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Development of SMOKE system and study on magnetic properties of ultra-thin film

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Abstract – We have setup a compact and useful *in-situ* SMOKE system in order to study surface magnetism of ultra-thin films. Since the longitudinal or polar magnetic fields can be applied to the sample by just rotating the sample manipulator, It is very simple to take hysteresis curve for in-plane or polar surface magnetism. The SMOKE system was tested by investigating the surface magnetism of ultra-thin Co film deposited on Pt(111) surface.

I. Introduction

Recently there has been much interest in the surface magnetism of ultra-thin magnetic films and magnetic superlattices. There are many techniques for studying surface magnetism. Experimental techniques used for this purpose are magneto-optic Kerr effect [1], spin-polarized photoemission spectroscopy [2], ferromagnetic resonance [3], spin-polarized neutron scattering [4], etc. However, experimental equipments mentioned above are usually very expensive and need lots of effort to analyse the data. In general, the Kerr effect has been used as a standard technique to obtain bulk magnetic hysteresis loops. However, the magneto-optic Kerr effect has been proved to be a valuable probe in the studying surface magnetism of the ultra-thin films. In 1985, S. D. Bader applied this technique to study of magnetic properties of ultra-thin films and took a hysteresis loop of ultra-thin Fe film on Ag(100) substrate for the first time [5]. The SMOKE (surface magneto-optic Kerr effect) setup provides *in-situ* characterization probe of the magnetic behavior of the ultra-thin magnetic films during the growth process [6, 7]. In this paper, we report a result of an easy and inexpensive SMOKE system construction. The SMOKE system was tested by investigating the surface magnetism of Co ultra-thin film on Pt(111) surface. The SMOKE setup is used to measure not the absolute Kerr rotation but the relative SMOKE signal which is proportional to the Kerr rotation angle.

II. Principle of SMOKE

The principle of SMOKE is that when a plane polarized light is incident on magnetized material, the plane of polarization of the reflected light is rotated with respect to the plane of polarization of the incident light. As applied magnetic field intensity and direction on the sample changes, the SMOKE signals are changed and results in a drawing a hysteresis curve. The height of the hysteresis loop is referred to as the Kerr intensity which is proportional to the Kerr rotation and magnetization of the sample. Magneto-optic Kerr effect involves a rotation of the polarization. The degree of the rotation in the polarization is determined by the interaction between the incident polarized light and the magnetization in the sample. The magnitude of the rotational angle of the Kerr effect for a ferromagnetic material is generally between 10^{-4} to 10^{-3} degrees per mono-layer (ML). The descriptions of the magneto-optic effect are presented either in microscopic quantum theory [8] or in microscopic dielectric theory [9]. SMOKE setup has three configurations, *i.e.*, polar, longitudinal, and transverse configuration. In the normal incidence of a polar configuration, the magneto-optic Kerr effects are only sensitive to the normal magnetization component to the film surface. For a Longitudinal configuration, the magneto-optic Kerr effects are only sensitive to the parallel magnetization component to the film surface. If the magnetization is in the film surface, a large oblique incidence of the polarized laser beam is generally required in order to achieve high SMOKE signals. It has been proven that the longitudinal Kerr signal is more pronounced when incident angle of the laser light respect to the surface normal is larger [10]. In a Transverse configuration, it is also in-plane but perpendicular to the longitudinal configuration.

III. SMOKE Setup

In Fig. 1 is shown a schematic of SMOKE system. *In-situ* SMOKE system consists of an electromagnet, optical system, power supply and preamplifier, and software(program) in order to control the power and detecting/analysing the signals. In our system we have used three 8-inch viewports which are orthogonal each other. By just rotating the sample 90° in the gap of the electromagnet poles, polar and longitudinal SMOKE signals can be easily detected. SMOKE setup for polar and longitudinal configuration is shown in Fig. 2.

3.1. Electromagnet

A custom-made rectangular-shaped electromagnet is made of Vanadium Permendur (Co 49%, Fe 49%, V 2%), which is one of the highest flux density material and is UHV compatible. Electromagnet core has a width of 80 mm, a height of 80 mm, and a cross sectional area of magnet is 10×10 mm^2. The gap between the poles is 20 mm. The electromagnet is wound by UHV compatible polyimide-coated 0.025 inch wire (California Fine Wire Com.) in 700 turns on each side and current is driven by a computer controlled bipolar power supply (Kepco BOP50-8M). 1 A of current running through the coil generates a magnetic field of 640 Oe in the center of the gap. Electromagnetic field can be easily reached over 1000 Oe on the sample position without any outgasing from the polyimide-coated wire. The current I running through the copper wire wrapped around the electromagnet can be converted from the input voltage V of the bipolar power supply by a factor of 1.2457.

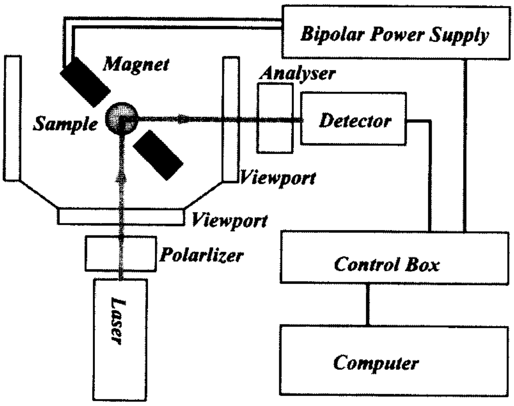

Fig. 1. A schematic diagram of *in-situ* UHV SMOKE system.

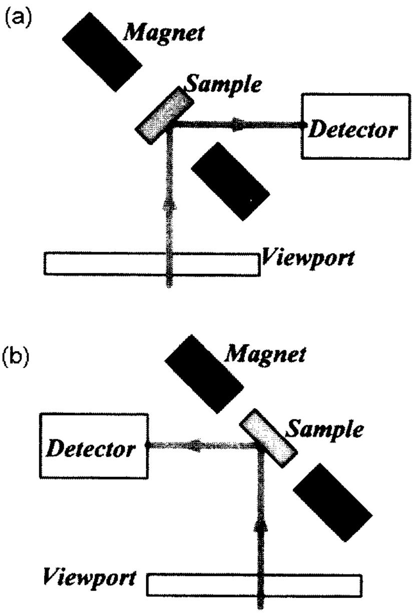

Fig. 2. (a) Polar configuration : magnetic field is perpendicular to the sample surface. (b) Longitudinal configuration : magnetic field is parallel to the incident polarized LASER beam.

We have checked the magnetic field intensity in the gap by mapping magnetic field strength Ho as a function of x, y, z position. While the mapping is carrying out, the current is fixed at 1 ampere (DC field). The mapping result is shown in Fig. 3. The uniform region of the field in gap is about 4 mm in diameter which is much larger than the laser beam

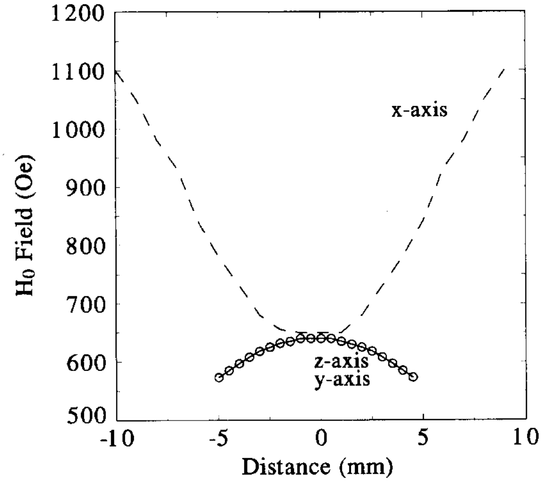

Fig. 3. Magnetic field strength Ho as a function of *x*, *y*, *z* position. The current is fixed at 1 ampere (DC field).

diameter of <<1 mm. The uniformities of magnetic field in the center of the gap ensure that the measured SMOKE signal is reliable.

3.2. Optical System

Optical system consists of a 10 mW He-Ne laser with wavelength of 632.8 nm, one band-pass filter, and two Glan-Taylor prisms, of which one is used as a polarizer and the other is used as an analyzer. The polarized laser beam goes through the first Glan-Taylor prism and pass quartz viewport. The incident beam reflects from the ultra-thin magnetic film which is positioned on 45° respect to the incident beam. A reflected beam goes through another quartz viewport which is positioned on 90° respect to the incident beam, band pass filter, another Glan-Taylor prism, and is finally detected by the photocell (Si-photocell). All items for optical parts are purchased from Melles-Griot Com. except for a Si-photocell which is purchased from Centronic Inc.

3.3. Power Supply and Preamplifier

We can adjust magnetic field strength by changing amount of current and direction using a bipolar power supply which we have purchased from Kepco (Model: BOP50-8M). Its current range is ±8 A and voltage range is ±50 V. A generated photovoltage in the photocell by a rotated outgoing LASER light after passing through the analyser (polarizer) is varied according to the magnetization of deposited magnetic films and film thickness. Because of very small photovoltage difference due to the magnetization reversal, the signal should be amplified using preamplifier before going to the computer. We have designed and developed our own SMOKE preamplifier (differential amplifier). The gain of the amplifier can be changed by switching the resistor in the amplifier circuits. The total amplification of a present SMOKE setup can be as high as 40000 times. Under the such a high amplification, even a very small signal due to the existence of the magnetization in ultra-thin film can be easily detected. In the signal processing, we have used a interface board which is manufactured by National Instrument in order to control both D-A and A-D converting processes. The D-A converting process is necessary for controlling the external magnetic field at different field strengths and frequencies through a bipolar power supply. The A-D converting process is necessary in order to amplify the signal detected by the photocell and analyse it in the computer. In the interface board, ±5 V for both the digital output and analog input is set at working mode.

3.4. Software (Program)

In order to control the power and detecting/analysing the signals by using a computer, we have developed our own program software. The program is written in visual C^{++}. The program control the output current for the electromagnet and the data acquisition process, and also display a hysteresis loop on the monitor in real time. A different hysteresis curve for polar and longitudinal configurations can be collected and analyzed. The program controls frequency, amount of current and direction, multiplier voltage, number of scanning times, and data acquisition rate, *etc*. The frequency regime in the SMOKE setup is ranged from 0.005 to 1 kHz.

IV. Results

Before setting the electromagnet inside UHV chamber, we have checked the magneto-optic Kerr signal from a Fe-Co alloy sample on the table in order to test the performance of the system. A very clear hysteresis curve from the sample is shown in Fig. 4. Also we have developed four-point probe to measure magneto-resistance (MR) of the sample

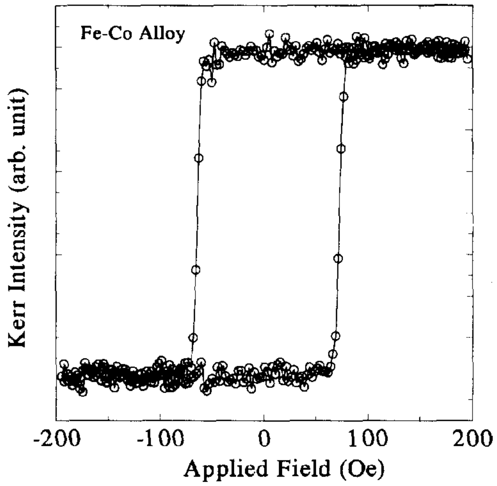

Fig. 4. Magneto-optic Kerr effect (MOKE) hysteresis curve from a Fe-Co alloy sample in atmosphere.

while SMOKE data is taking at the same time. A MR data from a Ta on 10(/NiFe/Cu/Co/Cu) multi-layer sample is shown in Fig. 5. For a MR experimental setup will be described in the other paper in detail.

SMOKE system was tested by investigating the surface magnetism of Co ultra-thin film on Pt(111) surface in an UHV chamber. A clean Pt(111) single crystal surface was prepared after several times of cycles of annealing and Ar^+ sputtering. The base pressure of chamber is below 3×10^{-10} Torr. The

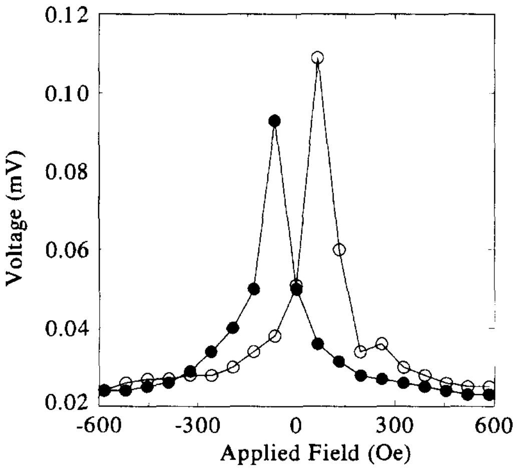

Fig. 5. Magneto-resistance (MR) data from a Ta (/NiFe/Cu/Co/Cu)$_{10}$ multi-layer sample. Applied field increases from 0 to 600 Oe(opened circle), after then decreases and increases again to the opposite direction (filled circle).

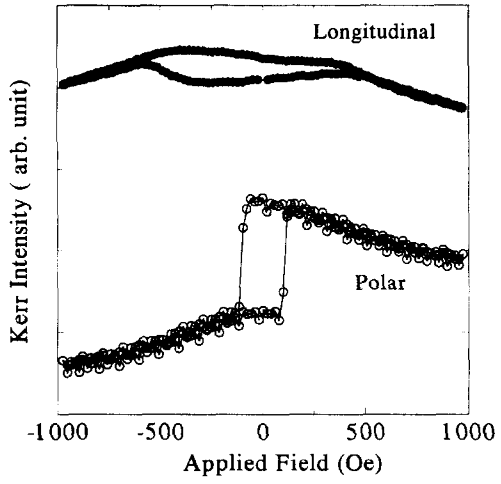

Fig. 6. Polar and Longitudinal surface magneto-optic Kerr effect (SMOKE) hysteresis curve for 2 ML thick Co films grown on Pt(111) surface at 300 K.

thickness of the deposited Co film was monitored by using a quartz oscillator. The incident angle of polarized He-Ne LASER beam is fixed at 45° for both longitudinal and polar configuration. The number of scanning times are 100. Scanning speed is 3 seconds per cycle and the acquisition step between the data points is 2 mA which is correspond to 2 Oe. The experimental (polar and longitudinal) data of *in-situ* UHV hysteresis curve taken from 2 ML Co film deposited on a Pt(111) surface at room temperature are shown in Fig. 6. The surface magnetic anisotropy of ultra-thin Co film can be investigated. This signal allows us to study the magnetic phase transition and coercivity of ultra-thin magnetic films. We found that a magnetic anisotropy of both perpendicular and parallel to the film plane coexist at more than 2 ML ordered ultra-thin Co films. Our SMOKE data are somewhat different from the previously examined results [11]. We know that our SMOKE system is sensitive enough to measure a monolayer range surface magnetism.

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