Optimization of the Thickness Ratio of Pd/Si Intermediate Layer in Co/Pd Multilayer Perpendicular Magnetic Recording Medium

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The effect of the thicknesses of Pd and Si films in the Pd/Si dual intermediate layer on magnetic properties of the Co/Pd multilayer for double-layered perpendicular magnetic recording medium was studied with the aim of developing an ultra-thin intermediate layer for producing fine magnetic clusters in the Co/Pd multilayered film. The magnetic properties were found to be strongly dependent on the ratio of the Pd or Si layer thickness to the total thickness of the Pd/Si dual film. When the ratio of the Pd layer thickness to the total thickness was 0.7–0.8, high perpendicular coercivity and small slope parameter of the major hysteresis loop were attained simultaneously, which resulted from weak intergranular exchange coupling of the Co/Pd multilayered film. In addition, the total thickness of the Pd/Si intermediate layer was successfully reduced to 4 nm, while retaining its high perpendicular coercivity and fine magnetic clusters, by optimizing the thicknesses of Pd and Si layers. Read-write experiments revealed that improvements in reproducing resolution and signal-to-noise ratio of the Co/Pd multilayered media were achieved by the decrease in the intermediate layer thickness.

Key words: Co/Pd multilayered film, perpendicular magnetic recording media, intermediate layer, Pd/Si dual thin film, spacing loss, initial disordered layer

1. Introduction

A Co/Pd multilayered film ($[\text{Co/Pd}]_n$ film) exhibits high perpendicular magnetic anisotropy due to the surface anisotropy originating from the interface between Co and Pd sub-layers¹⁾, and it has been attracting much attention as a recording layer of double-layered perpendicular magnetic recording media. One critical issue of the $[\text{Co/Pd}]_n$ medium is formation of large magnetic clusters by strong intergranular exchange coupling of the $[\text{Co/Pd}]_n$ film, which results in high medium noise. To decrease the magnetic cluster size, the introduction of a proper intermediate layer between the $[\text{Co/Pd}]_n$ film and the soft magnetic underlayer (SUL) is as effective as the optimization of sputtering conditions^{2)–4)} and the addition of other elements to the $[\text{Co/Pd}]_n$ film^{5)–7)}. It has been reported that thin films of Pd/ITO⁸⁾, Pd-SiN⁹⁾, Pd-SiO¹⁰⁾, and PtB/Pd/MgO¹¹⁾ are useful as an intermediate layer for $[\text{Co/Pd}]_n$ media with fine magnetic clusters.

In our previous study, a Pd (5 nm)/Si (5 nm) dual thin film was developed as the seedlayer of $[\text{Co/Pd}]_n$

single-layered media without SUL. Intergranular exchange coupling was substantially reduced when the Pd/Si seedlayer was fabricated by combining the two preparation techniques: N₂ addition to the sputtering gas and post-annealing of the deposited Pd/Si layer¹²⁾. Additionally, the introduction of a Pd (5 nm)/Si (5 nm) film as an intermediate layer for the $[\text{Co/Pd}]_n$ double-layered medium with CoZrNb SUL has also been found to be effective for reducing the intergranular exchange coupling¹³⁾. The $[\text{Co/Pd}]_n$ double-layered media with a Pd (5 nm)/Si (5 nm) intermediate layer prepared by the combined process consisted of physically isolated, fine grains of $[\text{Co/Pd}]_n$, which led to weak intergranular exchange coupling and the formation of fine magnetic clusters. Thus, the dual layer composed of Pd and Si films is a promising intermediate layer for improving the magnetic properties and read-write (R/W) performance of $[\text{Co/Pd}]_n$ media. On the other hand, the lamination of Pd and Si sub-layers increases the total thickness of the dual intermediate layer, which is not desirable because of the *spacing loss* between the recording head and SUL or between the recording layer and SUL. Therefore, the dual intermediate layer should be as thin as possible.

In this study, to reduce the total thickness of the Pd/Si intermediate layer without degrading magnetic properties, we optimized the thicknesses of Pd and Si layers. The effects of thicknesses of Pd and Si layers on the magnetic properties of $[\text{Co/Pd}]_n$ film were investigated together with the effect of decreasing the intermediate layer thickness on the R/W performance of the medium.

2. Experimental details

Thin film media composed of $[\text{Co} (0.2 \text{ nm})/\text{Pd} (0.8 \text{ nm})]_n / \text{Pd} (x \text{ nm})/\text{Si} (y \text{ nm}) / \text{Co}_{91}\text{Zr}_5\text{Nb}_4 (300 \text{ nm}) / \text{glass}$ substrate were prepared by using a dc magnetron sputtering system, where n was the number of layers ranging from 5 to 20, and x and y were varied from 0 to 10. The Pd and Si sub-layers in the intermediate layer are designated as “Pd upper-intermediate layer” and “Si under-intermediate layer”, respectively. The CoZrNb SUL showed an isotropic magnetic property, and the saturation magnetic flux density and in-plane coercivity were 1.4 T and 10 Oe, respectively. After the CoZrNb film was deposited on a glass substrate at room temperature, the sample was taken out of the sputtering

chamber and exposed to air atmosphere. Then the sample was reloaded into the sputtering chamber, and a Pd/Si intermediate layer and a $[\text{Co/Pd}]_n$ film were successively deposited without any etching treatment of the SUL surface. The Ar sputtering gas pressure was set at 5, 20, and 100 mTorr for the CoZrNb, $[\text{Co/Pd}]_n$, and Pd/Si films, respectively. The Si under-intermediate layer was deposited in pure Ar gas, whereas the Pd upper-intermediate layer was deposited in an Ar gas atmosphere containing N_2 at 5 mTorr. After the deposition of Pd/Si layer, the sample was post-annealed at 400 °C for 50 minutes, and then it was allowed to cool down slowly in the sputtering chamber. Finally, $[\text{Co/Pd}]_n$ films were deposited at room temperature. The 5 nm carbon overcoat layer was deposited on the $[\text{Co/Pd}]_n$ film at an Ar gas pressure of 50 mTorr for the media used in R/W experiments.

Magnetic properties were evaluated by using a polar Kerr magnetometer with the maximum applied magnetic field of 15 kOe. Magnetization states of $[\text{Co/Pd}]_n$ media were observed by using a magnetic force microscope (MFM). Magnetic domain size was calculated as the average diameter of virtual circles with the same area as the magnetic domains in MFM images at the ac-demagnetized state. The R/W performance was estimated by a merged type giant magneto resistive (GMR) head under the conditions shown in Table 1, which also shows head specifications. The state of chemical bonding of the Pd/Si film surface was investigated by using x-ray photoelectron spectroscopy (XPS) with an Al- K_α radiation (acceleration voltage: 10 kV, emission current: 10 mA). To obtain information on the chemical bonding in the vicinity of only the uppermost layer of Pd/Si film, total reflection XPS¹⁴⁾ was used. In the total reflection XPS, an x-ray was irradiated onto the film surface with an incident angle less than the critical angle to prevent the x-ray from penetrating into the film. For comparison, XPS with an incident angle of *ca.* 10 deg was also performed, which is designated as “conventional

XPS” in this paper. From the result of a preliminary experiment, the penetration depth of x-ray was estimated to be greater than 10 nm in the conventional XPS.

Table 1 Conditions of read-write experiment.

Write head	Gap length	0.15 μm
	Track width	0.38 μm
Read head	Gap length	0.09 μm
	Track width	0.24 μm
Flying height		12 nm
Liner velocity		6.35 m/s

3. Results

3.1 Magnetic properties

The dependencies of perpendicular coercivity (H_c) and α value of the $[\text{Co/Pd}]_{20}$ films on the thicknesses of Pd upper- and Si under-intermediate layers (denoted as δ_{Pd} and δ_{Si} , respectively) are shown in Figs.1 (a) and 1 (b), for which the total thicknesses of Pd/Si intermediate layers ($\delta_{\text{Pd/Si}}$) were 10 nm and 5 nm, respectively. The α value of $[\text{Co/Pd}]_n$ film is the parameter reflecting the strength of intergranular exchange coupling of $[\text{Co/Pd}]_n$ film^{15), 16)}, and it is defined as follows:

$$\alpha = 4\pi(d\theta_k/dH)_{H=H_c} \times (M_s/\theta_{k\text{max}}), \quad (1)$$

where $(d\theta_k/dH)_{H=H_c}$ and $\theta_{k\text{max}}$ are the derivative at the coercivity and the maximum rotation angle of a Kerr hysteresis loop, respectively. In this study, the saturation magnetization (M_s) of all media was assumed to be equal to 320 emu/cm³, which is the value for the single-layered medium composed of $[\text{Co/Pd}]_{20}$ / Pd (5 nm)/Si (5 nm) / glass substrate¹²⁾. When $\delta_{\text{Pd/Si}}$ was fixed at 10 nm, the values of H_c and α were greatly dependent on δ_{Pd} and δ_{Si} . The value of H_c exhibited a maximum at $(\delta_{\text{Pd}}, \delta_{\text{Si}}) = (7 \text{ nm}, 3 \text{ nm})$, while the α value was at its minimum at the same values of δ_{Pd} and δ_{Si} . Conceivably, the increase in H_c

Fig.1 Dependence of H_c and α of $[\text{Co/Pd}]_{20}$ media on the thicknesses of Pd upper- or Si under-intermediate layers, where the total thickness of the Pd/Si intermediate layer was 10 nm (a) and 5 nm (b), respectively.

Fig.2 MFM images at ac-demagnetized state of $[\text{Co/Pd}]_{20}$ media with intermediate layers composed of Pd(4 nm)/Si(1 nm) (a), Pd(3 nm)/Si(0.75 nm) (b), Pd(2 nm)/Si(0.5 nm) (c), and Pd(5 nm)/Si(5 nm) (d), respectively.

was due to a change in magnetization reversal mode from wall displacement to rotation magnetization¹⁷⁾, which apparently resulted from the reduction in intergranular exchange coupling of the $[\text{Co/Pd}]_{20}$ medium¹⁸⁾. This interpretation agrees with the result of measurement of α values. When $\delta_{\text{Pd/Si}}$ was 5 nm, the dependencies of H_c and α on δ_{Pd} and δ_{Si} were similar to those observed when $\delta_{\text{Pd/Si}} = 10$ nm. It is seen in both Figs. 1 (a) and 1(b) that the highest H_c and lowest α were attained simultaneously, when the ratio of δ_{Pd} to $\delta_{\text{Pd/Si}}$ ($\delta_{\text{Pd}}/\delta_{\text{Pd/Si}}$) was 0.7–0.8 (namely, $\delta_{\text{Si}}/\delta_{\text{Pd/Si}}$ was 0.2–0.3). These results suggest that magnetic properties of the $[\text{Co/Pd}]_{20}$ medium with Pd/Si intermediate layer strongly depend on the thickness ratio, $\delta_{\text{Pd}}/\delta_{\text{Pd/Si}}$ or $\delta_{\text{Si}}/\delta_{\text{Pd/Si}}$, and that intergranular exchange coupling of the medium is reduced significantly by using the Pd/Si intermediate layer with the characteristic thickness ratio of $(\delta_{\text{Pd}}/\delta_{\text{Pd/Si}}, \delta_{\text{Si}}/\delta_{\text{Pd/Si}}) = (0.7\text{--}0.8, 0.2\text{--}0.3)$. Based on these results, we attempted to reduce total thickness of Pd/Si intermediate layer with the thickness ratio fixed at $(\delta_{\text{Pd}}/\delta_{\text{Pd/Si}}, \delta_{\text{Si}}/\delta_{\text{Pd/Si}}) = (0.8, 0.2)$.

Figures 2 (a)-(c) show MFM images at the

Fig.3 Dependence of perpendicular coercivity of $[\text{Co/Pd}]_n$ media on the thickness of $[\text{Co/Pd}]_n$ film, where a Pd/Si intermediate layer consisted of Pd(5 nm)/Si(5 nm) or Pd(4 nm)/Si(1 nm).

ac-demagnetized state of $[\text{Co/Pd}]_{20}$ media with a Pd/Si layer at $(\delta_{\text{Pd}}/\delta_{\text{Pd/Si}}, \delta_{\text{Si}}/\delta_{\text{Pd/Si}}) = (0.8, 0.2)$. Magnetic properties and magnetic cluster sizes of the $[\text{Co/Pd}]_{20}$ media are tabulated in Table 2. For comparison, the results obtained with the $[\text{Co/Pd}]_{20}$ medium with a Pd(5 nm)/Si(5 nm) layer are also shown in Fig. 2 (d) and Table 2. The $[\text{Co/Pd}]_{20}$ medium with a Pd(4 nm)/Si(1 nm) or a Pd(3 nm)/Si(0.75 nm) layer, as well as the medium with a Pd(5 nm)/Si(5 nm) layer, exhibited a high H_c , a small α , and a small size of magnetic clusters. However, the medium with a Pd(2 nm)/Si(0.5 nm) layer showed a small H_c , a high α , and a stripe maze pattern, revealing that the Pd(2 nm)/Si(0.5 nm) intermediate layer was not effective to reduce the intergranular exchange coupling of $[\text{Co/Pd}]_n$ film. Clearly, the optimization of the Pd/Si thickness ratio made it possible for the Pd/Si thickness to be decreased to approximately 4 nm without any deterioration of magnetic properties.

Figure 3 shows the dependence of H_c value on the thickness of $[\text{Co/Pd}]_n$ film for the medium with a Pd(5 nm)/Si(5 nm) or a Pd(4 nm)/Si(1 nm) layer. The value

Table 2 Perpendicular coercivity, α value, and magnetic cluster size of $[\text{Co/Pd}]_n$ media containing a Pd/Si intermediate layer with various thickness ratios.

Thickness ratio of Pd/Si intermediate layer ($\delta_{\text{Pd}}/\delta_{\text{Pd/Si}}, \delta_{\text{Si}}/\delta_{\text{Pd/Si}}$)	δ_{Pd} [nm]	δ_{Si} [nm]	$\delta_{\text{Pd/Si}}$ [nm]	H_c [kOe]	α value [-]	Magnetic cluster size [nm]
(0.8, 0.2)	4	1	5	6.1	1.9	106±22
	3	0.75	3.75	6.1	1.9	110±19
	2	0.5	2.5	2.4	6.1	(not determined)
(0.5, 0.5)	5	5	10	5.7	1.9	128±15

of H_c decreased with decreasing $\delta_{\text{Co/Pd}}$ in both cases, which is likely to be due to a thermal fluctuation caused by the reduction of magnetic grain volume and to the influence of an initial disordered layer in the $[\text{Co/Pd}]_n$ film. The $[\text{Co/Pd}]_n$ medium with Pd(4 nm)/Si(1 nm) showed a higher H_c value than that with Pd(5 nm)/Si(5 nm), and the difference in H_c between the two media became larger with decreasing thickness of the $[\text{Co/Pd}]_n$ layer. This result implies that the formation of initial disordered layer was suppressed in the medium with Pd(4 nm)/Si(1 nm) in comparison with that with Pd(5 nm)/Si(5 nm), which is desirable for improving the R/W performance.

3.2 Effect of the intermediate layer thickness on read-write performance

As shown in Table 2, the $[\text{Co/Pd}]_{20}$ media with Pd (5 nm)/Si (5 nm) and with Pd (4 nm)/Si (1 nm), designated respectively as “medium I” and “medium II”, exhibit similar magnetic properties. Therefore, the effect of reduction of the intermediate layer thickness ($\delta_{\text{Pd/Si}}$) on R/W performance can be reasonably evaluated by comparing R/W performances of the two media. Figure 4 shows the dependence of normalized outputs of media I and II on recording current. When the recording current was smaller than 10 mA, the reproduced voltage of medium II increased more sharply with increasing recording current than that of medium I. The recording sensitivity was improved clearly by reducing $\delta_{\text{Pd/Si}}$ from 10 nm to 5 nm. Table 3 shows values of reproducing voltage at 25 kFRPI, D_{50} , and signal-to-noise ratio (S/N ratio) at 300 kFRPI of media I and II. The value of D_{50} is

Fig.4 Dependence of normalized output of media I and II on recording current at 300 kFRPI.

defined as the linear recording density where the reproducing voltage is equal to one half of that at 25 kFRPI. The reproducing voltage at low recording densities was increased and the reproducing resolution was improved by reducing $\delta_{\text{Pd/Si}}$. Decreasing the intermediate layer thickness resulted in the decrease in the distance between the recording head and SUL, causing the magnetic recorded bits to be easily reversed by the perpendicular magnetic flux from the recording head to SUL. Additionally, the decrease in the distance between the recording layer and SUL is expected to enhance the “mirror effect” of the SUL in the reproducing process¹⁹⁾. These effects are likely to improve the reproduced voltage and the reproducing resolution. On the other hand, there was no significant difference between media I and II in the medium noise normalized by the reproducing voltage at 25 kFRPI. Therefore, the slight increase in S/N ratio observed with the reduction of $\delta_{\text{Pd/Si}}$ shown in Table 3 is mainly attributable to the improvement of reproducing resolution.

4. Discussion

The thickness ratio of the Pd/Si intermediate layer strongly affects magnetic properties of the $[\text{Co/Pd}]_n$ film, which is related to the initial grain growth. In this section, the correlation between magnetic properties of the $[\text{Co/Pd}]_n$ film and the thickness ratio of Pd/Si in the intermediate layer is discussed, based on the microstructure of Pd(5 nm)/Si(5 nm) intermediate layer.

4.1 Microstructure of Pd(5 nm)/Si(5 nm) intermediate layer¹³⁾

As described in our previous reports^{12), 13)}, the Pd/Si intermediate layer prepared by combining N_2 addition to the sputtering gas and post-annealing effectively suppressed the intergranular exchange coupling. Our TEM observation of $[\text{Co/Pd}]_{20}$ media with a Pd(5 nm)/Si(5 nm) intermediate layer revealed that the addition of N_2 gas decreased the grain size of Pd upper-intermediate layer¹³⁾. On the other hand, the post-annealing process enhanced the diffusion of Si into the Pd upper-intermediate layer. This Si diffusion was clearly observed by XPS analysis. Figures 5 (a) and 5 (b) show conventional and total reflection x-ray photoelectron (XP) spectra at Si-2p region of the Pd/Si / CoZrNb films designated as films A, B, and C. The preparation conditions, the compositions of films A-C and the magnetic properties of $[\text{Co/Pd}]_{20}$ films deposited on them are summarized in Table 4. For film A, the XP signal from Si-compound, mainly Si-O, was observed in curve (i) of Fig.5 (a). However, the signal

Table 3 Reproducing voltage at 25 kFRPI, D_{50} value, and S/N ratio at 300 kFRPI of $[\text{Co/Pd}]_{20}$ media with a Pd (5 nm)/Si (5 nm) intermediate layer (medium I) and a Pd (4 nm)/Si (1 nm) intermediate layer (medium II).

Medium	Intermediate layer	Reproducing voltage at 25 kFRPI [mV _{p-p}]	D_{50} [kFRPI]	S/N ratio at 300 kFRPI [dB _{p-p/rms}]
I	Pd (5 nm)/Si (5 nm)	540	250	11.6
II	Pd (4 nm)/Si (1 nm)	590	265	12.4

was not detected under the total reflection condition as shown in curve (i') of Fig.5 (b). In contrast, for film B, the peak originating from Si-O was seen even in the total reflection XP spectrum ((ii') of Fig.5 (b)), indicating that

Fig.5 Si-2p x-ray photoelectron spectra of Pd/Si film deposited on CoZrNb layers recorded in the conventional (a) and total reflection (b) mode. Spectra labeled (i, i'), (ii, ii'), and (iii, iii') were obtained with films A, B, and C, respectively. Binding energies of Si-O (open triangle) and metal silicide (solid triangle) are indicated by dotted lines.

Fig.6 Schematic representation of the structure of $[\text{Co/Pd}]_n$ media with Pd(5 nm)/Si (5 nm) intermediate layer prepared with N_2 addition and post-annealing.

Si-compound existed in the uppermost layer of the Pd/Si film. These results suggest that the post-annealing enhanced the diffusion of Si in the intermediate layer. Furthermore, no signal from metal silicides was observed in film A, whereas it was observed in film B, which indicates that formation of alloys of Pd and Si such as Pd_2Si was also promoted by the post-annealing process¹²⁾.

Based on the above discussions, a schematic model for a $[\text{Co/Pd}]_n$ medium with a Pd (5 nm) /Si (5 nm) intermediate layer fabricated with N_2 addition and post-annealing was prepared, and it is shown in Fig.6. In TEM observation¹³⁾, Si was found not only to diffuse to grain boundaries of the Pd layer but also to penetrate readily through the Pd layer to the top surface of the intermediate layer. Consequently, the Pd/Si intermediate layer exhibited a granular structure with Si-compound matrices surrounding fine Pd grains, which provided suitable nucleation sites for physically isolated $[\text{Co/Pd}]_n$ grains, resulting in a decrease in intergranular exchange coupling.

4.2 Correlation between the thickness ratio of Pd/Si in the intermediate layer and magnetic properties of $[\text{Co/Pd}]_n$ film

In the Pd/Si intermediate layer prepared with N_2 addition and post-annealing, Si plays a significant role in the form of Si-compound matrices surrounding fine Pd grains. However, the presence of an excessive amount of diffused Si on the top surface of the Pd/Si intermediate layer seems to cause the formation of an initial disordered layer, as it has been reported that an initial disordered layer is formed at the interface between the multilayer and the underlayer in the $[\text{Co/Pd}]_n$ single-layered media with a Si (100 nm) underlayer^{20), 21)}. Figure 3 suggests that the perpendicular coercivity of a $[\text{Co/Pd}]_n$ film on Pd (5 nm)/Si (5 nm) intermediate layer is strongly affected by the initial disordered region compared with that on a Pd (4 nm)/Si (1 nm) layer. Therefore, the change in film composition of the Pd/Si layer is considered to affect the degree of Si diffusion in the intermediate layer. Here, we will estimate the degree of Si diffusion into the Pd upper-intermediate layer from the integrated intensity of the XP signal from Si. Figure 7 compares the normalized integrated peak intensities from Si compounds for films A, B, and C. The integrated intensity from Si-2p peak (Fig. 5) was normalized by that from Pd-3d peak shown in Fig. 8. As Si diffuses excessively through the Pd layer, the

Table 4 Film composition and preparation conditions of Pd/Si/CoZrNb thin films used in XPS measurement. Magnetic proprieties of $[\text{Co/Pd}]_{20}$ films deposited on Pd/Si/CoZrNb films are also shown.

Film	Film compositon	Preparation conditions		Magnetic properties of $[\text{Co/Pd}]_{20}$ film deposited on the films	
		N_2 addition	Post-annealing	H_c [kOe]	α [-]
A	Pd (5 nm)/Si (5 nm)	○	×	4.7	6.2
B	Pd (5 nm)/Si (5 nm)	○	○	5.7	1.9
C	Pd (4 nm)/Si (1 nm)	○	○	6.0	1.9

Fig. 7 XPS integrated peak intensity ratios of Si-2p to that of Pd-3d obtained in the conventional mode (white), and in the total reflection mode (gray) for films A, B, and C.

normalized integrated peak intensity becomes relatively large. Thus, it is possible to evaluate the difference in the degree of excessive diffusion of Si between the medium with Pd (5 nm)/Si (5 nm) and that with Pd (4 nm)/Si (1 nm) by comparing the results for films B and C. In Fig. 7, the normalized integrated intensity for film C was as large as that of film B in conventional XPS. On the contrary, the intensity for film C was smaller than that of film B in total reflection XPS. This indicates that the “excessive diffusion of Si” was suppressed more effectively with the Pd (4 nm)/Si (1 nm) layer than with the Pd (5 nm)/Si (5 nm) layer, preventing the formation of the initial disordered layer.

In the Pd/Si intermediate layer, the reduction of the thickness of Si under-intermediate layer is effective to suppress the formation of initial disordered layer, which is thought to improve the magnetic properties of $[\text{Co/Pd}]_n$ film. On the contrary, when the Si layer was much thinner than the Pd layer, Si did not seem to form matrices at grain boundaries of Pd crystals, which hindered the physical separation of $[\text{Co/Pd}]_n$ grains and thereby increased the intergranular exchange coupling of $[\text{Co/Pd}]_n$ film. In this case, strong intergranular exchange coupling decreased H_c value and increased α value as shown in Figs. 1 (a) ($8 < \delta_{\text{Pd}} < 10$) and 1 (b) ($4 < \delta_{\text{Pd}} < 5$).

In summary, the Si under-intermediate layer should be sufficiently thin to suppress the formation of initial disordered layer, but it must be thick enough to form the matrices. It is concluded that a Pd/Si intermediate layer with a thickness ratio of $(\delta_{\text{Pd}}/\delta_{\text{Pd/Si}}, \delta_{\text{Si}}/\delta_{\text{Pd/Si}}) = (0.7-0.8, 0.2-0.3)$ meets both requirements.

Fig. 8 Pd-3d x-ray photoelectron spectra of Pd/Si film on CoZrNb layer in the conventional (a) and total reflection (b) mode. Spectra labeled (i, i'), (ii, ii'), and (iii, iii') were obtained with films A, B, and C, respectively. Open and solid triangles denote Pd-3d_{5/2} binding energies of Pd and Pd₂Si, respectively. (Ref. 22)

5. Conclusion

The thicknesses of Pd upper- and Si under-intermediate layers were optimized to develop Co/Pd multilayer double-layered perpendicular recording media with the intermediate layer thinner than 10 nm. Magnetic properties of the Co/Pd multilayered media were found to be strongly dependent on the thickness ratios of Pd and Si to the total thickness of the Pd/Si dual layer. When the thickness ratios $(\delta_{\text{Pd}}/\delta_{\text{Pd/Si}}, \delta_{\text{Si}}/\delta_{\text{Pd/Si}})$ were in the range of (0.7–0.8, 0.2–0.3), high H_c , small α , and fine magnetic clusters were obtained. Conceivably, in the Pd/Si layer with an optimized thickness ratio, Pd formed isolated grains, while Si served as matrices at the grain boundaries without diffusing excessively to the top surface of the Pd/Si layer. The granular intermediate layer allowed to form the Co/Pd multilayered film with well-defined grains, which hardly contained any initial microstructurally disordered region. The optimization of thickness ratios allowed the total thickness of Pd/Si intermediate layer to be reduced successfully to as thin as 4 nm without deteriorating the magnetic properties of Co/Pd multilayered media. The reduction of the Pd/Si intermediate layer thickness led to the improvement of reproducing resolution, D_{50} , and S/N ratio. These results indicate that the use of an optimized Pd/Si intermediate layer is highly effective for improving the R/W performance of the Co/Pd multilayered medium.

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