Journal of Magnetics 3(3), 96-98 (1998)

Barium Ferrite Media for Extremely High Density Recording Applications

Yang-Ki Hong and Hong-Sik Jung

Magnetic and Electronic Materials Research Laboratory, Department of Metallurgical Engineering, University of Idaho, Moscow, Idaho 83844-3024, USA

(Received 21 August 1998)

In this paper a structurally coupled and magnetically decoupled Ba-ferrite thin film medium is proposed to evade the superparamagnetic limit and reduce media noise. The proposed medium consists of ferrimagnetic Ba-ferrite nano-grains (< 10 nm) and a non-magnetic grain boundary material. Magnetic grains are crystallographically matched with the grain boundary material. Spherical or cubic shaped Ba-ferrite particle is also proposed for above 100 Kfci particulate recording applications.

With GMR heads already in production and concerns over the thermal limit of recording media looming ahead, this may be the right time to reconsider Ba-ferrite (BaFe) as a candidate for high-density particulate and thin film media. As magnetic grain size approaches 10 nm or below, the spin-canting layer has a critical role in the thermal stability of a magnetic grain or particle. Media noise is originated from intergranular magnetic interaction and grain size [1]. In order to overcome the superparamagnetic limit (thermal limit) and also reduce the media noise, a high anisotropy field (H_k), a high coercivity (H_c), and nano-sized magnetic grains (<10 nm) are needed. BaFe offers high coercivity, low magnetization, chemical stability, and high hardness.

Iron-based alloy particulate (MP) media have been intensively studied and developed by information storage media groups in joint effort with drive design groups. This consistent joint effort has allowed the MP media to be dominant in the marketplace and also lead to creation of several pigment manufacturers. BaFe particulate and thin film media have been developed by industry and studied by academia for the last 15 years. This development effort has lead to commercial BaFe media products, such as the floppy disk, data tape, videotape and prototype of BaFe coated hard disks; however, these products were never produced in volume. Why? There are several reasons for this unfavorable market response. First, because of BaFe's low magnetic moment, read heads available at that time were unable to sense a low signal from BaFe media; second, it was difficult to disperse BaFe particles in a binder; and third, there was little communication between media and drive groups. Now that the GMR head is available, the low signal from BaFe media is no longer an issue.

Demand for high-density recording media requires ever scaling of magnetic particles, high coercivity, and excellent dispersion of particles in a binder system. Dispersion and orientation problems associated with BaFe particles can be solved with currently available particle technology. This technology involves the synthesis of nano-sized particles and controlling the aspect ratio to nearly one, i.e. spherical or cubic shape, while meeting all other required magnetic and physical properties. Spherical BaFe pigment is an absolute choice for future particulate recording applications with recording densities well above 100 kfci.

As recording density of thin-film media approaches and surpasses 10 Gbits/in^2, tailored media properties will include low saturation magnetization (M_s), high coercivity, and nano-sized grains. Over time, the saturation magnetization of CoCr-based alloy thin film media has been reduced to below 300 emu/cm^3, close to that of BaFe thin film media (100 to 280 emu/cm^3) as shown in Fig. 1 [2-10]. Higher coercivity has been achieved by enhancing Cr segregation [11-13], improving crystallinity of grains [14], precipitating a CoPt phase [15], and decreasing crystallographic mismatch between the underlayer and the magnetic layer [3, 7, 14-19]. Furthermore, smaller grain size has been achieved by alloying CoCrPt with Ta, by careful selection of underlayer (Cr → CrMo/Ti [3, 7] → Cr/NiAl [14] or FeAl [16] → Cr/CoCr [17] or CoCrTa [18] → CrMn [19]), and by using both the seed layer (MgO) [20] and thin magnetic layer. Magnetic cluster size has been reduced by using low cobalt composition and by adding both an inserting interlayer (Cr, Ag) [23] and elements with low solubility (*i.e.* SiO_2 [21, B [15, 22]). For further scaling of grains, compositional segregation would be difficult due to an increase in the relative amount of paramagnetic phase in the grain. All these attempts to

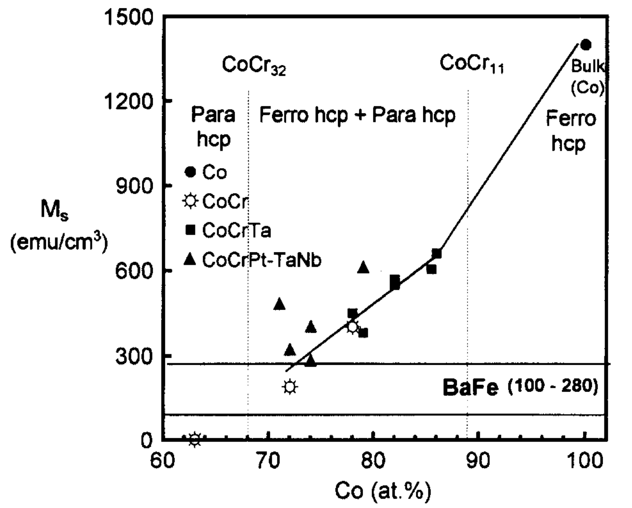

Fig. 1. Composition dependence of saturation magnetization of CoCr-based alloy thin film [2-10].

qualify CoCr-based alloy thin films for above 10 Gbits/in^2 create several possible drawbacks. These drawbacks may include multi-component alloy composition, complex film structure, difficult compositional segregation of grains by Cr, and limitation of further reduction in grain size. In addition, deposition of a carbon overcoat less than 5 nm thick is the most important task to accomplish for preserving this film in currently available disk technology. Developing such a thin carbon protective overcoat may restrict the use of CoCr-based alloy thin film even before the superparamagnetic limit is reached. Currently the thinnest coating that has been achieved is 10 nm thick.

So what is the alternative? A structurally coupled, magnetically decoupled BaFe thin film is the answer. Fig. 2 shows schematically the structure of this two-phase thin film consisting of ferrimagnetic BaFe grains and a non-magnetic oxide grain boundary phase, which form a network of BaFe grains. This structure is a proposed model of BaFe thin film media for recording applications higher than 20 Gbits/in^2. Magnetic grains are crystallographically matched with the grain boundary layer. By fabricating thin-film media in this way, the formation of the spin-canting layer on each magnetic grain can be avoided. Consequently, the superparamagnetic limit would be evaded, and intergranular coupling weaker than in the

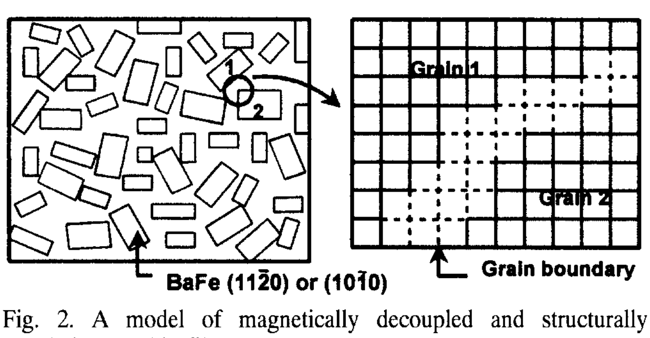

Fig. 2. A model of magnetically decoupled and structurally coupled BaFe thin film.

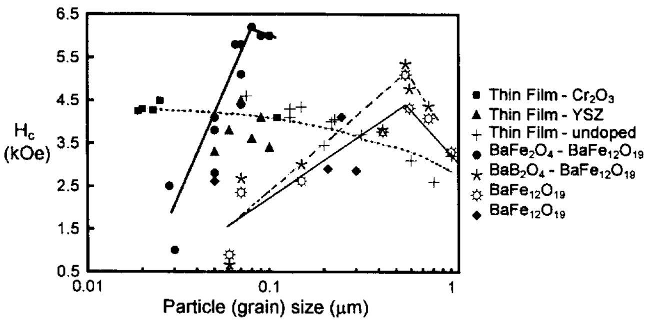

Fig. 3. Particle (grain) size dependence of BaFe coercivity [25-28].

CoCr-based alloy film. It is reported that the spin-canting layer preferentially forms on the *c*-plane of BaFe hexagonal structure [24]. Protection of the BaFe grains, having a *c*-axis in-plane grain orientation, from the formation of the spin-canting layer is easily achieved because the *c*-plane is structurally coupled with the grain boundary material. Published data [25-28] presented in Fig. 3 support that the proposed structure of BaFe thin film media herein, having smaller grains than 10 nm, would evade the superparamagnetic limit. As shown in Fig. 3, the coercivity of isolated BaFe particles dramatically decreases at about 500 nm, which is the critical size for a single magnetic domain. In contrast, BaFe particles coated with a $BaFe_2O_4$ layer shifts the critical size down to 80 nm. This shift is attributed to structural coupling between $BaFe_2O_4$ and BaFe phases. Furthermore, Cr_2O_3 doped BaFe thin film deposited on sapphire substrate retains high coercivity (about 4500 Oe) even at 20 nm grain size. Therefore, it is possible to stabilize nano-sized (<10 nm) magnetic grains (K_uV) against thermal energy (kT) by structurally coupling magnetic grains with a non-magnetic grain boundary material to achieve recording density above 20 Gbits/in^2 (illustrated in Fig. 2).

Is such a thin film technically feasible? Before this BaFe thin film can be used for high density recording applications, there are several challenges to resolve. The first is selecting the proper grain boundary material; second, the deposition temperature needs to be reduced; and third, a higher deposition rate is needed. These challenges can be addressed by evaluating crystallographic match and thermodynamic data for grain boundary oxide, selecting a non-magnetic phase oxide with a low solubility in BaFe, providing copious nucleation of BaFe crystallites, and developing semiconducting BaFe sputtering targets.

References

[1] T. Yogi and T. A. Nguyen, IEEE Trans. Magn., **29**, 307 (1993).
[2] J. E. Snyder and M. H. Kryder, J. Appl. Phys., **73**, 5551 (1993)
[3] H. Kisker, E. N. Abarra, Y. Yamada, P. Glijer, and T. Suzuki, J. Appl. Phys., **81**, 3937 (1997).
[4] H. Akimoto, I. Okamoto, and M. Shinohara, IEEE Trans. Magn.,

34, 1597 (1998).
[5] H. Sato, A. Kikuchi, J. Nakai, H. Mitsuya, T. Shimatsu, and M. Takahashi, IEEE Trans. Magn., **32**, 3596 (1996).
[6] M. R. Khan, S. Y. Lee, S. L. Duan, J. L. Pressesky, N. Heiman, D. E. Speliotis, and M. R. Scheinfein, J. Appl. Phys., **69**, 4745 (1991).
[7] Y. Sonobe, Y. Ikeda, H. Uchida, and T. Toyooka, J. Appl. Phys., **81**, 4667 (1997).
[8] Y. Hirayama and M. Futamoto, J. Mag. Soc. Jpn., **19 S2**, 14 (1995).
[9] C. Okuyama, I. Okamoto, K. Sato, and M. Shinohara, Digests of INTERMAG'97, CP-08 (1997)
[10] S. Ohkijima, M. Oka, and H. Murayama, IEEE Trans. Magn., **33**, 2944 (1997).
[11] J. E. Wittig, T. P. Nolan, C. A. Ross, M. E. Schabes, K. Tang, R. Sinclair, and J.Bentley, IEEE Trans. Magn., **34**, 1564 (1998).
[12] R. Mukai, K. Yamanaka, and M. Oshiki, J. Appl. Phys., **81**, 3931 (1997).
[13] J. Nakai, A. Kikuchi, M. Kuwabara, T. Sakurai, T. Shimatsu, and M. Takahashi, IEEE Trans. Magn., **31**, 2833 (1995).
[14] L. Lee, D. E. Laughlin, L. Fang, and D. N. Lambeth, IEEE Trans. Magn., **31**, 2728 (1995).
[15] N. Tani, T. Takahashi, M. Hashimoto, M. Ishikawa, Y. Ota, and K. Nakamura, IEEE Trans. Magn., **27**, 4736 (1991).
[16] L. Lee, D. E. Laughlin, and D. N. Lambeth, J. Appl. Phys., **81**, 4366 (1997).
[17] B. Zhang, W. R. Bennett, C. Gao, G. C. Rauch, and J. R. Blachere, IEEE Trans. Magn., **32**, 3590 (1996).
[18] J. Zou, D. E. Laughlin, and D. N. Lambeth, IEEE Trans. Magn., **34**, 1582 (1998).
[19] L. Lee, D. E. Laughlin, and D. N. Lambeth, IEEE Trans. Magn., **34**, 1561 (1998).
[20] L. Lee, D. E. Laughlin, and D. N. Lambeth, J. Appl. Phys., **79**, 4902 (1996).
[21] A. Murayama, S. Kondoh, and M. Miyamura, J. Appl. Phys., **75**, 6147 (1994).
[22] S. McKinlay, M. Doerner, C. Qian, M. Mirzamaani, and R. Sinclair, Digest of INTERMAG'97, AB-02 (1997).
[23] Y. C. Feng, D. E. Laughlin, and D. N. Lambeth, IEEE Trans. Magn., **30**, 3960 (1994).
[24] X. Batlle, X. Obradors, M. Medarde, J. Rodriguez-Carvajal, M. Pernet, and M. Vallet-Regi, J. Magn. Magn. Mater., **124**, 228 (1993).
[25] T. L. Hylton, M. A. Parker, M. Ullah, K. R. Coffey, R. Umphress, and J. K. Howard, J. Appl. Phys., **75**, 5960 (1994).
[26] T. Yanagase, K. Morinaga, Y. Kuromitsu, and S. Fuchigami, J. Non-Crystalline Solids, **56**, 361 (1983).
[27] B. T. Shirk and W. R. Buessem, IEEE Trans. Magn., **7**, 659 (1971).
[28] Z. Yang, J. Liu, P. Zheng, S. Geng, and Z. Chen, IEEE Trans. Magn., **23**, 3131 (1987).