Bending characteristics of anisotropic magnetoresistance in permalloy thin films on ultra-smooth polyimide substrates

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Flexible magnetic sensors have attracted much attention for various device applications due to the advantages of lightweight nature, excellent durability, and compatibility to curved surfaces[1]. Recent studies have demonstrated the modulation in magnetic properties on magnetic thin films by bending[2,3]. The anisotropic magnetoresistance (AMR) effect has also been investigated in magnetic thin films on various organic substrates such as polyethylene naphthalate (PEN) and polycarbonate (PC)[3]. In this study, we focus on ultra-smooth polyimide (us-PI) substrates (XENOMAX®; TOYOBO Co., Ltd.) as flexible substrates. The us-PI, with a surface roughness of less than 0.5 nm, is beneficial to form single magnetic domain structures when applied as the substrate for magnetic thin films. The us-PI substrates also provide a high thermal and mechanical durability. Therefore, magnetic thin films on us-PI substrates are expected to show high AMR ratio, and it could be suitable for flexible magnetic sensors. In this study, we fabricate permalloy (Py) thin films on us-PI flexible substrates and investigate surface morphologies and magnetic/electrical properties, including the bending characteristics of AMR effect.

Py thin films were thermally evaporated on us-PI substrates with in-plane magnetic field in a high vacuum chamber. Au thin films electrodes were deposited on both ends of Py/us-PI by magnetron sputtering. The dimensions of us-PI substrates are 9 mm in length, 2 mm in width, and 38.6 μm in thickness. The atomic ratio of Py is Ni_xFe_{100-x} (x = 83–85). The surface morphology of Py/us-PI thin films was analyzed by atomic force microscopy (AFM). The AMR curves were measured by DC four-probe method. The magnetic properties were investigated by using a focused magneto-optical Kerr effect (MOKE) magnetometer.

Fig. 1 shows the surface AFM image of Py/us-PI. The surface roughness is small at 0.44 nm, which indicates the formation of an ultra-smooth surface of Py/us-PI. Fig. 2 demonstrates the AMR curves of Py/us-PI. The AMR ratio improves with increasing Py thickness d, and it exhibits a high AMR ratio of 0.72% for d = 83 nm. Fig. 3 shows the strain dependence of AMR ratio in Py/us-PI. The AMR ratios of both samples decrease with increasing the strain in convex shape, whereas it increases or shows almost the same value with increasing the strain in concave shape. The change in AMR ratio can be attributed to the inverse magnetostrictive effect, in which the easy-axis direction of magnetization rotates by bending. The modulation of AMR ratio is consistent with magnetization curves obtained by MOKE measurements.

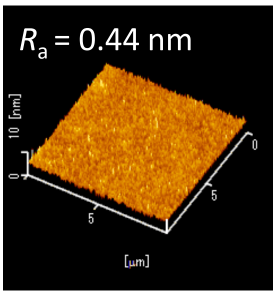

Fig. 1 AFM image of Py/us-PI.

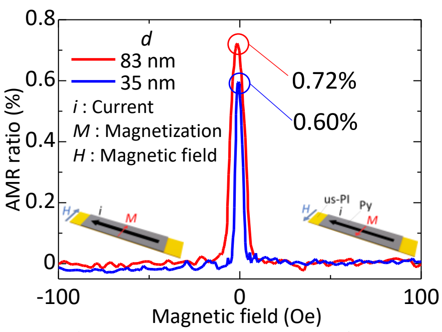

Fig. 2 AMR curves of Py/us-PI.

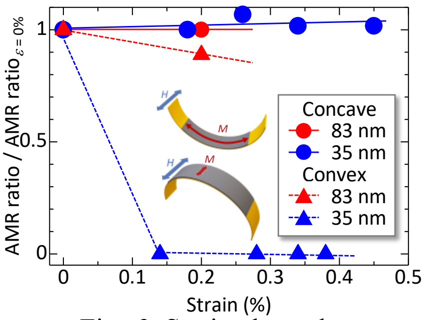

Fig. 3 Strain dependence of AMR ratio.

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