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Research Article

Determining Contact Angle and Surface Energy of $Co_{60}Fe_{20}B_{20}$ Thin Films by Magnetron Sputtering

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This study examined the deposition of CoFeB thin films on a glass substrate at room temperature (RT), as well as the effects of conducting postannealing at heat annealing $T_A = 150°C$ for 1 h. The thickness (t_f) of the CoFeB thin films ranged from 100 Å to 500 Å. The microstructure, average contact angle, and surface energy properties were also investigated. X-ray diffraction (XRD) revealed that CoFeB films are nanocrystalline at RT and that post-annealing treatment increases in conjunction with the crystallinity. The surface energy of the CoFeB thin films is related to adhesive strength. The CoFeB films form a contact angle of larger than 90° with water as a test liquid. This finding demonstrates that the CoFeB film is hydrophobic. As t_f increases from 100 Å to 500 Å, the surface energy at RT decreases from 40 mJ/mm^2 to 32 mJ/mm^2. During post-annealing treatment, the surface energy increases from 32 mJ/mm^2 to 35 mJ/mm^2, as t_f increases from 100 Å to 300 Å; then it decreases to 31 mJ/mm^2, as t_f increases from 300 Å to 500 Å. The surface energy of the as-deposited CoFeB thin films exceeds that during post-annealing treatment at thicknesses of 100 Å and 200 Å, suggesting that as-deposited CoFeB thin film increases the adhesion.

1. Introduction

The performance of magnetic tunnel junctions (MTJs) is critical to nonvolatile magnetoresistive random access memory (MRAM), magnetic read heads, and sensor industries [1–5]. Ferromagnetic (FM) CoFeB thin film can form a free and pinned layer in the MTJ device because of its high spin polarization. Additionally, the free layer CoFeB adhesion of MTJ is essential, and this adhesion was determined to be compatible with other film layers, including the antiferromagnetic (AFM) layer, synthetic antiferromagnetic (SAF) layer, and seed layer. The magnetic CoFeB thin film is also inserted into the MTJ junction, which is compatible with the semiconductor process. However, investigations of the adhesive properties of CoFeB thin films in memory devices have been few. Researching the surface energy and devices that adhere to something in magnetic read-head operations and MRAM should be performed with reference to operations conducted at both room temperature (RT) and high temperatures. The amorphous CoFeB free layer of MTJ can induce a high tunneling magnetoresistance (TMR) ratio at RT [6]. Furthermore, the amorphous CoFeB free layer of MTJ can enhance a significantly higher TMR ratio during postannealing $T_A = 150°C$ treatment [7–9]. The contact angle and surface energy properties, such as amorphous, noncrystalline, and crystalline status, are associated with the crystalline degree of thin film [10, 11]. However, few previous studies have focused on the contact angle, surface energy, or adhesion properties of CoFeB thin films at RT, and they have not examined postannealing treatments adequately. Therefore, investigating such properties of CoFeB thin films is worthwhile.

This study examined the sputtering of CoFeB thin films with a thickness (t_f) ranging from 100 Å to 500 Å on glass substrates under various conditions: (a) substrate temperature (T_s) sustained at RT; (b) T_s = RT, conducting postannealing at $T_A = 150°C$ for 1 h. This study also examined the contact angle, microstructure, and surface energy properties of typical CoFeB films using X-ray diffraction (XRD) and contact angle measurements. The XRD results indicate that CoFeB thin films exhibit a body-centered cubic (BCC) structure.

2. Experimental Details

CoFeB thin films with a thickness (t_f) between 100 Å and 500 Å were deposited on a glass substrate by dc magnetron sputtering under two conditions: (a) T_s sustained at RT; (b) T_s = RT, conducting postannealing at T_A = 150°C for 1 h. The typical base chamber pressure was lower than 1×10^{-7} Torr, and the Ar-working chamber pressure was 5×10^{-3} Torr.

The structure of the CoFeB thin film was determined using the X-ray diffraction (XRD) method, employing a $CuK_{\alpha 1}$ line (Philips X'pert). The surface energy of the CoFeB thin films was obtained from measurements of contact angles, with water and diiodomethane as test liquids.

3. Results and Discussion

Figure 1 presents the X-ray diffraction results under two sets of conditions, revealing that the CoFeB thin film is in a noncrystalline state and yields BCC (110) diffraction peaks at RT. Moreover, the crystallinity of the postannealed film markedly exceeded that of the film at RT because the annealing treatment increased the grain size. The results demonstrate that postannealing treatment yields a crystalline state. Scherrer's formula enables the mean crystallite grain size (D) to be estimated from the measured width of the diffraction peak under two different conditions [12]. Scherrer's formula can be described as

$$D = \frac{k\lambda}{B\cos\theta}, \tag{1}$$

where k (0.9) is the Scherrer constant, λ is the X-ray wavelength of the $CuK_{\alpha 1}$ line, B is the relative value of the full width at half maximum (FWHM) of the (110) peak, and θ is the half angle of the diffraction peak. Applying Scherrer's formula, the grain sizes of CoFeB-500 Å, at (a) the substrate temperature (T_s) kept at RT and (b) post-annealing at heat annealing T_A = 150°C for 1 h, are 62 Å and 64 Å, respectively.

Figures 2(a) and 2(b) display the contact angles of the as-deposited CoFeB film with a thickness of 500 Å at RT, postannealed at T_A = 150°C for 1 h and determined using water as a test liquid. The contact angle results for the as-deposited CoFeB film with a thickness of 500 Å at RT, postannealed at T_A = 150°C for 1 h, are θ = 97.3° and 93.1°.

Figures 3(a) and 3(b) present the contact angles of the as-deposited CoFeB film with a thickness of 500 Å at RT, postannealed at T_A = 150°C for 1 h, and determined using diiodomethane as a test liquid. The contact angle results for the as-deposited CoFeB film with a thickness of 500 Å at RT and following postannealing at heat annealing T_A = 150°C for 1 h are θ = 54.4° and 56.55°.

Figure 4 displays the contact angle of the CoFeB film under two sets of conditions, determined according to the results with water as a test liquid, revealing that the contact angle increased with the thickness of the CoFeB thin film at RT. By contrast, the contact angle decreased as the thickness of the CoFeB thin film increased, following postannealing treatment. The contact angles of the CoFeB films formed under the two sets of conditions, with the test liquid water exceeding 90°, revealed that the CoFeB film is hydrophobic. Figure 4 can be divided into two regions. When the thickness ranges from 100 Å to 300 Å, the contact angle of CoFeB thin films at RT is larger than that during postannealing treatment. Correspondingly, as the thickness is from 300 Å to 500 Å, the contact angle of CoFeB thin films at RT is smaller than that during postannealing treatment. It can be reasonably concluded that the different CoFeB thicknesses are related to the contact angle result because of the crystalline degrees of CoFeB thin film. Based on this result, we can infer that 300 Å was a critical point in this experiment.

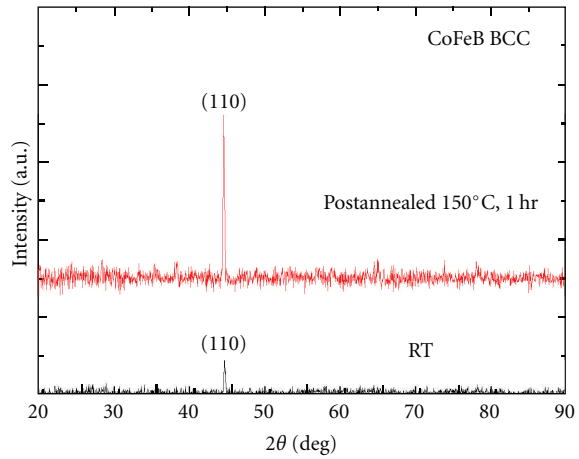
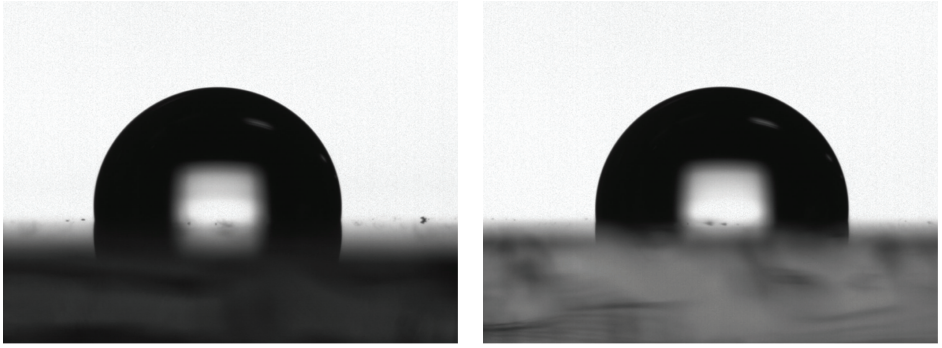


Figure 1: XRD patterns of BCC 500 Å-thick CoFeB thin films formed under two sets of conditions.

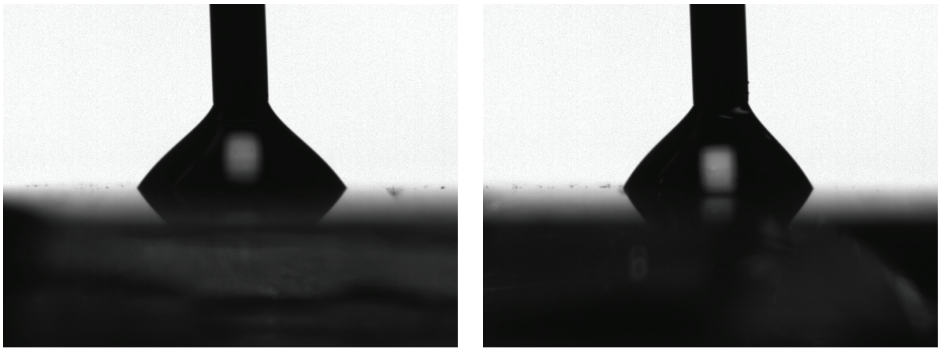
Figure 5 plots the contact angle of the CoFeB film under two sets of conditions, obtained using the test liquid, diiodomethane, indicating that the contact angle increases with the thickness of the CoFeB thin film at RT. However, during postannealing treatment, the contact angle decreases as the thickness of the CoFeB film increases, from 100 Å to 300 Å. The contact angle then increases with the thickness of the CoFeB film from 300 Å to 500 Å. This also indicates that 300 Å was a critical point in this experiment.

Figure 6 plots the surface energy results for the CoFeB films formed under the two sets of conditions. The surface energy was determined by the previously discussed calculation [13–15]. As t_f increases from 100 Å to 500 Å, the surface energy at RT decreases from 40 mJ/mm^2 to 32 mJ/mm^2. During postannealing treatment, the surface energy increases from 32 mJ/mm^2 to 35 mJ/mm^2 in conjunction with the thickness of the CoFeB film from 100 Å to 300 Å. The surface energy then decreases to 31 mJ/mm^2 with the thickness of the CoFeB film from 300 Å to 500 Å. This result also indicates that 300 Å of CoFeB thin film is a critical point in postannealing treatment. This phenomenon is consistent with the contact angle result. The surface energy of the as-deposited CoFeB thin films exceeds that of those underwent postannealing treatment at thicknesses of 100 Å and 200 Å. Moreover, the surface energy of the as-deposited CoFeB thin films is lower than that during postannealing treatment, at a thickness of 300 Å. This result indicates that the adhesion of the CoFeB layer at RT is more favorable than



(a) (b)

Figure 2: Contact images between 500 Å-thick CoFeB thin films and water as a test liquid under two sets of conditions: (a) deposited at RT; (b) postannealed at $T_A = 150^\circ$C for 1 h.



(a) (b)

Figure 3: Contact images between 500 Å-thick CoFeB thin films and diiodomethane as a test liquid under two sets of conditions: (a) deposited at RT; (b) postannealed at $T_A = 150^\circ$C for 1 h.

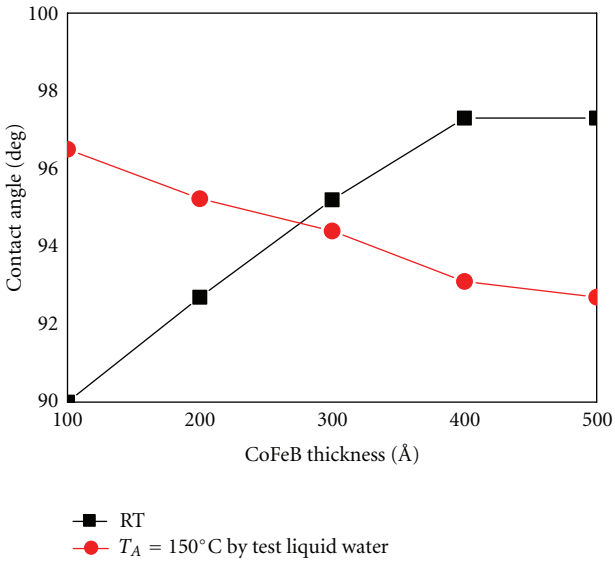


Figure 4: Contact angle between as-deposited CoFeB films at RT, postannealed at $T_A = 150^\circ$C for 1 h and water as test liquid.

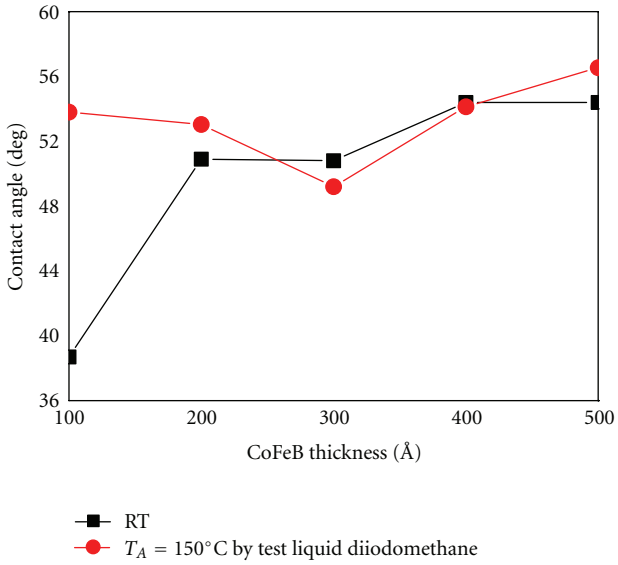


Figure 5: Contact angle between as-deposited CoFeB films at RT, postannealed at $T_A = 150^\circ$C for 1 h and test liquid diiodomethane.

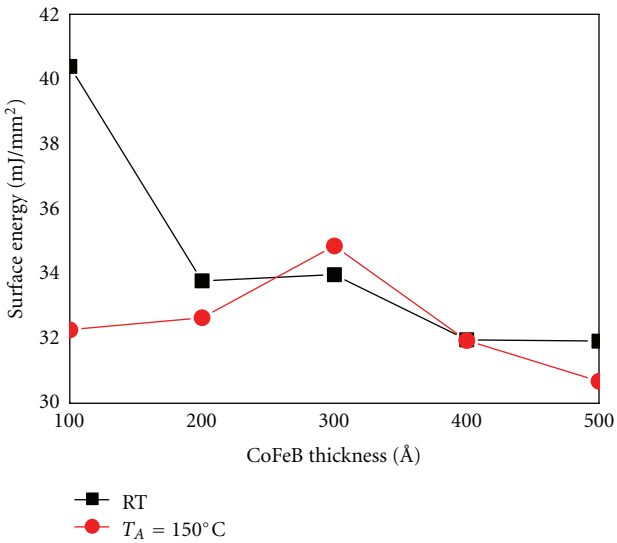


Figure 6: Surface energy of as-deposited CoFeB film at RT, postannealed at $T_A = 150°C$ for 1 h.

at postannealing when the CoFeB thickness ranges from 100 Å to 200 Å. Furthermore, this result is appropriate for antiferromagnetic (AFM) layers and seed layers in MTJ and MRAM applications.

4. Conclusions

The structural and adhesive characteristics of CoFeB thin films were deposited by implementing a sputtering system under two sets of conditions at RT and during postannealing treatment. Analyzing the XRD diffraction results reveals that the CoFeB thin films exhibited a BCC structure. Furthermore, contact angle analysis reveals that the contact angle of the CoFeB thin films using water as the test liquid exceeds that of using diiodomethane as the test liquid. Additionally, the surface energy is calculated according to the contact angle. The surface energy of the as-deposited CoFeB thin film exceeds that obtained during postannealing treatment at thicknesses of 100 Å and 200 Å, suggesting that as-deposited CoFeB thin film increases the adhesion.

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References

[1] S. Yuasa, A. Fukushima, H. Kubota, Y. Suzuki, and K. Ando, "Giant tunneling magnetoresistance up to 410% at room temperature in fully epitaxial Co/MgO/Co magnetic tunnel junctions with bcc Co(001) electrodes," *Applied Physics Letters*, vol. 89, no. 4, Article ID 042505, 3 pages, 2006.

[2] X. F. Han and A. C. C. Yu, "Patterned magnetic tunnel junctions with Al conduction layers: fabrication and reduction of pinhole effect," *Journal of Applied Physics*, vol. 95, no. 2, pp. 764–766, 2004.

[3] M. Sato and K. Kobayashi, "Spin-valve-like properties of ferromagnetic tunnel junctions," *Japanese Journal of Applied Physics*, vol. 36, no. 2, pp. L200–L201, 1997.

[4] T. Moriyama, C. Ni, W. G. Wang, X. Zhang, and J. Q. Xiao, "Tunneling magnetoresistance in (001)-oriented FeCoMgOFeCo magnetic tunneling junctions grown by sputtering deposition," *Applied Physics Letters*, vol. 88, no. 22, Article ID 222503, 3 pages, 2006.

[5] Y. T. Chen, S. U. Jen, Y. D. Yao, J. M. Wu, and A. C. Sun, "Interfacial effects on magnetostriction of CoFeB/A/Ox/Co junction," *Applied Physics Letters*, vol. 88, no. 22, Article ID 222509, 3 pages, 2006.

[6] D. Wang, C. Nordman, J. M. Daughton, Z. Qian, and J. Fink, "70% TMR at room temperature for SDT sandwich junctions with CoFeB as free and reference layers," *IEEE Transactions on Magnetics*, vol. 40, no. 4, pp. 2269–2271, 2004.

[7] H. Meng, W. H. Lum, R. Sbiaa, S. Y. H. Lua, and H. K. Tan, "Annealing effects on CoFeB-MgO magnetic tunnel junctions with perpendicular anisotropy," *Journal of Applied Physics*, vol. 110, no. 3, Article ID 033904, 4 pages, 2011.

[8] A. T. Hindmarch, G. I. R. Anderson, C. H. Marrows, and B. J. Hickey, "In situ transport in alumina-based magnetic tunnel junctions during high-vacuum annealing," *Journal of Applied Physics*, vol. 99, no. 8, Article ID 08K701, 3 pages, 2006.

[9] K. M. Wu, Y. H. Wang, W. C. Chen et al., "Repair effect on patterned CoFeB-based magnetic tunneling junction using rapid thermal annealing," *Journal of Magnetism and Magnetic Materials*, vol. 310, no. 2, pp. 1920–1922, 2007.

[10] H. J. Jeong, D. K. Kim, S. B. Lee, S. H. Kwon, and K. Kadono, "Preparation of water-repellent glass by sol-gel process using perfluoroalkylsilane and tetraethoxysilane," *Journal of Colloid and Interface Science*, vol. 235, no. 1, pp. 130–134, 2001.

[11] S. D. Evans, E. Urankar, A. Ulman, and N. Ferris, "Self-assembled monolayers of alkanethiols containing a polar aromatic group: effects of the dipole position on molecular packing, orientation, and surface wetting properties," *Journal of the American Chemical Society*, vol. 113, no. 11, pp. 4121–4131, 1991.

[12] B. D. Cullity, *Elements of X-Ray Diffraction*, Addison-Wesley, Reading, Mass, USA, 2nd edition, 1978.

[13] K. Ma, T. S. Chung, and R. J. Good, "Surface energy of thermotropic liquid crystalline polyesters and polyesteramide," *Journal of Polymer Science*, vol. 36, no. 13, pp. 2327–2337, 1998.

[14] D. K. Owens and R. C. Wendt, "Estimation of the surface free energy of polymers," *Journal of Applied Polymer Science*, vol. 13, no. 8, pp. 1741–1747, 1969.

[15] D. H. Kaelble and K. C. Uy, "A reinterpretation of organic liquid- polytetrafluoroethylene surface interactions," *Journal of Adhesion*, vol. 2, pp. 50–60, 1970.