Parallel-line number dependence of magneto-impedance effect in multilayer permalloy [Ni$_{80}$Fe$_{20}$/Cu]$_N$ films

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Abstract. In this paper, we studied the magneto-impedance effect in multilayered [Ni$_{80}$Fe$_{20}$/Cu]$_N$ with variation in the number of parallel-line on Cu PCB substrate. The method used in this research is the electrodeposition at a room temperature with Pt as an electrode. The results show that the magneto-impedance ratio increases with the increase in the number of parallel-line on Cu PCB. The maximum magneto-impedance ratio obtained in Cu PCB substrate which four parallel lines were 4.5%. Likewise, frequency variation, the magneto-impedance ratio increases with increasing frequency.

1. Introduction
Magneto-Impedance (MI) is a phenomenon of the change in impedance caused by changes in the external magnetic field [1-8]. Interestingly, the magnetic sensor based on magneto-impedance operating at room temperature, with sensitivity ultra high, high thermal stability, high spatial resolution, small size, light weight and low power consumption [9].

The magneto-impedance effect depends on different factors, such as the alloy composition, temperature, frequency and geometry of the sample. In this study, the sample was made using electrodeposition method [10-16]. It caused metal layers can deposit on the substrate instead of conduction. Additionally, the deposited layer typically has a microstructure and strong corrosion resistance [17].

Determination of the magneto-impedance ratio using Equation (1),

$$MI\% = \frac{Z(H) - Z(H_{\text{max}})}{Z(H_{\text{max}})} \times 100$$

with $Z(H_{\text{max}})$ is applied to the impedance maximum magnetic field and $Z(H)$ is a rated impedance of the magnetic field [4,18-20].

Skin effect can influence the magneto-impedance at low frequencies less than 100 kHz. In thin films, values depth $\delta_m$ expressed by the transverse permeability ($\mu_T$), to obtain Equation (2).

$$\delta_m = \frac{c}{\sqrt{4\pi^2f\sigma\mu_T}}$$

where $c$ is the speed of light, $\sigma$ is the electrical conductivity and $f$ is the frequency of AC current flowing in the sample [6].
In this paper, we will examine the phenomenon of magneto-impedance on Cu PCB substrate electrodeposition results [NiFe/Cu]₃ at low frequencies. Based on the results obtained in this study, it will be known parallel-line number dependence of the magneto-impedance on Cu PCB substrate.

2. Experimental Methods
The method used in this research is electrodeposition at room temperature with Pt as an electrode. Pt was used as an electrode, while the sample used was Cu PCB. The area of the deposited sample of 1 cm². Modification of patterned samples the parallel-line number on Cu PCB substrates was 1, 2 and 4 (see Figure 1). Electrolyte solution used was Ni₈₀Fe₂₀ and Cu. The materials utilized for the manufacture of the electrolyte as in Table 1. The ingredients in Table 1 then added H₂SO₄ 0.1 M as producing acidic conditions.

![Figure 1. Modification of parallel-line number on the Cu PCB](image)

Cu PCB was deposited with Ni₈₀Fe₂₀ using 2 nm/s deposition rate. As for the Cu layer using 6 nm/s deposition rate. The deposition process is carried out as in Figure 2. Each sample was deposited to form 5 layers. No treatment furthermore of the deposition.

| Electrolyte | Material          | Concentration |
|-------------|-------------------|---------------|
| NiFe        | NiSO₄·6H₂O        | 0.099 M       |
|             | FeSO₄·7H₂O        | 0.012 M       |
|             | H₃BO₃            | 0.149 M       |
|             | C₆H₄O₃           | 0.002 M       |
| Cu          | CuSO₄·5H₂O       | 0.065 M       |
|             | C₆H₄O₃           | 0.002 M       |
Magneto-impedance measurements in this study using LCR meter 819 GW Instek and performed at low frequency (see Fig. 3). Figure 3 shows the magneto-impedance measurement scheme. In this study, a large external magnetic field($H$) is measured using Gaussmeter LZ-641 H made by Hunan Link Join Technology.
3. Results and Discussion

Figure 4 (a) shows the effect of increasing the parallel-line number on Cu PCB substrate to magneto-impedance at a frequency of 100 kHz. The measurement results show the same typical magneto-impedance ratio reached a maximum at \( H = 0 \) mT. Figure 4(a) shows that the magneto-impedance ratio will decrease significantly with increasing external magnetic field and achieve stable conditions in the external magnetic field \( H = 20 \) mT. The magneto-impedance effect reaches its peak as a consequence of the permeability contribution of both the domain wall movement and the magnetization rotation to the magneto-impedance [21]. Figure 4 (a) also shows that the more of the parallel-line number on the Cu PCB substrate the magneto-impedance ratio also increased.

![Figure 4](image)

**Figure 4.** (a) A typical MI curve as a function of the magnetic field for variation in the parallel-line numbers on Cu PCB (b) Graph of MI variation of the parallel-line numbers on Cu PCB

Fig. 4(b) is a summary of Fig. 4(a). Figure 4 (b) show that the improved magneto-impedance ratio by increasing the number of parallel-line in more details Cu PCB substrate. In this study, the magneto-impedance ratio increased from 1.8% to 4.5% with an increase in the number of parallel-lines 1 to 4 lines. This study shows the more parallel-line on Cu PCB substrate, the magneto-impedance ratio also increases linearly. This can be explained as follows: when the conductor is flowed by current it will produce magnetic induction. Because the adjacent lines will mutually induce each other. This allegedly increases the magneto-impedance ratio.

In thin films, the maximum impedance decreases affected by the longitudinal field applied to the material that follows the dependence transverse permeability \( (\mu_T) \) to the field [6]. Therefore, an increase in the parallel-line number will improve permeability transverse magnetic material in thin films causing magneto-impedance ratio will increase. As well as with the frequency variation, the magneto-impedance ratio increases with the increase in frequency. In general, low-frequency magneto-impedance influenced by magneto-inductive [6]. Impedance material that responds to the current distribution depends not only on the form of conductor and frequency but also on the permeability of the material concerning the current flowing in material.

Figure 5 (a) shows the influence of the frequency of AC current to magneto-impedance ratio multilayer \([\text{Ni}_{80}\text{Fe}_{20}\text{Cu}]\) on the Cu PCB substrate with four parallel-line number. Because in this study used a low frequency, the frequency range used was between 20 kHz - 100 kHz. It can show that at each frequency variation shows a typical curve of the same magneto-impedance. Fig. 5(b) is a summary of Fig. 5(a). Improved magneto-impedance ratio with an increase in the frequency of AC
current at Cu PCB substrate more details shown in Figure 5 (b). The result of measurement shows that the magneto-impedance ratio equal to 0.4% was obtained at frequency of 20 kHz and ratio magneto-impedance increase to 4.6% at frequency of 100 kHz.

Increasing the frequency of AC current can cause the reactance value of the material also increased [22], thus improving magneto-impedance ratio. In addition to affecting the value of substance reactance, the frequency of AC current also affects the skin depth. In Eq. 2 show that the skin depth is inversely proportional to the root frequency. An increase in the frequency of material permeability can decrease the value of skin depth. So the smallest skin depth values are obtained at higher frequencies. Therefore, the highest magneto-impedance ratio is obtained at higher frequencies.

4. Conclusion
The phenomenon of magneto-impedance multilayer [NiFe/Cu] was modified by varying of the parallel-line number on Cu PCB substrate. Coating multilayer [NiFe/Cu] on the Cu PCB substrate formed from the electrodeposition with Pt as an electrode. The results showed that the increase in the parallel-line number on the Cu PCB [NiFe/Cu], causes an increase in the magneto-impedance ratio. The experimental results show that the maximum magneto-impedance ratio on the Cu PCB substrate having four parallel-lines of 4.5%. Likewise, frequency variation, the magneto-impedance ratio increases with increasing frequency.

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