Effect of the TiN content in the Pd–TiN seed layer on the microstructure and magnetic properties of Co/Pd multilayered media

Sung Man Kim,^{1,2,a)} Dong Won Chun,¹ Jung Joong Lee,² and Won Young Jeung,³

¹*Division of Materials Research, Korea Institute of Science and Technology, 39-1 Haweolgok-dong, Seongbuk-gu, Seoul 136-791, South Korea*

²*Department of Materials Science and Engineering, Seoul National University, San 56-1, Silim-dong, Kwanak-gu, Seoul 151-742, South Korea*

³*Institute of Advanced Composite Materials, KIST Jeonbuk Institute, 864-9, Dunsan-ri, Bongdong-eup, Wanju-gun, Jeollabuk-do 565-902, South Korea*

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[Co(0.2 nm)/Pd(0.8 nm)]₂₀ multilayered films on 15 nm Pd–TiN seed layers were fabricated by dc magnetron sputtering without heating the substrate. The effects of TiN content on microstructure and magnetic properties of the [Co/Pd] multilayered media were studied. By increasing the TiN content in the Pd–TiN seed layer to an optimum level, coercivity of the [Co/Pd] multilayered media increased to 6.7 kOe. However, further increase of TiN content beyond 22 vol % reduced coercivity (H_c), implying that there exists a critical TiN concentration to enhance the magnetic property of the [Co/Pd] multilayered media. Transmission electron microscopic observations revealed that well-isolated [Co/Pd] multilayered grains with apparent grain boundaries were achieved by controlling the TiN content in the Pd–TiN seed layer. The average grain diameter was 8 nm with a dispersion of 11.2%, grown on the Pd–TiN seed layer with TiN content of 22 vol %. © 2011 American Institute of Physics. [doi:10.1063/1.3554205]

I. INTRODUCTION

The magnetic cluster size, D_{cluster} in perpendicular recording media, a key factor of media noise, is likely to be a function of activation diameter, D_{act} , and the strength of intergranular magnetic exchange coupling,¹ and both of them should be lowered to reduce the value of D_{cluster} . A [Co/Pd] multilayered film can be applied to a perpendicular magnetic recording media owing to its high perpendicular magnetic anisotropy, which originates from the interface anisotropy between Co and Pd sublayers.^{2,3} However, one of the critical issues in the [Co/Pd] multilayered media is the high medium noise caused by large magnetic clusters.^{4,5} Therefore, reduction of magnetic cluster size of the [Co/Pd] multilayered media by reducing grain size and magnetic exchange coupling among grains is essential for a low medium noise. In relation to this issue, intensive studies^{6–9} have been carried out on the [Co/Pd] multilayered media and their seed layers, and especially Pd-based seed layers such as Pd/ITO,¹⁰ PtB/Pd/MgO,¹¹ Pd–SiN,¹² and Pd/Si (Ref. 13) have been reported to improve magnetic properties of the [Co/Pd] multilayered media. In our previous study,¹⁴ a Pd–TiN seed layer consisting of Pd seed grains surrounded by a nonmagnetic TiN network was found to be useful for decreasing the intergranular exchange coupling of the [Co/Pd] multilayered media. In this study, Pd–TiN seed layer with various TiN concentration were experimented and the effects of TiN content in the Pd–TiN seed layer on the microstructure and magnetic properties of the [Co/Pd] multilayered media were investigated.

II. EXPERIMENTAL PROCEDURES

A Pd–TiN seed layer (15 nm) was prepared by a dc magnetron cosputtering system on a glass substrate whose dimension is 15 mm by 15 mm. Water-cooled Pd and TiN targets with diameters of 2 in. and purities of 99.99% were mounted 25 cm apart from the substrate holder, and the background pressure of the sputtering chamber was better than 5×10^{-8} Torr. The volume percent of TiN, with respect to Pd, was calculated and controlled from 0 to 24 vol % by monitoring respective deposition rates of TiN and Pd. Sequentially, a [Co(0.2 nm)/Pd(0.8 nm)]₂₀ multilayered thin film was deposited on the Pd–TiN seed layer by the dc magnetron sputtering system. According to the TiN content in the Pd–TiN seed layer, the [Co/Pd] multilayered media were numbered I, II, III, IV, V, and VI, as shown in Table I. In all cases, deposition of Pd–TiN and [Co(0.2nm)/Pd(0.8nm)]₂₀ multilayer was carried out at a constant process pressure of 30 mTorr of Ar (99.999%) gas without substrate heating. Magnetic properties of the samples were measured by VSM where the maximum applied field was 16.5 kOe. The microstructure of the Pd–TiN seed layer and Co/Pd multilayer were characterized by HRTEM with an acceleration voltage of 300 kV.

III. RESULTS AND DISCUSSION

A. The magnetic properties of the [Co/Pd] multilayered media and the effect of TiN content in the Pd–TiN seed layer

The VSM hysteresis loops for the [Co/Pd] multilayered media with various concentrations of TiN are shown in

^{a)}Electronic mail: novasaint@kist.re.kr.

TABLE I. Media preparation conditions and magnetic properties of [Co/Pd] multilayered media.

Medium	TiN content (vol %)	H _c (kOe)	H _k (kOe)	K _{eff} (10 ⁶ erg/cm ³)	α
I	0	4.5	15.3	3.84	10
II	15	5.8	12.8	3.23	7.86
III	17	5.9	12.5	3.15	6.23
IV	20	6.5	12.1	3.01	5.18
V	22	6.7	12.0	3.00	5.15
VI	24	2.5	14.6	1.82	2.47

Fig. 1. The corresponding parameters such as saturation magnetization (M_s), squareness (M_r/M_s), coercivity (H_c), anisotropy field (H_k), effective anisotropy constant (K_{eff}), and loop slope at coercivity (α) are also summarized in the Table I. It is clear that the TiN content in the Pd–TiN seed layer strongly affected the magnetic parameters as shown in Table I and Fig. 1. As can be seen from the result, the perpendicular coercivity of the [Co/Pd] multilayered media increases remarkably up to 6.7 kOe as the TiN content in the Pd–TiN seed layer increases. Coercivity is very difficult to explain as it is related to grain size, grain size distribution, degree of grain isolation, imperfection, and magnetostatic interaction among grains. Although the average grain size of the [Co/Pd] multilayer grown on 20 and 22 vol % TiN seed layers were 14 and 8 nm, respectively, the coercivity was almost the same, and the value of α was similar as shown in Fig. 1 and Table I. This may indicate that magnetic reversal mechanism is the same in these grain size regions. However, further increase of TiN content in the Pd–TiN seed layer significantly reduces the value of H_c as well as the effective magnetic anisotropy constant (shown in Table I), and the possible reason for these phenomena will be discussed later. From the result, it can be declared that the intergranular exchange coupling of the [Co/Pd] multilayered media is effectively reduced by introducing suitable TiN content in the Pd–TiN seed layer.

B. Microstructure of the [Co/Pd] multilayered media and the effect of TiN content in the Pd–TiN seed layer

In order to ascertain the effects of TiN content in the Pd–TiN seed layer on the magnetic properties of the [Co/Pd] multilayered media, microstructure observations were performed. The plane-view HRTEM images of the [Co/Pd] multilayered media grown on the Pd–TiN seed layers of various TiN vol % are shown in Fig. 2. From the results, it can be stated that the grain size decreases and the area of grain boundary region increases with the increment of TiN content in the Pd–TiN seed layer. When the TiN content is in the 15–17 vol % range, the average grain size of the [Co/Pd] multilayer is about 16–18 nm, with wide deviation of 15.5–15.3%. The grains are more coupled each other, and the separation of the grains is not sufficient or sometimes unclear. This is consistent with smaller H_c and larger loop slope α in Fig. 1. At optimum TiN content, the grains becomes smaller (about 8 nm), well-isolated, and exhibit a

FIG. 1. (Color online) Out-of-plane hysteresis loops of [Co/Pd] multilayered media grown on Pd–TiN seed layer with various TiN contents.

narrower distribution in their size as revealed in Fig. 2(e). According to our previous study, nonmagnetic TiN network was found to contribute to the formation of physically and magnetically well-isolated [Co/Pd] multilayered grains.

FIG. 2. Plane-view HR-TEM images of [Co/Pd] multilayered media grown on Pd–TiN seed layer with various TiN contents. (a) medium I, (b) medium II, (c) medium III, (d) medium IV, (e) medium V, and (f) medium VI.

FIG. 3. (Color online) Coercivity and average grain size of [Co/Pd] multilayered media as a function of TiN content in the Pd–TiN seed layer.

With 24 vol % of TiN incorporation in the Pd–TiN seed layer, the diameter of [Co/Pd] multilayered grains to width of their boundary regions have a ratio about 1:2, and their granular structure disappeared, but the formation of particulate nanocomposite microstructure was observed. It is not clear why the grain boundary region became so much widened by only 2 vol % increase in TiN content compared to the previous Pd (22 vol %)-TiN seed layer. It is speculated that as size of the Pd islands becomes much smaller than 8 nm, either (111) orientation of Pd islands do not form or epitaxial growth of the (111) [Co/Pd] multilayer is difficult to form on the small Pd islands of the seed layer.

Figure 3 presents a diagram of perpendicular coercivity and average grain size of the [Co/Pd] multilayered media as a function of TiN content in the Pd–TiN seed layer. The average grain size of the [Co/Pd] multilayered media was found to keep decreasing with the increment of TiN content in the Pd–TiN seed layer. In the case of 24 vol % of TiN content, the [Co/Pd] multilayered grains have the lowest value of 3.6 nm. Hc is found to increase from 4.5 to 6.7 kOe when TiN content in the Pd–TiN seed layer is increased from 0 to 22 vol %. However, with the further increase of TiN content, the value of Hc showed a drastic drop to 2.5 kOe. The significant decrease of the coercivity can be explained as the particle size reduction with increasing the TiN content. Sun *et al.*^{15–17} reported the lattice contracts due to the imperfection in coordination number at the surface or interface of the nanoscale particles. They predicted that the smaller the particle size is, the larger lattice contraction would be.¹⁵ Therefore, the lattice contraction for nanoparticles in our result may lead to the decrease of magnetic anisotropy constant and the relatively lower value of coercivity compared with continuous or granular structure.

IV. CONCLUSIONS

The effects of TiN content in the Pd–TiN seed layer on the microstructure and magnetic properties of [Co/Pd] multilayered media were investigated. Experimental results indicate that with a low TiN content, adequate grain segregation is not achieved, which results in relatively low Hc values. As the TiN content increases to optimum level, TiN network surrounds the Pd grains and constrains the lateral growth of them so that they could provide physically separated seeds to the upper [Co/Pd] multilayer, resulting in the formation of granular structure with refined size. Further increment of the TiN content was found to destroy the granular structure of the [Co/Pd] multilayered media. Under suitable processing conditions, the [Co/Pd] multilayered media were obtained with average grain size of 8 nm and with perpendicular coercivities in the range of 4.5–6.7 kOe. Adjustable coercivity, fine grain size, and reduced intergranular magnetic exchange coupling make this composite system a promising candidate for high-density magnetic recording media.

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