Mapping the magnetic domain imaging for nano-magnetic films using novel MFM tips

MFM is an extended measurement function of the tapping-mode scanning and lift-mode controlling modes of atomic force microscopy (AFM), where the magnetic domain image is obtained by detection of magnetic force gradient changes between a magnetic tip and a sample. Topographic and magnetic domain images are obtained simultaneously in MFM and can be used to examine the relationship between the sample's surface magnetic domains and its crystal anisotropy or defects. Also, the magnetic force gradient changes detected by MFM are of the order of 10?6 N in magnitude. When MFM is used in conjunction with conducting-AFM measurement technology (Chen et al., 2008; Lin et al., 2002), it is possible to observe and analyze the response of the electron spin direction in the magnetic domains of giant magnetoresistance materials in the presence of electric current and resistance. This approach is thus a very useful research tool for the development of novel nano-magnetic films.

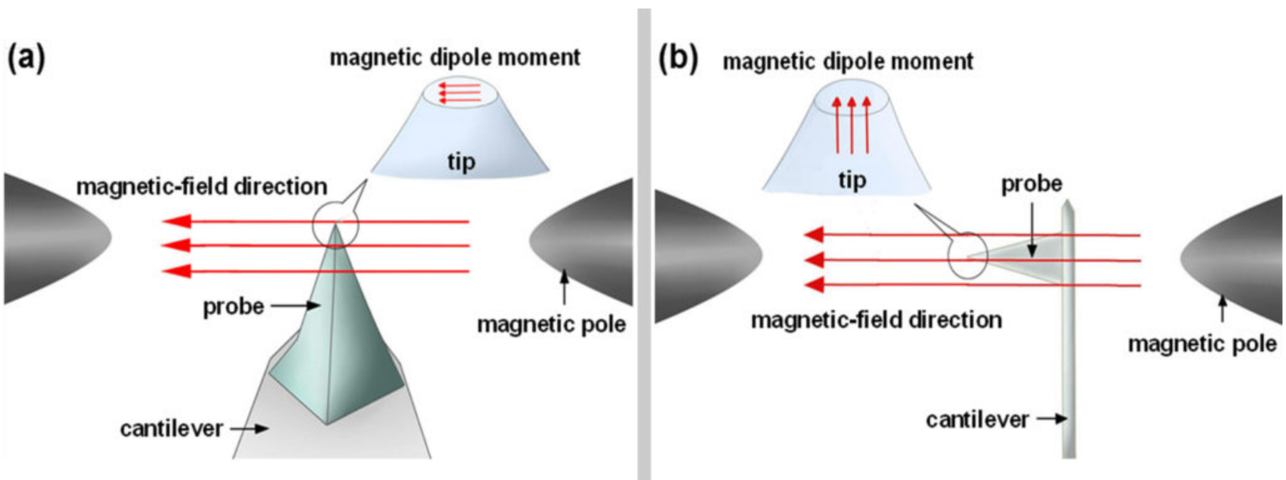

Fig. 1. Schematic diagrams of the magnetization processes used to form (a) LM- and (b) PM-tips.

The tip magnetization is performed using an electromagnet system before MFM scanning. The iron core of the electromagnet is composed of pure iron (AISI 1006, Advanced Magnetic and Cryogenic, LLC), and the magnetization field strength is adjusted using the current to precisely control the power when magnetizing the tip. At current settings of 10, 20, 30, 40, and 50 A, the centers of the resulting magnetization fields are 680, 1360, 2040, 2720, and 3400 Oe, respectively. A tip that is processed using parallel magnetization has a magnetic dipole moment orientation perpendicular to the normal vector of the tip plane, as shown in Figure 1(a). These tips are therefore called longitudinally magnetized tips (LM-tips). A tip that is processed using perpendicular magnetization has a magnetic dipole moment orientation parallel to the normal vector of the tip plane, as shown in

Figure 1(b). These tips are therefore called polar magnetized tips (PM-tips).

Figure 2(a) shows a topographic image of the Co thin film. The root-mean-square surface roughness is approximately 2.01 nm, and the grain size is 64 nm. Figure 2(b) and 2(c) show the polar-MFM (P-MFM) and longitudinal-MFM (L-MFM) images captured by scanning the Co thin film using a PM-tip at 2720 Oe and an LM-tip at 680 Oe, respectively, with the LH set at 80 nm. Figure 2(b) shows a weak magnetic field signal with average relative intensity of 0.05°, and the sample surface at which the perpendicular magnetization occurs shows uniform regions that cannot be magnetized. Figure 2(c) shows magnetic fields with average relative intensities as high as 0.30°, and the magnetizable regions on the Co thin film surface can be clearly observed. The average relative intensity of magnetic fields in Figure 2(c) is 6-fold of that in Figure 2(b). It has been clearly evidenced that the Co thin film can be only magnetized by LM-tip scanning process. The bright spots in Figure 2(c) represent the areas of the sample surface at which parallel magnetization occurs, and these regions have an irregular distribution.

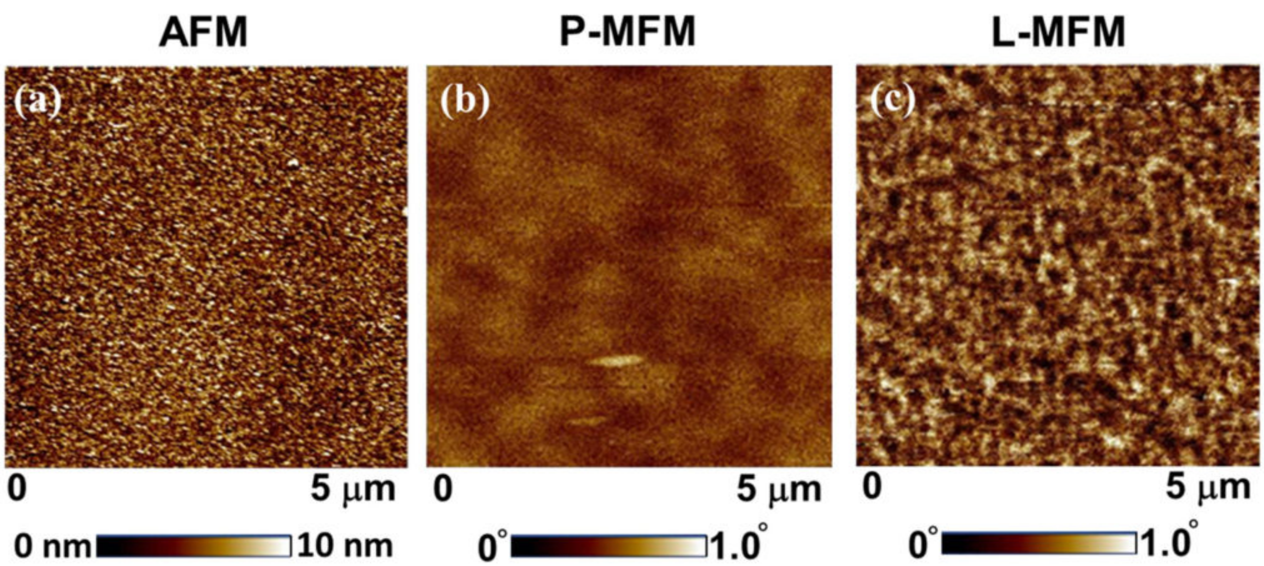

Fig. 2. (a) Topography, (b) polar-MFM and (c) longitudinal-MFM images of a Co thin film. Parts (b) and (c) present scanned images captured using a PM-tip with 2720 Oe and an LM-tip with 680 Oe, respectively, with the LH set at 80 nm.

The mean size per magnetizable region is approximately 250 nm. By comparison of Figure 2(a) and 2(c), we verify that there is no correlation between the magnetizable regions and the Co thin film surface morphology. The above MFM analysis and MOKE measurement data are in good agreement, indicating that MFM and MOKE can be combined to form a complementary measurement system that can be used for comprehensive analysis of the microscopic and macroscopic surface magnetic properties of magnetic films. This approach therefore represents an important research tool for the development of novel nano-magnetic films in the future.

Sy-Hann Chen [1], ***Yu-Hsiang Chang*** [1], ***Chiung-Wu Su*** [1], ***Jyh-Shen Tsay*** [2]
[1]*Department of Electrophysics, National Chiayi University, Taiwan*
[2]*Department of Physics, National Taiwan Normal University, Taiwan*

Publication

Magnetic domain imaging of nano-magnetic films using magnetic force microscopy with polar and longitudinally magnetized tips.
Chen SH, Chang YH, Su CW, Tsay JS
Microsc Res Tech. 2016 Oct