

## Faraday rotation in $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$ spinel ferrite nanoparticulate films under low applied fields

Richard M. Anderson, Christy R. Vestal, Anna C. S. Samia, and Z. John Zhang

Citation: *Appl. Phys. Lett.* **84**, 3115 (2004); doi: 10.1063/1.1712031

View online: <http://dx.doi.org/10.1063/1.1712031>

View Table of Contents: <http://apl.aip.org/resource/1/APPLAB/v84/i16>

Published by the [American Institute of Physics](http://www.aip.org).

---

### Additional information on *Appl. Phys. Lett.*

Journal Homepage: <http://apl.aip.org/>

Journal Information: [http://apl.aip.org/about/about\\_the\\_journal](http://apl.aip.org/about/about_the_journal)

Top downloads: [http://apl.aip.org/features/most\\_downloaded](http://apl.aip.org/features/most_downloaded)

Information for Authors: <http://apl.aip.org/authors>

## ADVERTISEMENT

An advertisement banner for Applied Physics Letters. It features the journal's logo at the top left, a stylized envelope icon, and the text 'Accepting Submissions in Biophysics and Bio-Inspired Systems'. A 'Submit Today' button is located in the center, and the AIP Publishing logo is at the bottom right.

**AIP | Applied Physics Letters**

Accepting Submissions in  
Biophysics and Bio-Inspired Systems

*Submit Today*

**AIP**  
Publishing

## Faraday rotation in $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$ spinel ferrite nanoparticulate films under low applied fields

Richard M. Anderson, Christy R. Vestal, Anna C. S. Samia, and Z. John Zhang<sup>a)</sup>  
*School of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, Georgia 30332-0400*

(Received 24 November 2003; accepted 24 February 2004)

Films of  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticles were prepared on silanized glass substrates using aminobenzoic acid/imidazole-modified magnetic nanoparticles. Dispersive Faraday rotations in the nanoparticulate films were observed as  $1.0^\circ$ – $3.0^\circ$  under relatively low applied magnetic field strengths of less than 500 Oe. The magnitude of the Faraday rotation increases with increasing thickness of the prepared films. No differences in the Faraday rotation were observed for  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticles as the particle size varied from 12 to 18 nm. © 2004 American Institute of Physics. [DOI: 10.1063/1.1712031]

Magneto-optical properties of ferrite magnetic nanoparticles have attracted considerable attention due to their potential use as magneto-optical storage materials.<sup>1–4</sup> For example, interest has focused upon the use of cobalt ferrite ( $\text{CoFe}_2\text{O}_4$ ) thin films as magneto-optical memory materials because of their large magneto-optical rotation.<sup>5–9</sup> Thin polycrystalline films of  $\text{CoFe}_2\text{O}_4$  are known to show Faraday rotations of  $0.37 \text{ deg}/\mu\text{m}$  at 632 nm and  $3.8 \text{ deg}/\mu\text{m}$  at 800 nm under an applied field of 1 T.<sup>5</sup> However, the practical use of  $\text{CoFe}_2\text{O}_4$  as magneto-optical rewritable media is restricted due to its high Curie temperature of 790 K. Such a temperature would require a too high intensity of the laser pulse for heating the bit area of the recording media to overcome the Curie temperature in order for remagnetization to occur during the write process.<sup>10</sup> The unique superparamagnetic behavior of magnetic nanoparticles could lower temperatures for reorientation of the magnetization vector. For example, using 14 nm  $\text{CoFe}_2\text{O}_4$  nanoparticles, the reorientation temperature can be in principle as low as 420 K, which is the blocking temperature of the nanoparticles.<sup>11</sup>

In addition to improving the thermomagnetic aspect, nanometer size materials have shown promise for enhanced optical rotation. Recently, it was reported that  $\text{Co}_{0.5}\text{Fe}_{2.5}\text{O}_4$  nanostructured films showed Faraday rotations as large as  $4 \text{ deg}/\mu\text{m}$  at 740 nm although the applied field strength was not mentioned.<sup>9</sup> This rotation is double that of  $\text{Co}_{0.4}\text{Fe}_{2.6}\text{O}_4$  polycrystalline film at 740 nm.<sup>12</sup> The studies of  $\gamma\text{-Fe}_2\text{O}_3$  nanoparticles embedded in silica matrixes have shown that Faraday rotations of  $\sim 2 \text{ deg}$  can be observed at 789 nm under applied fields as low as 100 Oe.<sup>13</sup> In this letter, we report the dispersive Faraday rotations under low applied field in  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  magnetic nanoparticulate films determined by using a simple instrument similar to a traditional polarimeter.

The basic setup of the instrument used in this study appears in Fig. 1. The modulated signal from the detector is compared to the reference frequency sent directly from the chopper to a lock-in amplifier. Since only the modulated signal is amplified, identification of very small differences in

light intensities is achievable and thus relatively weak Faraday rotation signals are discernable. The film sample is surrounded by two homemade solenoids, which are capable of creating a homogenous static field up to 500 Oe. All measurements were performed at room temperature using wavelengths of 475 or 625 nm.

$\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticles used in this study were prepared via microemulsion synthesis methods.<sup>14</sup> The magnetic properties of these nanoparticles have been studied using a Quantum Design MPMS-5S SQUID magnetometer. The blocking temperature is 432 K for 15 nm nanoparticles (Fig. 2). The saturation magnetization and coercivity are  $64.6 \text{ emu/g}$  and  $40 \text{ G}$  at room temperature, respectively (inset of Fig. 2).

The nanoparticles were chemically derivatized on their surface and then bound to glass substrates through silane groups (Fig. 3). The mechanisms of silane self-assembly on glass surfaces are well understood.<sup>15</sup> Using this well established method, an amine-coated glass substrate is created through 3-aminotriethoxypropylsilane. The  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticles were divided into two groups. The surface of one group of nanoparticles was terminated with imidazole by using imidazole carboxylate (C1

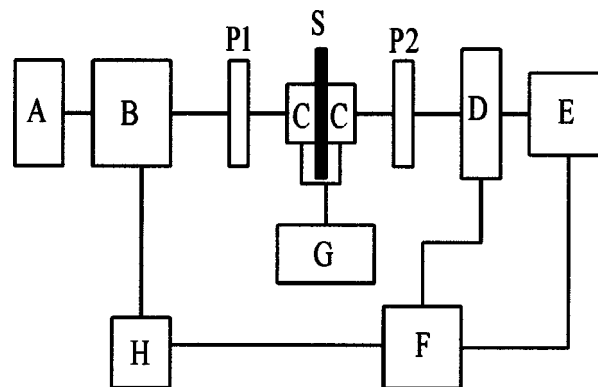


FIG. 1. Instrumental apparatus schematic: (A) light source of a 1000 W xenon lamp; (B) monochromator for wavelength selection; (C) hand-wound solenoids; (D) optical chopper for modulating the transmission light; (E) photodiode detector; (F) lock-in amplifier; (G) dc power supply; (H) computer (P1) initial polarizer set to  $45^\circ$  relative (P2) fixed analyzer polarizer (S) nanoparticulate sample films.

<sup>a)</sup>Author to whom correspondence should be addressed; electronic mail: john.zhang@chemistry.gatech.edu

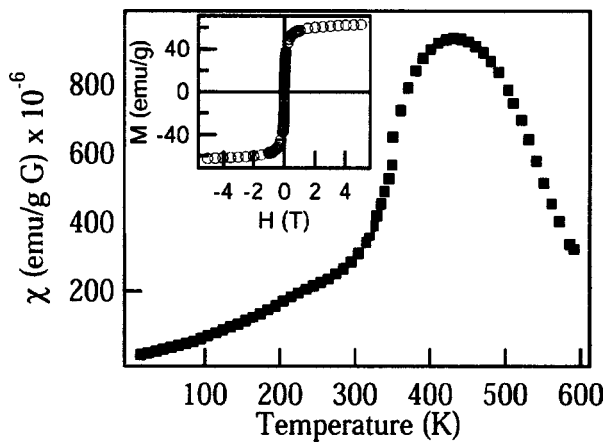


FIG. 2. Susceptibility of 15 nm  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticles under a 100 G field. Inset shows room temperature hysteresis with applied fields up to 5 T.

in Fig. 3). The surface of the other group of nanoparticles was terminated with amine by using aminobenzoic acid (C2 in Fig. 3). For terminating the surface with imidazole ligands,  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticles were added to an imidazole carboxylate solution at  $\text{pH}=4.0$  and stirred for  $\sim 3$  h. The carboxyl functional group bound onto the particle surface through coordinating to metal cations. Coated nanoparticles were separated from unbound imidazole by a magnet. Similar procedures were used to create nanoparticles with an amine-terminated surface by replacing the imidazole carboxylate solution with an aminobenzoic acid solution. The amine-modified glass slide was first dipped in a solution of the imidazole-terminated nanoparticles. The surface amine ligand replaced imidazole by nucleophilic substitution to form an amide bond with the carboxyl group. Because of the requirement to form an amide bond, only a single layer of nanoparticles was able to bind to the slide at this step. The unreacted imidazole became the available terminal ligands on the slide for binding at next step (F2 in Fig. 3). The slide was then soaked in a solution of the amine-terminated nanoparticles. A second layer of nanoparticles was bound through the formation of an amide bond, which in turn left the termi-

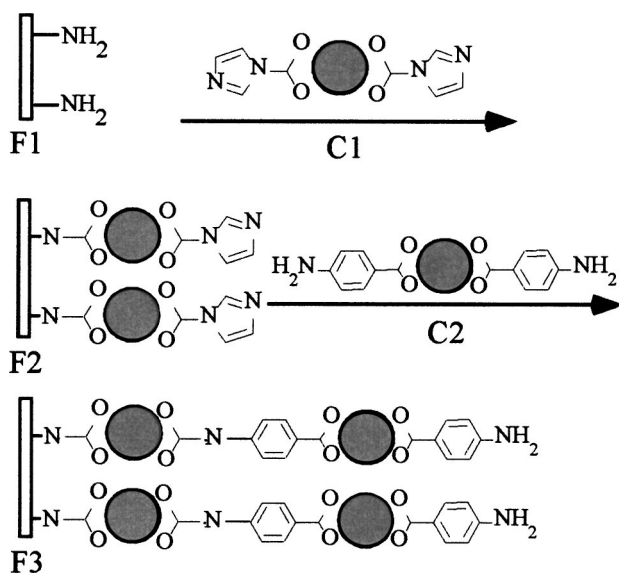


FIG. 3. Schematic of the deposition procedures for nanoparticulate films.

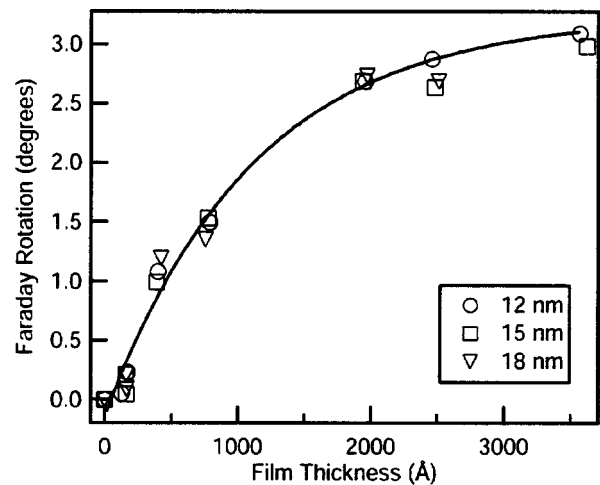


FIG. 4. Faraday rotation of  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticles under a 450 G field.

nal amine ligands available for further binding (F3 in Fig. 3). By alternating between these two types of nanoparticle solutions, successive particle layers were deposited. The thickness of such nanoparticulate films can be estimated based upon particle size, ligand length, and number of layers, which is consistent with ellipsometry studies. Transmission electron microscopy confirmed the multilayer structures.

The Faraday rotation ( $\theta_F$ ) of a material is given as:

$$\theta_F = VBL \quad (1)$$

where  $V$  is the Verdet constant that is material and wavelength dependent,  $B$  is applied magnetic field strength, and  $L$  is the path length of light through the material. The rotation can be determined experimentally by the following relationship:

$$\theta_R = \frac{1}{2} [\sin^{-1}(I_B/I_O) - 1], \quad (2)$$

where  $I_B$  and  $I_O$  are the light intensities recorded with and without an applied magnetic field, respectively. As a result of Faraday rotation, the polarization direction of the light changes. The output light intensity passing through the analyzer polarizer therefore decreases, and this intensity decrease is used to determine the Faraday rotation.

Dispersive Faraday rotations for  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  films of variable thickness are shown in Fig. 4. Clearly, increasing film thickness results in an increase in the Faraday rotation angle, which is consistent with the observations from a variety of ferrite and garnet media.<sup>16,17</sup> Such an increase is also consistent with Eq. (1) as larger film thicknesses provide a larger path length  $L$  for the light to pass through and hence the Faraday rotation  $\theta_F$  increases. Only negligible differences are observed for the Faraday rotation signatures of variable sized  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticles. It is worth noticing that other studies on nanoparticulate films have shown that the Faraday rotation increases as the grain/particle size is decreased.<sup>17,18</sup> The range of particle sizes investigated here is likely too small to observe significant differences. It is important to note that the Faraday rotations of the nanoparticulate film is much larger than that of polycrystalline films. Certainly, more detailed systematic studies are required for understanding such great enhancements. It can

be speculated that the superparamagnetic features of nanoparticles are the origin for the enhanced Faraday rotation at very low magnetic field. Even though the blocking temperature of these spinel ferrite nanoparticles is 432 K, the coercivity is already small at room temperature and the magnetization rises rapidly with increasing field strength (Fig. 2). Therefore, sizable magnetization can be obtained even with a low field.

In conclusion, Faraday rotations up to  $3^\circ$  have been observed in very thin  $\text{Co}_{0.85}\text{Zn}_{0.15}\text{Fe}_2\text{O}_4$  nanoparticulate films under relatively low field strengths of  $<500$  G. The combination of thin films and low field requirements implies the high potential for use of the Faraday rotation of spinel ferrite nanoparticulate films in miniature devices.

This work was supported in part by NSF (DMR-9875892).

<sup>1</sup>P. Tailhades, C. Bonningue, A. Rousset, L. Bouet, I. Pasquet, and S. Lebrun, *J. Magn. Magn. Mater.* **193**, 148 (1999).

<sup>2</sup>P. Tailhades, L. Bouet, L. Presmanes, and A. Rousset, *J. Phys. IV* **7**, C1/691 (1997).

<sup>3</sup>E. V. Anokin and P. J. Sides, *IEEE Trans. Magn.* **31**, 3239 (1995).

<sup>4</sup>K. Shono, S. Kuroda, M. Alex, and S. Ogawa, *J. Magn. Magn. Mater.* **88**, 205 (1990).

<sup>5</sup>J. W. D. Martens and W. L. Peeters, in *Optical Storage Media*, edited by A. E. Bell and A. A. Jamberdino (SPIE, Bellingham, WA, 1983), Vol. 420, p. 231.

<sup>6</sup>K. Suzuki, T. Namikawa, and T. Yamazaki, *Jpn. J. Appl. Phys., Part 1* **27**, 361 (1988).

<sup>7</sup>W. L. Peeters and J. W. D. Martens, *J. Appl. Phys.* **53**, 8178 (1982).

<sup>8</sup>H. Y. Zhang, B. X. Gu, H. R. Zhai, M. Lu, Y. Miao, Z. S. Y. Zhang, and H. B. Huang, *J. Appl. Phys.* **75**, 7099 (1994).

<sup>9</sup>B. X. Gu, *Appl. Phys. Lett.* **82**, 3707 (2003).

<sup>10</sup>A. K. Zvezdin and V. A. Kotov, in *Modern Magneto-optics and Magneto-optical Materials* (Institute of Physics, Bristol, UK, 1997), p. 311.

<sup>11</sup>C. Liu, B. Zou, A. J. Rondinone, and Z. J. Zhang, *J. Am. Chem. Soc.* **122**, 6263 (2000).

<sup>12</sup>I. S. Edelman and V. D. Baurin, *Phys. Status Solidi A* **46**, K83 (1978).

<sup>13</sup>H. Guerrero, G. Rosa, M. P. Morales, F. del Monte, E. M. Moreno, D. Levy, R. P. del Real, T. Belenguier, and C. J. Serna, *Appl. Phys. Lett.* **71**, 2698 (1997).

<sup>14</sup>A. C. S. Samia, Thesis, Georgia Institute of Technology, 2002.

<sup>15</sup>F. Schreiber, *Prog. Surf. Sci.* **65**, 151 (2000).

<sup>16</sup>M. Kishimoto, Y. Sakurai, and T. Ajima, *J. Appl. Phys.* **76**, 7506 (1994).

<sup>17</sup>H.-W. Zhang, H. J. Kim, and S. Q. Kim, *Mater. Sci. Eng., B* **34**, 53 (1995).

<sup>18</sup>Y. Yamazaki, T. Namimawa, T. Hirano, and K. Yoshida, *J. Phys. IV* **7**, C1/543 (1997).