

# Effects of $(\text{Ho}_x\text{In}_{1-x})_{1.9}\text{Sn}_{0.1}\text{O}_3$ matrix on magnetization of dispersed $\text{Fe}_3\text{O}_4$ nanocrystals

Minemaru Tanabe<sup>1</sup>, Takuro Manabe<sup>1</sup>, Shigemi Kohiki<sup>\*1</sup>, Masanori Mitome<sup>2</sup>, and Kunio Yubuta<sup>3</sup>

<sup>1</sup> Department of Materials Science, Kyushu Institute of Technology, Kitakyushu, Japan

<sup>2</sup> National Institute for Materials Science, Tsukuba, Japan

<sup>3</sup> Institute for Materials Research, Tohoku University, Sendai, Japan

Received ZZZ, revised ZZZ, accepted ZZZ

Published online ZZZ (Dates will be provided by the publisher.)

**Keywords**  $(\text{Ho}_x\text{In}_{1-x})_{1.9}\text{Sn}_{0.1}\text{O}_3$ ,  $\text{Fe}_3\text{O}_4$ , spontaneous magnetization, matrix effects

\* Corresponding author: e-mail kohiki@che.kyutech.ac.jp, Phone: +81 93 884 3310, Fax: +81 93 884 3300

Solid solutions  $(\text{Ho}_x\text{In}_{1-x})_{1.9}\text{Sn}_{0.1}\text{O}_3$  with  $x = 0 - 0.3$  were synthesized to employ as dispersion matrix for oleic acid coated  $\text{Fe}_3\text{O}_4$  nanocrystals. The  $x = 0.05$  matrix exhibited a resistance minimum at a non-zero temperature in each temperature dependent resistivity with magnetic fields of

0 T and 1 T, and a negative magnetoresistance. The sample of oleic acid coated  $\text{Fe}_3\text{O}_4$  nanocrystals dispersed in the  $x = 0.05$  matrix showed enhanced spontaneous magnetization as the factor of  $\approx 1.3$  relative to as-synthesized oleic acid coated  $\text{Fe}_3\text{O}_4$  nanocrystals.

Copyright line will be provided by the publisher

**1 Introduction** Transparent conducting oxides doped with  $3d$  transition metal elements exhibiting room temperature ferromagnetism (RT-FM) have been studied intensively for realizing spintronics devices [1-20]. Tin doped indium sesquioxide (ITO) exhibiting RT-FM is promising for practical device applications because ITO has been the most widely used transparent conducting oxide in electronic and semiconductor industry.

Magnetite ( $\text{Fe}_3\text{O}_4$ ) is well known as a half-metal material accompanied with fully spin-polarized carriers due to the minority-spin of octahedrally coordinated  $\text{Fe}^{2+}$ . Spontaneous magnetization ( $M_s$ ) of  $\text{Fe}_3\text{O}_4$  below 585 °C, resulted from uncompensated majority-spin of octahedrally coordinated  $\text{Fe}^{2+}$ , is antiparallel to the spin of polarized carriers. Okada et al. [21] reported that pulsed-laser-deposited  $\text{Fe}_3\text{O}_4$  nanocrystals (NCs) dispersed in a single-crystalline ITO film exhibited RT-FM and a negative magnetoresistance (MR) due to collinear arrangement of  $M_s$  of the  $\text{Fe}_3\text{O}_4$  NCs. Okada et al. [22] modified the matrix from ITO to  $(\text{Ho}_x\text{In}_{1-x})_2\text{O}_3$ , and observed enlarged  $M_s$ . If the spin of polarized carriers itinerating around the conduction band of  $(\text{Ho}_x\text{In}_{1-x})_2\text{O}_3$  is antiparallel to the magnetic moments of localized  $\text{Ho}^{3+}$  ( $10.6 \mu_B$ ), localized  $\text{Ho}^{3+}$  moments align parallel with  $M_s$  of dispersed  $\text{Fe}_3\text{O}_4$  NCs, and enlarge observed  $M_s$ .

It is known as the Kondo effect for diluted magnetic conductors that antiparallel arrangement between the spin of carriers and the localized magnetic moments accompanies a resistance minimum at a non-zero temperature in temperature dependent resistivity ( $\rho$ - $T$ ). Therefore, it is of great interest to examine effects of matrix with and without a resistance minimum at a non-zero temperature on magnetization ( $M$ - $H$ ) of dispersed  $\text{Fe}_3\text{O}_4$  NCs. We employed  $(\text{Ho}_x\text{In}_{1-x})_{1.9}\text{Sn}_{0.1}\text{O}_3$  with  $x = 0 - 0.3$  as dispersion matrix. Hereafter, we denote  $(\text{Ho}_x\text{In}_{1-x})_{1.9}\text{Sn}_{0.1}\text{O}_3$  as  $\text{Ho}_x\text{ITO}$  for convenience. The  $\text{Ho}_x\text{ITO}$  matrix with  $x = 0.05$  demonstrated a resistance minimum and a negative MR. We dispersed oleic acid coated (OA-)  $\text{Fe}_3\text{O}_4$  NCs in  $\text{Ho}_x\text{ITO}$  ( $x = 0 - 0.3$ ) matrix, and examined changes in  $M$ - $H$  with  $x$ . Carboxyl groups of OA were reported to combine with Fe atoms at surface of  $\text{Fe}_3\text{O}_4$  NCs, and OA layer with thickness  $\approx 3$  nm was formed on the surface [23]. It is expected that spin-polarized carriers of  $\text{Fe}_3\text{O}_4$  NCs tunnel into  $\text{Ho}_x\text{ITO}$  matrix through insulating OA layer, and the carriers in the matrix facilitate parallelization of localized  $\text{Ho}^{3+}$  moments and  $M_s$  of dispersed OA- $\text{Fe}_3\text{O}_4$  NCs if the matrix exhibits both a resistance minimum and a negative MR.

## 2 Experiment

**2.1 Sample preparation**  $\text{Ho}_x\text{ITO}$  with  $x = 0 - 0.3$  were synthesized from powders of  $\text{Ho}_2\text{O}_3$  and  $\text{In}_2\text{O}_3$  mixed

Copyright line will be provided by the publisher

in accordance with  $x = 0, 0.025, 0.05, 0.1, 0.2,$  and  $0.3$ , and  $\text{SnO}_2$  powders weighed as  $[\text{Ho} + \text{In}] : [\text{Sn}] = [1.9] : [0.1]$  in molar ratio. The mixtures were heated at  $1500^\circ\text{C}$  for 6 h in flowing  $\text{O}_2$  gas, and then re-heated at  $1200^\circ\text{C}$  for 2 h in flowing Ar gas.

OA- $\text{Fe}_3\text{O}_4$  NCs were synthesized from  $\text{Fe}(\text{acac})_3$  in a solution of dibenzylether mixed with OA [24].  $\text{Fe}(\text{acac})_3$ , dibenzylether, and OA, weighed with the molar ratio of  $[1] : [26] : [2]$ , were mixed with vigorous stirring for 1 h at RT. The mixture was kept at  $300^\circ\text{C}$  for half an hour. After cooling to RT, OA- $\text{Fe}_3\text{O}_4$  NCs were precipitated from the crude solution by adding toluene/hexane (1:1) followed by centrifugation. The precipitation was washed with anhydrous chloroform.

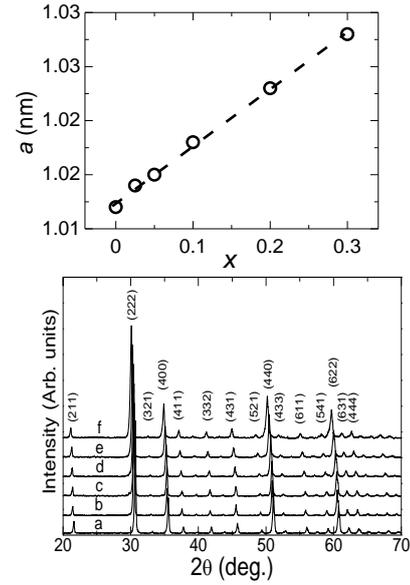
As-synthesized OA- $\text{Fe}_3\text{O}_4$  NCs were dispersed into  $\text{Ho}_x\text{ITO}$  powders with the molar ratio of  $[\text{Fe}_3\text{O}_4] : [\text{Ho}_x\text{ITO}] = [0.05] : [1]$ . The mixtures were heated at  $900^\circ\text{C}$  for 1 h in flowing Ar gas.

**2.2 Characterization** X-ray diffraction (XRD) was measured with a Rigaku CN2013 diffractometer with Cu  $K\alpha$  radiation at RT. For electrical measurement by four probes method,  $\text{Ho}_x\text{ITO}$  powders were pressed into a coin-type pellet before heating at  $1200^\circ\text{C}$  for 2 h in flowing Ar gas. Then, the pellet was cut into a bar-shaped sample. Pt electrodes were bonded by gold wires to a Quantum Design MPMS 5S system. Current-voltage ( $I$ - $V$ ) characteristics at various temperatures under  $H = 0$  and 1 T were measured for all the samples and some selected samples, respectively.  $M$ - $H$  curve at 300 K was recorded by using a Quantum Design MPMS 5S SQUID magnetometer.

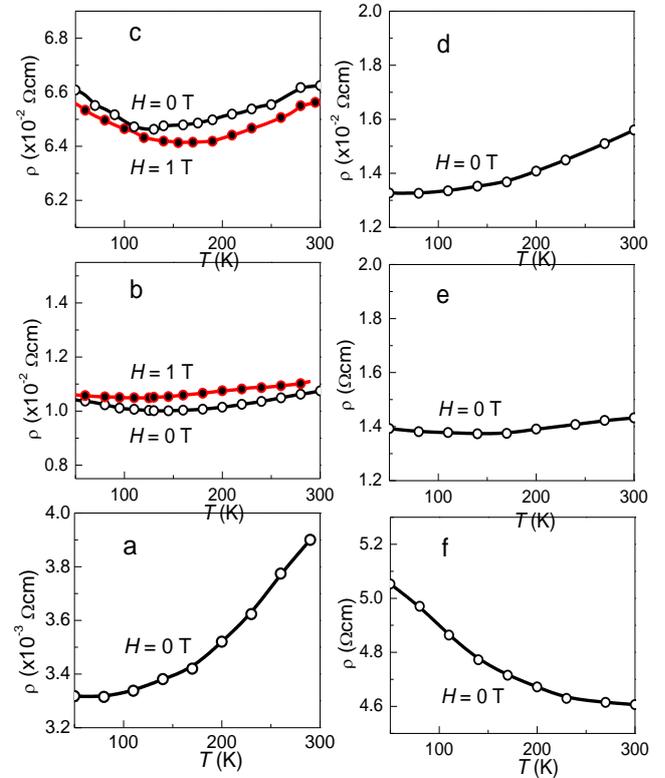
### 3 Results and discussion

**3.1  $\text{Ho}_x\text{ITO}$  matrix** As shown in the lower panel of Fig. 1,  $\text{Ho}_x\text{ITO}$  matrix showed diffraction peaks can be indexed only to the  $C$ -rare earth type cubic lattice. Both  $\text{Ho}_2\text{O}_3$  and  $\text{In}_2\text{O}_3$  are known to crystallize into the  $C$ -rare earth type cubic lattice, and the lattice constant  $a$  of  $\text{Ho}_2\text{O}_3$  and  $\text{In}_2\text{O}_3$  are 1.0606 nm (JCPDS 43-1018) and 1.0118 nm (JCPDS 06-0416), respectively. As shown in the upper panel of FIG. 1, the  $a$  value of  $\text{Ho}_x\text{ITO}$  matrix varied linearly with  $x$  from 0 to 0.3, obeying the Vegard's law.

Temperature dependent resistivity at  $H = 0$  T ( $\rho^0$ - $T$ ) for all the  $\text{Ho}_x\text{ITO}$  matrices are shown in Fig. 2. The  $x \leq 0.1$  matrices were conductive ( $\rho^0 < 0.1 \Omega\text{cm}$ ), but the  $x > 0.2$  matrices were rather resistive ( $\rho^0 > 1 \Omega\text{cm}$ ). The  $x = 0.05$  matrix showed larger  $\rho^0$  than the  $x = 0.025$  and 0.1 matrices.  $\rho^0$  of the  $x = 0.025$  and 0.1 matrices were so close each other, and larger than the  $x = 0$  matrix. In each  $\rho^0$ - $T$ , the  $x = 0.025$  and 0.05 matrices exhibited the resistance minimum respectively at  $\approx 150$  K and  $\approx 125$  K, while the  $x = 0$  and 0.1 matrices indicated no resistance minimum. As known as the Kondo effect, the resistance minimum for diluted magnetic conductors accompanied with antiparallel configuration between spin of carriers and localized mag-



**Figure 1** Lower panel: XRD pattern of the  $\text{Ho}_x\text{ITO}$  matrix with  $x = 0$  (a), 0.025 (b), 0.05 (c), 0.1 (d), 0.2 (e), and 0.3 (f). Upper panel: lattice constant  $a$  of the matrix with  $x$ . Straight line is a guide for eye.



**Figure 2**  $\rho^0$  -  $T$  measured with  $H = 0$  T for the  $\text{Ho}_x\text{ITO}$  matrix with  $x = 0$  (a), 0.025 (b), 0.05 (c), 0.1 (d), 0.2 (e), and 0.3 (f), shown by open circle.  $\rho^H$  -  $T$  measured with  $H = 1$  T for the matrix with  $x = 0.025$  (b) and 0.05 (c), shown by closed circle.

netic moments. Such antiparallel arrangement is expected to bring about  $MR = (\rho^H - \rho^0)/\rho^0$  with a negative sign, here  $\rho^H$  represents  $\rho$  measured at  $H \neq 0$ . Figures 2b and 2c show also temperature dependent resistivity at  $H = 1$  T ( $\rho^H-T$ ) for the  $x = 0.025$  and  $0.05$  matrices, respectively. For the  $x = 0.025$  matrix, the resistance minimum disappeared in  $\rho^H-T$ , and  $\rho^H$  was larger than  $\rho^0$ . The  $x = 0.05$  matrix demonstrated  $\rho^H-T$  with the resistance minimum at  $\approx 175$  K, and  $\rho^H$  smaller than  $\rho^0$ . Such a negative MR supports antiparallel arrangement between the spin of carriers and the localized magnetic moments of  $\text{Ho}^{3+}$  in the  $x = 0.05$  matrix.

**3.2 OA-Fe<sub>3</sub>O<sub>4</sub> NCs** XRD pattern and  $M-H$  curve of as-synthesized OA-Fe<sub>3</sub>O<sub>4</sub> NCs are shown in Fig. 3. All the XRD peaks were attributable to the inverse spinel type Fe<sub>3</sub>O<sub>4</sub> cubic lattice (JCPDS 19-0629). Crystallite size of  $\approx 65$  nm for the NCs was estimated from the (511) reflection by Scherrer's equation.

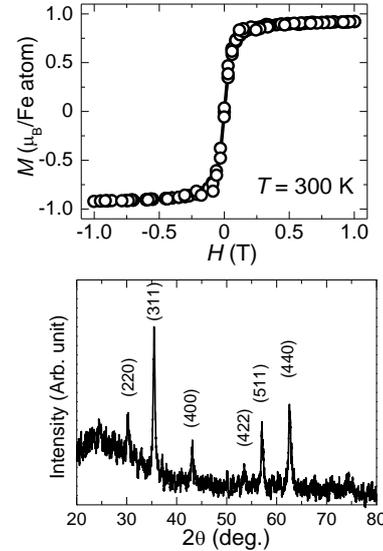
At 300 K, as-synthesized OA-Fe<sub>3</sub>O<sub>4</sub> NCs demonstrated sigmoidal  $M-H$  curve almost saturated at  $H = 0.3$  T. The small coercive field ( $H_c \approx 27$  Oe) indicates that OA prevented agglomeration of Fe<sub>3</sub>O<sub>4</sub> NCs leading to larger second particle formation. Present  $M-H$  curve looks similar to those of reported OA-Fe<sub>3</sub>O<sub>4</sub> NCs [23,25-27]. The magnetization at 1 T ( $M_{1T}$ ) of  $\approx 1 \mu_B/\text{Fe}$  atom for present NCs is rather large than those reported ( $\approx 0.85 \mu_B/\text{Fe}$  atom [23] and  $\approx 0.82 \mu_B/\text{Fe}$  atom [25]), and almost the same to that ( $\approx 0.95 \mu_B/\text{Fe}$  atom) reported in ref. 26.

**3.3 OA-Fe<sub>3</sub>O<sub>4</sub> NCs/Ho<sub>x</sub>ITO matrix** All the samples of OA-Fe<sub>3</sub>O<sub>4</sub> NCs dispersed in the Ho<sub>x</sub>ITO matrix showed hysteresis loop at 300 K, as seen in Fig. 4. The  $M-H$  curve of the  $x \leq 0.05$  samples almost saturated at  $H = 0.5$  T, although the  $x \geq 0.1$  samples showed no saturation below  $H = 1$  T.  $M_s$  of the samples, derived from an intercept of a tangent line for each  $M-H$  curve, were larger than that of the as-synthesized NCs. As shown in Fig. 5,  $M_s$  of the samples normalized to that of the as-synthesized NCs, increased slightly with  $x$  from 0 to 0.025, peaked at  $x = 0.05$ , decreased at  $x = 0.1$ , and then slightly decreased with further increases in  $x$  to 0.3. The  $x = 0.05$  sample showed enhancement of  $M_s$  as the factor of  $\approx 1.3$ . Both  $M_{0.5T}$  and  $M_{1T}$  behaved almost parallel to  $M_s$  for the  $x \leq 0.05$  samples, while those for the  $x \geq 0.1$  samples deviated from  $M_s$ . Increments in  $M_{0.5T}$  and  $M_{1T}$  for the  $x \geq 0.1$  samples reflect increases of thermally excitable  $\text{Ho}^{3+}$  paramagnetic moment at 300 K with  $x$  of the matrix.

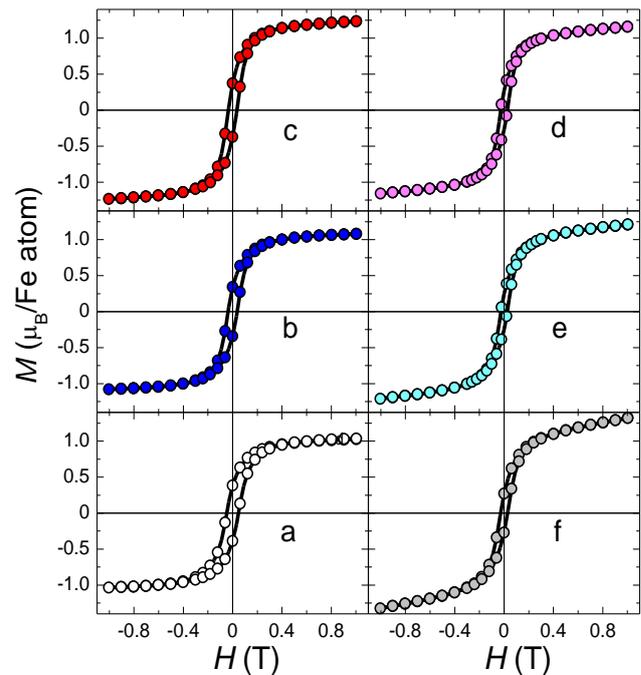
Figure 6 shows  $\rho^0-T$  and  $\rho^H-T$  for the sample of OA-Fe<sub>3</sub>O<sub>4</sub> NCs dispersed in the Ho<sub>x</sub>ITO matrix with  $x = 0.05$ . The resistance minimum in both  $\rho^0-T$  and  $\rho^H-T$  disappeared for the  $x = 0.05$  sample. A positive MR ( $\rho^H > \rho^0$ ) can arise from parallel configuration of localized  $\text{Ho}^{3+}$  moments with  $M_s$  of dispersed OA-Fe<sub>3</sub>O<sub>4</sub> NCs.

As shown in Fig.7,  $H_c$  of the samples also varied with  $x$ , and peaked at  $x = 0.05$ . The  $x$  dependence of  $H_c$  looks similar to that of  $M_s$  for the samples. Enlarged  $H_c$  and enlarged  $M_s$  for the  $x = 0.05$  sample suggest carriers

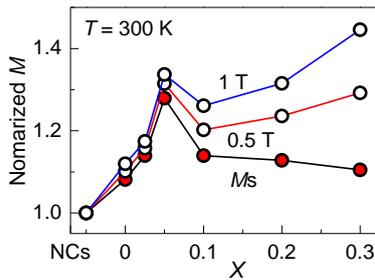
facilitated parallelization of localized  $\text{Ho}^{3+}$  moments and  $M_s$  of dispersed OA-Fe<sub>3</sub>O<sub>4</sub> NCs.



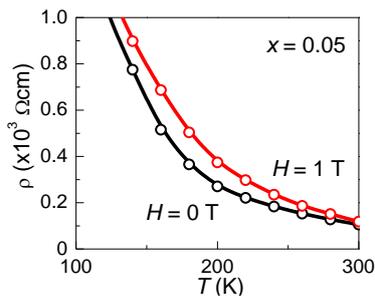
**Figure 3** Lower panel: XRD pattern of as-synthesized OA-Fe<sub>3</sub>O<sub>4</sub> NCs. Upper panel:  $M-H$  ( $H \geq 1$  T) curve of as-synthesized OA-Fe<sub>3</sub>O<sub>4</sub> NCs.



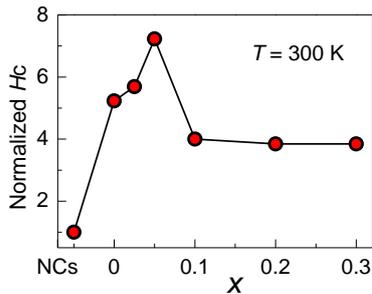
**Figure 4**  $M-H$  curve for the samples of OA-Fe<sub>3</sub>O<sub>4</sub> NCs dispersed in the Ho<sub>x</sub>ITO matrix with  $x = 0$  (a), 0.025 (b), 0.05 (c), 0.1 (d), 0.2 (e), and 0.3 (f).



**Figure 5**  $M_s$ ,  $M_{0.5T}$  and  $M_{1T}$  for the samples with  $x$ . Values were normalized to those of as-synthesized OA-Fe<sub>3</sub>O<sub>4</sub> NCs.



**Figure 6**  $\rho^0 - T$  with  $H = 0$  T and  $\rho^H - T$  with  $H = 1$  T for the sample of OA-Fe<sub>3</sub>O<sub>4</sub> NCs dispersed in the Ho<sub>x</sub>ITO matrix with  $x = 0.05$ .



**Figure 7**  $H_c$  for the samples with  $x$ . Values were normalized to that of as-synthesized OA-Fe<sub>3</sub>O<sub>4</sub> NCs.

**4 Summary** The Ho<sub>x</sub>ITO matrix with  $x = 0.05$  exhibited both a resistance minimum at a non-zero temperature and a negative MR. The sample of OA-Fe<sub>3</sub>O<sub>4</sub> NCs dispersed in the Ho<sub>x</sub>ITO matrix with  $x = 0.05$  demonstrated enlarged  $M_s$  as the factor of  $\approx 1.3$  relative to the as-synthesized NCs. In the sample of OA-Fe<sub>3</sub>O<sub>4</sub> NCs dispersed in the Ho<sub>x</sub>ITO matrix with  $x = 0.05$ , the resistance minimum in both  $\rho^0 - T$  and  $\rho^H - T$  disappeared, and the sign of MR turned from negative to positive. Similar behavior in  $M_s$  and  $H_c$  with  $x$  also supports that the enlarged  $M_s$  for the  $x = 0.05$  sample arose from parallel configuration of localized Ho<sup>3+</sup> moments in the Ho<sub>x</sub>ITO matrix to  $M_s$  of dispersed OA-Fe<sub>3</sub>O<sub>4</sub> NCs.

**Acknowledgements** S.K. thanks Dr. H. Shimooka for assistance and Prof. T. Shishido of Tohoku University for discussion. This work was partly supported by the "Nanotechnology Support Project" of the Ministry of Education, Culture, Sports, Science and Technology, Japan, and the "Inter-university cooperative research program" of the Advanced Research Center of Metallic Glasses, Institute for Materials Research, Tohoku University.

## References

- [1] Y. Matsumoto, M. Murakami, T. Shono, T. Hasegawa, T. Fukumura, M. Kawasaki, P. Ahmet, T. Chikyow, S. Koshihara, and H. Koinuma, *Science* **291**, 854 (2001).
- [2] D. H. Kim, J. S. Yang, K. W. Lee, S. D. Bu, T. W. Noh, S.-J. Oh, Y.-W. Kim, J.-S. Chung, H. Tanaka, H. Y. Lee, and T. Kawai, *Appl. Phys. Lett.* **81**, 2421 (2002).
- [3] K. Ueda, H. Tabata, and T. Kawai, *Appl. Phys. Lett.* **79**, 988 (2001).
- [4] J. H. Kim, H. Kim, Y. E. Ihm, and W. K. Choo, *J. Appl. Phys.* **92**, 6066 (2002).
- [5] P. Sharma, A. Gupta, K. V. Rao, F. J. Owens, R. Sharma, R. Ahuja, J. M. O. Guillen, B. Johansson, and G. A. Gehring, *Nat. Mater.* **2**, 673 (2003).
- [6] S. B. Ogale, R. J. Choudhary, J. P. Buban, S. E. Lofland, S. R. Shinde, S. N. Kale, V. N. Kulkarni, J. Higgins, C. Lanci, J. R. Simpson, N. D. Browning, S. Das Sarma, H. D. Drew, R. L. Greene, and T. Venkatesan, *Phys. Rev. Lett.* **91**, 077205 (2003).
- [7] J. M. D. Coey, A. P. Douvalis, C. B. Fitzgerald, and M. Venkatesan, *Appl. Phys. Lett.* **84**, 1332 (2004).
- [8] J. Philip, N. Theodoropoulou, G. Berera, J. S. Moodera, and B. Satpati, *Appl. Phys. Lett.* **85**, 777 (2004).
- [9] N. H. Hong, J. Sakai, N. T. Huong, N. Poirot, and A. Ruyter, *Phys. Rev. B* **72**, 045336 (2005).
- [10] Y. K. Yoo, Q. Xue, H.-C. Lee, S. Cheng, X.-D. Xiang, G. F. Dionne, S. Xu, J. He, Y. S. Chu, S. D. Preite, S. E. Lofland, and I. Takeuchi, *Appl. Phys. Lett.* **86**, 042506 (2005).
- [11] J. He, S. Xu, Y. K. Yoo, Q. Xue, H.-C. Lee, S. Cheng, X.-D. Xiang, G. F. Dionne, and I. Takeuchi, *Appl. Phys. Lett.* **86**, 052503 (2005).
- [12] N. H. Hong, J. Sakai, N. T. Huong, and V. Brize, *Appl. Phys. Lett.* **87**, 102505 (2005).
- [13] H. S. Kim, S. H. Ji, H. Kim, S.-K. Hong, D. Kim, Y. E. Ihm, and W. K. Choo, *Solid State Commun.* **137**, 41 (2006).
- [14] J. Philip, A. Punnoose, B. I. Kim, K. M. Reddy, S. Layne, J. O. Holmes, B. Satpati, P. R. Leclair, T. S. Santos, and J. S. Moodera, *Nat. Mater.* **5**, 298 (2006).
- [15] N. H. Hong, J. Sakai, N. T. Huong, and V. J. Brize, *Mag. Mater.* **302**, 228 (2006).
- [16] G. Peleckis, X. L. Wang, and S. X. Dou, *Appl. Phys. Lett.* **88**, 132507 (2006).
- [17] G. Peleckis, X. L. Wang, and S. X. Dou, *Appl. Phys. Lett.* **89**, 022501 (2006).
- [18] T. Ohno, T. Kawahara, H. Tanaka, T. Kawai, M. Oku, K. Okada, and S. Kohiki, *Jpn. J. Appl. Phys.* **45**, L957 (2006).
- [19] S. R. Shinde, S. B. Ogale, J. S. Higgins, H. Zheng, A. J. Millis, V. N. Kulkarni, R. Ramesh, R. L. Greene, and T. Venkatesan, *Phys. Rev. Lett.* **92**, 166601 (2004).

- 1 [20] K. Okada, S. Kohiki, S. Nishi, H. Shimooka, H. Deguchi, M.  
2 Mitome, Y. Bando, and T. Shishido, *Jpn. J. Appl. Phys.* **46**,  
3 L823 (2007).
- 4 [21] K. Okada, S. Kohiki, M. Mitome, H. Tanaka, M. Arai, M.  
5 Mito, and H. Deguchi, *ACS Appl. Mater. Interfaces* **1**, 1893  
6 (2009).
- 7 [22] K. Okada, S. Kohiki, F. Tsutsui, H. Shimooka, M. Mitome,  
8 Y. Bando, M. Mito, H. Deguchi, and T. Shishido, *Scripta*  
9 *Materialia* **59**, 444 (2008).
- 10 [23] D. Li, D. Jiang, M. Chen, J. Xie, Y. Wu, S. Dang, and J.  
11 Zhang, *Materials Letters* **64**, 2462 (2010).
- 12
- 13
- 14
- 15
- 16
- 17
- 18
- 19
- 20
- 21
- 22
- 23
- 24
- 25
- 26
- 27
- 28
- 29
- 30
- 31
- 32
- 33
- 34
- 35
- 36
- 37
- 38
- 39
- 40
- 41
- 42
- 43
- 44
- 45
- 46
- 47
- 48
- 49
- 50
- 51
- 52
- 53
- 54
- 55
- 56
- 57
- [24] D. Kim, N. Lee, M. Park, B. H. Kim, K. An, and T. Hyeon, *J. Am. Chem. Soc.* **131**, 454 (2009).
- [25] Y. Hou, Z. Xu, and S. Sun, *Angew. Chem. Int. Ed.* **46**, 6329 (2007).
- [26] L. Zhang, J. Wu, H. Liao, Y. Hou, and S. Gao, *Chem. Commun.* 4378 (2009).
- [27] P. C. Papapilippou, A. Pourgouris, O. Marinica, A. Taculescu, G. I. Athanasopoulos, L. Vekas, and T. Krasia-Christoforu, *J. Mag. Mater.* **323**, 557 (2011).