

Effect of Coating and Annealing on Giant Magneto Impedance in Co and Fe-Based Amorphous Wires

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Abstract
Effect of coating with different chemical complexes on giant magneto impedance effect (GMI) was experimentally investigated in Fe and Co-based amorphous wires. The successive ionic layer adsorption and reaction (SILAR) technique was used for coating of the samples at room temperature. The SILAR method mainly based on adsorption and reaction on the ions from the solution and rinsing. Co and Fe-based amorphous wires were coated with CoO, asphaltene and ZnO chemical complexes. The coating thickness was determined to be about 1 μm thick. Maximum GMI ratio for Co and Fe-based samples were measured at 4 MHz and 5 MHz frequency, respectively.
Influence of annealing at different temperatures on GMI effect was also experimentally investigated in the same samples. The coated samples were annealed at 300 °C, 400 °C, 500 °C and 600 °C temperatures in order to stress relief for 30 minutes. It is observed that the GMI ratio on Co- and Fe-based ZnO coated samples was highest at 500 ºC, while it was maximum on CoO coated Co-based samples at 400 ºC and on CoO coated Fe-based samples at 500 ºC.
The highest GMI ratio among the measured samples was detected as 216 on the Fe-based, ZnO coated and annealed sample at 500 ºC at 5 MHz, while the smallest GMI ratio, was found to be as 88 on Co-based as-cast sample at 4 MHz. The measurements show that the GMI ratio is a combined effect of coating, annealing and frequency of ac current in a static magnetic field.

Keywords Amorphous magnetic materials, SILAR technique, giant magneto impedance.

Special Issue of Educational Sciences

DOI: 10.7176/JSTR/6-06-03

1. Introduction

GMI effect is termed as the giant variation of impedance of a ferromagnetic conductor with an ac current in an applied dc magnetic field [1]. The origin of GMI effect is related to classical effect, which refers to the fact that an applied ac current of high frequency concentrates mainly on the outer part of the magnetic material [2]. The GMI effect of Fe-based amorphous wire has attracted great attention and studied due to its important applications such as magnetic sensor and recording head. Impedance of Co and Fe-based amorphous wires changes with static magnetic field (H_{dc}) [3]. This expressed in GMI% ($\Delta Z/Z$) is defined by the largest value of the ratio;

$$\frac{\Delta Z}{Z}\% = \frac{Z(H)-Z(H_m)}{Z(H_m)} x100 \qquad (1)$$

where H_m maximum dc applied field which is ± 8 kA/m produced by a solenoid as shown in Fig. 1.
The SILAR method is relatively a novel method, first reported in 1985 by Ristov et al [4]. The SILAR technique is a suitable method for making uniform coating for Co and Fe-based amorphous wires. This method is mainly based on the absorption and reaction of the ions from the solution and rinsing between every immersion with deionised water to avoid homogeneous precipitation in the solution [5, 6] shown as in Fig. 2. The method does not require high quality substrates, the deposition rate and the thickness of

the film can be easily controlled over a wide range with changing the deposition cycles, there are virtually no restrictions on substrate material, dimensions or its surface profile; moreover, it is convenient for large amount of deposition [7].

The best conditions for the oxides ZnO, CoO, Asphaltene, coated to the sample, were 0.1 molar concentration, about 12-pH value and at 80 ºC temperature. It was four cycles for coating as shown in Fig.2 and the time period for coating was 8, 25, 25 and 8 seconds in each coating cycle. This process was repeated 30 times to obtain desirable coating

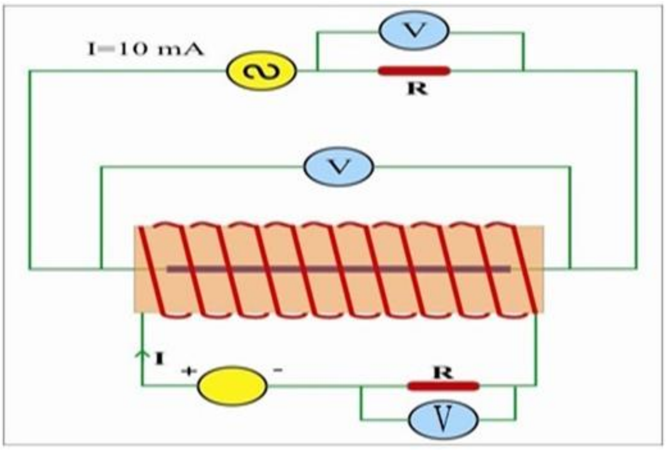


Fig. 1. Experimental schematic measuring system.

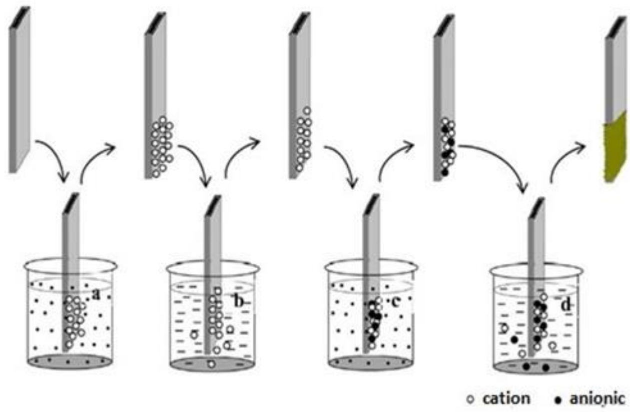


Fig. 2. Schematic diagram of SILAR method.

thickness, which is about 500 nm. Finally, the detail characterization of surface coating like homogeneity, thickness, etc. was carried out using the AFM and SEM [3, 5]. This research is concentrated on the effect of coating and annealing on the GMI effect under ac current passing thorough the near zero (AC-20) and high magnetostriction (AF-10) amorphous wires in static magnetic field.

2. Experimental measurements

CoO, ZnO and asphaltene coated Co and Fe-based amorphous wires with the diameter 125 µm, 120 µm and 12 cm long were used for the GMI ratio measurements. The Co-based (AC-20) amorphous wire has a $Fe_{4.3}Co_{68.2}Si_{12.5}B_{15}$ chemical formula and near zero magnetostriction, while Fe-based (AF-10) amorphous wire has a $Fe_{77.5}Si_{7.5}B_{15}$ chemical formula and $35x10^{-6}$ saturation magnetostriction. A conventional setup was designed to measure the GMI ratio. The voltage drop across the sample was measured using a selective digital multimeter model HP-3458A made by Agilent Technology. An ac excitation signal was obtained from a function generator model HP-33250A in the range of 0.01-9.0 MHz. A dc axial magnetic field was produced by a long solenoid connected to a dc current source. The

ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/6-06-03
Special Issue of Educational Sciences, Vol.6, No.6, 2020

magnetic field in the solenoid was calculated using the voltage drop across a series non-inductive resistor connected to the solenoid. The ac current passing through the wire was kept constant at 10 mA using a commercial power amplifier during the sweep of the dc axial field while the impedance changed. The samples are carefully located and fixed in the middle of the solenoid, which the magnetic field is uniform. An air-drying silver conductive paint was used to obtain better contact between the sample ends and connection wires [8]. The optimum operation frequency was defined for all coated Co and Fe based samples and the highest GMI ratio were also defined for the CoO and ZnO coated samples. Samples were annealed at varied temperatures such as 300 ºC, 400 ºC, 500 ºC and 600 ºC respectively for stress relief and 30 minutes to understand the annealing-stress effect on the GMI ratio.

3. Results and Discussions

The GMI effect can be improved by measuring at a reasonable frequency that gives maximum enhancement without magnetisation. In general, the coating the sample surface with different complex thin film has improved the GMI ratio at all frequencies. However, there exists an optimum frequency, where the GMI ratio was maximum for the sample investigated. It was about 4.0 and 5.0 MHz for Co-based and Fe-based samples respectively, shown as in Fig. 3 and Fig. 4. The GMI ratio was measured on the Co-based near zero magnetostriction as-cast, CoO, asphaltene and ZnO coated amorphous wire samples. The highest GMI ratio was detected on ZnO coated sample. It was about 221% as compared with as-cast uncoated sample and then, CoO and asphaltene coated samples were followed respectively [Fig. 3].

Maximum GMI ratio was recorded on the Fe-based ZnO coated and without annealed sample, it was 147% higher than as-cast sample measured and then, CoO and asphaltene coated samples were followed. When the GMI ratio was evaluated among the Co-based and Fe-based untreated amorphous wires, which have near zero and high magnetostriction values respectively the Fe-based (AF-10) amorphous wire has higher GMI ratio, which was 235% than the Co-based (AC-20) amorphous wire [Fig. 4]. This behavior can be attributed to intrinsic magnetic properties of the sample such as magnetic domain wall movements, magnetostriction and anisotropy of the material [1].

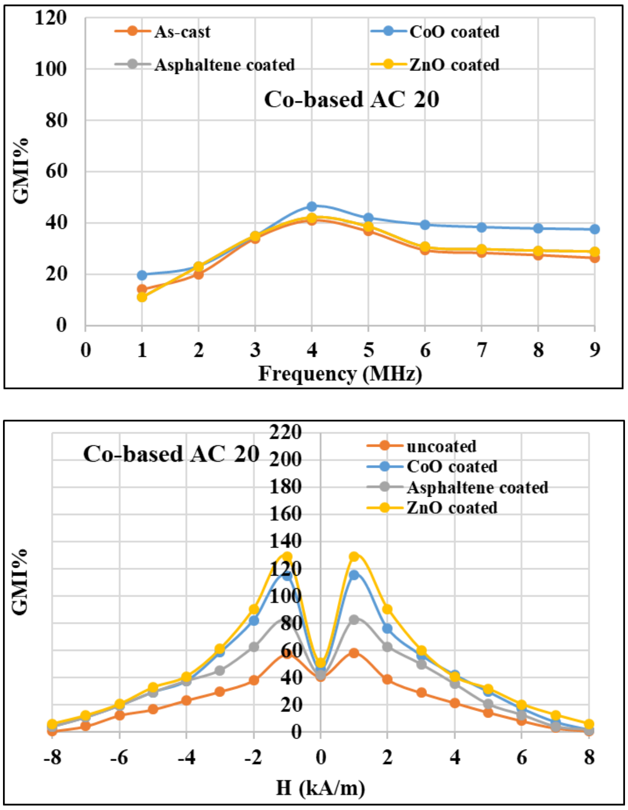
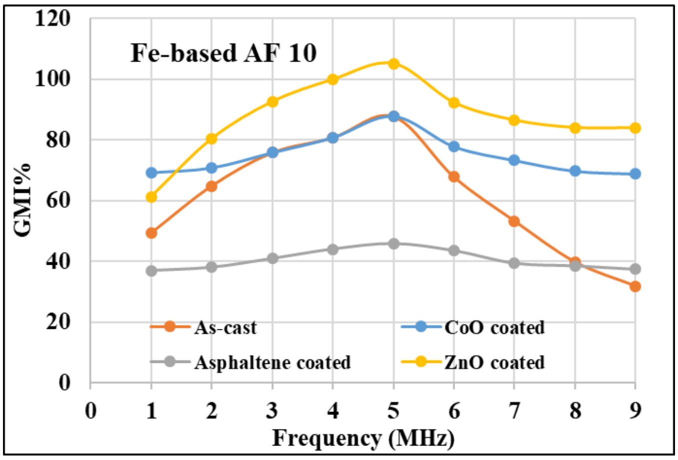


Fig. 3. Variation of GMI ratio with frequency of excitation current under constant static magnetic field (left) and magnetic field at 4 MHz (right) for Co-based amorphous wire.

The frequency of excitation current has much less pronounced on sensitivity of GMI ratio, while the chemical composition of sample has a significant effect, which means that the sample with high magnetostriction has high GMI ratio as compared with the sample with near zero magnetostriction. Fig. 5 shows variation of the GMI ratio with dc magnetic field on CoO coated Co-based and Fe-based amorphous wires at different annealing temperatures. The highest GMI% was obtained at 400 ºC for both samples. The GMI ratio was 187% higher than as-cast sample on Co-based sample, while it was 149% on Fe-based sample at 400 ºC annealing temperature. However, the highest GMI ratio, which was 162% high, was measured on Fe-based sample as compared with Co-based sample.
A similar trend was obviously obtained on ZnO coated Co-based and Fe-based amorphous wires at different annealing temperatures as shown Fig. 6. For these samples the GMI ratio was 134% higher than as-cast sample on Co-based sample, while it was 173% on Fe-based sample at 500 ºC annealing temperature. Nevertheless, the highest GMI ratio, which was 147% high, was recorded on Fe-based sample as compared with Co-based sample.



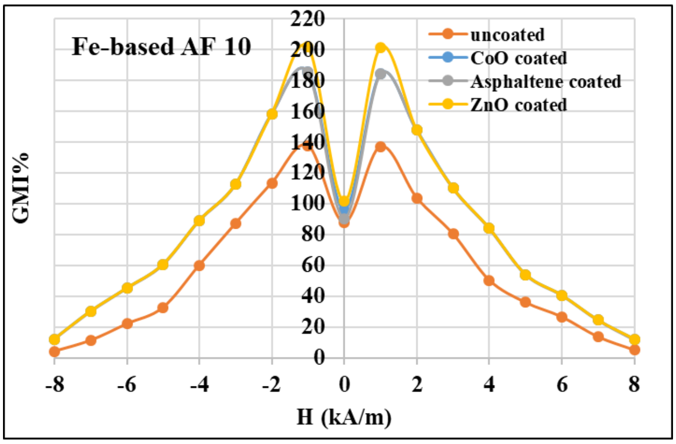


Fig. 4. Variation of GMI ratio with frequency of excitation current under constant static magnetic field (left) and magnetic field at 5 MHz (right) for Fe-based amorphous wire.

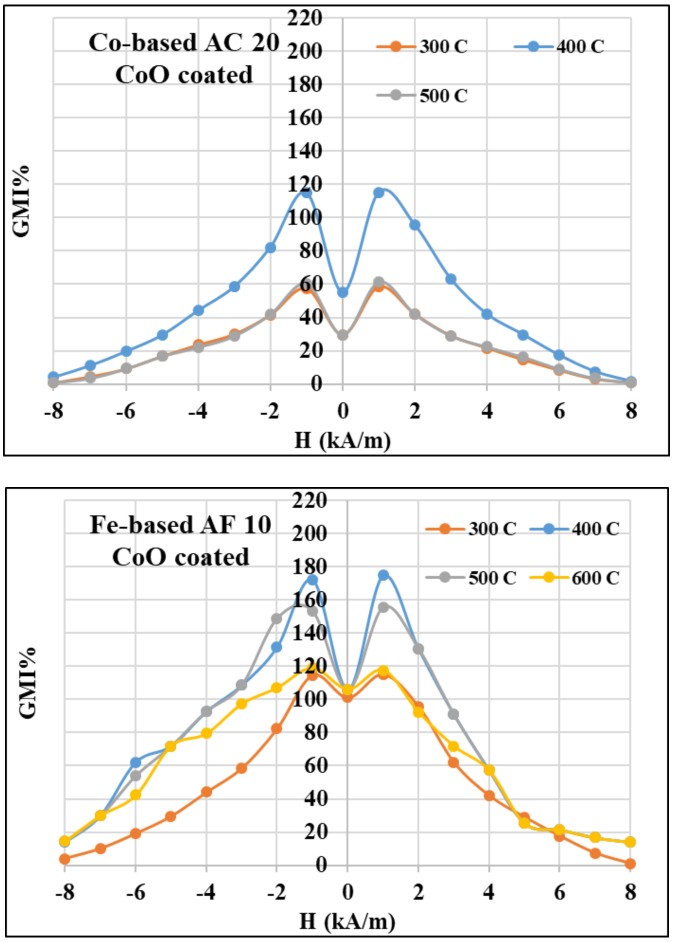


Fig. 5. Variation of GMI ratio with static magnetic field for Co-based (left) and Fe-based (right) CoO coated amorphous wires with different annealing temperatures.

The results show that the GMI ratio is a combined effect of coating, annealing and frequency of exciting current under static applied magnetic field. It can be attributed to the intrinsic magnetic properties of the sample such as domain wall movements, magnetostriction and anisotropy of material. It is difficult to understand clearly, which effect is more dominant on the GMI effect. However, the highest GMI ratio among the investigated samples at 5 MHz was detected on the sample, which is the Fe-based, high magnetostriction, ZnO coated and annealed at 500 ºC, while the smallest GMI ratio was found to be on Co-based, near zero magnetostriction as-cast sample at 4 MHz.
Table 1 summarizes the measured samples and treated methods. It can be understood from the evaluation of Table 1 that the sample, which is Fe-based, high magnetostriction, ZnO coated and annealed at 500 ºC measured at 5 MHz is more sensitive to the magnetic field and suitable for defined sensors applications.

ISSN 2422-8702 (Online), DOI: 10.7176/JSTR/6-06-03
Special Issue of Educational Sciences, Vol.6, No.6, 2020

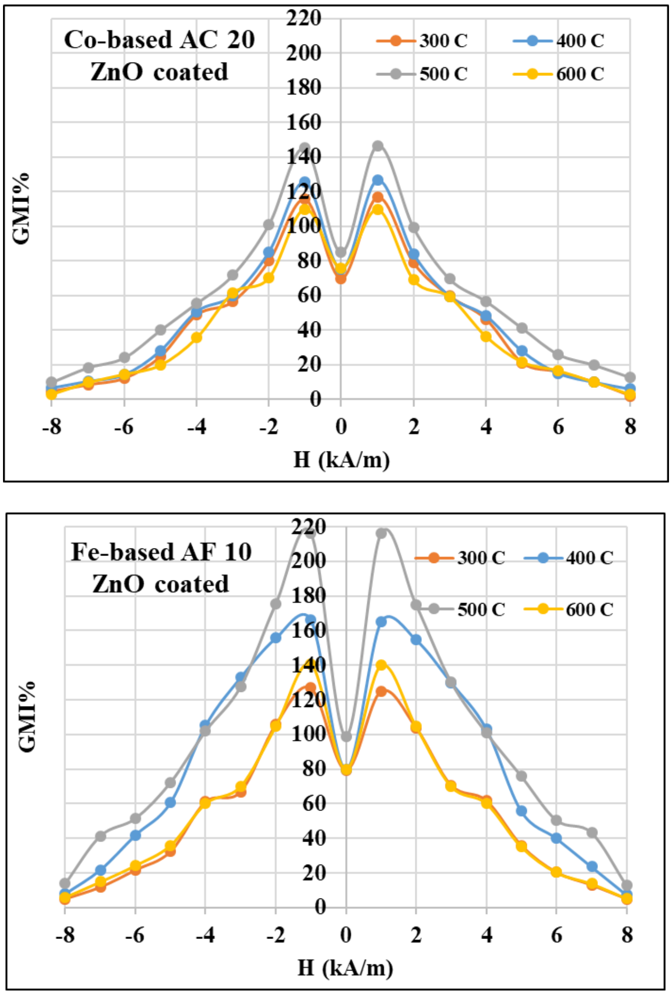


Fig. 6. Variation of GMI ratio with static magnetic field for Co-based (left) and Fe-based (right) ZnO coated amorphous wires with different annealing temperatures.

Table 1. Summary of GMI % ratios for as-cast and treated Co and Fe based samples.

Sample No	Chemical composition	Coating material	Operating frequency (MHz)	Annealing temperature	Max. GMI ratio (as-cast)	GMI ratio (coated)
1.	$Fe_{4.3}Co_{68.2}Si_{12.5}B_{15}$	CoO, ZnO, Asphaltene	4	No annealing	58	129 (ZnO)
2.	$Fe_{77.5}Si_{7.5}B_{15}$	CoO, ZnO, Asphaltene	5	No annealing	137	201 (ZnO)
3.	$Fe_{4.3}Co_{68.2}Si_{12.5}B_{15}$	CoO, ZnO, Asphaltene	4	400 °C	58	145 (ZnO)
4.	$Fe_{77.5}Si_{7.5}B_{15}$	CoO, ZnO, Asphaltene	5	400 °C	137	203 (ZnO)
5.	$Fe_{4.3}Co_{68.2}Si_{12.5}B_{15}$	CoO	4	300 °C, 400 °C, 500 °C	58	115 (400 °C)
6.	$Fe_{77.5}Si_{7.5}B_{15}$	CoO	5	300 °C, 400 °C, 500 °C	137	175 (400 °C)
7.	$Fe_{4.3}Co_{68.2}Si_{12.5}B_{15}$	ZnO	4	300 °C, 400 °C, 500 °C, 600 °C	58	147 (500 °C)
8.	$Fe_{77.5}Si_{7.5}B_{15}$	ZnO	5	300 °C, 400 °C, 500 °C, 600 °C	137	216 (500 °C)

4. Conclusions

The highest GMI ratio was obtained at exciting frequencies of 4 MHz for Co-based and 5 MHz for Fe-based amorphous wires. The exciting frequency is not depended on coating or annealing of the sample. The GMI effect sensitively depends on not only the post-production treated process such as coating and annealing, but also exciting frequency and applied magnetic field. This behavior can be attributed to the intrinsic magnetic properties of the sample, which are domain wall movements, magnetostriction and anisotropy. As the highest GMI ratio among the measured samples was detected on the Fe-based, high magnetostriction, ZnO coated and annealed at 500 °C sample, these conditions are optimum to detect sensitively the magnetic field and suitable for designing a GMI sensor at desired applications.

Acknowledgment

The author would like to thank Dr. Osman Caylak for collecting experimental data. This work was supported by Bursa Uludag University Research Grant No. BAP 2009/29. The author would also like to thank for this support.

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ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/6-06-03
Special Issue of Educational Sciences, Vol.6, No.6, 2020

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