Magnetic Characteristics of Nanocomposites Fabricated from Nanoparticles Embedded in Transparent Organic Resins

Sohaib S. Ahmed, Rand B. Lutfi, Hayder G. Fahad, Oday A. Hammadi*

Department of Physics, College of Education, Al-Iraqia University, Baghdad, IRAQ
Email: oday.hammadi@aliraqia.edu.iq

Abstract
In this letter, magnetic nanocomposites were fabricated by embedding Co_3O_4 nanoparticles at different weight percentages (2, 6, 10, 15, and 20 wt.%) in transparent resin matrix to develop magneto-optic sensors. The magnetic properties of these samples were studied under laser irradiation and the remaining magnetization after irradiation was also measured. The results showed that these properties depend on the nanoparticles content as the sample with higher content exhibited lower normalized magnetization and higher remaining magnetization due to the localized heating resulted from enhanced laser energy absorption by the nanoparticles and thermal saturation condition after relatively long time after irradiation.

Keywords: Nanocomposites; Magneto-optic effect; Nanoparticles; Metal ferrite
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1. Introduction

Magnetic nanocomposites (MNCs) are one of the most important achievements of nanotechnology as they combine the characteristics of conventional magnetic materials and the advantages of nanoscale materials. Such combination provides superior performance and adjustability of structural and functional characteristics [1-5]. The significance of MNCs can be seen in their various applications ranging from medical to environmental and industrial fields [6-8]. The magnetic characteristics allow guiding samples of MNCs remotely using an external magnetic field, therefore, they represent ideal tools guided drug delivery towards the cancer cells without affecting the surrounding tissues [9]. They also act as contrast agents in the magnetic resonance imaging (MRI) to enhance the diagnosis resolution [10]. These MNCs are used in magnetic isolation of cells and biomolecules and localized thermal treatment of tumors throughout generating heat under the effect of periodic field [11]. MNCs can be used as effective absorbing agents to remove heavy pollutants and organic materials from water as they can be easily restored and reused using magnet. This would reduce the cost and limit secondary pollution [12-15].

MNCs fabricated by incorporation of magnetic nanomaterials in transparent organic resins represent an ideal platform to develop magneto-optic sensors combining the flexibility, optical transparency, and controllable magnetic response of the polymer to convert the variations in magnetic field into high-accuracy measurable optical signals [16]. The main value of these nanocomposites is observed in their ability to modify their refractive index and polarization angle when subjected to a magnetic field, which is known as Faraday's effect [17]. This make the MNCs a base for optical fiber sensors (OFS) used to measure high-voltage electric currents remotely, to monitor electrical transformer quality, and to detect failures in smart networks [18-20]. These MNCs show lightweight, easy formation as thin films or flexible fibers, easy incorporation into smart structures, magnetic-sensing coatings employed in robotics and virtual reality devices to respond to the hand motion [21].

The employment of transparent resins provides mechanical toughness and chemical stability with possibility to modify the concentration and size of nanoparticles to control the sensitivity and measuring range [22]. They can merged with compact optical circuits to fabricated magneto-optic switches and insulators operating in the visible and IR regions [23].

In this work, magnetic nanoparticles (Co_3O_4) were embedded with different weight percentages into transparent organic resin to fabricated compact MNCs. The magnetic characteristics of the fabricated samples under the effects of magnetic field and incident light was introduced to show their feasibility in practical applications as magneto-optic sensors.

2. Experimental Part

The solid host medium was made from epichlorohydrin resin with 1x1x1 cm^3 dimensions. This resin is totally optically transparent and can be solidified within 24 hours after mixing the epoxy with the hardener with mixing ratio of 3:1 in room temperature. The mixture was sonicated for 15 minutes to remove all bubbles formed during mixing step. The nanocomposite samples were fabricated by embedding cobalt oxide (Co_3O_4) nanoparticles with average particle size of 25 nm in the resin host. Six different weight percentage were used (2 wt.%, 6 wt.%, 10 wt.%, 15 wt.%, and 20 wt.%). The sample was sonicated for 15 minutes to ensure homogeneous distribution of nanoparticles in the host. Figure (1) shows these samples.

Fig. (1) A photograph of the nanocomposite sample fabricated in this work with different weights of Co_3O_4 NPs in the transparent resin host (from left to right: 0%, 2%, 6%, 10%, 15%, and 20%)

To perform the experimental measurements on the fabricated samples, different permanent magnets with different magnetic field intensities (H) were used as sources of the external magnetic field, while a precise Gaussmeter was used to record the intensity. A 1 mW diode laser operating at 530 nm wavelength was used as the irradiation source.

3. Results and Discussion

Figure (2) shows the variation of normalized magnetization (M/M_0) with laser irradiation time of the samples fabricated with different weight percentages. The sample of 0% weight percentage nanoparticles were not included as it didn't exhibit any magnetic activity within the range of magnetic field intensity used in this work. Initially, the normalized magnetization exhibited a rapid decrease during the first two minutes of irradiation, then kept gradual decrease to reach minimum values after 6 minutes or longer irradiation time. This behavior is attributed to the localized heating effect resulted from the absorption of laser beam energy by the nanoparticles, which leads to increase the temperature of the polymeric matrix and decrease the magnetic momenta of the nanoparticles [24]. Partial phase transformations or redistribution of electronic hybridization may be occur as well. It is clear that increasing the weight percentage of the Co_3O_4 nanoparticles caused to accelerate the decrease in normalized magnetization. The sample of 20 wt.% nanoparticles showed lower than 0.03 normalized magnetization, while the sample of 2 wt.% nanoparticles showed 5 times the values (~0.15) after 10 minutes irradiation. This reveals that the higher content of nanoparticles enhances the thermal-photonic conversion efficiency as well as demagnetization rate. All samples shows linear decrease during the initial duration of irradiation, which confirms the concentration-dependent variation of normalized magnetization. The final slow variation means that the system approaches the thermal saturation condition or stable microstructure of nanoparticles after sufficiently long irradiation time.

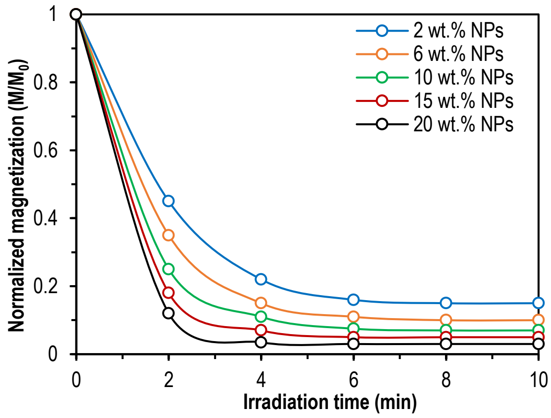

Fig. (2) Variation of normalized magnetization (M/M_0) with irradiation time for the fabricated nanocomposite samples

Figure (3) shows the behavior of remaining magnetization in the fabricated sample with time after irradiation. During the first 10 seconds after irradiation, a sharp decrease in the remaining magnetization to the minimum value was observed, which refers to an identical rapid response for all samples due to demagnetization under the effect of photo-heating. During 20-30 s after irradiation, the remaining magnetization started to gradually increase with time with much more observable differences with nanoparticles content.

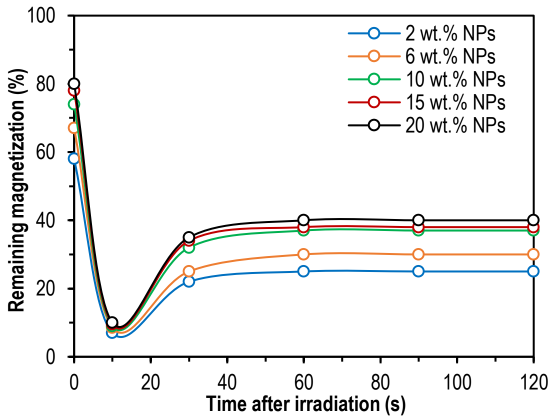

Fig. (3) Variation of remaining magnetization with time after irradiation for the fabricated nanocomposite samples

After 40 s, all samples showed approximately constant values of the remaining magnetization. In general, the laser irradiation make a major difference in the magnetic dissipation dynamics to serve the design of composite materials with temporally-stable magnetic response for optical applications [25].

These results are useful to evaluate the feasibility of the fabricated samples for the magnetic-thermal-photonic exchange applications and the possibility of controlling the material's sensitivity throughout the weight fraction of nanoparticles in the sample.

4. Conclusion

In conclusions, increasing the weight fraction of Co_3O_4 nanoparticles in the nanocomposite sample enhances the thermal-photonic conversion efficiency and accelerates the demagnetization rate. The higher contents of nanoparticles is reasonably appropriate for rapid sensing applications whereas the lower contents showed much more stable response with long irradiation time. The sensitivity of the sample to magnetic-optical variations san be controlled by optimizing the nanoparticles content to develop systems with stable magnetic response after sufficiently long time of laser irradiation for optic fiber sensors (OFSs) and magnetic-optic isolation devices in medical and industrial fields.

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