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Full vectorial spin-reorientation transition and magnetization reversal study in ultrathin ferromagnetic films using magneto-optical Kerr effect

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자기광학 Kerr 효과의 벡터해석을 이용한 강자성 초박막에서의 스핀 재배열 및 자화 역전 현상 연구

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I. INTRODUCTION

The magneto-optical Kerr effects (MOKE) have been utilized as a premier surface magnetism technique to study magnetic anisotropy, magnetic switching process, and spin-reorientation transition in thin films because of sub-monolayer (ML) sensitivity and easy implementation. Full vectorial determination of magnetization components in ferromagnetic thin films is very important to better understand magnetic phenomena related with magnetization reversal and spin reorientation. In this paper, we describe a novel method for a complete vector analysis of magnetization in thin film and present an analysis of spin-reorientation transition in ultrathin Co films on Pt(111) single crystal.

II. DESCRIPTION OF METHOD

For vectorial determination of magnetization we utilize simplified analytic expressions for the magneto-optical Kerr effects in ultrathin magnetic films which have an arbitrary direction of magnetization.[1] When the scattering plane is located in the yz plane as depicted in Fig. 1(a), the p- and s-wave complex Kerr angles, $\Theta^P(m_y, m_z)$ and $\Theta^S(m_y, m_z)$, are given as follows:

$$\Theta^P(m_y,m_z)=\frac{\cos\theta_0}{\cos(\theta_0+\theta_2)}\left(m_y\frac{\sin^2\theta_1}{\sin\theta_2}+m_z\cos\theta_2\right)\Theta_n \qquad (1\text{-}1)$$

$$\Theta^S(m_y,m_z)=\frac{\cos\theta_0}{\cos(\theta_0-\theta_2)}\left(m_y\frac{\sin^2\theta_1}{\sin\theta_2}-m_z\cos\theta_2\right)\Theta_n \qquad (1\text{-}2)$$

where θ_0, θ_1, θ_2, and Θ_n are the incident angle, complex refractive angles of the magnetic thin film and the nonmagnetic substrate, and the complex polar Kerr angle for normal incidence in the ultrathin film limit, respectively. Here, m_y and m_z are the components of the normalized magnetization vector in the y and z directions, respectively. When the scattering plane is placed in the xz plane as shown in Fig. 1(b), m_y in Eqs. (1) will be replaced by m_x. Measuring the Kerr angles in the geometries depicted in Fig. 1, one can obtain all components of magnetization vector from the p- and s-wave MOKE measurements in two scattering planes orthogonal with each other as the following:

$$m_{x,y}=\frac{\Theta_P^s\Theta^p(m_{x,y},m_z)-\Theta_P^p\Theta^s(m_{x,y},m_z)}{\Theta_L^p\Theta_P^s-\Theta_P^p\Theta_L^s} \qquad (2\text{-}1)$$

$$m_z=\frac{\Theta_L^s\Theta^p(m_{x,y},m_z)-\Theta_L^p\Theta^s(m_{x,y},m_z)}{\Theta_P^p\Theta_L^s-\Theta_L^p\Theta_P^s} \qquad (2\text{-}2)$$

Here, Θ_J^i denotes the saturation Kerr angle of the *i*-polarization in the *J*-measurement (polar or longitudinal) configuration shown in Fig.1.

On the other hand, one can easily obtain the magnetization components using only single polarization wave (p or s) considering the fact that the magnetization components in Eqs. (1) are real values. After the Kerr angles and prefactors are separated into real and imaginary part, all components of magnetization vector are also determined as follows:

$$m_{x,y} = \frac{-\theta_P \varepsilon^{p,s}(m_{x,y}, m_z) + \varepsilon_P \theta^{p,s}(m_{x,y}, m_z)}{\varepsilon_P \theta_L - \varepsilon_L \theta_P} \qquad (3\text{-}1)$$

$$m_z = \frac{\theta_L \varepsilon^{p,s}(m_{x,y}, m_z) - \varepsilon_L \theta^{p,s}(m_{x,y}, m_z)}{\varepsilon_P \theta_L - \varepsilon_L \theta_P} \qquad (3\text{-}2)$$

Here, θ_J and ε_J denote the saturation Kerr rotation and ellipticity, respectively, in the *J*-measurement geometry. θ^i and ε^i denote the measured Kerr rotation and ellipticity of the *i*-polarization in the each measurement geometry, respectively.

III. RESULTS AND DISCUSSION

Fig. 2 (a), (b), and (c) show the magnetization components determined with p- *and* s-waves, p-wave only, and s-wave only, respectively, in 13 ML Co/Pt(111). As clearly seen in the figures, these methods are remarkably consistent within the measurement error and the m_z components calculated at the each geometry are also consistent. The insets of Fig. 2 (a) are the imaginary parts of the magnetization components which are almost negligible. Using this vector analysis of the magnetization, we confirmed the second order spin-reorientation transition from perpendicular to in-plane easy axis via canted phase increasing the Co thickness on Pt(111)

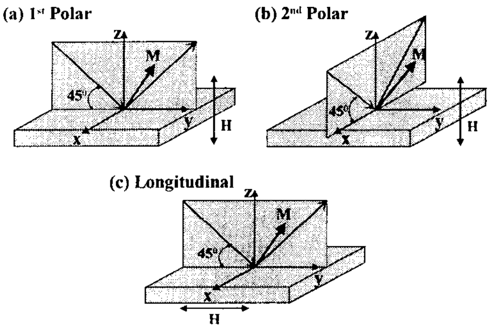

Fig. 1. The coordinate systems of three MOKE measurement configurations: (a) polar measurements in the yz and (b) xz scattering planes under an applied field normal to the film plane; (c) longitudinal measurements under an applied field parallel to the y-axis.

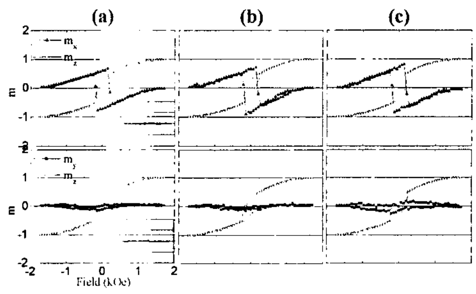

Fig. 2. Magnetization components of 13 ML Co/Pt(111) determined from (a) p- and s-waves, (b) only p-wave, and (c) only s-wave. The applied magnetic field direction is normal to film plane.

IV. ACKNOWLEDGEMENT

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V. REFERENCES

[1] C.-Y. You and S.-C. Shin, Appl. Phys. Lett. **69**, 1315 (1996); J. Appl. Phys. **84**, 541 (1998).