A short review of magneto–impedance effect for biosensor

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Abstract. This short review paper is organized the following: a material with high magnetoimpedance effect, a various of the patterned in magneto-impedance sensor and biomagneto impedance application. Various of the magnetic material is presented such as a wire magnetic, ribbon, a magnetic thin films as well as multilayers structure. A pattern of the magneto impedance sensor is also presented in this paper. Finally, recently progress of the bio-magneto-impedance sensing biomagnetic fields of human are reviewed.

1. Introduction
The change in the impedance of the magnetic films conductor under the magnetic field as known the magneto-impedance effect complement the magnetic sensors that have existed before. This magneto-impedance phenomenon was first observed in FeCoSiB amorphous wire, which is explained as a result of the combination of skin-effect and circumferential permeability dependence with the magnetic field[1]. Magnetoimpedance also appears in multilayer magnetic material systems such as permalloy [2,3] and CoSiB [2] with copper and silver spacer layer. So, sample fabrication is possible by conventional methods such as melt spinning, Taylor wire process, electroplating, sputtering etc.

In its development, the magnetoimpedance ratio has increased dramatically so that it also increases sensor sensitivity. The sensitivity of the magneto impedance sensor is defined not only in relation to the high magnetoimpedance ratio, but also the maximum width of the half height of the curve. At present, the resolution of magnetoimpedance-based sensors reaches the order of pT, thus opening up opportunities for magnetic nano particle application, magnetic bead, gradiometer, and other biosensor applications. In addition, the magneto-impedance sensor is also applied in hybrid car technology [4,5]. The magneto impedance is a quantity that depends on dimensions, so modification of the geometry structure will change or affect the sensitivity of this sensor. In order to increase the magnetoimpedance ratio (or sensor sensitivity), the researchers modified the geometry of the thin layer of the sensor sample. Configuring this geometry structure also takes into account the desired sensor application [6–10]. The preparation of the magnetoimpedance sensors on flexible substrates is a one advantage that other types of magnetic sensors do not have[6].

In this paper, a brief review of magneto-impedance is presented. Review focus on the design of magneto-impedance sensor geometry. The bio-sensor application that has been carried out in the last few years is the next discussion. Conclusion remarked for the next research opportunity, closing this manuscript.

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2. Experimental Methods

Several sample preparation procedures for supplying magneto impedance samples have been presented in full by Phan and Peng [11]. With regard to practical application, fabrication methods based on vacuum sputtering systems followed by lithography procedures dominated in preparation of the nanometer-thickness-order multilayer systems as magnetoimpedance sensors. Because the impedance is the electrical quantity that depends on the geometry, the submicron-order of the sensor pattern can be reconstructed in the millimeter order on the printed circuit board using conventional methods. So, the magnetoimpedance sensor material can be prepared using the electrodeposition method. Moreover, the phenomenon of magnetoimpedance is still present until the order thickness of tens of micrometers.

![Sensor Design Magneto Impedance](image)

**Figure 1.** Schematic diagram of sensor design magneto impedance, (a-c) strip line configurations and (d-e) meander like configurations.

Figure 1 shows a schematic diagram of a lithographic pattern that is often used in magneto impedance sensors. Because alternating current flowing produces an induction field, the bias field between patterns significantly influences the magnetoimpedance ratio. These results have confirmed in previous studies. The magnetoimpedance ratio for measurements with a frequency of 100 kHz increases linearly with the increase in the number of lines, which is around 1.8% for the single line, and becomes 4.5% when the number of lines is four. Therefore, the meander like pattern is the best choice for researchers to present high-sensitivity magnetoimpedance sensors [12].

3. Result and Discussion: application of the biomagnetic measurement

![Schematic Diagram](image)

**Figure 2.** Schematic diagram of measuring magneto-impedance effects on a soft magnetic materials.

Figure 2 shows a schematic diagram measuring the magneto-impedance effect or giant Magneto Impedance (GMI) effect on samples of soft magnetic materials. The magneto impedance effect can be realized in soft magnetic materials in the form of magnetic amorphous ribbons, magnetic wires or thin/thin multilayers. While the GMI measurement frequency used is starting from kilohertz (kHz) to
Giga Hertz (GHz). Here, the measurement frequency may modify the skin depth and also transverse permeability of the material, with the result of the magneto impedance changes [11].

In general, the ratio of the giant magneto impedance is defined as

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

where \( Z(H) \) and \( Z(H_{\text{max}}) \) is the total impedance when the magnetic field is applied \( H \) and the total impedance when the magnetic field is maximum (\( H_{\text{max}} \)). More detail, the magneto impedance can be expressed in the reactance component and its resistance as follows

\[
\frac{\Delta X}{X} = \frac{X(H) - X(H_{\text{max}})}{X(H_{\text{max}})} \times 100\%  \tag{2}
\]

\[
\frac{\Delta R}{R} = \frac{R(H) - R(H_{\text{max}})}{R(H_{\text{max}})} \times 100\%  \tag{3}
\]

Where \( X(H) \) and \( X(H_{\text{max}}) \) is the total impedance when the magnetic field is applied \( H \) and \( H_{\text{max}} \). Analog to reactance, \( R(H) \) and \( R(H_{\text{max}}) \) is the resistance under magnetic field \( H \) and \( H_{\text{max}} \). Equation 1 is known as the first or fundamental harmonic characteristic. While equations 2 and 3 are evaluations of magnetoimpedance from the real and imaginary components.

Figure 3 shows the fundamental definition of detecting bio–source–object. When the bio–source–object is not a magnetized material, the present of the sample reduce the ratio of the magneto-impedance. Contrary, when the magnetic nano particle or the bio-magnetic-source object present, the ratio of the magneto-impedance effect increase. Beato-López et al reported that the change in the magnetoimpedance ratio was \( \sim 1\% \) after the addition of distilled water. While the magnetoimpedance ratio increases \( \sim 6\% \) after the addition of magnetic nano particle[13]. This change in the magnetoimpedance ratio is dominated by a component of reactance rather than resistance. This change is caused by the field effect generated by magnetic nano particles on the transverse permeability magnetic of the GMI sensor[14].

![Figure 3](image-url)
3.1. Detection of Cardiac Magnetic Activity
Conventional cardiac activity is evaluated through electrocardiogram (ECG) measurements. Now, the sensitivity of the magneto impedance sensor in the range of the Tesla order pico. The electric signal of the cardiac activity will result a nT (nano tesla) order magnetic field, so that heart activity can be observed by pulse driven magneto impedance namely as a magnetic cardigram (MCG) signal. Nakayama et al. have successfully demonstrated cardiac activity using pulse driven magneto impedance sensors. EMG signal patterns are similar to ECG signals. The ECG amplitude is in the range of mV while EMG is in the tesla nano range [4].

3.2. Magnetoecephalogram
As is well known that between brain cells is communicated through electrical signals which present an order of pico Tesla magnetic fields as bio-magnetic-source. The presence of magneto impedance sensors with the resolution and sensitivity of the pico Tesla order can describe brain activity, for example when the eyes are closed and open. Uchiyama et al. have succeeded in recording brain activity by measuring magneto impedance gradiometer, which is to place MI sensors perpendicularly as far as 5 millimeters at the back of the head with no shield environmental conditions. The observed magnetic field signal pattern is different when the eyes are closed and open with an amplitude of ~ 500 pT [5]. This is a new breakthrough in the modern technology that can replace SQUID-based technology which is relatively more expensive in operational and maintenance.

3.3. Bio-magnetic source in the living cell tissue
In order to observe bio-magnetic sources, Uchiyama et al. used the guinea pig stomach muscles in the experiment. The sample is placed in a glass preparation and put on the head of the magneto impedance sensor. For comparison, an electric field that reflects a longitudinal direction field is also observed simultaneously. The results show that the shape of the electric field signal ranges from 250 \( \mu V \) corresponding to the biological source magnetic field signal ranging from 450 pT [5].

3.4. Bioanalyte alpha-fetoprotein (AFP) detection
Detection of alpha-fetoprotein (AFP), as a very sensitive indicator of hepatocellular carcinoma and primary liver cancer, is crucial for medical diagnosis. So that it becomes a necessity for a responsive and sensitive device to detect AFP. Guo et al. utilized magneto impedance sensors for detection of dynabead-labeled AFP biomarkers. The sensitivity of the magneto impedance sensor is defined as the difference in the magneto impedance ratio before and after the presence of an AFP sample. For evaluation of concentrations up to 1000 \( \mu g/ml \), sensitivity increases linearly with an increase in AFP concentration[8]. Furthermore, the system has a highly specific detection capability for AFP.

4. Conclusion
A brief review of magneto impedance sensors has been presented. The discussion is organized the following: a material with high magnetoimpedance effect, a various of the patterned in magneto-impedance sensor and bio-magneto impedance application. Various of the magnetic material is presented such as a wire magnetic, ribbon, a magnetic thin films as well as multilayers structure. A pattern of the magneto impedance sensor is also presented in this paper. Finally, this review opens up opportunities for the use of magneto impedance sensors to detect other bio-magnetic sources.

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