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Soft x-ray Resonant Magneto-optical Kerr Effect as a Depth-sensitive Probe of Magnetic Heterogeneity

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At the core of current issues in the research area of nanomagnetism are magnetic multilayer thin films that consist of two or more ultrathin layers of different types of nonmagnet, insulator, ferromagnet, antiferromagnet, superconductors, etc [1]. Many interesting phenomena in such hybrid structures are relevant to a rich variety of magnetic interactions at the multiple length scales, as well as intrinsically modified electronic structures at interfaces [1-5]. Therefore, Identification of the details of chemical and magnetic structures varying in depth on the atomic scale is crucial in understanding of the physical originof the overall magnetic properties observed in the inhomogeneous magnetic films. In this presentation, we report a noticeable depth sensitivity of soft x-ray resonant magneto-optical Kerr effect that allows us to resolve depth-varying magnetic heterostructures in ultrathin multilayer films.

For a model system of depth-varying magnetization orientations in the ultrathin Co layer of Si / SiO_2(1500 Å) / Ta(50 Å) / $Ni_{81}Fe_{19}$ (80 Å) / $Fe_{50}Mn_{50}$ (200 Å) / Co (35 Å) / Pd (15 Å), we calculated the Kerr rotation, ellipticity, intensity spectra versus grazing angle of incidence and their hysteresis loops at different values of the incidence angle for photon energies near the Co absorption edges using a matrix approach developed by Zak [6] with experimentally obtained magneto-optical parameters of Co near its absorption edges. It is found from the simulation results that the Kerr effect has a much improved depth sensitivity and that its sensitivity varies remarkably with the incidence angle and energy in the vicinity of the resonance edges. These novel properties originate from a rich variety of wave interference effects together with the noticeable features of the refractive and absorptive optical effects near the resonance regions. Consequently,these allow us to resolve depth-varying magnetizations and their reversals varying with depth in a single magnetic layer, and allow us to distinguish interface magnetism from the bulk properties in multilayer films.

The atomic-scale depth resolution of the soft x-ray magneto-optical Kerr effect will be demonstrated and discussed in details in several manners with the help of model simulations for various depth-varying spin configurations.

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Differential Circular Reflectivity from Magnetic thin Films at the Grazing Incidence

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In the current research field of magnetic thin films and magnetism, the orthogonal eigenstates of not only the circular but also linear polarizations of high photon-flux synchrotron x rays have been widely used as an essential probe to investigate both the magnitude and orientation of element-specific magnetic moments in multi-component magnetic materials and multilayers, their responses to an applied magnetic field, as well as their spatial correlations at the multiple-length scales ranging from a few nanometer to micrometer. Hence, special insertion devices such as an elliptically polarizing undulator (EPU) have been facilitated to produce high photon-flux, energy tunable, circularly or linearly polarized x rays. Although such various polarization states of soft x rays have been produced from EPU, their optical productions have also been made using variously designed polarizing optical elements made of artificially fabricated magnetic thin films, such as phase retarders, [1] magneto-optical circular polarizing filters [2], and a tunable linear polarizer.Here, we propose a newly designed soft x-ray polarizer that enables to optically convert a linear polarization to any orthogonal states of not only the left (L)- and right(R)-handed circular polarizations (LCP and RCP) but also the linear s- and p-polarizations in reflection, using a simple magnetic thin-film structure, as found from numerical calculations. Calculation results, using the known linear-polarization-mode based Kerr matrix as well as a newly derived circular-polarization-mode based Kerr matrix, indicate that a +45° or −45° linearly polarized incident beamcan be readily converted to any orthogonal states of both circular and linear polarization modes, i.e., RCP and LCP and s- and p-linear polarizations through reflection, at certain grazing angles of incidence near the critical angle from a simple Co(9.0 nm)/Si substrate model. These results suggest that various orthogonal polarizations of the circular and linear-polarization-modes, converted from such a polarizing optical element through reflection can be practically used in probing the vector quantities of element specific magnetizations in multi-component magnetic materials [3]. This work was supported by Creative Research Initiatives (ReC-SDSW) of MOST/KOSEF.

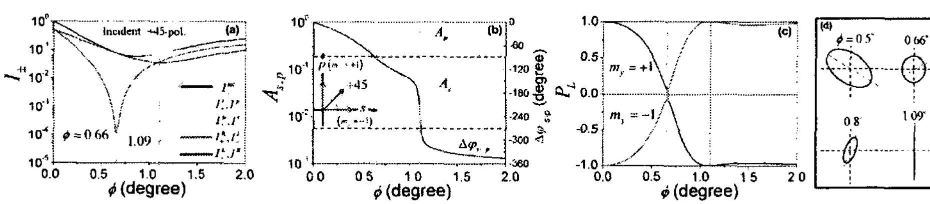

Fig. 1. (a) Total and individual intensities of the orthogonal components in reflected waves versus ϕ, from a model system of Co (9.0 nm)/Si substrate with either orientation of my=+1 or my=−1 at $h\nu$ = 770.1 eV. (b) shows the calculated electric-field amplitudes of the linear s- and p-polarization components, respectively, for my=+1and their phase difference. Their corresponding PL is shown in (c) and their various polarization states obtained at several grazing angles of incidence are illustrated in (d).

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