Magneto-impedance in Multilayered \([\text{Ni}_{80}\text{Fe}_{20}/\text{Cu}]_4\) with modification of the line-length pattern on Cu printed circuit board

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Abstract. Magneto-impedance of multilayer \([\text{Ni}_{80}\text{Fe}_{20}/\text{Cu}]_4\) on Cu PCB substrate has successfully studied. To enhance the magneto-impedance we modify the geometry the Cu PCB substrate. The multilayer is made by electro-deposition with Pt (Platinum) as electrodes. Electro-deposition is made at room temperature. Magneto-impedance total is evaluated under the external magnetic field. The results shows that magneto-impedance curve is symmetry. The difference of line-length result in the difference of the magneto-impedance. The samples is with the longest line-length has the largest magneto-impedance ratio. The homogeneity of the samples is on account estimated the increase magneto-impedance ratio.

Keywords: magneto-impedance ratio, electro-deposition, \([\text{Ni}_{80}\text{Fe}_{20}/\text{Cu}]_4\)

1. Introduction

The change of the impedance magnitude in a magnetic material (magnetic films, magnetic multilayer films or magnetic ribbon) due to the external magnetic field is called magneto-impedance. This phenomenon is a complement to the magneto-resistance which open spin electronic (spintronic) era. The magneto-impedance effect is given as different impedance when sample under and without magnetic field (\(\Delta Z\)) and is formulated as follows:

\[
\frac{\Delta Z}{Z} (100\%) = \frac{(Z(H) - Z(H_{\text{max}}))}{Z(H_{\text{max}})} \times 100\% 
\]

(1)

In general, the total impedance consists of resistance and reactance following formula \(Z^2 = R^2 + X^2\). Where the magnitude of reactance include capacitance and impedance which depend on frequency. In the case of magnetic material, the magnetic permeability also influences the impedance magnitude.

The magneto-impedance effect realizes on amorphous metal wire (amorphous metallic wire), amorphous metal ribbon (amorphous metal ribbon), magnetic thin film, and nano crystalline magnetic alloy [1]. Furthermore, the impedance magnitude is a geometrical physics-property, so that the phenomenon of magneto-impedance possible to create in two dimensions of micro-conductor [2,3] such kind of Cu printed circuit board. The ease of this design is one of the advantages of the magneto-impedance sensor that meets the flexibility aspects of sensor fabrication on the substrate.
Therefore, this magneto-impedance effect can be apply on a wide of magnetic sensors [4]. Moreover, magneto-impedance has a high sensitivity. So that a current magneto-impedance much developed in the manufacture of biomedical magnetic sensors [5]. Magneto-impedance sensors [6] are relatively easy, cost-efficient, the ability of lightweight, reliable, rapid response, and can be cread as portable sensors [7].

In this paper, an attempt to increase the value of the magneto-impedance ratio on Cu PCB substrate are evaluation with a modification of the geometry of the track line-length on Cu PCB substrate. Multilayer [Ni$_{80}$Fe$_{20}$/Cu]$_4$ Permalloy deposited with electro-deposition method [8,9] use the sample a magneto-impedance sensor.

2. Methods

A thin film of multilayer [Ni$_{80}$Fe$_{20}$/Cu]$_4$ produces by using an electro-deposition method using Pt (Platinum) electrodes [10]. The substrate used is a Cu Printed Circuit Board (PCB) with modification of geometry. Before use, the substrates are clean with an ultrasonic cleaner.

The electrolyte solutions in electro-deposited multilayer procedure are list in Table 1. Electrolyte solution adjust a range 2,5-3 of pH with H$_2$SO$_4$ 0,1 M.

| Electrolyte solutions used to deposition the sample of multilayer [Ni$_{80}$Fe$_{20}$/Cu]$_4$ | Electrolyte | Materials | Total of Number |
|-----------------------------------------------|------------|-----------|----------------|
| For deposited NiFe                          | NiSO$_4$,6H$_2$O | 0,099 M |
|                                              | FeSO$_4$,7H$_2$O | 0,012 M |
|                                              | H$_3$BO$_4$     | 0,149 M |
|                                              | C$_6$H$_8$O$_3$ | 0,002 M |
| For deposited Cu                            | CuSO$_4$,5H$_2$O | 0,065 M |
|                                              | C$_6$H$_8$O$_3$ | 0,002 M |

The current density of 15.5 mA/cm$^2$ is used to deposited Ni$_{80}$Fe$_{20}$ and 8 mA/cm$^2$ for Cu spacer layer. The procedure is repeated to obtain a multilayer of [Ni$_{80}$Fe$_{20}$(800 nm)/Cu(300 nm)]$_4$. Multilayer samples are do at room temperature. The magneto-impedance characteristic is evaluated with the measure of the total impedance for the various magnetic field as depicted in Figure 1.

![Figure 1](image.png)

**Figure 1. The scheme of the characterization of magneto-impedance (MI)**

The value of the impedance total is $Z^2=R^2+X^2$ with resistance as areal component and donation of the imaginary component of reactance. The schematic of the samples is shown in Fig1(b). The distance between of the line track is 500 µm, and the width of the line track is 250 µm. Here, the MI
ratio modify by the change of the line-length total, should be 14.2 (later call A), 21.2 (B), 25.7 (C) and 28.7 cm (D).

3. Results and Discussion

Figure 2 shows the multilayer samples of [Ni$_{80}$Fe$_{20}$/Cu]$_4$ on a patterned PCB. Observed from the Figure that the geometrical design of the samples is same but different in the length-line. Without magnetic field, the initial impedance of sample A is 0.4598 Ω. Then the total impedance change become 0.7789 Ω and 0.7957 Ω for sample B and C. Finally, the total impedance is 1.056 Ω for sample of D. From this result confirm that the change of the line-length modify the total impedance of the multilayer [Ni$_{80}$Fe$_{20}$/Cu]$_4$. It is prediction that the reactance component of the impedance total will response the magnetic field in the electrical measurement under magnetic field. So that, it also modifies the ratio magneto-impedance of the samples.

Figure 2. The modified of the multilayers [Ni$_{80}$Fe$_{20}$/Cu]$_4$ on a patterned Cu PCB substrates

Figure 3. The magneto-impedance curve of the multilayers [Ni$_{80}$Fe$_{20}$/Cu]$_4$ for $l = 14.2$ cm and 28.7 cm are measured at 100 kHz.
The typical magneto-impedance curve in electrodeposited [Ni$_{80}$Fe$_{20}$/Cu]$_4$ for $l = 14.2$ cm and 28.7 cm are performed at a frequency of 100 kHz. The magnetic field strength variations from 0 mT to $\pm 40$ mT generate by electromagnetic field source of a Helmholtz coil. The symmetry characteristic of the magneto-impedance curve is obtained. The $Z$ maximum when zero magnetic fields and the $Z$ become saturate at some magnitude magnetic field. In case the longest sample, magneto-impedance effect realize much a larger than the shorter one. It is indication that reactance component significantly attributes to MI effect. The ratio of the MI calculate by using formula, MI ratio ($\%$) = $[Z(H)-Z(H_{max})]/Z(H_{max}) \times 100\%$ and is depicted as Figure 4. The figure is other expression of magneto impedance ratio as a function of the length. It clearly that the MI ratio increase with the increase of the length. This result is in accordance with the results that have been published by Vasques [11,12]. In Fig. 4, the MI ratio of 5.98% is obtained for sample D and the largest one of 7.84% for sample A.

Also, the magneto-impedance ratio reflects the sensitivity of the samples. Using the equations $\eta = 2\left(\frac{\Delta Z/\Delta H}{\%}\right)_{max}$ so that the value of the greatest sensitivity for the multilayer samples (Sample A) is 932.7 %/T. Thus the sample with the longest line-length has the largest of the magneto-impedance ratio as well as a sensitivity value.

![Figure 4. The ratio of MI max (%) as function of the line-length samples](image)

4. Conclusion

Multilayer [Ni$_{80}$Fe$_{20}$/Cu]$_N$ is successfully produced with an electro-deposition method on a patterned Cu PCB substrates. The results show that the MI ratio increase with the increase of the line-length samples. The largest MI ratio of 7.84% is obtained for the sample with $l = 28.7$ cm.

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