Annealing temperature dependence of magnetoimpedance effect in electrodeposited [Ni$_{80}$Fe$_{20}$/Cu]$_3$ multilayers

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Abstract. We have conducted an experiment of magnetoimpedance with a variation of annealing temperature of [Ni$_{80}$Fe$_{20}$/Cu]$_3$ multilayers. The multilayer is electrodeposited on Cu-PCB substrate. Magnetoimpedance effect is impedance measure on account of external magnetic field. The found MI (magnetoimpedance) ratio is 7.63 % (without annealing) and 4.75 % (using annealing) of 100 ºC. We find that MI ratio depends on to annealing temperature and current frequency. MI ratio decreases due to rising temperature and identified increase due to the frequency. The highest MI ratio is on a sample without annealing temperature and measurement at 100 kHz frequency.

1. Introduction
Since the effect magnetoimpedance (MI) was first discovered by Mohri et al. have a lot of growing techniques and methods were applied to the sample MI, one of which with annealing. During the annealing process, in general a sample is given the heat (temperature) which is maintained until a several time, and after that the sample can be measured [1]. Magnetoimpedance (MI) is a state of impedance change of magnetic material due to an external magnetic field when AC (alternative current) passes [1-5]. The phenomenon of impedance changes associated with the modification of the value of skin depth which is dominated by circumferential permeability and to the wire transverse permeability in the ribbon-thin layer [1-3]. In the fact, the phenomenon of MI effect observed on the wire with the high-frequency range (several MHz) with sufficiently high annealing temperature (300ºC). Better MI is observed with the increase in permeability and saturation magnetization of the sample. Annealing process affects the magnetic anisotropy and magnetic softness in the form of permeability and saturation magnetization have been reported [1,6]. This new step with annealing is quite important considering the better results will be oriented to more effective sensor applications.

In recent years, fluxgate sensors, giant magnetoresistive sensors, hall sensors and sensor-based MI is an example of a magnetic sensor that continues to grow along with the development of research results. The MI-based sensors are very attractive to develop because these sensor-based solutions offer several advantages over other sensors such as better sensitivity, stability and linearity. A good sensor is characterized by high sensitivity. The sensitivity of the sensor can be expressed by the equation $\xi = \{ 2(\Delta Z/Z)_{\text{max}}/ \Delta H \}$, where $H$ a full width at half maximum ratio curve MI [7].

In the purpose of this study, the effect of MI on samples multilayers [Ni$_{80}$Fe$_{20}$/Cu]$_3$ was evaluated by the addition of annealing temperature variation and measurement in the low-frequency range (f<100 kHz). The sample [Ni$_{80}$Fe$_{20}$/Cu]$_3$ is produced through deposition NiFe and Cu using electroplating or electrodeposition method. The magnitude of the impedance is represented as the sum
of the values of resistance and reactance \( Z = \sqrt{R^2 + X^2} \). While the change in a value of MI ratio is expressed using the equation:

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

with \( Z(H) \) is the impedance measured at the time given the external magnetic field, and \( Z(H)_{\text{max}} \) is the measured impedance value at the time of maximum \( H \) [1].

2. Methods

Multilayers is grown by adopting a multi-layered configuration of NiFe/Cu/NiFe through electrodeposition method. A non-magnetic layer is inserted between the magnetic layer to keep the deposition rate for 400 seconds NiFe layer and a layer of Cu 50 seconds. The potential difference is used to permalloy Ni\(_{80}\)Fe\(_{20}\) was 3.5 V at the current density of 15.5 mA / s while Cu as a spacer coating with 3 V at the current density of 8 mA/s. During this study, we keep the set-up device in accordance procedural previous experiments [5, 8, 9]. The solution of ethanol and acetone used to cleanerization processes Cu-PCB substrate using Ultrasonic cleaner.

The composition of the electrolyte solution forming successive magnetic layers is NiSO\(_4\) \cdot 6H\(_2\)O (0.009 M), FeSO\(_4\) \cdot 7H\(_2\)O (0.012 M), H\(_2\)BO\(_3\) (0.149 M), C\(_6\)H\(_8\)O\(_3\) (0.002 M), and 120 ml of distilled water. While the composition of the solution forming a conductive spacer layer is Cu as CuSO\(_4\) \cdot 5H\(_2\)O (0.065 M), C\(_6\)H\(_{12}\)O\(_6\) (0.002 M), and 120 ml of distilled water [10]. In this study, the additive liquid H\(_2\)SO\(_4\) concentration of 0.1 M (± one drop) each added to two of the electrolyte solution to maintain the acidity of pH = 2.6 [10, 11]. In his book, Kanani (2004) explains that the function of the additive in electrodeposition process is as stabilizers, reducing agents, complexing agents and to maintain the pH of the electrolyte solution. Both electrolyte solution to be used pursued in condition fresh (new) and the room temperature is kept constant during the fabrication process progresses. The mechanism of the electrodeposition process is shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Experimental set up for electrodeposition of the multilayers [Ni\(_{80}\)Fe\(_{20}\)/Cu]).

The multilayered sample of electrodeposition results in annealing using an oven with a 10-minute stand-up time setup as well as the selection of temperature variations at 28 °C, 50°C, 75°C and 100°C. The characterization structure of [Ni\(_{80}\)Fe\(_{20}\)(800 nm)/Cu(200 nm)] is entirely determined by XRF and XRD analysis (not shown here). The set-up of MI measurement is presented by Figure 2.
3. Results and Discussion

Figure 2. The setup of magneto-impedance measurement for multilayer samples of [Ni$_{80}$Fe$_{20}$/Cu]$_3$.

Figure 3: (a),(c) the MI ratio curve at 100 kHz and (b),(d) MI ratio as functions of annealing temperature ($C^0$).
Figure 3 (a) (c) expressing the phenomenon of MI ratio as a function of the external magnetic field ($H$). In this study, the phenomenon of MI is observed in samples annealed at various temperature by looking at the change impedance ($Z$) caused by a magnetic field. The results are presented in the form of MI ratio curves. In the samples, the MI maximum is achieved when no external magnetic field is given (when $H$ is equal to zero). And then the increasing external magnetic field, MI ratio is obtained gradually decreases to approach the relative saturation value after $\pm 34.36$ Oe (measurements of the first day) and $34.62 \pm$ Oe (fifth day).

Overall MI ratio decreased significantly from samples without treatment of annealing with samples after annealing treatment up to 100 °C. The effect of this annealing treatment resulted in a decreased MI ratio of the first day measured from $\pm 7.6$ % to $\pm 4.7$ % and measured the fifth day from $\pm 6.39$ % to $\pm 4.25$ %. The identified MI ratios decreased by 0.61 and 0.66-fold during the measurement (samples with 100 °C annealing or without annealing treatment). The decrease MI ratio is believed to be due to transverse anisotropy fluctuations in the transverse direction of the sample [6]. In this discussion, the presence of the magnetic anisotropy of the sample may be related to the change in MI ratio values during the measurement activity. Samples without annealing proved to have greater MI ratios due to their small magnetic anisotropy. While the annealing process will reduce the magnetic transverse anisotropy in the sample and further increase the permeability according to Somer and Chein (1995).

In general, samples with high permeability is required to achieve a greater MI effect [3]. If the terms of this assumption given the annealing process will tend to increase the ratio of MI. However, this condition is not fully applicable since the fact that the ratio of MI was identified in this study is identical to decline and only on the sample at a temperature of 28 °C which MI ratio values greater than the given sample without annealing. The results were found is believed to be due to the consequences of the low frequencies ($f < 100$ kHz) measurement. The result is likely to be different if the sample is measured in the high-frequency range ($f > 1$MHz) [1].

MI ratio analysis shows the effect of different sample measurements on MI behavior. The MI ratio decreased significantly in the samples measured on the first day compared with measurements on the fifth day. The trend of MI ratio decline is believed to be due to degraded or contaminated samples by the environment causing microstructural changes in the sample. The measurement of MI ratio and the complete difference is shown in Figure 4

![Figure 4](image_url)

Figure 4. The difference in the measurement of the ratio of MI as a function of annealing temperature variations.
Another expression is shown in Figure 5 as the ratio of MI against frequency curves. Observed very clearly shows an MI curve typically the same as in the previous annealing temperature variation curve. The measured results obtained at several frequencies ranging from the MI ratio increased during the addition of frequency AC current. The maximum MI ratio was found 0.03 % during measurement at a frequency of 20 kHz. the MI ratio increased dramatically to 7.63 % when the frequency of 100 kHz. This means that the increase in the ratio of MI responded very well during the addition of the frequency ratio. Overall the ratio of MI increased ± 254.3 times over four times the measurement range (20 kHz to 100 kHz). This is indicated by the dominance of skin depth [1,2]. The smaller of the skin depth will be increased value of the sample resistance marked by increasing frequency. The resistance contributes predominantly in increasing the Z oriented impedance value of the MI ratio [8].

![Figure 5: (a) MI curve \([Ni_{80}Fe_{20}/Cu]\)_3 of the 20 kHz to 100 kHz on a frequency measurement, (b) MI ratio as function of frequency.](image)

4. Conclusion
The phenomenon of magnetoimpedance has been observed in thin film multilayers \([Ni_{80}Fe_{20}/Cu]\)_3 in low frequency range (f < 100 kHz). The MI ratio can be improved by increasing frequency. analysis of the measurement showed that the MI ratio decreased by increasing the annealing temperature (ºC) resulted the transverse anisotropy fluctuation in the sample.

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