MAGNETIC MATERIALS FOR DATA STORAGE

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ABSTRACT

Required properties and design idea for magnetic data storage medium to attain high density recording are studied, followed by the descriptions of experimentally obtained properties of thin films of Ba-ferrite, NdFeB, FePt, SmCo prospected for high density storage.

Key word : Magnetic materials, data stored, thin films

INTRODUCTION

Storage devices for large capacity consisting of semiconductor (DRAM, flash memory), magnetic (HDD, tape, FDD, card), and optical (CD, DVD) media have been congruously and complementarily used. It is because the requirement of storage device is numerous; large storage capacity, short access time, reduced size/weight, low cost/price, and stability /non-volatility. The areal density of hard disk drive (HDD) has been highest among others which attains now 70Gb/in^2 in commercial base. The CGR in late 1990s has been 100-140%/year (now returns to 60%/year) and the production/shipment has rapidly increased until 2001, which still keeps high level. The application of HDD is expanding from PC to the game machines, mobile (phone, car navigator), video/audio/camera, home consumer appliances.

Since the magnetic thin film of CoNiCr alloy was used for hard disk media around 1990, its composition has changed to CoCrTa, CoCrPt, CoCrPtTa, CoCrPtB with its properties and morphology. However, the finding of the other kind of materials and tailoring them into the suitable properties for high density storage medium are strongly demanded.

REQUIREMENT AND DESIGN OF HIGH DENSITY STORAGE MEDIUM MATERIAL

Most fundamental requirement for high density storage medium material to be magnetized stably is described in the terms of thermal stability factor as $K_uV/k_BT>>1$, where K_u is magnetic anisotropy, V is magnetic switching volume, k_BT is thermal energy which is 4.0x10^{-21}J at room temperature. We are preparing the films of $BaFe_{12}O_{19}$, $Nd_2Fe_{14}B$, FePt and $SmCo_5$. Their values of K_u are all much larger than that of CoCrPtB. Particularly those of $Nd_2Fe_{14}B$, FePt and $SmCo_5$ are 23-100 times larger. If it is assumed that the necessitated stability factor is 40 and the grain shape of switching volume is sphere, the minimum diameter of sphere to be stably magnetized is calculated 2.5-4.0nm, which are much smaller than the value for CoCrPtB (11.5nm).

The coercivity H_c of medium material should be high enough within the range where the recording head can write and rewrite, which appears 4-5kOe. High squareness hysteresis property in the magnetization direction and high *OR*(orientation ratio) are also essential. To obtain high squareness, (1) material must have large exchange stiffness, (2) the volume V must separate from the others to reduce the effect of magnetostatic interaction.

The grains observed by SEM consist of crystallites in all above mentioned films. The volume V^* of crystallite, activation volume, was obtainable from the relation $H_c= (k_BT/(V^*M_s)\ln(dH/dt)$ +const by changing sweep velocity of field and evaluating the resulting H_c, or by Scherrer's equation, $\langle D\rangle=0.9\lambda/(\beta\cos\theta)$, in XRD measurements.

To examine the magnetization mechanism, the angular dependence of H_c was measured, and compared with theoretically calculated results and measured results by several magnetic powder coated tape samples (g-Fe_2O_3, CrO_2, metal-alloy). Here NdFeB film was used. The results showed that measured sample revealed neither so strong incoherent rotation as in tape samples nor the coherent rotation as in S-W model. It suggests that in a grain each crystallite behaves partially independent coherent rotation with some interaction between crystallites. So, the grain size might not cause critical limitation of bit density.

The relation of size between grain volume V_g, crystallite volume V^* and the volume corresponding one bit, V_b, is; $V_b>V_g>V^*$. The increase in bit volume also causes the stability of recorded magnetization, which is composed by double or multi-layer called synthetic ferromagnetic media or AFC(antiferro-coupled) media with such forms as; (1) with soft or semi-hard magnetic underlayer, (2) double layer of CoCrPtB with middle layer of Ru thinner than 1nm[1], (3) double underlayer of soft

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magnetic layer(CoZrNb) on very hard magnetic layer (SmCo)[2], (4) double underlayer of soft magnetic layer on the antiferro magnetic layer. In the latter two cases, the underlayer causes strong magnetic anisotropy in plain resulting in the improvement of magnetization properties.

As high M_r materials have the benefit in view of thermal stability because they generate high K_u for constant H_c. However, it is ambiguous whether high M_r is suitable or not for the media of ultra high density storage. Following equations[3],[4] of output voltage and pulse width by MR readout generated from single longitudinal magnetization transition were calculated;

$$M_x=(2/\pi)M_r\tan^{-1}(x/a)$$
$$V_{pp}=(4\sqrt{2}/\pi)iw\Delta\rho(M_r\delta/(M_st))[\tan\text{-}1(g/(a+d))-((a+d)/(2g)\ln(1+(g/(a+d))^2]$$
$$P_{50}=[g^2+4(a+d)(a+d+\delta)]^{1/2}$$
$$a=0.87[(M_r\delta/H_c)(d(d+\delta)^{1/2}]^{1/2}$$

The following parameters on MR element in MR readout were used; i(current density) $=10^{11}$A/m^2, w (width) =180nm, $\Delta\rho=2\times10^{-8}\Omega$m($\rho=2\times10r^{-7}\Omega$m, $\Delta\rho/\rho$=10%), M_s=1000emu/cc, t(thickness)=10nm. $2g$(gap length of MR head)=60nm: d(flying height)=6nm. For media H_c=4kOe, 100Gbit/in^2, BAR=5, b=36nm, $[P_{50}]=\sqrt{2}b$=50.9nm.

Calculated results show the relation of media thickness δ and the suitable M_r and $M_r\delta$ are to be as follows; for δ=18nm, M_r=420emu/cc, $M_r\delta$=0.76 emu/cm^2, for δ=12nm, M_r=730emu/cc, $M_r\delta$=0.88 emu/cm^2, for δ=9nm, M_r=1050emu/cc, $M_r\delta$=0.95 emu/cm^2.

For perpendicularly magnetized media, the application of the same equations or similar analysis is possible.

PROPERTIES AND THEIR COMPARISON OF THIN FILMS OF Ba-FERRITE, NdFeB, FePt AND SmCo FOR HIGH DENSITY STORAGE MEDIA

The very attractive characteristics of Ba-ferrite thin film is its chemical stability and mechanical hardness. The Vickers hardness measured under 5gf of weight for its film prepared without heat treatment on the pure Cu substrate(Hv=105) was 600, while those of the other kind of films were between 125-163. Its thinner films than 30nm did not generate higher H_c than 4kOe. M_r was as low as 210emu/cc. Although XRD analysis showed highly c axis orientation with $\Delta\theta_{50}$ of 4 degree and OR in H_c of 14, S^* is small($H_N\approx0$). To crystallize the film either the substrate temperature of as high as 500°C or post-annealing temperature of 850°C is required. The activation volume was 10×10^{-24} m^3, much biggest among the others. Surface roughness is as large as 4-5nm, peculiar to perpendicularly oriented films.

NdFeB($Nd_{24}Fe_{72}B_6$) films with tungsten as underlayer and caplayer showed $H_c\perp$ of 4kOe in the thickness of 10nm. Its M_r was as large as 790 emu/cc. $OR(H_c)$ was also 25. The significant drawback of this material is to be vulnerable to oxidation, whose degradation is avoided to incorporate the caplayer of tungsten thicker than 3nm.0

FePt($Fe_{52}Pt_{48}$) films are stable against oxidation. It showed $H_{c//}$ of 4kOe in the thickness of 8nm the same as in SmCo films. The $S^*_{//}$ was as large as 0.88. The activation volume and surface roughness(Ra) were much smaller among others, particularly when Al_2O_3 is included in the film(25vol% or more); $(0.2\text{-}0.4)\times10^{-24}$ m^3 and 0.2-0.3nm, respectively.

SmCo($SmCo_5$) films could be crystallized by comparably low substrate temperature. The films degrade magnetic properties by oxidation after film preparation, which could be extricated by the cap coating of 1nm or thicker of chromium.

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