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Research articles

The Modification of Magneto Impedance Effect with N Number Layer of Multilayers Structure [NiFe/Cu/NiFe]$_N$/Cu/[NiFe/Cu/NiFe]$_N$

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Abstract

The effect of N number of layers [NiFe/Cu/NiFe]$_N$/Cu/[NiFe/Cu/NiFe]$_N$ on the Magneto Impedance (MI) ratio has been investigated. The multilayer structure was made using the electrodeposition method on a meander-patterned Cu PCB substrate. Measurement of the MI ratio is performed at a low frequency of 100 kHz. The MI ratio increased from 1.34% for N = 1 to 1.86% for N = 3. This is because the increase in the number of N increases the permeability of the sample, thereby increasing the MI ratio.

1. Introduction

The magnetoimpedance (MI) effect is the change in the AC impedance of a ferromagnetic material when subjected to a DC magnetic field [1]. The MI effect is related to the skin effect, which depends on the resistivity and magnetic permeability of an alternating current-carrying magnetic conductor [2]. The MI effect has been studied for magnetic sensor applications [3]. The thin-film magnetoimpedance sensor is compatible with integrated electronic circuits and miniaturization aimed at field detection with high spatial resolution [4]. It can be applied in automatic control [5], biomedical sensing [1, 6], and others.

Several fabrication methods of magneto-impedance films are evaporation, sputtering, chemical vapor deposition, electrolytic deposition, and atomic layer epitaxy [7]. Highly sensitive MI occurs in a multilayer having two soft ferromagnetic layers and a nonmagnetic conductive layer with an F/M/F arrangement. The impedance change in multilayer arrays is greater than that of single-layer films [8]. This is because the permeability of multilayer films is greater than that of single-layer films. As research progresses, multilayer structures with symmetrical and nonsymmetrical configurations have been successfully created. In that study, it was found that modification of the structure and the number of multilayers can affect the MI ratio [1]. $Ni_{81}Fe_{19}$ permalloy is the material most commonly used material to investigate the MI effect because it is a soft magnetic material with low coercivity, high magnetic permeability, and saturation magnetization [9].

Several modifications of the multilayer structure have been made to increase the magneto impedance ratio. Variations in the number of layers have been carried out in previous studies using multilayer [NiFe/Cu]$_N$ on Cu PCB meander substrates. The result shows that increases in multilayer numbers on a Cu-patterned substrate cause an increased MI ratio [13]. In this paper, we have investigated the effect of MI on a symmetric multilayer structure with a different number of layers. The [NiFe/Cu/NiFe]$_N$/Cu/[NiFe/Cu/NiFe]$_N$ multilayer is deposited on the Cu PCB meander substrates by the electrodeposition method. The number of layers of [NiFe/Cu/NiFe]$_N$/Cu/[NiFe/Cu/NiFe]$_N$ varied from N = 1 to N = 3. The MI ratio is measured at a low frequency (< 100 kHz) at room temperature.

2. Experimental Methods

The sampling process was carried out using the electrodeposition method as in previous studies [10]. The electrodeposition method was performed at room temperature using Pt electrodes. The substrate used in this study is a meander-patterned Cu PCB. Before electrodeposition, the substrate was placed in a beaker containing ethanol and then put into an ultrasonic cleaner for a 30-minute cleaning process. The NiFe layer electrolyte solution consists of $NiSO_4.6H_2O$ (Merck), $FeSO_4.7H_2O$ (Merck), H_3BO_4 (Merck), $C_7H_5NO_3S$ (Merck) and $C_{12}H_{25}NaO_4S$ (Merck). Meanwhile, the electrolyte solution of the Cu layer consists of $CuSO_4.5H_2O$ (Merck), $C_7H_5NO_3S$ (Merck) and $C_{12}H_{25}NaO_4S$ (Merck). This experiment used a saccharin concentration of 0.1 g/*l*. These materials are placed in a container and then dissolved with distilled water. The electrodeposition process for the NiFe and Cu layers was performed alternately until the number of layers N = 1, 2, and 3. The electrodeposition process for the NiFe layer used a current density of 15.5 mA/cm^2, while the Cu layer used a current density J = 8 mA/cm^2.

Fig. 1. (a) Experimental schematic of the measurement of MI effects and (b) The multilayer structure in the meander pattern of the electrodeposited samples

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Figure 1 (a) shows the magneto impedance measurements set up and (b) the meander pattern of the Cu printed circuit board. The magneto-impedance measurement process is carried out by the total electrical impedance of the sample under various magnetic fields (H) ranging from +60 mT to -60 mT. The alternating current flow of the sample during the magnetoimpedance measurement at a frequency of 100 kHz. The MI magnitude is calculated through Equation (1).

$$\frac{\Delta z}{z}(\%) = \frac{z(H)-z(H_{max}}{z(H_{max}x100\%(1)} \quad (1)$$

where *Z(H)* is the measured impedance when *H* is applied and *Z(Hmax)* is the measured impedance when *Hmax* is applied. The value of *Z(0)* depends on the remanence state of the magnetic material [11]. The fundamental properties of the sample were also characterized by their crystalline structure using an X-ray diffractometer (XRD) and magnetic properties with a vibrating sample magnetometer (VSM).

3. Results and Discussion

Figure 2 shows the thickness *d* of the NiFe and Cu layer as a function of the deposition time *t* on the Cu substrate. The thickness *d* of the sample is evaluated using gravimetric i.e., the mass deposited material is the difference in mass before and after being coated on the substrate. Thus, the equations used in the gravimetric method to determine the thickness of the layer is presented in Equation (2).

$$t = \frac{\Delta m}{A x \rho} \quad (2)$$

where *Δm* is the difference in mass before and after the electrodeposition process, *A* is the area of the substrate, and ρ is the density. The density used for NiFe is 8.75 g/cm^3 and the density of Cu is 8.94 g/cm^3.

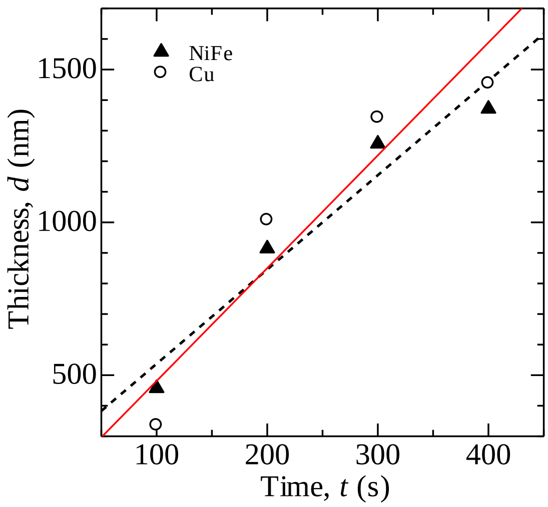

Fig. 2. The thickness of the NiFe and Cu layers as a function of electrodeposition time

Based on the slope of the linear graph, the deposition rate for the NiFe layer is 3.0857 nm/s while the deposition rate for the Cu layer is 3.6913 nm/s. Furthermore, the element composition of the sample study by the XRF. In a thin layer with a thickness of 150 nm, the mole-percentage composition of Ni:Fe is 84.4:15.5. A thin layer with a thickness of 450 nm has a Ni:Fe composition percentage of 84.90:15.09. A thin layer with a thickness of 600 nm has a Ni:Fe composition percentage of 84.58:15.41. The obtained calculation is a reasonable fit to stochiometric, which is close to the percentage of the permalloy composition.

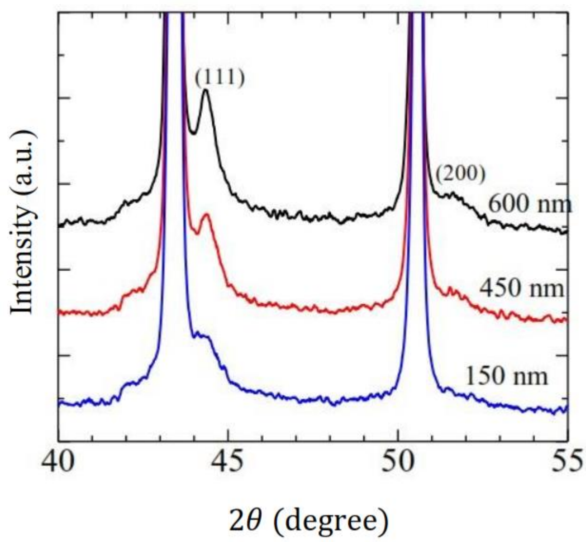

Fig. 3. XRD spectra of NiFe layers for different thicknesses of 150 nm, 450 nm, and 600 nm

Figure 3 shows the XRD pattern of the NiFe layer for different thicknesses of 150 nm, 450 nm, and 600 nm for an angle 2θ in the range of 30°-60°. These results are in accordance with the International Center for Diffraction Data (ICDD) database number 120736 of permalloy. Another peak is caused by the Cu PCB used as a substrate. This indicates that the layer formed on the Cu PCB substrate from the electrodeposition results is NiFe permalloy.

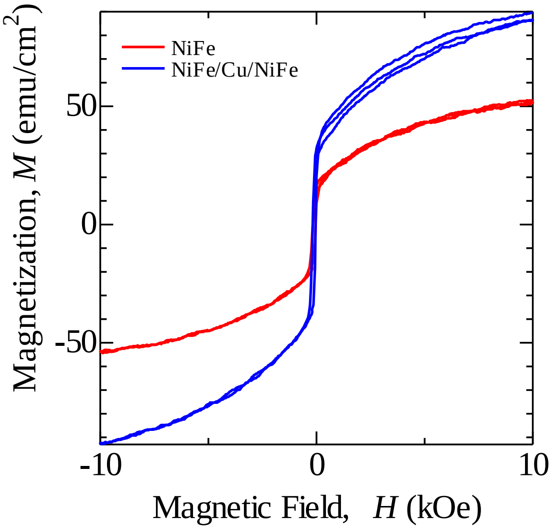

Fig. 4. Result of VSM characterization on multilayer NiFe/Cu/NiFe

Figure 4 shows the hysteresis curve of the NiFe layer (150 nm) and multilayer NiFe(150 nm)/Cu(50 nm)/NiFe(150 nm). The magnetization value tends to increase with the increase in the number of multilayers. In the case of the NiFe layer, the Mr value of 10.314 emu/cm^2 and Ms of 19.91 emu/cm^2 are obtained. Whereas in the NiFe/Cu/NiFe layer, the Mr value of 22.281 emu/cm^2 and Ms of 37.679 emu/cm^2 are attained. This indicates that the crystalline anisotropy and magnetic depinning domain walls increase with increasing NiFe thickness [16]. The coercive field Hc magnitude in the NiFe/Cu/NiFe layer is 49.42 Oe, which is higher than the NiFe layer of 48.35 Oe.

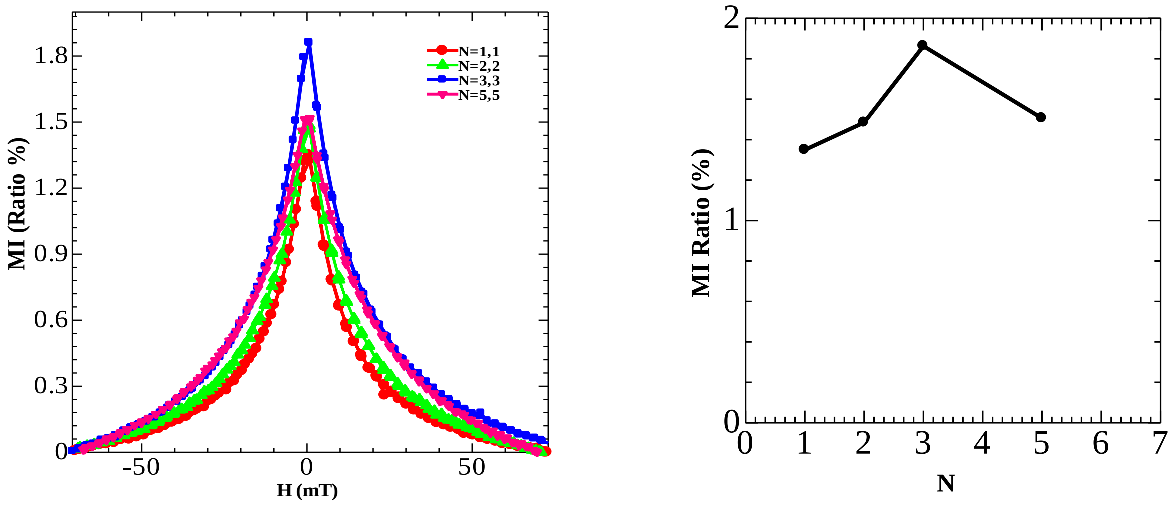

Fig. 5. (a) Typical MI curve and (b) MI curve as a function of the number of multilayer films $[NiFe/Cu/NiFe]_N/Cu/[NiFe/Cu/NiFe]_N$ at a frequency of 100 kHz

Figure 5 (a) shows the MI characteristic curve for magnetic field applications with variations in the number of N layers of $[NiFe/Cu/NiFe]_N/Cu/[NiFe/Cu/NiFe]_N$ at a frequency of 100 kHz. From the figure, it can be seen that the variation of N layers of $[NiFe/Cu/NiFe]_N/Cu/[NiFe/Cu/NiFe]_N$ shows the same MI graph shape, but with different MI peak values. Figure 4 (b) shows the relationship between changes in the MI ratio with variations in the frequency of AC for the sample $[NiFe/Cu/NiFe]_N/Cu/[NiFe/Cu/NiFe]_N$. From the figure, it is clear that the MI ratio increases with the increase in the number of N layers. For N = 1, the MI ratio is 1.34%, for N = 2, the MI ratio is 1,41% and then increases again to 1.86% for N = 3. Therefore, it can be said that the higher the number of N layers in the multilayer configuration, the greater the resulting MI ratio. This is because an increase in the number of repetitions of the thin layer will increase the permeability of the material. The permeability of the material has a relationship with the skin effect on the MI which is given by Equation (3).

$$\delta = (\pi f \sigma \mu)^{-\frac{1}{2}} \quad (3)$$

where f is the field frequency and σ is the conductivity of the material. The external magnetic field can modify the value of the permeability of the material, which in turn can change the cross section of the conductor so as to produce impedance variations. The maximum impedance *Zmax* is obtained when the permeability reaches the maximum value while the minimum impedance is obtained when the sample is magnetically saturated and the permeability reaches the minimum value [12]. As a result, this study achieved the highest MI ratio in samples with N = 3 layers. Similarly, previous studies indicated that magnetic conductors with more layers have a higher MI ratio than magnetic conductors with fewer layers.

4. Conclusions

This study investigated the MI ratio in the $[NiFe/Cu/NiFe]_N/Cu/[NiFe/Cu/NiFe]_N$ multilayer system that was electrodeposited on a Cu PCB substrate. The electrodeposition method was performed at a low frequency of 100 kHz at room temperature using Pt electrodes. The MI ratio was modified by varying the number of layers. Based on the data analysis, it can be concluded that the MI ratio increases the number of layers. Furthermore, the highest MI ratio of 1.86% is obtained for samples with N = 3 layers.

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