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Development of thin film media for high-density perpendicular magnetic recording

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The development of thin film media technologies for high-density perpendicular magnetic recording is reviewed focusing on the microstructure control of Co-alloy recording layer. Some of the important technologies for the soft magnetic back-layer are also described.

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1. Introduction

Perpendicular magnetic recording (PMR) has been employed in the commercial hard disk drive (HDD) since the year 2005. The use of PMR enables us to increase the areal recording density more than several times than that achievable with the conventional longitudinal magnetic recording [1]. The areal density of 230 Gb/in^2 has been demonstrated [2] and the feasibility of several hundreds Gb/in^2 areal density with PMR are now being challenged. Fig. 1 shows the decreasing trend of magnetic bit size in HDDs.

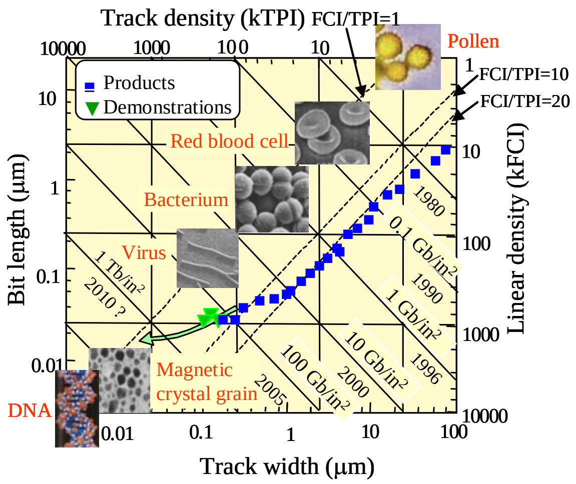

Fig. 1. Magnetic bit size trend in hard disk drives.

The concept of PMR was first introduced in 1976 [3] and since then the PMR technologies have been investigated by researchers for nearly 30 years until they are finally applied to commercial HDDs. In the PMR technologies, the recording media and the writing head are quite different from those for the conventional longitudinal magnetic recording while other technologies like the reading head and the mechanical positioning have much in common. One of the key PMR technologies, the thin film perpendicular recording media, has been improved in the past 30 years to follow the areal density increase that has been leaded until recently by the longitudinal magnetic recording. The PMR is now recognized as the recording scheme with which we can increase the recording areal density while coping with some of the arising difficulties such as the writing head capability, the super-paramagnetic effect of recording media and etc. [1, 4]. The present paper briefly reviews the development of perpendicular magnetic recording media that is the key technology for high-density magnetic recording.

2. Perpendicular recording media

There are two types of perpendicular recording media. One is the single-magnetic-layer perpendicular medium, which is deposited on a substrate, generally via an underlayer to promote the magnetic layer growth with the easy magnetization direction perpendicular to the substrate surface. The other is the double-magnetic layer perpendicular recording medium, where a soft magnetic back-layer is placed beneath the recording layer and it acts as a part of writing head in a recording process. Thus, the writing efficiency is enhanced and this type of medium is more suitable for ultra-high-density magnetic recording applications. In commercial HDDs, this type of medium is employed.

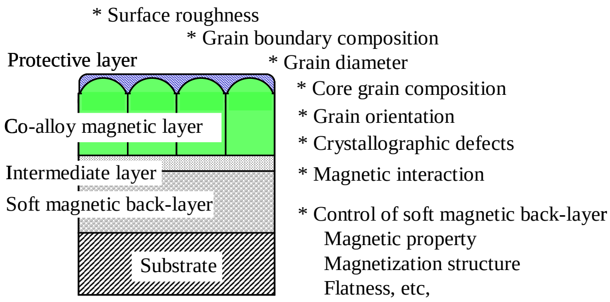

Fig. 2. Technical issues of Co-alloy perpendicular recording media.

2.1 Technical issues

Fig. 2 shows the technical issues of double-magnetic-layer type perpendicular recording media. The two magnetic layers have different magnetic properties. The recording layer has hard magnetic property while the back-layer has soft magnetic property. The microstructure and magnetic properties of these two layers must be optimized for high-density magnetic recording and need to be combined. Generally a thin intermediate layer is introduced between the two magnetic layers and it plays important roles to control the easy magnetization axis, grain diameter, crystallographic property of the recording layer and also to control the magnetic interaction between the two magnetic layers. The magnetic interaction control is very important to get recording media with low noise characteristics [5].

2.2. Improvement of microstructure of Co-alloy recording layer

When a Co-alloy magnetic material of hcp crystal structure is deposited on a substrate, a texture growth develops with the c-axis direction perpendicular to the film plane. However an initial growth region, where grains with different growth directions are competing, exists near the substrate as shown in Fig. 3 (a) [6]. The initial growth region is undesirable for perpendicular magnetic recording. Various underlayer materials were investigated to promote the c-axis oriented crystal growth and materials like Ti, Ta, Si, and Ge were found to be suitable for this purpose [7, 8]. Fig. 3 (b) shows the cross-sectional structure of a CoCr-alloy layer deposited on a Ti underlayer [9]. The perpendicular magnetic anisotropy was greatly enhanced by introducing such an underlayer. This type of highly c-axis oriented medium was used for high density magnetic recording demonstrations with PMR in the mid ‘80s [7, 10].

With increasing the linear recording density, the perpendicular coercivity must be increased while the recording layer thickness needs to be reduced to enhance the writing efficiency of a recording head. When the recording layer thickness was decreased smaller than 30 nm, the perpendicular coercivity started to decrease. Careful examinations of the interface between the Co-alloy recording layer and the underlayer have revealed that there is a disordered region of less than several nanometers existing at the interface. Fig. 4 shows a series of RHEED pattern observed during film deposition [11]. The diffuse RHEED pattern from the initial growth region of CoCr-alloy on a Ti underlayer indicates that the crystallographic structure is disturbed. A high-resolution TEM of this region shows that the lattice packing is disordered for 3 – 5 nm in thickness as shown in Fig. 5 [12]. This is partially due to a large lattice misfit of about 15 % between the CoCr-alloy magnetic layer and the Ti underlayer and partially due to diffusion of elements. An introduction of nonmagnetic interlayer with hcp crystal structure such as $CoCr_{35}$, $CoCr_{25}Ru_{25}$, or Ru was effective to form a sharp interface [12, 13]. Such an example is shown in Fig. 6. Perpendicular magnetic properties were improved for the recording layer in reduced thicknesses as shown in Fig. 7.

Another origin to deteriorate the perpendicular magnetic property is stacking faults (SFs) in the hcp crystal structure. When a SF exists in an hcp-Co-crystal, the local atomic arrangement is similar to that of fcc structure. The magnetocrystalline anisotropy energy of fcc-Co is a magnitude lower that that of hcp-Co. The perpendicular coercivity decreases when SFs exist in the crystals of hcp-Co-alloy recording layer. The SFs are also undesirable in assuring the thermal stability of recorded information. The distribution of SF was examined for Co-alloy recording layers using a high-resolution TEM and was revealed that it depends on the process condition such as substrate temperature and deposition rate as well as the underlayer or intermediate layer material. An example of such analysis is shown in Fig. 8 [14]. In a recent PMR media production, the structure and the process are carefully controlled to lower the SF density in the recording layer.

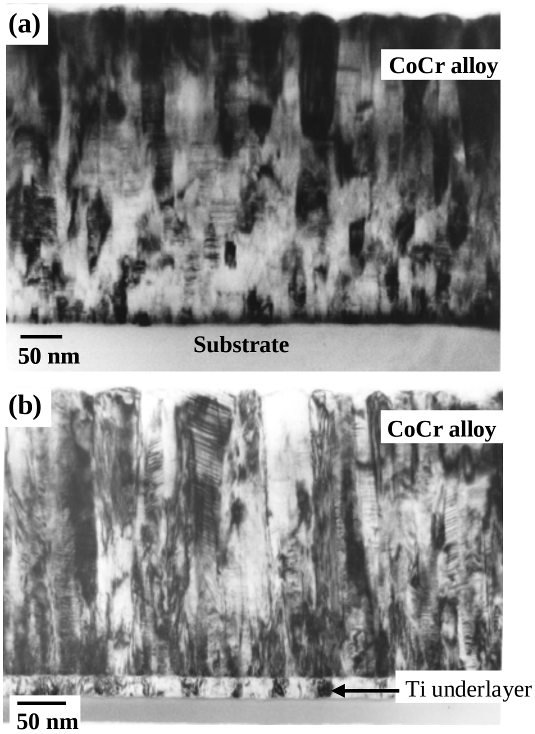

Fig.3 Cross-sectional microstructure of CoCr-alloy PMR media: (a) no underlayer[6], (b) Ti underlayer[9].

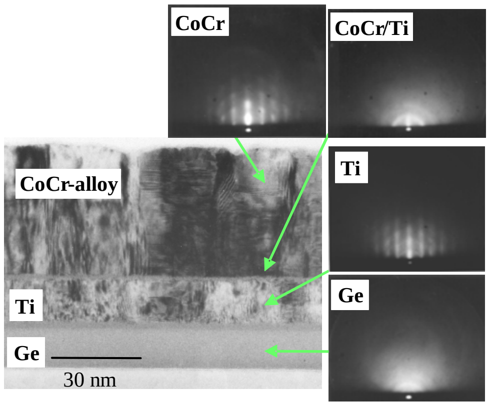

Fig.4 RHEED patterns observed during thin film deposition. PMR medium structure is CoCr/Ti/Ge/substrate[11].

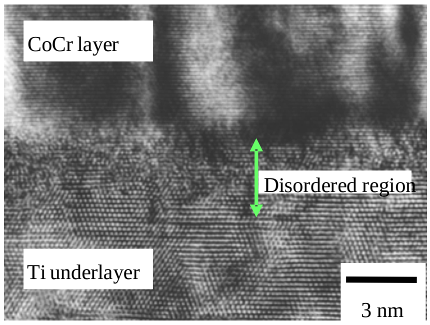

Fig.5 Cross-sectional TEM image of CoCr/Ti interface[12].

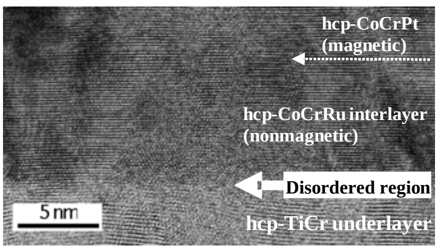

Fig.6 Cross-sectional TEM image of interface between underlayer and magnetic layer. Nonmagnetic hcp-CoCr-alloy interlayer is introduced between the Ti-alloy underlayer and the hcp-CoCr-alloy magnetic layer[13].

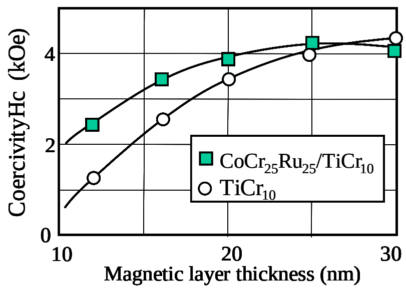

Fig.7 Improvement of perpendicular magnetic property by introducing nonmagnetic hcp-CoCrRu interlayer[12].

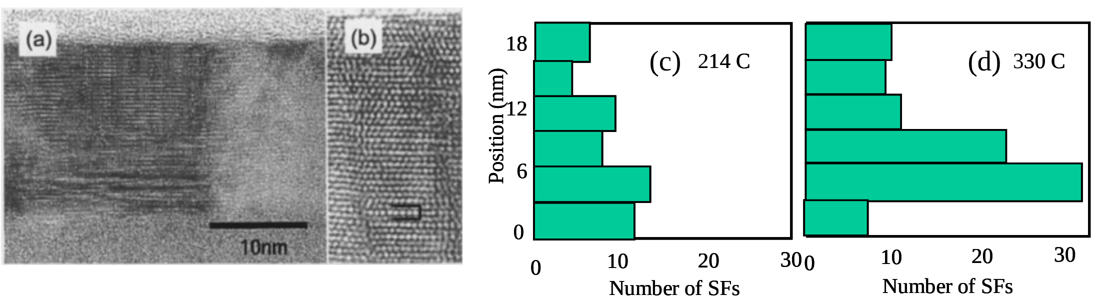

Fig. 8. Distribution of stacking faults (SFs) in CoCrPt recording layer. (a) cross-sectional TEM image, (b) an example of stacking fault, (c) SF distribution along a CoCrPt layer grown at a substrate temperature of 214 C, (d) SF distribution along an another CoCrPt layer grown at 330 C. The medium structure is CoCrPt (18 nm)/NiTaZr/Glass substrate [14].

Magnetic isolation and diameter control of crystalline grain of the recording layer is necessary for high-density magnetic recording in order to increase the coercivity and to reduce the medium noise. Magnetic isolation is achieved by enhancing segregation or precipitation of nonmagnetic elements at the crystalline grain boundaries. Fig. 9 shows the Cr distribution in CoCrTa perpendicular recording media when deposited at different substrate temperatures [15]. Nonmagnetic Cr element's segregation along the grain boundaries is recognizable for the recording medium deposited at a substrate temperature of 230 C. Addition of oxygen or oxide to the CoPt or CoCrPt layer was shown effective to enhance the magnetic crystalline grain isolation. This technology was first applied to longitudinal recording media and then to perpendicular recording media [16-18]. Perpendicular magnetic properties including coercivity and squareness were greatly improved by adding oxides like SiO_x. A plan-view TEM picture of CoCrPt-SiO_x perpendicular medium is shown in Fig. 10. The addition of SiO_x to a CoCrPt film reduces the magnetocrystalline anisotropy energy, Ku, of the film. However, the crystalline Ku value estimated for isolated grains is reported to be as high as 8×10^6 erg/cm^3 for the $(Co_{90}Cr_{10})_{80}Pt_{10}$ film added with 10 at.%-SiO_x [19]. This Ku value is higher than that of pure Co. The reason for such a high Ku value is still unclear but could be due partially to some ordering of Co and Pt atoms. The high Ku value is desirable for increasing the perpendicular coercivity and to keep the thermal stability of recorded information with a reduced crystalline grain diameter. This type of recording layer is employed in commercial HDDs.

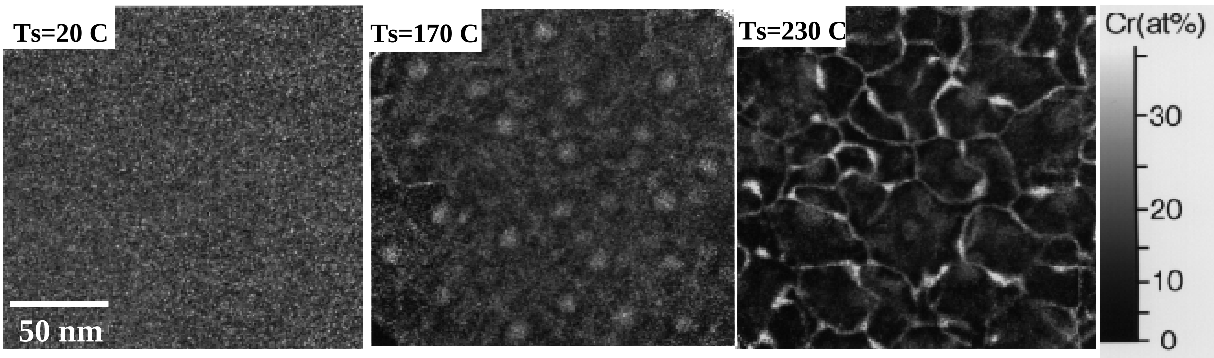

Fig. 9. Cr distribution of CoCrTa perpendicular recording media observed by EELS-TEM. Brighter contrast shows the region with higher Cr concentration. The films were sputter-deposited at different substrate temperature [5].

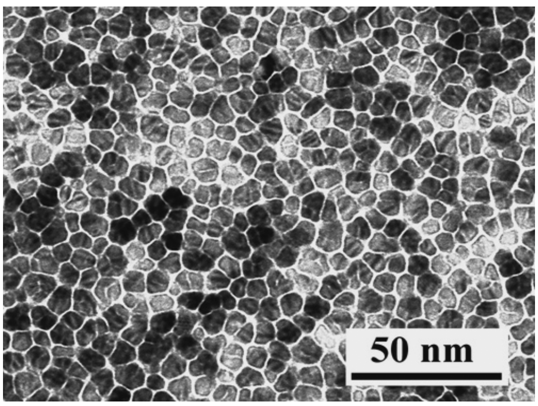

Fig. 10. Plan-view TEM of CoCrPt-SiOx perpendicular recording media.

2.3 Improvement of soft magnetic back-layer

The soft magnetic back-layer plays as a part of the writing head in a recording process. In this case, the recording layer is essentially placed between the writing head gap, thus enhancing the writing capability. The thickness of the soft magnetic back-layer is far greater that that of the recording layer and is generally in the range of 50 – 500 nm. Magnetic softness is required for the layer material because the layer plays as a part of writing head. Other than the magnetic softness, flatness of the surface is important to realize a perpendicular medium with which low flying height of a magnetic head can be realized. Various soft magnetic materials were sputter deposited on glass substrates 400 nm in thickness and were investigated by cross-sectional TEM. When the soft magnetic back-layer has a crystalline textured structure, the surface became rough due to a dome-like shape of individual columnar crystal, which is not suitable for media for high-density magnetic recording. Thus it is necessary that the soft magnetic layer should be either an amorphous or a fine grain structure to assure a flat surface [4].

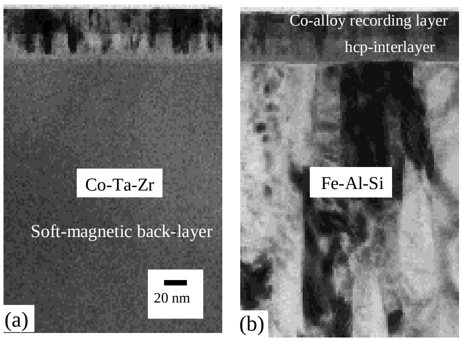

Fig. 11. Cross-sectional TEM of Co-alloy perpendicular recording media with soft magnetic underlayer with different structures. (a) amorphous Co-Ta-Zr. (b) crystalline Fe-Al-Si [14].

Noise properties including the DC noise and the spike noise were investigated for various soft magnetic layers [20]. The remanent magnetization structures of the soft magnetic layers and those for the double layer perpendicular media which have a common CoCrPt recording layer on respective soft magnetic back-layers were investigated by magnetic force microscopy(MFM). The magnetization irregularities observed by MFM correspond to the medium noise observed by using a magnetic head. Fig. 12 shows an example of such observation. Soft magnetic back-layer of amorphous CoNbZr or FeTaC with fine grain structure was confirmed to be suitable for the media for high-density magnetic recording [1, 21]. These kinds of soft magnetic back-layers are widely investigated from additional point of view to suppress the spike noise and have been practically used in commercial HDDs [22]. Spike noise suppression is realized by forming a quasi-single domain structure in the soft magnetic back-layer by combining with an antiferromagnetic material layer, or by avoiding the magnetic leakage flux from the domain walls through employing an antiparallel-coupled soft magnetic layer structure.

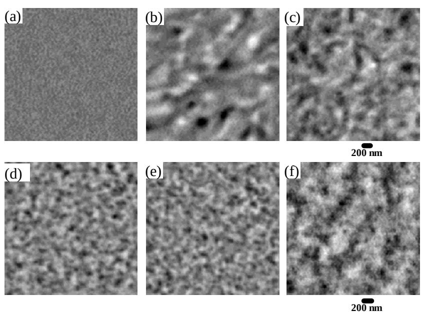

Fig. 12. Remanent magnetization structure of soft magnetic layers and double-layer perpendicular media. (a) Co-Ta-Zr soft magnetic alyer, (b) Fe-Ta-C soft magnetic, (c) Fe-Al-Si soft magnetic layer and Co-alloy perpendicular media with (d) Co-Ta-Zr, (e) Fe-Ta-C, (f) Fe-Al-Si soft magnetic back-layers [21].

2.4 PMR media, past and present

Fig. 13 compares the perpendicular recording media, past and present. The medium developed in 1985 is a single-layer while the medium used today is a double-layer type. In the past 20 years, the recording layer thickness decreased from around 350 nm to 15 – 20 nm, while the perpendicular coercivity increased from 850 Oe to 4000 – 5000 Oe. The crystal grain diameter of the recording layer decreased from around 40 nm to 8 – 10 nm. A drastic scale down in the recording layer structure is realized while the perpendicular magnetic property is greatly increased. The improvement owes much to the progress of material and process technologies that have been investigated and developed by many researchers for a long period of time.

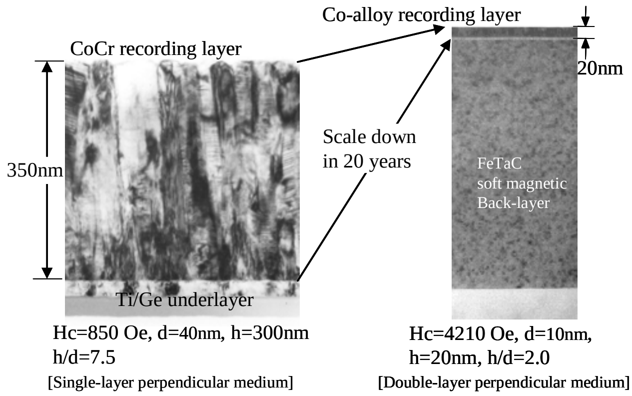

Fig. 13. Comparison of perpendicular recording media. Recording layer heigh(h) and grain diameter (d) have been reduced greatly while perpendicular coercivity has been increased in the past 20 years.

3. Summary

Development of perpendicular recording media is briefly reviewed focusing on the microstructure control of the recording layer and the soft magnetic back-layer. The difficulties that arise in conventional longitudinal recording media can be reduced through the use of perpendicular media. An areal recording density exceeding 200 Gb/in^2 has been shown possible using a Co-alloy recording layer in combination with an amorphous or fine grain soft magnetic back-layer. The PMR scheme has started to be applied to commercial HDDs and it will more widely used in the coming years. Further improvement of perpendicular recording media will make it possible to realize 1 Tb/in^2 ultra-high-density magnetic recording. The author believes when a new technology such as a heat-assisted magnetic recording or a patterned media technology is combined with the current perpendicular magnetic recording, an areal density of greater than several Tb/in^2 will become possible in the future.

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References

[1] M. Futamoto, Y. Hirayama, Y. Honda, N. Inaba, Proc. of the NATO Advanced Study Institutes on "Magnetic Storage Systems Beyond 2000, ed. by G. C. Hadjipanayis, Kluwer Academic Pub., 2001, p.103.
[2] Hitachi GST, Press Release (2005. 4. 5).
[3] S. Iwasaki, Y. Nakamura, IEEE Trans. Magn. **MAG-13,** 1272 (1977).
[4] M. Futamoto, Y. Hirayama, Y. Honda, A. Kikukawa, T. Tanahashi, A. Ishikawa, J. Mag. Mag. Mater. **235,** 281(2001).
[5] Y. Honda, K. Tanahashi, Y. Hirayama, A. Kikukawa, M. Futamoto, IEEE Trans. Magn. **37,** 1315(2001).
[6] M. Futamoto, Y. Honda, H. Kakibayashi, T. Shimotsu, Y. Yoshida, Japan. J. Appl. Phys. **24**, L460(1985).
[7] M. Futamoto, Y. Honda, H. Kakibayashi, K. Yoshida, IEEE Trans. Magn. **MAG-21,** 1426 (1985).
[8] H. S. Gill, T. Yamashita, IEEE Trans. Magn. **MAG-20**, 776 (1984).
[9] M. Futamoto, Y. Honda, K. Yoshida, J. de Physique Colloque, c8, Suppl. Au n.12, **Tome 49**, C8-1979(1988).
[10] Y. Honda, M. Futamoto, S. Hasegawa, T. Kawasaki, F. Kugiya, M. Koizumi, K. Yoshida, A. Tonomura, J. de Physique Colloque, c8. Suppl. Au. n.12, **Tome 49**, C8-1969(1988).
[11] M. Futamoto, Y. Honda, Y. Matsuda, N. Inaba, Technical Report of IEICE, **MR9-46**, 29 (1991).
[12] M. Futamoto, Y. Hirayama, Y. Honda, N. Inaba, J. Mag. Mag. Mater. **226-230,** 1610 (2001).
[13] Y. Hirayama, A. Kikukawa, Y. Honda, N. Shimizu, M. Futamoto, IEEE Trans. Magn. **36**, 2196 (2000).
[14] Y. Takahashi, K. Tanahashi, and Y. Hosoe, J. Appl. Phys. **91**, 8022 (2002).
[15] M. Futamoto, N. Inaba, Y. Hirayama, K. Ito, Y. Honda, J. Mag. Mag. Mater. **193**, 36 (1999).
[16] T. Hikosaka, T. Komai, Y. Tanaka, IEEE Trans. Magn. **30**, 4026 (1994).
[17] S. Oikawa, A. Takeo, T. Hikosaka, Y. Tanaka, IEEE Trans. Magn. **36**, 2393 (2000).
[18] Y. Tanaka, T. Hikosaka, J. Mag. Mag. Mater. **235**, 253 (2001).
[19] T. Shimatsu, H. Sato, T. Oikawa, Y. Inaba, O. Kitakami, S. Okamoto, H. Aoi, H. Muraoka, Y. Nakamura, IEEE Trans. Magn. **41**, 566 (2005).
[20] A. Kikukawa, Y. Honda, Y. Hirayama, M. Futamoto, IEEE Trans. Magn. **36**, 2402 (2000).
[21] Y. Honda, A. Kikukwa, Y. Hirayama, M. Futamoto, IEEE Trans. Magn. **36,** 2399 (2000).
[22] K. Tanahashi, R. Arai, Y. Hosoe, IEEE Trans. Magn. **41**, 577 (2005).

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