Process optimization studies of high performance recordable minidiscs

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In this study, the effect of process parameters on magnetic and recording properties of MiniDiscs is reported. Processes have been tailored to optimize the recording performance of MiniDiscs, such as carrier-to-noise ratio (CNR) at low magnetic fields, recording power margin, and recording power threshold. At higher deposition pressures or lower deposition rates of TbFeCoCr, the external bias field sensitivity of the carrier becomes worse but the noise at high bias fields (>200 Oe) decreases, resulting in improved CNR at high bias fields. Disks with TbFeCoCr sputtered at low pressure or high deposition rates produce a high error rate at high recording power (>4.5 mW), due to jitter noise caused by interference of neighboring magnetic domains. The power margin of the disks is strongly affected by the pressure and deposition rate of TbFeCoCr. When the Curie temperature of the TbFeCoCr layer is lowered by 30 °C (alloy change), the power margin decreases significantly and CNR is decreased by ~2 dB because of low Kerr rotation. CNR values well above 49.5 dB are easily achieved on MiniDiscs with optimized TbFeCoCr and SiN layers. © 1997 American Institute of Physics. [S0021-8979(97)58308-3]

I. INTRODUCTION

The recordable 2.5 in. audio disk (MiniDisc) employing magnetic field modulation overwrite technology has been introduced into the market and has strong potential to be the dominant media for the audio compact cassette, since it offers features such as direct overwrite, quick random access, high density recording, and long term reliability. MiniDiscs are, however, required to exhibit an improved magnetic bias field sensitivity compared to conventional magneto-optical disks. MiniDiscs developed by Sony were reported to exhibit an excellent carrier-to-noise ratio (CNR) at low bias field. Extensive studies on enhancement of the magnetic bias field sensitivity of magneto-optical (MO) disks, such as using plasma treatment or magnetic capping layer, have been performed by other researchers. Both nucleation and wall motion for domain formation are known to be important factors in determining the recording characteristics of MO disks. In particular, MiniDiscs employing a magnetic field modulation method are required to meet recording power thresholds and margins that are different from conventional MO disks for data storage applications.

In this study, without making any significant changes to the disk structure or the composition of the magnetic layer, the effects of process parameters on magnetic and recording properties of MiniDiscs are investigated in order to optimize the recording performance characteristics such as CNR at low bias fields, recording power margin, and recording power threshold. Besides, we report on the effect of a marginal change in Curie temperature of the recording layer on power margin and CNR.

II. EXPERIMENTS

A four layer structure of SiN, TbFeCoCr, SiN, and AlTi was deposited onto polycarbonate substrates using a high throughput MRC in-line modular system. All of the films were sputtered using dc rotating magnetron cathodes providing complete surface erosion of the target and arc-free, reactively sputtered SiN film deposition. The background pressure of the sputter chamber was less than $1 \times 10^{-7}$ Torr. The SiN films were deposited by dc reactive magnetron sputtering using a boron doped Si target 10 in. in diameter with a mixture of Ar and N$_2$ gases. The refractive index of the SiN films was fixed at 2.06 and film stress was measured to be less than $3 \times 10^9$ dyne/cm$^2$. The deposition rate of the TbFeCoCr layer was varied from 27 Å/s to 105 Å/s under varying Ar pressures between 1.5 and 8 mTorr. Magnetic properties of TbFeCoCr films sandwiched between SiN layers were studied using a vibrating sample magnetometer (VSM). Kerr rotation and coercivity ($H_c$) were measured using a Kerr hysteresis loop tracer with a maximum field of 20 kOe. Read and write characteristics of MiniDiscs were measured at a linear velocity of 1.4 m/s with recording frequency of 720 kHz and 3 T mark signal of eight-to-fourteen modulation (EFM).

III. RESULTS AND DISCUSSION

Figure 1 shows the effect of Ar pressure on the recording characteristics of MiniDiscs prepared with TbFeCoCr sputtered at various pressures. Dependence of the carrier and noise levels on the bias field ($H_{ex}$) was measured at a write power ($P_w$) of 4.5 mW. MiniDiscs sputtered at 8 mTorr...
exhibit a gradual increase of the carrier level with increasing $H_{ex}$, while those sputtered at low pressure show a sharp increase of the carrier level at low $H_{ex}$. However, the noise level of the disks sputtered at high pressure is significantly lower than that of the disks sputtered at low pressure. For the disks sputtered at low pressure, in spite of the constant carrier level at high bias fields, the noise level increases sharply with increasing $H_{ex}$. As indicated from the initial magnetization curves of these disks (Fig. 5), the disks sputtered at low pressure exhibit a nucleation-dominant domain formation with a subsequent fast domain wall motion to saturation. Therefore, when the bias field is too strong, the recorded domain can expand to the adjacent groove, causing an increase in jitter noise. This effect is more clearly illustrated by the block error rate (BLER) measurements made with varying write power. Figure 2 shows the laser power dependence of BLER at $H_{ex}$ of 300 Oe for the disks sputtered at different Ar pressures. The power threshold ($P_{th}$) is not significantly affected by the pressure condition, as seen by the sharp and consistent fall-off in BLER at about 3.5 mW. However, as the pressure increases from 1.5 to 8 mTorr, the power margin calculated by $[P_{opt} - 220 errors] \times 100/P_{opt}$ is improved by 5% and the optimum power increases from 4.25 to 4.55 mW, respectively. The disks sputtered at 1.5 mTorr produce a high BLER at high recording power (>4.5 mW), due to jitter noise caused by interference of neighboring magnetic domain patterns.

A similar effect is observed on the disks sputtered at various deposition powers. Figure 3 shows the carrier and noise levels with respect to $H_{ex}$ for the disks recorded with $P_w$ of 4.5 mW. With increasing deposition rate of the TbFeCoCr layer at 3 mTorr, the bias field sensitivity at low $H_{ex}$ improves, but the CNR at high $H_{ex}$ decreases due to high jitter noise. The disks sputtered at 105 Å/s show a significant increase of noise at high bias fields and their optimum power level is 3.8 mW at $H_{ex}$ of 300 Oe as compared to 4.6 mW for the disks sputtered at 27 Å/s. Figure 4 shows the write power dependence of BLER at $H_{ex}$ of 300 Oe as a function of the TbFeCoCr deposition rate. With increasing deposition rate, the power margin is decreased significantly from 25% to less than 15%, although the power threshold remains constant. The high BLER of the disks sputtered at high deposition rates is associated with the interference effect of the enlarged domains at high write powers.

As shown in the Kerr loops (Fig. 5), $H_c$ at room temperature is affected by the TbFeCoCr sputtering pressure or deposition rate. The terbium concentration decreases slightly due to the preferential resputtering of Tb atoms for films sputtered at high deposition rates or low pressures. Since the film composition is close to the compensation composition which is below room temperature, an increase in Tb compo-

![FIG. 2. Recording power dependence of BLER for the disks with TbFeCoCr layers sputtered at different pressures (deposition rate=53 Å/s).](image)

![FIG. 3. Bias field dependence of carrier and noise for the disks with TbFeCoCr layers sputtered at different deposition rates (pressure=3 mTorr).](image)

![FIG. 5. Kerr hysteresis loops of the disks with TbFeCoCr layers sputtered at different deposition conditions: (a) 105 Å/s, 3 mTorr, (b) 53 Å/s, 1.5 mTorr, (c) 53 Å/s, 3 mTorr, and (d) 53 Å/s, 8 mTorr.](image)
sition of only 0.1 at. % results in a 1 kOe increase in $H_c$. However, the Curie temperature is insensitive to Tb concentration, and is nearly constant at 200 °C. Therefore, $H_c$ at elevated temperatures, where domain formation takes place, is not affected by the sputtering conditions. Figure 5 shows the different initial magnetization curves from the demagnetized state for disks sputtered at different deposition rates and Ar pressures. For all the disks, when the applied field approaches the nucleation field of the reversed domains or the pinning field of the domain walls, the disks become saturated, i.e., at the field close to $H_c$. However, the frictional force associated with the domain pinning sites is apparently higher for the disks sputtered at high pressures or low deposition rates, and thus impedes the domain wall movement, as indicated by the slow saturation curve. This result indicates that the nucleated, reverse domain sites of the disks sputtered at high pressure or low deposition rates persist due to strong pinning, resulting in the low bias field sensitivity of the carrier, whereas the domains of the disks having high bias field sensitivity may collapse due to low frictional force as well as fast domain wall motion.

The above results indicate that the external bias field sensitivity of CNR and the power margin are strongly affected by the process conditions of the TbFeCoCr layer that influence the domain wall motion. In this study, the effect of Curie temperature on recording properties of MiniDiscs was investigated as well. When the Curie temperature ($T_c$) of the TbFeCoCr layer is lowered from 200 °C to 170 °C by adding 3 at. % of Cr, the power margin decreases significantly from 25% to 12% due to high jitter noise at high recording powers, although the power threshold remains constant at 3.5 mW. Figure 6 shows the bias field dependence of CNR as a function of $T_c$ of TbFeCoCr layer for disks prepared under the optimum process conditions. For the disk with $T_c =$200 °C, CNR increases sharply with increasing bias field, exceeds 49 dB at 100 Oe, and is nearly flat with further increasing bias field. The disk with $T_c$=170 °C shows good external bias field sensitivity of the CNR, although its best CNR is lower than the disk with higher $T_c$ and falls off at high bias field due to large domains interfering with domains of the adjacent groove. Figure 7 shows the reflectivity versus Kerr rotation for the disks with different magnetic layer Curie temperatures. Kerr rotation and reflectivity of the MiniDiscs are seen to vary as a function of TbFeCoCr and overcoating SiN layer thicknesses without significant change in recording properties. The best CNR value remains unaffected by the layer thickness changes that cause the change in Kerr rotation and reflectivity. The disk with higher $T_c$ exhibits higher CNR by ~2 dB due to higher Kerr rotation of TbFeCoCr at the same value of reflectivity.