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Physics Procedia 54 (2014) 16 – 22

Physics Procedia

International Conference on Magnetic Materials and Applications, MagMA 2013

Giant Magnetoimpedance (GMI) Effect and Field Sensitivity of Ferrofluid Coated $Co_{66}Fe_2Si_{13}B_{15}Cr_4$ Soft Magnetic Amorphous Microwire

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Abstract

$Co_{66}Fe_2Si_{13}B_{15}Cr_4$ based amorphous microwire was developed at the laboratory using in-water quenching apparatus. The field sensitivity of the wire was enhanced when coated with ferrofluids. The presence of coating also decreased the frequency of the magnetising field 5MHz to 1MHz at which the maximum GMI ratio observed.

Keywords: Amorphous microwire; Quenching, Field Sensitivity; Ferrofluid. GMI, Magnetizing field

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1. Introduction

doi:10.1016/j.phpro.2014.10.031

The Giant Magnetoimpedance (GMI) effect in soft magnetic materials witnessed substantial attention to the scientific community due to its fundamental and technological reasons [1, 2]. It has become more attractive when the magnetic materials are of composite structures consisting of more than one layer [3] in the recent times. It is demonstrated that the GMI effect significantly increases in these composite structures consisting of more than one layer. It also lowers the driving frequencies compared to their single layers counterparts of the magnetizing field at which maximum GMI ratio observed [4]. From the application perspective, composite microwires have been found to be most promising candidates for developing high performance GMI sensors and sensing devices operating at low and intermediate frequencies. In recent investigations, focuses are being paid on the chemical and biological sensors [5, 6]. Biological sensors incorporate a biologically derived sensitive element embedded with a physical transducer. Most of the previous researches on composite wires have been documented pertaining to scientific and fundamental aspects of the GMI phenomena with special reference to ferromagnetic and non-magnetic coating. A special advantage of this present attempt is its application for in-situ measurement during fabrication of biomaterials with high level attraction with nanoparticles employed as biomolecular level.

2. Experimental

A soft magnetic amorphous microwire of diameter ~ 100 μm consisting nominal composition $Co_{66}Fe_2Si_{13}B_{15}Cr_4$ (at %) was prepared by in-water quenching technique [8,]. A length of ~ 3 cm of the microwire was taken for the study. It was cleaned by distilled water carefully before being immersed in low concentrated poly vinyl alcohol (PVA) for 5 hours. An amount of ~ 100 ml ferrofluid [9] (synthesized through a patented process; A biomimetic process for the synthesis of aqueous ferrofluids for biomedical applications; S Nayar, A Shinha, A. K. Pramanik; India, Oct, 2009; Pat. No.: 0672DEL 2010) was taken in a non-magnetic glass beaker and the microware was dipped in the beaker. The beaker was placed on an electromagnetic stirrer for one hour and the temperature was kept constant during this entire period. The microwire was dried under an IR heating source before being used for GMI investigation. The GMI properties of the microwire (diameter ~ 100 μm and length ~ 3 cm) were evaluated by four probe technique through automated GMI measurement system. In this system, ac excitation was provided by an impedance analyzer (Agilent 4294A). The wire was positioned at the centre of the Helmholtz coil as well as perpendicular to the earth's magnetic field. The Helmholtz coil was excited by bi-polar power supply (BOP -20) under the control of a flux meter (Lakeshore 480).The magnetic field was measured by a Gaussmeter (Lakeshore 450).The set-up was automated through RS-232 port and LAN. LabVIEW 2010 and VISA 5.0.3 were used to develop the software program. The GMI ratio and the field sensitivity of GMI were calculated using the following relations

$$\frac{\Delta \mathrm{Z}}{\mathrm{Z}} = \frac{\mathrm{Z(H)} - \mathrm{Z(H_{sat})}}{\mathrm{Z(H_{sat})}} \times 100 \qquad (1)$$

$$\eta = \frac{d}{dH}\left(\frac{\Delta Z}{Z}\right) \qquad (2)$$

where *Z(H)* and $Z(H_{sat})$ represent the impedance in a magnetic field H and saturated magenetic field respectively.

3. Results and Discussions

The giant magnetoimpedance properties of as-cast and ferrofluid coated $Co_{66}Fe_2Si_{13}B_{15}Cr_4$ microware was obtained in the presence of an ac driving current of 5 mA and plotted in Fig. 1.

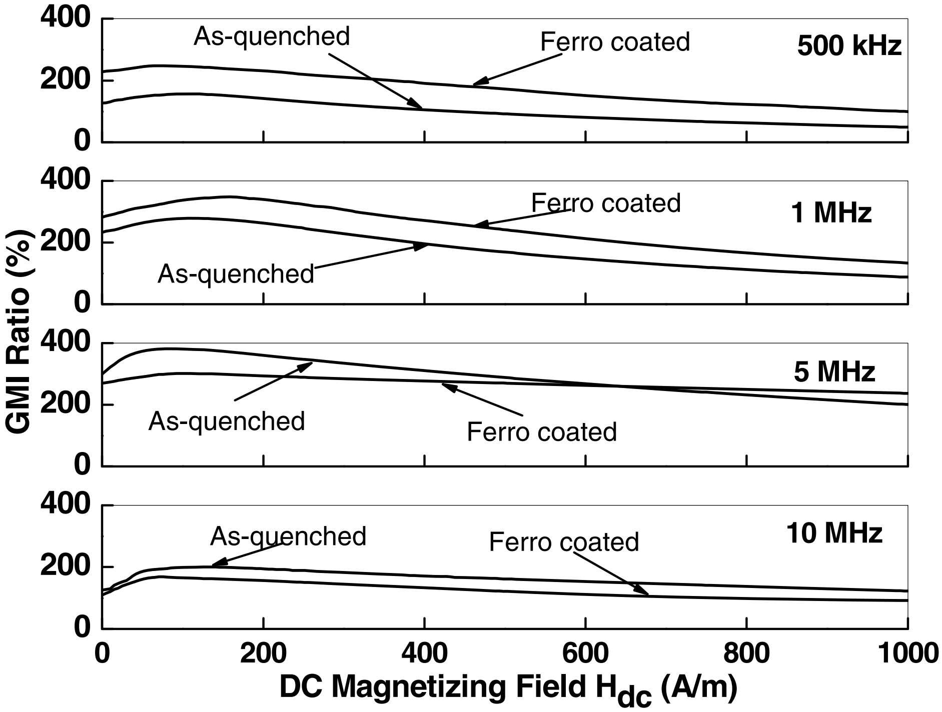

Fig. 1: GMI ratio of as quenched and ferrofluid coated microwire as a function of magnetizing field.

It was observed from Fig. 1 that the GMI ratios on increasing the driving frequency, the maxima of GMI ratio, $(GMI)_{max}$, of the as quenched microwire increased upto 5 MHz beyond which there was a drop in GMI_{max}. In the present case, it is expected that in the frequency of 500 kHz - 5 MHz, both domain wall and magnetisation rotation contribute to the effective circular permeability [6, 7] and thus increase in GMI. However, beyond 5 MHz domain wall motion is damped by eddy current with a corresponding reduction in circular permeability. On the other hand, on increasing the driving frequency, the GMI_{max} of the ferrofluid coated microwire increased upto 1 MHz beyond which there was a drastic drop in GMI_{max} as shown. It was also observed that, GMI_{max} of ferrofluid coated microwire is higher than its as-quenched counterpart at frequencies 500 kHz and 1 MHz. These consequences can be attributed to the cross sectional current distribution under the influence of external magnetic field and the electromagnetic interaction between the ferrofluid layer and the microwire. This electromagnetic interaction is expected to determine the current distribution over the cross section at a certain frequency.

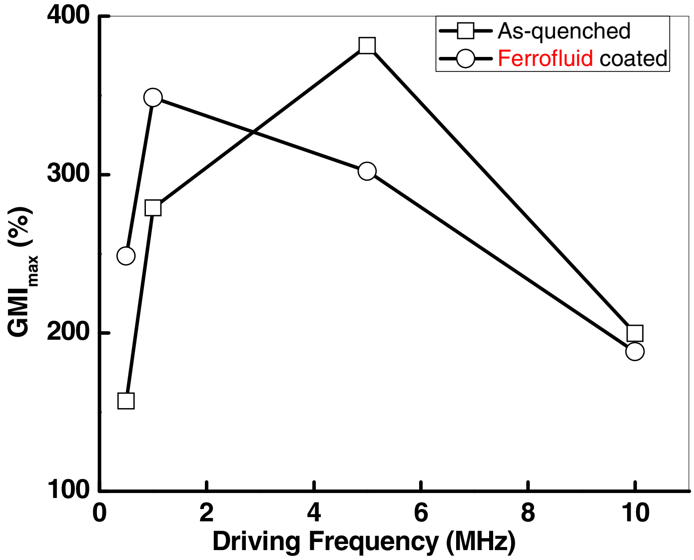

Fig. 2: GMI_{max} as a function operating frequency of as-quenched and ferrofluid coated microwire.

In order to observe the GMI sensitivity $(GMI)_S$ the GMI ratio was normalized with respect to the zero-field value and shown in Fig.3. It was observed that the field sensitivity of the ferrofluid coated microwire was higher (0.35 %/ Am^{-1} and 0.46 %/ Am^{-1}) at frequencies 500 kHz and 1 MHz respectively than the as quenched counterpart (0.14 %/ Am^{-1} and 0.18 %/ Am^{-1})

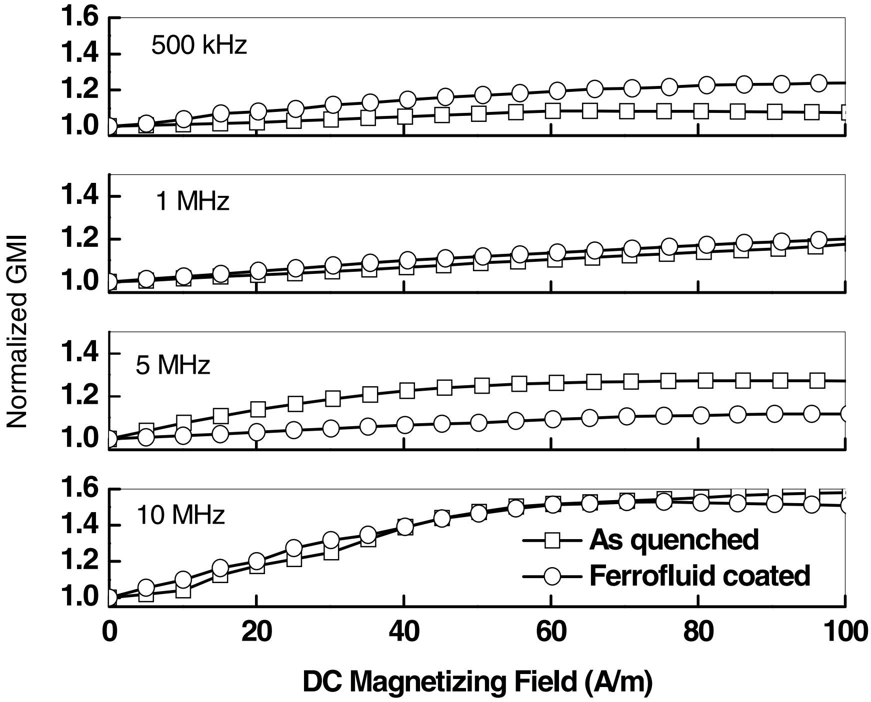

Fig. 3: Normalized GMI of as-quenched and ferrofluid coated microwire as a function magnetizing field

There has been a constant effort in the present decade to focus more on application criteria of the GMI technology. The potential applications involve development of sensor for magnetic field detection or non-destructive evaluation of degradation in materials that occur in components during extended period of service [17, 18]. Such applications indeed demand high sensitivity of the GMI sensor materials as well as optimum driving frequency. To meet such requirement, the sensor should operate at lower driving frequency alongwith optimum performances. Table 1 summarizes the GMI_{max} and field measured sensitivity at different frequencies of as-quenched and ferrofluid coated microwire. The table indicates that at much lower frequency (1 MHz), the GMI_{max} (349 %) and field sensitivity (0.46 %) of the ferrofluid coated microwire is optimum. Thus, from the application point of view, ferrofluid coated microwire has distinct advantages over their as- quenched counterpart in terms of ease in designing the sensors, lowering electromagnetic interference/electromagnetic compatibility (EMI/EMC).

Table 1: Maximum GMI ratio and sensitivity of As-quenched and ferrofluid coated sample

Operating Frequency	500 kHz		1 MHz		5 MHz		10 MHz	
Sample	GMI_{max} (%)	Sensitivity (%)	GMI_{max} (%)	Sensitivity (%)	GMI_{max} (%)	Sensitivity (%)	GMI_{max} (%)	Sensitivity (%)
As-quenched	157	0.14	279	0.18	381	0.56	199	1.06
Ferrofluid coated	249	0.35	349	0.46	302	0.16	188	0.94

4. Conclusion

$Co_{66}Fe_2Si_{13}B_{15}Cr_4$ based amorphous microwire was developed at the laboratory using in-water quenching apparatus. The field sensitivity of the wire was enhanced when coated with ferrofluids. The GMI_{max} and field measured sensitivity at different frequencies of as-quenched and ferrofluid coated microwire. It can be inferred that at relatively lower frequencies, the ferrofluid coated microwire showed optimum value. Thus, from the application point of view, ferrofluid coated microwire has distinct advantages over their as-quenched counterpart in terms of ease in designing the sensors, lowering electromagnetic interference/electromagnetic compatibility (EMI/EMC).

Acknowledgement

The authors express sincere gratitude to Director, CSIR - National Metallurgical Laboratory, Jamshedpur for kindly giving permission to publish the work.

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