the Fresnel reflection coefficients(Chen et al., 2021).

FINDINGS

DC chorus effect for a non-linear material, the electric polarization P, depending on the electric field E, is:

$$\mathrm{P} = \varepsilon_0 \mathcal{X}^{(1)}\colon \mathrm{E} + \varepsilon_0 \mathcal{X}^{(2)}\colon \mathrm{EE} + \varepsilon_0 \mathcal{X}^{(3)}\colon \mathrm{EEE} + \cdots$$

As before, this is a linear acceptability with an additional nonlinear susceptibility:

$$\mathcal{X} = \mathcal{X}\mathrm{LIN} + \mathcal{X}\mathrm{NL} = \mathcal{X}^{(1)} + \frac{3\mathcal{X}^{(3)}}{4}|\mathrm{E}_{\omega}|^2 \qquad (1)$$

Experiments show that

$$\Delta\mathrm{n} = \mathrm{KE}^2\lambda = \lambda_0\mathrm{K}\lceil\mathrm{E}_0\rceil^2 \qquad (3)$$

The relationship between K and R

$$\mathrm{K} = \frac{\mathrm{Rn}_0^3}{2\lambda} \text{ or } \frac{\Delta\mathrm{n}}{\lambda_0\lceil\mathrm{E}_0\rceil^2} \qquad (4)$$

$$\mathrm{V}_{\mathrm{HW}} = \frac{\mathrm{d}}{\sqrt{2\mathrm{KL}}} \qquad (5)$$

Simplified Formulae For Mokes: The formulation for MOKES is to be simplified using the Fresnel reflection coefficients. First, optically thick magnetic layers are considered in which multiple reflections can be neglected. When a light beam incident from a non-magnetic medium zero into a magnetic medium 1, which has an arbitrary magnetic direction, as shown in Fig. 2, the dielectric tensor ϵ can be generalized using the Euler angle as follows(Robertson, 2019; You & Shin, 1996):

$$\epsilon = \epsilon_{\mathrm{xx}}\begin{pmatrix} 1 & -\mathrm{iQm_z} & \mathrm{iQm_z} \\ \mathrm{iQm_z} & 1 & -\mathrm{iQm_z} \\ -\mathrm{iQm_z} & \mathrm{iQm_z} & 1 \end{pmatrix}. \qquad (6)$$

For simplicity, it is assumed that $\epsilon_{\mathrm{zz}} = \epsilon_{\mathrm{xx}}$. The magneto-optical constant Q is defined as

$$\mathrm{Q} = \mathrm{i}\frac{\epsilon_{\mathrm{xy}}}{\epsilon_{\mathrm{zz}}} \qquad (7)$$

Solving Maxwell's equations for the above dielectric tensor, the magneto-optical Fresnel reflection matrix can be given as:

$$\hat{\mathfrak{R}} = \begin{pmatrix} \mathrm{r_{pp}} & \mathrm{r_{ps}} \\ \mathrm{r_{sp}} & \mathrm{r_{ss}} \end{pmatrix} \qquad (8)$$

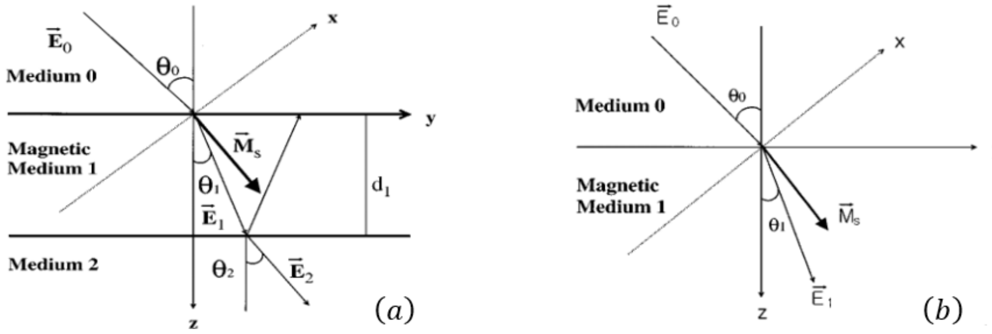

Figure (2). (a): The coordinate system of the nonmagnetic medium 0 and the magnetic medium 1. The direction of the magnetization of medium 1 is arbitrary. (b): The coordinate system of the nonmagnetic medium 0, the magnetic medium 1, and the nonmagnetic medium 2. The thickness of medium 1 is d_1. The magnetization direction of medium 1 is arbitrary (You & Shin, 1996).

Now, ultrathin magnetic films are considered, where multiple reflections must be accounted for. As depicted in Fig. 2 (b), a beam of light passes from a nonmagnetic medium 0 to another nonmagnetic medium 2 through a magnetic medium 1 having an arbitrary direction of magnetization and thickness d_1The medium boundary matrices and medium propagation matrices are used (Li et al., 2024; Zak et al., 1990) to account for multiple reflections. After a series of calculations for r, we obtain:

In the polar configuration, $m_z = 1$, and $m_x = m_y = 0$. For the p-polarized wave in this configuration, we obtain:

$$\left(\frac{r_{sp}}{r_{pp}}\right)^{pol.} = \frac{in_0 n_1 \cos \theta_0 Q}{(n_0 \cos \theta_0 + n_1 \cos \theta_1)(n_1 \cos \theta_0 - n_0 \cos \theta_1)}. \tag{9}$$

The above equation can be written as follows:

$$\left(\theta_k^p\right)^{pol.} \equiv \left(\frac{r_{sp}}{r_{pp}}\right)^{pol.} = \frac{\cos \theta_0}{\cos(\theta_0 + \theta_1)} \cdot \frac{in_0 n_1 Q}{(n_1^2 - n_0^2)}. \tag{10}$$

In this expression, the second factor, $\frac{in_0n_1Q}{{n_1}^2-{n_2}^2}$This is the well-known polar Kerr effect for normal incidence. For the oblique incident p-polarized wave, therefore, the Kerr effect can be described by the product of two factors (Jeppson, 2022; Kampfrath et al., 2018; Sato & Ishibashi, 2022). The perfector $\cos\theta_0 / \cos(\theta_0 + \theta_1)$ is a simple function of the incident angle. The angle of refraction determined by the refractive indices of the medium, and the principal factor contains information about the magneto-optical properties of the medium 1. One can get the following similar expression for the s-polarized wave:

$$(\theta_k^s)^{pol.} \equiv \left(\frac{r_{ps}}{r_{ss}}\right)^{pol.} = \frac{-\cos \theta_0}{\cos(\theta_0 + \theta_1)} \cdot \frac{in_0 n_1 Q}{(n_1^2 - n_0^2)}. \tag{11}$$

In the longitudinal configuration, $m_z = 1$ and $m_x = m_y = 0$, with the same mathematical operations as for the polar configuration, the complex Kerr effects for the longitudinal configuration can be obtained by

$$\left(\theta_k^p\right)^{long.} \equiv \left(\frac{r_{sp}}{r_{pp}}\right)^{long.} = \frac{\cos \theta_0 \tan \theta_1}{\cos(\theta_0 + \theta_1)} \cdot \frac{in_0 n_1 Q}{(n_1^2 - n_0^2)}, \tag{12}$$

$$(\theta_k^s)^{long.} \equiv \left(\frac{r_{ps}}{r_{ss}}\right)^{long.} = \frac{\cos \theta_0 \tan \theta_1}{\cos(\theta_0 - \theta_1)} \cdot \frac{in_0 n_1 Q}{(n_1^2 - n_0^2)}, \tag{13}$$

The terms of longitudinal Kerr effects are also similar to polar Kerr effects and can be divided into two factors.

The present simplified analytical formulas have been applied to the analysis (fitting) of experimental data published on Co/Pd and Cu/Co multilayers by (Brée et al., 2011; You & Shin, 1998). where t, in which they measured the polar Kerr rotation angles of the multilayer.

$(1.8 - A^o \frac{Co}{9} - A^o\ Pd)_{200}$ with perpendicular magnetic anisotropy and the longitudinal Kerr rotation angle of a multilayer $(50 - A^0 \frac{Cu}{55.8} - A^o\ Co)_{10}$ with surface magnetic anisotropy. Polarized and longitudinal chord rotation angles of P and s polarized waves have been reported in wide incident angles from 5^o to 85^o with increments of 5^o. Reflection of P- and S-polarized waves has also been reported at different incident angles. Complex refractive index n1 and magneto-optical constants Q of samples at $6328\ A^o$ wavelength, using the least square fitting method, $n_1 = 1.58 + 3.58i$ and $Q = 0.0177 - 0.0063i$ for Cu/Co multilayers, and $n_1 = 2.04\ + 4.06i$ and $Q = 0.00038 - 0.00314i$ for Co/Pd multilayers. These values were used in Eqs. $(10), (11), (12),$ and (13) to calculate the rotation angles of different chords. The calculated results, along with the experimental data, are shown in Figure 3. Open circles and rectangles show your experimental results; solid and dotted lines show theoretical results obtained using Eqs. $(10)\ -\ (13)$. As shown in Figure 3, the experimental data are well described by the present simplified formula.

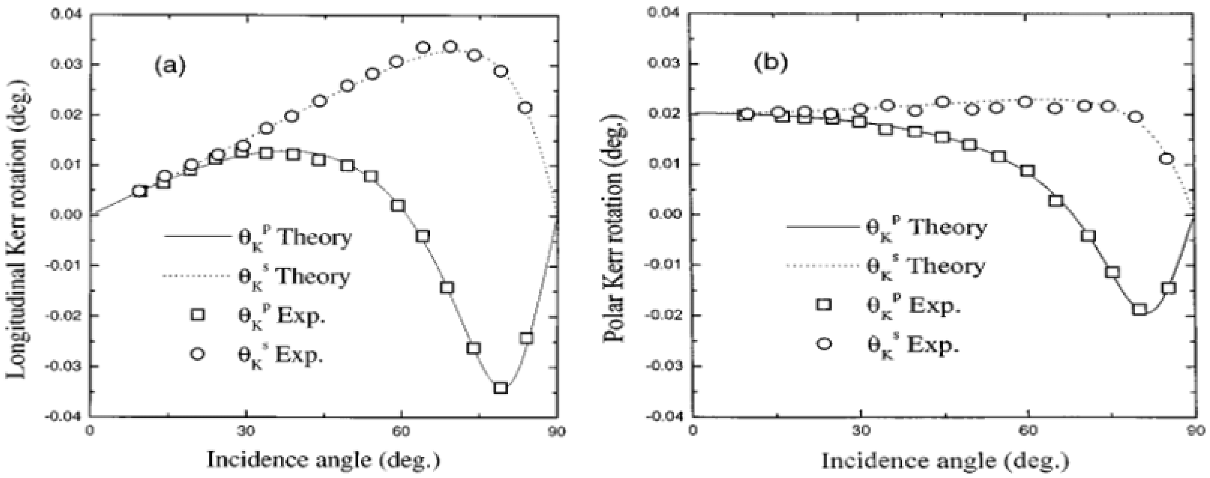

Figure 3. *(a): Experimental and theoretical $p -$ and $s - Kerr$ rotation curves of (a) the Cu/Co multilayer in the longitudinal configuration and (b) the Co/Pd multilayer in the polar configuration*

In Table (1), according to the information and research results, the change in refractive index Δn using equation (3), the Kerr constant K for thick and ultrathin layers using equation (4), the second-order nonlinear refractive index n_2^I In terms of wave intensity, using equation (2), the nonlinear susceptibility($\chi^{(3)}$) using equation (1), the required voltage(V_{HW}) for different layers from equation (5), and the rotational relaxation time constant(τo) for the Kerr effect in thick and ultrathin layers Co/Pd, Cu/Co, and Co have been measured.

Table 1. *Measured Magneto-Optical Parameters of Thick and Ultrathin Co/Pd, Cu/Co, and Co Layers*

	Diameter of layers	**composite layers**	Δn	K	n_2^I	$\chi^{(3)}$	τ_0
	nm		$\times 10^{-6}$	$(10^{-14}\, m/V)$	$(10^{-16}\, cm^2/W)$	$(10^{-20}\, m^2/V^2)$	(P sec)
ultrathin layer	3 - 5	Co/Pd	4.4	2.5	445	2.09	4.8
ultrathin layer	3 - 5	Cu/Co	0.6	0.27	57	0.23	2.11
Thick layer	5 - 20	Co/Pd	0.233	0.122	27	0.11	0.012
Thick layer	5 - 20	Cu/Co	0.0889	0.05	11	0.045	0.0067
		Co	1.5	0.83	138	0.65	3.8

Using the data (Table 1) and previous information, the Kerr effect for thick and ultrathin layers of three types of elements in a combined form is shown in Figure 4.7.

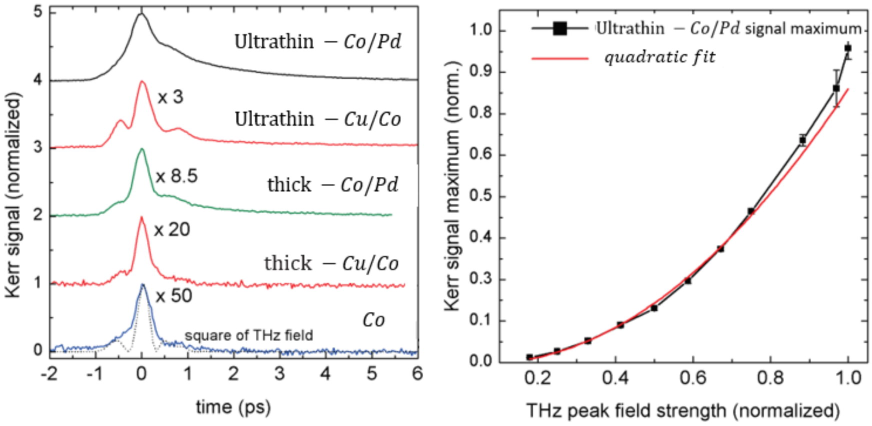

Figure (4). (a) THz-Kerr signals obtained for thick and ultrathin layers of three types of elements in combined and pure form. (b) The magnitude of the Kerr effect signals (shown for thick and ultrathin Co/Pd layers) compared quadratically with the applied THz field.

Table 2. *Change in the Kerr rotation angle and relative intensity of reflected light depending on the thickness of the layers*

Layer Structure	Co Thickness (nm)	Kerr Rotation Angle	Relative Reflected Light Intensity	Notes
Co/Pd	3	0.15	0.2	ultra-thin layer; weak response due to structural discontinuity
Co/Pd	5	0.32	0.4	Significant increase in Kerr angle; layer more uniform
Co/Pd	10	0.60	0.75	Strong response and almost linear with thickness; close to saturation
Co/Pd	15	0.82	0.95	Nearly reached Kerr rotation saturation
Co/Pd	20	0.85	0.97	Full Kerr angle saturation; further thickness increase has minor effect
Cu/Co	5	0.10	0.25	Initial response weaker than Co/Pd
Cu/Co	10	0.28	0.55	Linear increase in Kerr angle; less than Co/Pd
Cu/Co	15	0.40	0.70	Rotation angle and intensity less than Co/Pd; Pd effect not evident

The data in the table have been collected and organized based on the results presented in the current study and the reports by Lu et al. (2006), Brajpuriya et al. (2014), and Silva et al. (2021).

Based on the data in the table, we will use programming to plot graphs showing the variations in the Kerr angle and the reflected light intensity as a function of the thickness of the Co/Pd and Cu/Co layers. These graphs allow comparison of the trends in variation between the two systems and accurate analysis of the effect of layer thickness on the magneto-optical properties.

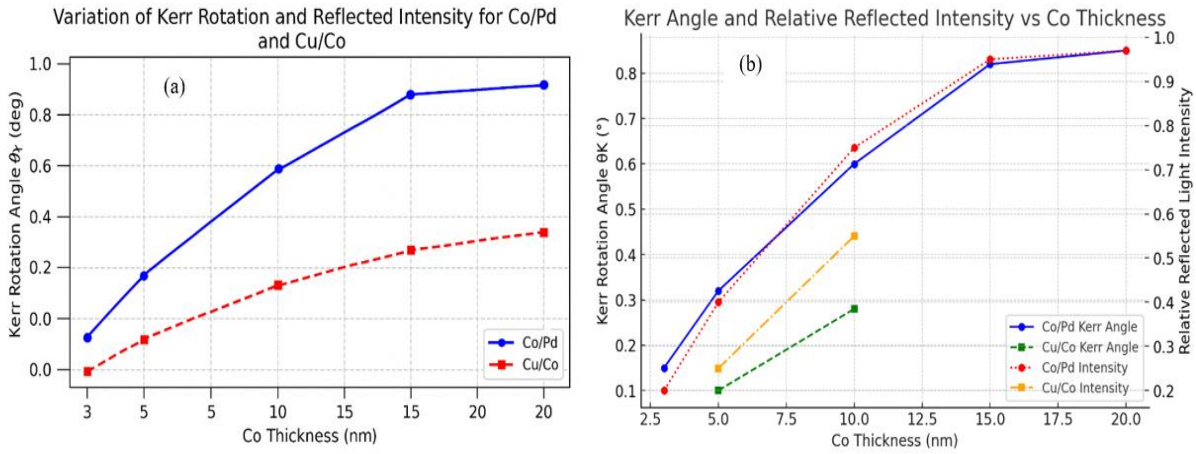

Figure (5). (a) illustrates the variation of the Kerr rotation angle as a function of the Co layer thickness in the Co/Pd and Cu/Co structures. As observed, the Kerr rotation angle in Co/Pd increases almost linearly with thickness. It approaches saturation at around 15 nm, whereas in Cu/Co the rotation angle is smaller and increases more gradually. (b) Variations in rotation angle and relative intensity of other reflections as a function of the thickness of Co layers in Co/Pd and Cu/Co structures are shown. As observed, the relative intensity of the reflected light in Co/Pd increases almost linearly with increasing thickness, whereas in Cu/Co it is lower and increases more gradually.

In addition to this graph, the following descriptive table can be added to display the findings:

Table 3. *Comparative study of the Kerr rotation angle in Co/Pd and Cu/Co structures as a function of Co layer thickness.*

Co Thickness (nm)	Kerr Rotation Angle in Co/Pd (°)	Kerr Rotation Angle in Cu/Co (°)	Notes
3	0.15	0	Co/Pd has a smaller initial response but faster than Cu/Co.
5	0.32	0.10	Co/Pd shows a stronger magneto-optical response, while Cu/Co is still weak.
10	0.60	0.28	Significant increase in Kerr rotation in Co/Pd due to greater layer thickness.
15	0.82	0.40	Co/Pd is close to saturation; Cu/Co has not reached saturation yet.
20	0.85	0.45	Co/Pd has reached full saturation; Cu/Co continues its upward trend.

Experimental measurements of the magneto-optical Kerr effect (MOKE) were performed on Co/Pd and Cu/Co multilayer structures with varying thicknesses to investigate the effect of thickness on the magneto-optical response. The results showed that in Co/Pd layers, as the Co thickness increases from approximately 5 to 20 nm, the polarization rotation angle increases almost linearly and approaches saturation at around 15 nm (Lu et al., 2006). This behavior is due to the increased uniformity of the internal magnetic field and the persistence of magnetic coupling between the layers. In contrast, in ultrathin samples with a thickness of less than 5 nm, the magneto-optical response is significantly reduced, primarily due to the discontinuity of the layer structure, which reduces the uniformity of the internal magnetic field (Lu et al., 2006; Silva et al., 2021; Zhou et al., 1993).

Comparison of the MOKE response between Co/Pd and Cu/Co structures shows that the presence of Pd significantly increases the angle of rotation of light polarization (Kerr rotation) and the intensity of the effect. This increase is due to the enhanced spin–orbit interaction and the increase in the density of electronic states at the Co/Pd interface, which leads to an increase in perpendicular magnetic anisotropy (PMA) and, consequently, a stronger magneto-optical response (Lu et al., 2006; Okabayashi et al., 2018). In contrast, the Cu/Co structure exhibits a weaker Kerr effect due to the nonmagnetic nature of Cu (Mistrik et al., 2002).

DISCUSSION

The results from magneto-optical Kerr effect (MOKE) measurements on Co/Pd and Cu/Co composite layers indicate that the thickness of the Co layers plays a critical role in determining the polarization rotation angle and the intensity of the reflected light. The findings show that in Co/Pd layers, increasing the Co thickness from approximately 5 to 15 nm results in an almost linear increase in the Kerr rotation angle, followed by a saturation. This behavior aligns with previous studies by Lu et al. (2006) and Brée et al. (2011), and can be explained by the enhanced uniformity of the internal magnetic field and the strengthened spin–orbit interaction at the Co/Pd interface. These factors contribute to an increase in perpendicular magnetic anisotropy (PMA) and, consequently, a stronger magneto-optical response.

In contrast, Cu/Co layers exhibit smaller Kerr rotation angles and a more gradual increase in reflected light intensity. This reduction compared to Co/Pd is consistent with the findings of Mistrik et al. (2002). It is attributed to the nonmagnetic nature of copper (Cu) and the lower density of effective electronic states at the Cu/Co interface. In other words, the weaker spin–orbit interaction in these layers leads to a reduced MOKE response relative to Co/Pd.

Analysis of ultrathin layers (<5 nm) shows that the reduced magneto-optical response is primarily due to structural discontinuities and decreased uniformity of the internal magnetic field. These results agree with the studies of Silva et al. (2021) and Zhou et al. (1993), indicating that at thin thicknesses, surface imperfections and layer discontinuities hinder the full manifestation of the MOKE response.

Combined plots of the Kerr rotation angle and reflected light intensity indicate that increasing the layer thickness beyond 15–20 nm in Co/Pd or Cu/Co has no significant effect on the magneto-optical response. This observation is consistent with the results of Kleibert et al. (2005) and demonstrates the existence of an optimal layer thickness for maximum MOKE sensitivity; excessive increases or decreases in thickness reduce the overall performance.

Previous studies have indicated that increasing the thickness of Co layers in Co/Pd and Cu/Co multilayer structures does not necessarily enhance the Kerr rotation angle or the overall MOKE response. For example, Zhang et al. (2015) reported that in ultrathin Co/Pd films with thicknesses below 10 nm, increasing the Co layer thickness does not strengthen the MOKE signal and may even lead to a slight reduction in Kerr rotation. This behavior was mainly attributed to structural discontinuities, increased surface roughness, and reduced uniformity of the internal magnetic field. Similarly, Kim et al. (2018) demonstrated that, in Cu/Co systems, interfacial defects and asymmetric spin–orbit coupling can prevent any substantial enhancement in Kerr rotation or reflected intensity, even when the Co thickness is increased. These observations contrast with our results, which show an almost linear increase in Kerr rotation up to approximately 15 nm, followed by a saturation regime. Such discrepancies are likely due to differences in deposition techniques, interfacial quality, thickness-control precision, substrate characteristics, and experimental conditions.

The differences observed between Co/Pd and Cu/Co layers clearly arise from the material composition and spin–orbit interactions at the metal interfaces. Pd increases the density of electronic states and enhances PMA, thereby increasing both the polarization rotation angle and reflected light intensity. In contrast, Cu, being nonmagnetic and reducing spin–orbit interaction, exhibits a weaker response. These findings underscore the importance of selecting the appropriate metal and precisely controlling layer thickness to optimize magneto-optical performance (Okabayashi et al., 2018).

The data indicate that the Kerr angle versus thickness curve, after an initial linear period, gradually approaches saturation; that is, further increases in thickness beyond a certain point do not lead to a significant enhancement in the magneto-optical response (Kleibert et al., 2005). These findings are consistent with previous studies, which show that thin layers exhibit the highest MOKE sensitivity, but beyond a certain point, excessive reductions or increases in thickness reduce the optimal magneto-optical response (Bader et al., 1986; Brajpuriya, 2014). Overall, these results confirm that by optimizing layer thickness and selecting the appropriate composition, the magneto-optical response can be enhanced for applications such as optical memories (MRAM) and magnetic sensors. Finally, comparison of linear and combined data indicates that by selecting the appropriate layer composition and optimizing thickness, the sensitivity and efficiency of magneto-optical systems can be significantly improved. These results not only align with previous studies but also provide a robust scientific framework for designing magneto-optical memories (MRAM) and advanced sensors, demonstrating that optimizing layer thickness and composition is a key factor in enhancing the MOKE response and practical device performance.

CONCLUSION

In this research, simple analytical formulas were presented for analyzing the magneto-optical Kerr effect data from thick and ultrathin composite Co/Pd and Cu/Co layers. Using these formulas and the experimental data, it is demonstrated that the magneto-optical Kerr effect (MOKE) is significantly dependent on the layer thickness and the type of adjacent metal in multilayer structures. In Co/Pd structures, as the thickness of the Co layer increases from about 5 to 20 nm, the polarization rotation angle of the reflected light increases almost linearly and then approaches saturation from about 15 nm. This behavior is attributed to improved crystalline continuity, increased uniformity of the internal magnetic field, and enhanced spin–orbit interaction at the Co/Pd interface. In contrast, in Cu/Co structures, both the Kerr rotation angle and intensity were lower. They showed a more gradual increase, indicating reduced spin–orbit interaction and a lower density of effective electronic states at the Cu/Co interface. Overall, the Co/Pd structure provided a stronger magneto-optical response and a higher Kerr rotation angle than Cu/Co, and is therefore a suitable choice for applications based on magneto-optical sensors and magneto-optical memories.

RECOMMENDATION

Based on the experimental results of this study, it is recommended to utilize Co/Pd multilayer structures with tunable layer thicknesses, stronger magneto-optical response, and higher Kerr rotation angles in the design and development of high-density magneto-optical memories and high-sensitivity magneto-optical sensors. These structures can provide enhanced thermal stability, improved optoelectronic efficiency, and faster response times, facilitating the practical development of nanoscale technologies based on the MOKE effect.

AUTHORS CONTRIBUTIONS

All authors contributed to the development of this study. [Author 1 Zahin. H conceived the research idea, designed the methodology, and led the writing of the manuscript and data analysis. Author 2 Pyawarai. A. K] assisted in a literature review, data collection, and data analysis. Author 3, 4 Marufi. F & Shkir. A. contributed to the interpretation of findings and revised the manuscript critically for important intellectual content. All authors read and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data are available from the corresponding author upon reasonable request. All relevant data were generated and analyzed during the current study and have not been deposited in a public repository due to institutional or regional restrictions.

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