Bending characteristics of emergent magneto-inductance effect in flexible magnetic thin films

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Flexible magnetic sensors have attracted much attention for various device applications. It has been reported that the magnetic properties such as magnetic anisotropy and magnetoresistance can change in magnetic thin films by bending [1]. A concept of emergent magneto-inductance (EML) has also attracted attention as a new principle for detecting magnetic fields with high sensitivity. The EML effect is a phenomenon that the inductance changes with magnetic field, originating from the spin electromotive force (SMF) generated from non-collinear spin dynamics [2]. Recently, the magnetic domain wall (DW) motion has been modulated in permalloy (Py) thin films on polycarbonate (PC) substrates by a step-wise magnetic field, leading to the observation of a novel EML effect at room temperature [3]. In this study, we investigate the bending characteristics of EML effect in Py/PC at room temperature.

Fig. 1 shows the schematic of sample structures and measurement setup. Au electrodes were patterned onto both sides of PC substrates using magnetron sputtering. Then, Py thin films (45 nm thickness) were deposited on Au electrodes and PC substrates using thermal evaporation. The atomic ratio of Py is $Ni_{84}Fe_{16}$. To induce the magnetic anisotropy in Py thin films, an external magnetic field was applied in the transverse direction of Py thin films during the evaporation. The EML curves were measured by AC two-probe method with a 4 Oe stepwise magnetic field. The magnetic field was applied up to ±100 Oe and the AC measurement frequency was 4–48 kHz. As shown in Fig. 1, when Py/PC is bent in the positive direction of the z-axis, the strain ε is defined as positive.

Fig. 2 shows the magnetization curves under convex bending for Py/PC. The anisotropic field H_k decreases from 6.8 to 2.7 Oe with increasing the strain ε from 0% to 0.399%. The anisotropic field reduction can be explained by the inverse magnetostrictive effect. Fig. 3 shows the strain dependence of emergent inductance ΔL. The ΔL increases from 983 to 1429 nH with increasing ε from 0% to 0.24%, and then it decreases to 809 nH with increasing ε to 0.399% at 4 kHz. The enhancement of ΔL is attributed to the increase of the number of DWs, which is caused by the anisotropic field reduction under convex bending. The decrease of ΔL is due to the decrease of the number of DWs as a result of the rotation of magnetic easy axis to the longitudinal direction (y-axis). Thus, the bending dependence of EML can be explained by SMF from the transient DW motion and inverse magnetostrictive effect. Our study may benefit the EML research and flexible magnetic sensing.

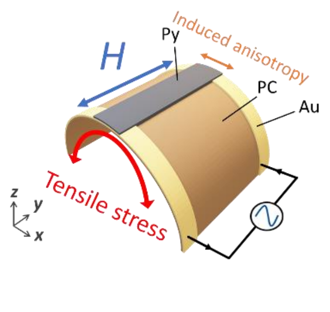

Fig. 1 Schematic of Py/PC.

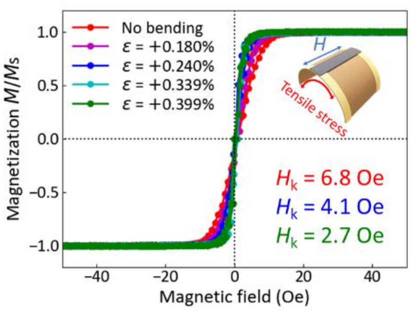

Fig. 2 Magnetization curves of Py/PC under convex bending.

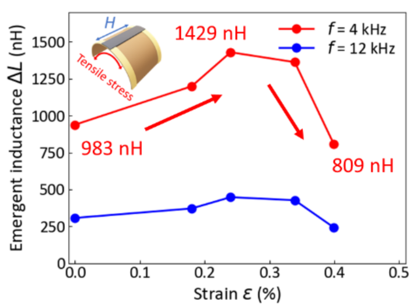

Fig. 3 Strain dependence of EML under convex bending.

[1] Y. Ohashi, Y. Matsushima, and H. Kaiju: *J. Magn. Magn. Mater.* **570**, 170497 (2023).
[2] T. Yokouchi *et al.*: *Nature* **586**, 232 (2020).
[3] Y. Matsushima *et al.*: *Appl. Phys. Lett.* **124**, 022404 (2024).