

MAGNETIC RECORDING MEDIUM, METHOD FOR MANUFACTURING RECORDING
MEDIUM AND MAGNETIC RECORDING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application is based upon and claims the benefit of
priority from the prior Japanese Patent Application No. 2004-090670,
filed on March 25, 2004; the entire contents of which are
incorporated herein by reference.

10 BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

 The present invention relates to magnetic recording media,
methods for manufacturing recording media and a magnetic recording
apparatus, in particular, to magnetic recording media having high
15 recording density, methods for manufacturing the recording media
and magnetic recording apparatus such as hard disk drives in which
the high-density recording media are equipped.

2. DESCRIPTION OF THE RELATED ART

20 Hard disk drives (HDDs) have been expanding their application
scope from the first computer related application to various other
applications, such as home video recorder and car carrying
navigation system applications as magnetic recording systems for
recording and reproducing information. The expansion is due to
25 their advantage such as high data access speed and high data storage
reliability, in addition to their high recording capacity
performance with low cost. Requirements for HDDs with larger
recording capacity have been increased with the expansion of the

HDD application scope. Replying to the requirements, large capacity recording technology has been advanced by increasing recording density of the magnetic recording media.

With increasing recording density of the magnetic recording media of HDDs, the recording bit sizes and the diameters for the magnetization reversal units became very small. As the result, a decreasing of recorded signal magnetization caused by thermal fluctuation and that results to a degrading of the recording and reproducing performance became notable for the very small magnetization reversal units. Furthermore, noise signals which appear at boundary regions between recording bits became large as a result of decreasing recording bits to a very small size, and the noise gave large influences upon the signal to noise ratio. Therefore, in order to attain higher recording density, it is required to stabilize thermal stability of the recorded signal magnetization at one hand, it is also required to attain low noise characteristics at high recording density at the other hand.

To decrease magnetic recording medium noise, size of magnetic crystalline grains constructing recording layer have been made smaller up to now. For example, magnetic crystalline grains of Co-Cr magnetic layer of widely used magnetic recording media were made small by adding small amount of Ta or B (refer to Japanese Patent Laid-open Applications Nos. HEI 11-154321 and 2003-338029), and by precipitating nonmagnetic Cr by heat treating at appropriate temperature (refer to Japanese Patent Laid-open Applications Nos. HEI 3-235218, and HEI 6-259764). Recently, methods for obtaining magnetic recording layers having so called granular structure by adding oxides such as SiO_x to the magnetic layer were applied.

In the granular structured magnetic layer, nonmagnetic grain boundary materials enclose magnetic crystalline grains (refer to Japanese Patent Laid-open Applications Nos. HEI 10-92637, and 2001-56922).

5 These methods, however, cannot control the crystalline grains of the magnetic-layer and the under-layer by going back to the nucleation processes for the crystalline grains of the under-layer and the magnetic recording layer. These methods control average magnetic crystalline grain diameter and grain
10 boundary regions merely by choosing combination of raw materials, the raw material composition, or by choosing of depositing conditions. When the crystalline grains in the under-layer are made smaller, the crystalline quality and crystal orientation degree of the grains in the under-layer are degraded, and the
15 degraded crystalline grains of the under-layer influence upon the formation of magnetic crystalline grains. Actually it was found that the magnetic layer prepared using this method showed broad grain size distribution and broad distribution of grain boundary width. Magnetic recording media decreasing the average grain size
20 of the magnetic crystalline grains to 5 nm showed poor thermal fluctuation durability. Very small grains unstable to thermal fluctuation were included at large fraction. Then it was difficult to attain further high density using this method.

 To obtain low noise magnetic recording medium having small
25 magnetic crystalline grains, nucleation of magnetic crystalline grains were controlled using a layer of such as Nb for nucleation layer on a substrate for forming magnetic recording layer (refer to Japanese Patent Laid-open Application No. 2002-22518). To

attain higher recording density realizing thermal stability of recording magnetization and low noise, however, further additional advanced technology was needed.

5 SUMMARY

The important problems to be solved in order to attain higher recording density are to realize small average grain diameter of magnetic recording layer to obtain low noise magnetic recording medium and small grain diameter dispersion diminishing very small
10 particles unstable to thermal fluctuation.

The present invention is directed to give a solution to the problems. The purpose of the present invention is to present a novel magnetic recording medium having excellent recording signal resolution and signal to noise ratio (SNR) realizing small average
15 grain diameter dispersion, methods for manufacturing the magnetic recording medium, and magnetic recording apparatus equipped with the recording medium.

The inventors of the present invention have performed various exploring work and have got interesting finding that the magnetic
20 crystalline grains of the magnetic layer can be made small with very small grain size distribution when the magnetic recording layer is formed on a film of oxide or carbon deposited Cu, Ni, Rh or Pt film. After carrying out a further investigation, the inventors could solve the problems described above and completed
25 the present invention.

The magnetic recording medium of the present invention comprises a substrate, an under-layer formed on the substrate, and a magnetic recording layer on the under-layer formed on the

magnetic recording layer. The under-layer of the present invention includes grain diameter control under-layer comprising crystalline grains of a metal selected from the group consisting essentially of Cu, Ni, Rh and Pt, and a deposited layer of at least one element selected from the group consisting of oxygen and carbon on the grain diameter control layer surface.

The method for producing magnetic recording medium of the present invention comprises a process for forming a grain diameter control under-layer comprising crystalline grains of a metal selected from the group consisting essentially of Cu, Ni, Rh and Pt on a substrate, a process for forming an deposited atom layer depositing atoms of at least one element selected from the group consisting of oxygen and carbon on the grain diameter control layer surface, and a process for forming a magnetic recording layer on the substrate having the atom deposited grain diameter control under-layer.

Furthermore, the magnetic recording and reproducing apparatus of the present invention comprises the magnetic recording medium described above, a recording medium driving mechanism, driving the magnetic recording medium, a recording and reproducing head mechanism, recording information to the magnetic recording medium and reproducing from the magnetic recording medium, a head driving mechanism, driving the recording and reproducing head and a recording and reproducing signal processing system, processing

The present invention has a remarkable advantage in the point that the crystalline grain size of the grain diameter control under-layer comprising crystalline grains is not needed to be small for obtaining small magnetic crystalline grains. The problem of

employing small grain size under-layers, therefore, can be avoided to obtain small magnetic grains. The present invention presents a novel means for obtaining magnetic recording medium having increased recording and reproducing characteristics.

5 The detailed mechanism of obtaining small grain sizes by using grain diameter control under-layer comprising crystalline grains of a metal selected from the group consisting essentially of Cu, Ni, Rh and Pt, is not clear at present. Here, two papers concerned with reorientation of atoms such as oxygen or carbon
10 on clean metal single crystal surface are introduced and a comparison between the present invention and the two papers are given.

 In one of the papers appeared in Surface Science Vol.437 pp 18-28, regularly rearranged surface structure of deposited
15 oxygen atoms and carbon atoms on Ni and Rh surface cleaned up in high vacuum is reported.

 In the other paper appeared in Materials Science and Engineering Vol.B96 pp.169-177, an explanation for the ordered arrangement is given by stress interaction appeared on the clean
20 bulk single crystal surface.

 Comparing the present invention with the two papers on ordered arrangement of the nitrogen atoms described in the two papers, it can be pointed out that the under-layer in the present invention is films of Cu, Ni, Rh or Pt, and not of a bulk single
25 crystal. The state having stress in the thin film of the present invention is quite different from the bulk Cu single crystal surface of these papers. Therefore, the re-oriented ordered surface structure shown in the papers cannot be expected for the film of

the present invention. At present, the mechanism of the present invention obtaining small grain size is not clear. To find out the mechanism of the present invention is an important problem to be solved.

5 Descriptions about absorbing oxygen and absorbing nitrogen are found in the Japanese Patent Laid-open Application No. 2002-22518 mentioned above. In this patent application, Nb containing alloy under-layer for obtaining small crystalline grains is described. As an example of the invention, physical
10 absorption of oxygen and nitrogen to the under layer is described. In this case, notable effect found in the present invention is not obtained possibly because the absorbed oxygen and nitrogen are absorbed on Nb substrate and not on Cu, Ni, Rh or Pt. Furthermore, oxygen, fluorine and nitrogen contained magnetic recording medium
15 is described in Japanese Patent Laid-open Application No. HEI 5-128481. Notable effect found in the present invention is not obtained in this case, because oxygen, fluorine and nitrogen are contained in its substrate to obtain an effect similar to a textured structure and are not deposited on the under-layer.

20 The present invention provides a novel means for obtaining magnetic layer having very small magnetic crystalline grains and magnetic recording media for high density recording having increased signal to noise ratio.

25 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematically drawn cross section view of a magnetic recording medium according to an embodiment of the present invention.

Fig. 2 is a schematically drawn in-plane view of a magnetic recording layer for a magnetic recording medium showing magnetic crystalline grains arranged in a form of a tetragonal lattice structure according to an embodiment of the present invention.

5 Fig. 3 is a schematically drawn example of a ring pattern for the reciprocal lattice for the tetragonal lattice structure.

Fig. 4 is a schematically drawn a in-plane view of a magnetic recording layer for a magnetic recording medium showing magnetic crystalline grains arranged in a form of a hexagonal lattice
10 structure according to an embodiment of the present invention.

Fig. 5 is a schematically drawn example of ring pattern for the reciprocal lattice for the hexagonal lattice structure.

Fig. 6 is a schematically drawn cross section view of a magnetic recording medium comprising an orientation control
15 under-layer according to an embodiment of the present invention.

Fig. 7 is a schematically drawn cross section view of a magnetic recording medium having an intermediate under-layer according to an embodiment of the present invention.

Fig. 8 is a schematically drawn cross section view of a
20 magnetic recording medium having a soft magnetic under-layer according to an embodiment of the present invention.

Fig. 9 is a schematically drawn schematically drawn cross section view of a magnetic recording medium having a biasing layer for a soft magnetic under-layer according to an embodiment of the
25 present invention.

Fig. 10 is a schematically shown oblique view of a magnetic recording apparatus according to an embodiment of the present invention showing the construction by partially removing the

covers.

Fig. 11 is a graph showing the relation between the quantity of deposited oxygen atoms and the average grain diameter of the magnetic recording layer of Example 1.

5 Fig. 12 is a graph showing the relation between the quantity of deposited carbon atoms and the average grain diameter of the magnetic recording layer of Example 1.

Fig. 13 is a graph showing the relation between the average diameter of Ni and the average grain diameter of the magnetic
10 recording layer of Example 1.

Fig. 14 is a graph showing the relation between the average diameter of Ni and the average grain diameter of the magnetic recording layer of Example 1.

Fig. 15 is a graph showing the relation between the areal
15 density of magnetic crystalline grains and the dpw_{50} of the magnetic recording layer of Example 1.

Fig. 16 is a graph showing the relation between the areal density of magnetic crystalline grains and the dpw_{50} of the magnetic recording layer of Example 1.

20

DETAILS DESCRIPTION

Hereinafter, embodiments of the present invention will be described in detail with reference to the drawings.

Fig. 1 is a schematically shown cross section view of a
25 magnetic recording medium according to an embodiment of the present invention. A grain diameter controlling under layer 12a of at least one selected from Cu, Ni, Rh, and Pt is disposed on a substrate 11 shown in Fig. 1. A deposited atom layer 12b of at least one

element selected from the group consisting of oxygen and carbon is formed on the diameter control under-layer 12a. A magnetic recording layer 14 is disposed on the deposited atom layer 12b, and a protective and lubricant layer 15 is formed on the magnetic recording layer 14.

Quantity of the deposited oxygen or carbon atoms desirable for the deposited atom layer 12b on the surface of the grain diameter control under-layer 12a is in a range from 1×10^{13} atoms/cm² to 1×10^{15} atoms/cm² expressed by average number of atoms per unit area. When the quantity is less than 1×10^{13} atoms/cm², notable average grain diameter decreasing effect on the magnetic recording layer cannot be obtained. Furthermore, magnetic crystalline grain orientation of the magnetic recording layer decreases when the quantity is larger than 1×10^{15} atoms/cm². The quantity of the deposited oxygen or carbon atoms is more desirable to be in a range from 5×10^{13} atoms/cm² to 5×10^{14} atoms/cm².

Number and position of oxide atoms and carbide atoms can be evaluated by a secondly ion mass spectroscopy (SIMS) method. Other methods for example, nuclear reactor analysis (NRA) using high energy hydrogen ions or deuteron ions radiation as reported in Applied Physics Letters Vol.80 pp.1803-1805 and Applied Physics Letters Vol.61 pp.327-329, Rutherford back scattering, X-ray photoelectron spectroscopy (XPS), and Auger electron spectroscopy (AES) can be used for evaluating the number of the atoms. Furthermore, atom probe method described in Applied Physics Letters Vol.69 pp.3095-3097 can be used for the evaluation.

As a means for depositing oxygen atoms on the surface of grain diameter control under-layer 12a, a method of exposing grain

diameter control under-layer 12a after deposition to oxygen atmosphere, oxygen plasma or oxygen radicals can be applied. As a means for depositing carbon atoms, a method of exposing to ethylene or acetylene atmosphere can similarly be applied. Other methods
5 of exposing to carbon monoxide atmosphere can be applied to deposit both oxygen and carbon to the surface.

The crystalline grains desirable for the grain diameter control under-layer 12a are grains having broader flat surface for obtaining the magnetic recording layer 14 with better
10 crystallinity. Accordingly, larger average grain diameter of the Cu grains is desirable. The desirable average grain diameter of the Cu grains is 50 nm or larger, and more desirable average grain diameter is 100 nm or larger. A single crystal film having no grain boundary is much more desirable. When the film is uneven
15 at a certain degree, the film can be available provided that the film has large fraction of terrace surfaces that form the film surface.

The grain diameter control under-layer 12a in which the same crystallographic face of each grain is oriented parallel to the
20 same plane is desirable because higher magnetic crystalline grain orientation can be obtained in the magnetic recording-layer 14. For the grain diameter control under-layer 12a having Cu, Rh, and Ni crystalline grains, grain orientation of their (100) planes parallel to the substrate surface is desirable, and for the grain
25 diameter control under-layer 12a having Pt crystalline grains, grain orientation of their (111) planes parallel to the substrate surface is desirable for obtaining significantly small size magnetic crystalline grains in the magnetic recording layer 14.

The magnetic crystalline grains in the magnetic recording layer 14 are formed in plural per one crystalline grain of the grain diameter control layer 12a on average. The desirable average areal density of the magnetic crystalline grains in the magnetic recording-layer is in a range from 1×10^{12} grains/cm² to 8×10^{12} grains/cm² for obtaining large reproduced output of the recorded signal. When the average areal density of the magnetic crystalline grains is less than 1×10^{12} grains/cm², the SNR decreases and when the average areal density is above 8×10^{12} grains/cm², the SNR decreases again.

The experimental results of the present inventors show that the magnetic crystalline grain arrangement of an ordered structure in a tetragonal lattice is desirable, when the grain diameter control under layer 12a comprises crystalline particles of Cu, Rh, or Ni. The noise level of recording and reproducing characteristics can be substantially reduced when the ordered structure was formed compared when the ordered structure arrangement is not formed. Fig. 2 schematically shows an in-plane structure of the magnetic recording layer of the magnetic recording medium. The white subjects express magnetic grains 1. Tetragonal lattice structure arrangement of magnetic crystalline grains 1 can be evaluated by image processing and analyzing the transmission electron microscope (TEM) in-plane Figures of the magnetic recording layer 14.

Using an image processing and analyzing software, a spectrum can be obtained as a result of a fast Fourier transformation of a binary Figure obtained by increasing contrast of a Figure for magnetic crystalline grains and grain boundary

regions. The magnetic crystalline grains can be regarded to have an arrangement of tetragonal lattice structure essentially when patterns as shown in Fig. 3 can be recognized in the spectrum. Practically, the arrangement can be confirmed by finding two
5 type periodical spots or rings having a ratio of the distances to the center of $1:1/\sqrt{2}$ (R_1 and $R_1/2^{1/2}$ in Fig..3). Similar evaluation can be performed using low energy electron diffraction to the magnetic recording layer and analyzing the diffraction patterns.

10 Experimental results of the present inventors also shows that the magnetic crystalline grain arrangement essentially in an ordered structure of hexagonal lattice is desirable, when the grain diameter control under layer 12a comprises crystalline particles of Pt since the resolution of the recorded signal is
15 improved. Fig. 4 shows a schematically in-plane structure of the hexagonal lattice arrangement. Hexagonal lattice arrangement can be evaluated by methods similar to the case for the tetragonal crystal structure, when patterns as shown in Fig. 4 corresponding to a reciprocal lattice of a hexagonal structure can be recognized.
20 Practically, the arrangement can be confirmed by finding two type periodical spots or rings having a ratio of the distances to the center of $1:1/\sqrt{3}$ (R_1 and $R_1/\sqrt{3}$ in Fig. 4).

As shown in Fig. 6, an orientation control under-layer 12c for increasing (100) plane orientation of the crystalline grains
25 in the grain diameter control under-layer 12a can be disposed between the substrate 11 and grain diameter control under-layer 12a when crystalline grains of the grain diameter control under-layer 12a is Cu, Rh, or Ni. As the practical material for

orientation control under-layer 12c, at least one selected from the group consisting essentially of NiAl, MnAl, MgO, NiO, TiN, Si, and Ge can be used. The orientation control under-layer 12c need not be disposed directly adjacent to the grain diameter control under-layer 12a.

For the magnetic recording medium of the present invention, a magnetic recording layer 14 having a granular structure is desirable. The formation of nonmagnetic grain boundary regions of the granular structure in the magnetic recording layer 14 lead to a decrease in the exchange interaction between magnetic crystalline grains, a decrease in width of magnetization transition zone and an increase in recording resolution of recording and reproducing characteristics.

As the materials for the magnetic recording layer 14, disordered alloys such as Co-Cr and Co-Pt, ordered alloys such as Fe-Pt, Co-Pt and Fe-Pd, and multi layered film materials such as Co/Pt and Co/Pd can be desirably used. These alloys and multi-layered film materials have advantages of high thermal fluctuation durability because these materials have high crystalline anisotropy energy. Magnetic properties of these alloy and multi-layered materials can be improved by adding some additive elements such as Cu, B and Cr as necessary.

CoCrPt, CoCrPtB, CoCrPtTa, CoCrPtNd, CoCrPtCu and FePtCu alloys can be cited as more desirable materials for the magnetic recording layer 14.

As the materials for composing grain boundary regions of the granular structure, chemical compounds such as oxides, carbide and nitrides are desirable. These compounds are

suitable for composing grain boundary regions because these compounds do not form solid solution with the materials for forming the magnetic crystalline grains described above and these compounds can be separated easily. Compounds such as SiO_x , TiO_x , CrO_x , AlO_x , MgO_x , TaO_x , SiN_x , TiN_x , AlN_x , TaC_x , SiC_x , TiC_x and TaC_x can be cited as materials for forming the grain boundary regions.

The magnetic recording layer 14 can be double structure or more multi-layer structure, in which either one of the multi-layers is granular.

As shown in Fig. 7, an intermediate under-layer 12d for controlling characteristics of magnetic recording layer 14 can be disposed as one layer of the set of under-layers 12. The crystal orientation degree can be improved keeping the small average grain diameter and the homogeneity of the diameter by using a granular structured layer as the intermediate under-layer 12d. Furthermore, the recording and reproducing characteristics can be increased.

As the nonmagnetic crystalline materials of the intermediate under-layer 12d showing granular structure, Pt, Pd, Ir, Ag, Cu, Ru, and Rh can be used. These metal materials are desirable because these metal materials show good lattice compatibility with magnetic crystalline grains described above and can improve crystal orientation degree of the magnetic recording layer.

As the materials for forming grain boundary regions of the intermediate under-layer 12d, compounds such as oxides, carbides and nitrides are desirably used. These compounds are advantageous as the materials for composing grain boundary

regions because these compounds do not form solid solution with the nonmagnetic crystalline materials for forming the magnetic crystalline grains described above, and can easily be separated. Chemical compounds such as SiO_x , TiO_x , CrO_x , AlO_x , MgO_x , TaO_x , SiC_x , TiC_x , and TaC_x can be cited for forming the grain boundary regions. The materials constructing the under-layer can include magnetic metal provided that the under-layer is nonmagnetic as the whole.

The intermediate under-layer 12d with a granular structure can be constructed as multi-layer of two or more layers. The layer need not be placed adjacent to the magnetic recording layer.

When the magnetic recording medium of the present invention is applied to a perpendicular magnetic recording medium, a soft magnetic under-layer 16 can be placed between the under-layers and the substrate 11 as shown in Fig. 8.

Disposing the soft magnetic under-layer 16 in the magnetic recording medium described above, so-called perpendicular double-layered medium, comprising the magnetic recording layer 14 disposed on the soft magnetic layer 15, can be constructed. The soft magnetic under-layer 16 shares a partial function of a magnetic head by returning magnetic flux induced by the recording magnetic field from a single pole head passing horizontally through the magnetic recording medium and turning back to the magnetic head. Therefore, the soft magnetic under-layer 16 placed in the magnetic recording medium plays a role for giving a sharp perpendicular magnetic field with sufficient magnitude to the magnetic recording layer 14.

For the soft magnetic under-layer 16, for example, CoZrNb , FeSiAl , FeTaC , CoTaC , NiFe , Fe , FeCoB , FeCoN and FeTaN , can be

cited.

A biasing layer 17 can be disposed between the soft magnetic layer 16 and the substrate 11 as shown in Fig. 9. For the biasing layer 17, in-plane hard magnet film, antiferromagnetic film and
 5 so on can be applied. Magnetic domains are easily formed in the soft magnetic under-layer 16, and magnetic domain walls induce spike like noise. The formation of magnetic domains can be avoided by applying a magnetic field in one radial direction of the biasing layer 17 and applying biasing field to the soft
 10 magnetic under-layer 16 placed on the biasing layer 17. The biasing can be a multi-layered structure with finely dispersed anisotropy field to avoid formation of large magnetic domains. As the material for constructing the biasing layer 17, CoCrPt, CoCrPtB, CoCrPtTa, CoCrPtTaNd, CoSm, CoPt, FePt, CoPtO, CoPtCrO,
 15 CoPt-SiO₂, CoCrPt-SiO₂ and CoCrPtO-SiO₂ can be cited.

Glass substrates, Al alloy substrates or Si single crystal substrates with oxide surface, ceramic substrate and plastic substrates can be used for the substrate 11 as nonmagnetic substrates. These inorganic substrates plated with NiP, for
 20 example, can be used.

Protective and lubricant layer 15 can be formed on the magnetic recording layer 14. For the protective layer of the protective and lubricant layer 15, carbon or diamond like carbon (DLC) can be used. Other materials SiN_x, SiO_x, and CN_x can be
 25 cited as the protective layer material.

As the method for depositing each layer described above, vacuum evaporation method, every kind of sputtering method, molecular beam epitaxy method, ion beam evaporation method, laser

abrasion method and chemical vapor deposition method can be used.

Fig. 10 is oblique view of a magnetic recording apparatus according to an embodiment of the present invention schematically showing the construction by partially removing
5 covers.

In Fig. 10, the magnetic disk 101 according to the present invention is attached to the spindle 102, and is driven at a constant rotating speed by a spindle motor not shown in the Figure. The slider 103 having a recording head for
10 recording information and a MR head and reproducing the recorded information accessing to the surface of the magnetic disk 101 is attached at the top of a suspension 104 constructed by a thin plate shaped flat spring. The suspension 104 is connected to one side of an arm 105 having a bobbin holding a
15 drive coil not shown in the Figure.

At the other side of the arm 105, a voice coil motor 106, a kind of linear motor, is disposed. The voice coil motor 106 is constructed by a magnetic circuit composed of a drive coil rolled up to a bobbin of arm 105, permanent magnet and opposing yokes.

20 The arm 105 is supported by a ball bearing not shown in the Figure fixed at the upper and lower sides of fixed axis 107, and is driven to swing circularly by the voice coil motor 106. The voice coil motor 106 controls the position of the slider 103 on the magnetic disk 101. In the Fig. 10, a
25 cover 108 is shown partially.

Hereinafter, examples of the present invention will be described to explain the present invention further in detail.

(Example 1)

Nonmagnetic 2.5 inches (about 6.4 cm) glass substrates were
30 put into a vacuum chamber of an ANELVA Co. c-301 type sputtering

apparatus. The vacuum chambers of the sputtering apparatus were evacuated to 1×10^{-6} Pa or less.

Then substrates were heated using an infrared heater up to about 300°C. Keeping the substrate temperature to about 300°C, about
5 200 nm CoZrNb film was deposited as a soft magnetic under-layer, and then an about 30nm Ni film was deposited to each substrate.

Each substrate was then elevated to about 500°C, and exposed to oxide or ethylene atmosphere in a range of 1×10^{-5} to 1×10^{-2} Pa. After the oxide or ethylene exposure, a 5 nm thick Fe₅₀Pt₅₀ film was
10 deposited as a magnetic recording layer.

Then a 5 nm carbon film was deposited. For the deposition of CoZrNb, Ni, Fe₅₀Pt₅₀ and C films, the Ar gas pressure was controlled to 0.7Pa, 0.7Pa, 5Pa and 0.7Pa, respectively, and as the target material, CoZrNb, Ni, Fe₅₀Pt₅₀, and C, respectively was used. DC
15 sputtering was used for the sputtering deposition. Power inputted to the targets was fixed to 1,000 W for CoZrNb, Fe₅₀Pt₅₀ and C deposition, and varied from in a range from 100 to 1,000 W for Ni deposition.

Samples were prepared using the similar deposition procedure
20 except that the Ni described above was replaced by Cu, Rh, Ni and Pt. Furthermore, magnetic recording medium samples having Co₅₀Pt₅₀, Fe₅₀Pd₅₀ and Co₇₀Cr₁₀Pt₁₀ instead of Fe₅₀Pt₅₀ as the magnetic recording layers were fabricated using similar procedure described above. Quantity of deposited oxygen or carbon was controlled by the
25 partial pressure of oxygen or ethylene exposure atmosphere. The crystalline grain diameter of the Cu, Rh, Ni and Pt was varied changing input power to the targets.

After finishing these deposition, protective layer of each prepared samples was coated with about 1.3 nm thick lubricant of

perfluoropolyether (PFPE) by a dipping method and magnetic recording medium samples were obtained.

As Comparative Example 1, conventional perpendicular magnetic recording medium samples were fabricated by the following procedure. Nonmagnetic 2.5 inches (about 6.4 cm) glass substrates were put into the vacuum chambers of the sputtering apparatus and the vacuum chambers were evacuated to 1×10^{-6} Pa or less. After heating the substrates using an infrared heater up to about 300°C, 200 nm CoZrNb film as a soft magnetic under-layer, 10 nm Ta film as a seed layer, 20 nm Ru film as a under-layer, 15 nm Co₆₅-Cr₂₀-Pt₁₄-Ta₁ layer as a magnetic recording layer, and a 5nm protective layer were deposited to each substrate, and then the lubricant was coated similar to the example described above.

For depositing CoZrNb film, Ta film, Ru film and CoCrPtTa film, the Ar gas pressure was 0.7Pa, 0.7Pa, 0.7Pa, 5Pa and 0.7Pa, respectively, and target material was CoZrNb, Ta, Ru and Co₆₅Cr₂₀ Pt₁₄Ta₁, respectively. DC sputtering was used for these deposition. Power inputted to the targets was fixed to 1,000 W.

The microstructure, the crystalline grain diameters and the grain size distribution of each fabricated sample were evaluated by a transmission electron microscope (TEM) with accelerating voltage of 400 kV. The quantity of oxygen and carbon atoms deposited on the each film and its distribution toward the depth direction was obtained, using a method similar to the method described in Japanese Patent Laid-open Application 2003-338029, from NRA reaction spectra of each reaction of $^{16}\text{(d,p)}^{17}\text{O}$, $^{18}\text{O(p,}\alpha\text{)}^{15}\text{N}$, and $^{12}\text{C(d,p)}^{13}\text{C}$ by synchrotron irradiation of hydrogen

ions or deuterium ions to the oxygen and carbon atoms of the samples. The analysis was performed also by SIMS method using Cs^+ .

Recording and reproducing characteristics (read write characteristics, R/W characteristics) of each magnetic recording medium was evaluated by using a spin stand. The magnetic head applied was a combination of a $0.3 \mu\text{m}$ track width single pole head and a $0.2 \mu\text{m}$ track width MR head. The same measuring condition at a constant magnetic head position of 20 mm from the disk center and the magnetic disk rotating speed of 4,200 rpm was applied.

Signal to noise ratio for derivative waveforms as an output of a derivative circuit (SNR_m) was measured and characterized as the SNR of the magnetic recording medium. The measured signal S was output for linear recording density of 119 kfc/i, and the measured noise was root mean square value at 716 kfc/i. In addition, the half width of the derivative waveforms (dPW_{50}) was evaluated to obtain as an index for the resolution of the recording.

Table 1 shows the average crystalline grain diameter d_{Mag} and the standard deviation σ of the magnetic layer of each magnetic recording medium.

[Table 1]

Example	Atoms Deposited Layer	Diameter Control Under-layer	Magnetic Recording layer	d_{Mag} (nm)	σ (nm)
Example 1-1	Oxygen	Cu	FePt	5.0	1.3
Example 1-2	Oxygen	Cu	CoCrPt	4.9	1.3
Example 1-3	Oxygen	Cu	CoPt	5.4	1.5
Example 1-4	Oxygen	Cu	FePd	5.4	1.2
Example 1-5	Carbon	Cu	FePt	4.9	1.3
Example 1-6	Carbon	Cu	CoCrPt	5.0	1.5
Example 1-7	Carbon	Cu	CoPt	5.5	1.2
Example 1-8	Carbon	Cu	FePd	5.3	1.3
Example 1-9	Oxygen	Ni	FePt	5.0	1.4
Example 1-10	Oxygen	Ni	CoCrPt	4.8	1.1

Example 1-11	Oxygen	Ni	CoPt	5.1	1.2
Example 1-12	Oxygen	Ni	FePd	5.4	1.2
Example 1-13	Carbon	Ni	FePt	5.0	1.4
Example 1-14	Carbon	Ni	CoCrPt	5.1	1.3
Example 1-15	Carbon	Ni	CoPt	5.3	1.4
Example 1-16	Carbon	Ni	FePd	5.1	1.0
Example 1-17	Oxygen	Rh	FePt	5.1	1.1
Example 1-18	Oxygen	Rh	CoCrPt	4.9	1.3
Example 1-19	Oxygen	Rh	CoPt	5.4	1.5
Example 1-20	Oxygen	Rh	FePd	5.3	1.4
Example 1-21	Carbon	Rh	FePt	4.9	1.4
Example 1-22	Carbon	Rh	CoCrPt	5.0	1.5
Example 1-23	Carbon	Rh	CoPt	5.2	1.3
Example 1-24	Carbon	Rh	FePd	5.2	1.1
Example 1-25	Oxygen	Pt	FePt	5.1	1.1
Example 1-26	Oxygen	Pt	CoCrPt	5.1	1.2
Example 1-27	Oxygen	Pt	CoPt	5.3	1.0
Example 1-28	Oxygen	Pt	FePd	5.2	1.4
Example 1-29	Carbon	Pt	FePt	5.5	1.4
Example 1-30	Carbon	Pt	CoCrPt	5.3	1.0
Example 1-31	Carbon	Pt	CoPt	5.6	1.1
Example 1-32	Carbon	Pt	FePd	5.8	1.5
Comparative Example			(conventional medium)	7.1	2.5

As shown in Table 1, each magnetic recording medium of the Example 1 has smaller average crystalline grain diameter with smaller standard deviation compared with the magnetic recording medium of the Comparative Example 1.

Fig. 11 and Fig. 12 shows a relationship between the quantity of deposited oxygen θ_o and carbon θ_c , respectively, and the average magnetic crystalline grain diameter d_{Mag} obtained by a nuclear reaction analysis NRA for $Fe_{50}Pt_{50}$ magnetic layer and Ni diameter control under-layer samples. From this Figure, it can be found that when the θ value is in a range from 1×10^{13} atom/cm² to 1×10^{15} atom/cm², the crystalline grains were significantly small and desirable. Similar results were obtained for the cases of Cu, Rh, and Pt diameter control under-layer samples. Similar results were also obtained for the cases of $Co_{50}Pt_{50}$, $Fe_{50}Pd_{50}$ and $Co_{70}Cr_{10}Pt_{20}$ magnetic layer. For each magnetic recording medium, the fact that

deposited oxygen and carbon atoms were found on diameter control under-layer surface region and not exist insides of the diameter control under-layers was confirmed by a chemical element distribution measurement using SIMS toward the depth direction.

5 Fig. 13 and Fig. 14 show a relationship between the average diameter of Ni crystalline grains d_{Ni} at Ni layer and the average diameter of magnetic crystalline grains d_{Mag} for $Fe_{50}Pd_{50}$ magnetic layers for 2×10^{14} atom/cm² and 4×10^{14} atom/cm² deposited oxygen or carbon. The average grain diameter of the magnetic layer became
10 significantly small when the average grain diameter of Ni layer is 50 nm or larger than 50 nm. Similar result was obtained for samples for Cu, Rh, and Pt grain diameter control under-layer.

Fig. 15 and Fig. 16 shows dPW_{50} plotted as a function of average areal density of magnetic crystalline grains n in each
15 magnetic recording layer obtained by TEM observation for d_{Ni} of 100 nm and for areal density of oxygen or carbon deposition of 2×10^{14} atom/cm² and of 4×10^{14} atom/cm², respectively. When n is in a range from 1×10^{12} grains /cm² to 8×10^{12} grains /cm², dPW_{50} decreases desirably. When n is in a range from 1×10^{12} grains/cm² to 8×10^{12}
20 grains/cm², plural number of magnetic crystalline particles in the magnetic recording layer on one Ni crystalline grain on average was confirmed. Similar result was obtained for samples for Cu, Rh, and Pt grain diameter control under-layer.

Ordered arrangement of magnetic crystalline grains was
25 examined for magnetic recording layer in-plane TEM Figure of each magnetic recording medium using an image processing and analyzing software "Image-Pro Plus" (Media Cybernetics Co., USA). In-plane TEM Figure for each magnetic recording layer was transformed into

patterns expressed by two values increasing contrast between regions of magnetic grains and other regions and the pattern was transformed into a reciprocal lattice pattern by FFT and evaluated. As the result, no ordered arrangement could be found
 5 for conventional medium sample of Comparative Example 1.

On the other hand, every magnetic recording medium having n values in a range from 1×10^{12} gains/cm² to 8×10^{12} gains/cm², and having Ni, Rh and Cu grain diameter control under-layer, showed granular structured magnetic recording layer. FFT analysis for
 10 TEM Figure confirmed essentially tetragonal arrangement of crystalline particles two periodical pattern showing $1:1/\sqrt{2}$ relationship in distances from the center spot.

For every magnetic recording medium having Pt grain diameter control under-layer showed granular structured magnetic recording
 15 layer. FFT analysis for TEM Figure confirmed essentially hexgonal arrangement of crystalline particles two periodical pattern showing $1:1/\sqrt{3}$ relationship in distances from the center spot.

(Example 2)

Nonmagnetic 2.5 inches (about 6.4 cm) glass substrates were
 20 put into the vacuum chambers and the vacuum chambers were evacuated to 1×10^{-6} Pa or less. Then CoZrNb soft under-layer, Cu, Ni, Rh and Pt films were deposited respectively, using the method described in Example 1.

Oxygen deposited layer was formed irradiating oxygen ions at
 25 200 eV using ion gun on the under-layer surface in oxygen atmosphere in a range from 1×10^{-5} Pa to 1×10^{-2} Pa. Then magnetic recording layer of a 5 nm Co₇₀Cr₁₀Pt₂₀-TiN was formed using Co₇₀Cr₁₀Pt₂₀-10mol%TiN composite target. Magnetic recording

layers replacing $\text{Co}_{70}\text{Cr}_{10}\text{Pt}_{20}$ by $\text{Fe}_{50}\text{-Pt}_{50}$, $\text{Co}_{50}\text{Pt}_{50}$ and $\text{Co}_{50}\text{Pd}_{50}$, and replacing TiN by AlN , TaN , TiC and TaC were deposited respectively. Using similar procedure as described in Example 1, carbon protective layer was deposited and lubricant layer was coated.

5 Then, various magnetic recording media were prepared.

Table 2A and 2B show SNR_m values and dPW_{50} values for each magnetic recording medium. Magnetic recording layer structure composite with chemical compound leads desirably increased magnetic recording medium SNR_m . Every composite magnetic

10 recording layer including chemical compound showed granular structure, and magnetic crystalline grains on Ni , Rh , and Cu grain diameter control under-layer showed ordered structure arranged to form tetragonal lattice. On the other hand, magnetic crystalline grains on Pt grain diameter control under-layer

15 showed ordered structure arranged to form hexagonal lattice.

[Table 2A]

Example	Diameter Control Under-layer	Magnetic Recording Under-layer	SNR_m (dB)	dPW_{50} (nm)
Example 2-1	Cu	CoCrPt	16.0	92
Example 2-2	Cu	CoCrPt-TiN	16.5	85
Example 2-3	Cu	CoCrPt-AlN	16.3	85
Example 2-4	Cu	CoCrPt-TaN	16.4	84
Example 2-5	Cu	CoCrPt-Si ₃ N ₄	16.5	85
Example 2-6	Cu	CoCrPt-TiC	16.3	83
Example 2-7	Cu	CoCrPt-TaC	16.3	83
Example 2-8	Ni	CoCrPt-TiN	16.7	83
Example 2-9	Ni	CoCrPt-AlN	16.8	85
Example 2-10	Ni	CoCrPt-TaN	16.9	82
Example 2-11	Ni	CoCrPt-Si ₃ N ₄	16.9	86
Example 2-12	Ni	CoCrPt-TiC	16.7	82
Example 2-13	Ni	CoCrPt-TaC	16.6	83
Example 2-14	Rh	CoCrPt-TiN	16.3	84
Example 2-15	Rh	CoCrPt-AlN	16.4	85
Example 2-16	Rh	CoCrPt-TaN	16.4	84
Example 2-17	Rh	CoCrPt-Si ₃ N ₄	16.3	83
Example 2-18	Rh	CoCrPt-TiC	16.4	82
Example 2-19	Rh	CoCrPt-TaC	16.4	82

Example 2-20	Pt	CoCrPt-TiN	16.4	84
Example 2-21	Pt	CoCrPt-AlN	16.3	86
Example 2-22	Pt	CoCrPt-TaN	16.6	86
Example 2-23	Pt	CoCrPt-Si ₃ N ₄	16.6	83
Example 2-24	Pt	CoCrPt-TiC	16.5	82
Example 2-25	Pt	CoCrPt-TaC	16.6	85

[Table 2B]

Example	Diameter Control Under-layer	Magnetic Recording Under-layer	SNR _m (dB)	dPW ₅₀ (nm)
Example 2-26	Cu	FePt	15.9	90
Example 2-27	Cu	FePt-TiN	16.4	84
Example 2-28	Cu	FePt-AlN	16.4	82
Example 2-29	Cu	FePt-TaN	16.3	85
Example 2-30	Cu	FePt-Si ₃ N ₄	16.7	84
Example 2-31	Cu	FePt-TiC	16.7	85
Example 2-32	Cu	FePt-TaC	16.5	83
Example 2-33	Ni	FePt-TiN	16.5	82
Example 2-34	Ni	FePt-AlN	16.7	84
Example 2-35	Ni	FePt-TaN	16.3	84
Example 2-36	Ni	FePt-Si ₃ N ₄	16.2	85
Example 2-37	Ni	FePt-TiC	16.1	82
Example 2-38	Ni	FePt-TaC	16.4	83
Example 2-39	Rh	FePt-TiN	16.3	83
Example 2-40	Rh	FePt-AlN	16.3	82
Example 2-41	Rh	FePt-TaN	16.4	83
Example 2-42	Rh	FePt-Si ₃ N ₄	16.6	84
Example 2-43	Rh	FePt-TiC	16.7	83
Example 2-44	Rh	FePt-TaC	16.3	83
Example 2-45	Pt	FePt-TiN	16.3	83
Example 2-46	Pt	FePt-AlN	16.5	84
Example 2-47	Pt	FePt-TaN	16.2	85
Example 2-48	Pt	FePt-Si ₃ N ₄	16.4	84
Comparative Example		(conventional medium)	15.4	109

(Example 3)

5 Nonmagnetic 2.5 inches (about 6.4 cm) glass substrates were put into the vacuum chambers and the vacuum chambers were evacuated to 2×10^{-6} Pa or less. Then on the CoZrNb soft under-layer, Cu, Ni, Rh or Pt film was deposited, and then deposited carbon layer was formed using the method described in example 1

10 to each substrate.

Magnetic recording layer of a 5 nm Co₇₀Cr₁₀Pt₂₀-SiO₂ was formed

using 5 nm $\text{Co}_{70}\text{Cr}_{10}\text{Pt}_{20}$ -10 mol% SiO_2 composite target. Magnetic recording layers replacing $\text{Co}_{70}\text{Cr}_{10}\text{Pt}_{20}$ by $\text{Fe}_{50}\text{-Pt}_{50}$, $\text{Co}_{50}\text{Pt}_{50}$ and $\text{Fe}_{50}\text{Pd}_{50}$, and replacing SiO_2 by TiO , Al_2O_3 , TiN , AlN , and TaN , were deposited respectively. Using similar procedure described in Example 1, carbon protective layer was deposited and lubricant layer was coated. Then, various magnetic recording media were prepared.

Table 3A and 3B show SNR_m values and dPW_{50} values for each magnetic recording medium. Magnetic recording layer structure composite with chemical compound leads desirably increased magnetic recording medium SNR_m . Every composite magnetic recording layer including chemical compound showed granular structure, and magnetic crystalline grains on Ni, Rh, and Cu grain diameter control under-layer showed ordered structure arranged to form tetragonal lattice. On the other hand, magnetic crystalline grains on Pt grain diameter control under-layer showed ordered structure arranged to form hexagonal lattice.

[Table 3A]

Example	Diameter Control Under-layer	Magnetic Recording Under-layer	SNR_m (dB)	dPW_{50} (nm)
Example 3-1	Cu	CoCrPt	16.1	93
Example 3-2	Cu	CoCrPt-TiN	16.5	86
Example 3-3	Cu	CoCrPt-AlN	16.6	84
Example 3-4	Cu	CoCrPt-TaN	16.4	81
Example 3-5	Cu	CoCrPt- Si_3N_4	16.6	85
Example 3-6	Cu	CoCrPt-TiC	16.5	81
Example 3-7	Cu	CoCrPt-TaC	16.3	81
Example 3-8	Ni	CoCrPt-TiN	16.8	84
Example 3-9	Ni	CoCrPt-AlN	16.7	83
Example 3-10	Ni	CoCrPt-TaN	16.9	84
Example 3-11	Ni	CoCrPt- Si_3N_4	16.6	82
Example 3-12	Ni	CoCrPt-TiC	16.5	85
Example 3-13	Ni	CoCrPt-TaC	16.9	85
Example 3-14	Rh	CoCrPt-TiN	16.6	87
Example 3-15	Rh	CoCrPt-AlN	16.5	83

Example 3-16	Rh	CoCrPt-TaN	16.5	81
Example 3-17	Rh	CoCrPt-Si ₃ N ₄	16.6	84
Example 3-18	Rh	CoCrPt-TiC	16.3	80
Example 3-19	Rh	CoCrPt-TaC	16.4	83
Example 3-20	Pt	CoCrPt-TiN	16.4	83
Example 3-21	Pt	CoCrPt-AlN	16.5	81
Example 3-22	Pt	CoCrPt-TaN	16.3	80
Example 3-23	Pt	CoCrPt-Si ₃ N ₄	16.4	81
Example 3-24	Pt	CoCrPt-TiC	16.5	83
Example 3-25	Pt	CoCrPt-TaC	16.5	82

[Table 3B]

Example	Diameter Control Under-layer	Magnetic Recording Under-layer	SNR _m (dB)	dPW ₅₀ (nm)
Example 3-26	Cu	FePt	16.0	91
Example 3-27	Cu	FePt-TiN	16.4	84
Example 3-28	Cu	FePt-AlN	16.5	85
Example 3-29	Cu	FePt-TaN	16.3	83
Example 3-30	Cu	FePt-Si ₃ N ₄	16.4	86
Example 3-31	Cu	FePt-TiC	16.3	82
Example 3-32	Cu	FePt-TaC	16.5	84
Example 3-33	Ni	FePt-TiN	16.3	83
Example 3-34	Ni	FePt-AlN	16.7	80
Example 3-35	Ni	FePt-TaN	16.8	81
Example 3-36	Ni	FePt-Si ₃ N ₄	16.3	84
Example 3-37	Ni	FePt-TiC	16.5	83
Example 3-38	Ni	FePt-TaC	16.4	82
Example 3-39	Rh	FePt-TiN	16.3	82
Example 3-40	Rh	FePt-AlN	16.4	82
Example 3-41	Rh	FePt-TaN	16.3	81
Example 3-42	Rh	FePt-Si ₃ N ₄	16.5	83
Example 3-43	Rh	FePt-TiC	16.4	81
Example 3-44	Rh	FePt-TaC	16.3	82
Example 3-45	Pt	FePt-TiN	16.5	83
Example 3-46	Pt	FePt-AlN	16.7	84
Example 3-47	Pt	FePt-TaN	16.8	84
Example 3-48	Pt	FePt-Si ₃ N ₄	16.5	82
Example 3-49	Pt	FePt-TiC	16.7	85
Example 3-50	Pt	FePt-TaC	16.4	85
Comparative Example		(Conventional Medium)	15.4	109

(Example 4)

- 5 2.5 inch (about 6.4 cm) hard disk shaped nonmagnetic glass substrates were prepared and film depositions were performed using same process as shown in Example 1 up to oxygen deposition treatment.

Then 10 nm Pt-TiN was deposited using a composite target of Pt-10 mol% TiN to each substrate. On the Pt-TiN layer, 5 nm $\text{Co}_{70}\text{Cr}_{10}\text{Pt}_{20}\text{-SiO}_2$ magnetic recording layer was deposited using $\text{Co}_{70}\text{Cr}_{10}\text{Pt}_{20}\text{-10\%SiO}_2$ composite target.

5 Then various magnetic recording media were obtained depositing carbon protective layer and coating lubricant layer using the procedure described in Example 2. In addition, various magnetic recording media were prepared from the magnetic recording medium mentioned above replacing under-layer Pt by
10 Pd, Ir, Ag, Cu, Ru and Rh, and replacing TiN by AlN, TaNSi_2N_3 , TiC, and TaC, under-layer, respectively, were fabricated preparing targets for each deposition. Further more, magnetic recording layer of $\text{Fe}_{50}\text{-Pt}_{50}$, $\text{Co}_{50}\text{Pt}_{50}$ and $\text{Fe}_{50}\text{Pd}_{50}$ instead of $\text{Co}_{70}\text{Cr}_{10}\text{Pt}_{20}\text{SiO}_2$, and TiO, Al_2O_3 , TiN, AlN, TaN, TiC, and TaC instead
15 of SiO_2 , were deposited respectively, preparing targets for each deposition.

Tables 4A and 4B show SNR_m values and dPW_{50} values for every magnetic recording medium having CoCrPt-SiO₂ magnetic recording layer and respective under-layers. Magnetic recording layer
20 structure composite with chemical compound showed increased magnetic recording medium SNR_m . Similar result was also found when other magnetic recording layer was applied. Every magnetic recording layer and under layer showed granular structure, and magnetic recording media with Ni, Rh, and Cu grain diameter
25 control under-layer showed essentially ordered structure of magnetic crystalline grains arranged to form tetragonal lattice. On the other hand, magnetic recording media with Pt grain diameter control under-layer showed ordered structure of magnetic

crystalline grains arranged to form hexagonal lattice.

[Table 4A]

Example	Intermediate Under-layer	SNR _m [dB]	dPW ₅₀ [nm]
Example 4-1	Pt	17.3	77
Example 4-2	Pd	17.3	78
Example 4-3	Ir	17.2	77
Example 4-4	Ag	17.2	77
Example 4-5	Cu	17.2	76
Example 4-6	Ru	17.4	77
Example 4-7	Rh	17.4	77
Example 4-8	Pt-TiN	17.8	74
Example 4-9	Pd-TiN	17.6	75
Example 4-10	Ir-TiN	17.8	75
Example 4-11	Ag-TiN	17.5	74
Example 4-12	Cu-TiN	17.4	74
Example 4-13	Ru-TiN	17.7	73
Example 4-14	Rh-TiN	17.7	73
Example 4-15	Pt-AlN	17.7	75
Example 4-16	Pd-AlN	17.7	73
Example 4-17	Ir-AlN	17.5	72
Example 4-18	Ag-AlN	17.6	72
Example 4-19	Cu-AlN	17.6	74
Example 4-20	Ru-AlN	17.8	73
Example 4-21	Rh-AlN	17.7	73
Example 4-22	Pt-TaN	17.8	74
Example 4-23	Pd-TaN	17.5	72
Example 4-24	Ir-TaN	17.5	73
Example 4-25	Ag-TaN	17.6	74
Example 4-26	Cu-TaN	17.5	73
Example 4-27	Ru-TaN	17.7	73
Example 4-28	Rh-TaN	17.6	72

5 [Table 4B]

Example	Intermediate Under-layer	SNR _m [dB]	dPW ₅₀ [nm]
Example 4-29	Pt-Si ₃ N ₄	17.9	76
Example 4-30	Pd-Si ₃ N ₄	17.9	73
Example 4-31	Ir-Si ₃ N ₄	17.7	74
Example 4-32	Ag-Si ₃ N ₄	17.7	74
Example 4-33	Cu-Si ₃ N ₄	17.8	75
Example 4-34	Ru-Si ₃ N ₄	17.8	75
Example 4-35	Rh-Si ₃ N ₄	17.6	72
Example 4-36	Pt-TiC	17.7	73
Example 4-37	Pd-TiC	17.9	73
Example 4-38	Ir-TiC	17.6	74
Example 4-39	Ag-TiC	17.7	73
Example 4-40	Cu-TiC	17.5	72

Example 4-41	Ru-TiC	17.8	74
Example 4-42	Rh-TiC	17.7	75
Example 4-43	Pt-TaC	17.6	75
Example 4-44	Pd-TaC	17.8	75
Example 4-45	Ir-TaC	17.7	72
Example 4-46	Ag-TaC	17.4	73
Example 4-47	Cu-TaC	17.3	73
Example 4-48	Ru-TaC	17.8	74
Example 4-49	Rh-TaC	17.9	72
Comparative Example	(Conventional medium)	15.4	109

(Example 5)

2.5 inch (about 6.4 cm) hard disk shaped nonmagnetic glass substrates were prepared and film depositions were performed using the same procedure as shown in Example 1 up to carbon deposition treatment. Then 10 nm Pt-SiO₂ was deposited using Pt-10 mol% SiO₂ composite target. Various magnetic recording medium were fabricated depositing various magnetic recording layer on the Pt-SiO₂ layer, depositing carbon protective layer and coating lubricant layer using the same fabricating conditions described in Example 4. Furthermore, various magnetic recording media were obtained replacing the Pt by Pd, Ir, Ag, Cu, Ru and Rh, and replacing the SiO₂ by TiO, Al₂O₃, TiN, AlN, TaN, TiC, and TaC, respectively, preparing and using each respective target.

Tables 5A and 5B show SNR_m values and dPW₅₀ values for each magnetic recording medium having CoCrPt-SiO₂ magnetic recording layer and respective under-layers. Disposing under-layer composite with chemical compound under the magnetic recording layer showed improvement of magnetic recording medium recording resolution. Similar result was also found when other magnetic recording layer was applied. Every magnetic recording layer and under layer showed granular structure, and magnetic recording media with Ni, Rh, and Cu grain diameter control under-layer showed

essentially ordered structure of magnetic crystalline grains arranged to form tetragonal lattice. On the other hand, magnetic recording media with Pt grain diameter control under-layer showed ordered structure of magnetic
5 crystalline grains arranged to form hexagonal lattice.

[Table 5A]

Example	Intermediate Under-layer	SNR _m [dB]	dPW ₅₀ [nm]
Example 5-1	Pt	17.3	78
Example 5-2	Pd	17.3	77
Example 5-3	Ir	17.2	78
Example 5-4	Ag	17.3	79
Example 5-5	Cu	17.0	77
Example 5-6	Ru	17.3	77
Example 5-7	Rh	17.1	78
Example 5-8	Pt-TiN	17.7	75
Example 5-9	Pd-TiN	17.6	74
Example 5-10	Ir-TiN	17.6	73
Example 5-11	Ag-TiN	17.7	75
Example 5-12	Cu-TiN	17.6	74
Example 5-13	Ru-TiN	17.8	72
Example 5-14	Rh-TiN	17.8	75
Example 5-15	Pt-AlN	17.8	75
Example 5-16	Pd-AlN	17.7	72
Example 5-17	Ir-AlN	17.9	73
Example 5-18	Ag-AlN	17.6	74
Example 5-19	Cu-AlN	17.8	72
Example 5-20	Ru-AlN	17.9	75
Example 5-21	Rh-AlN	17.9	73
Example 5-22	Pt-TaN	17.7	74
Example 5-23	Pd-TaN	17.6	73
Example 5-24	Ir-TaN	17.7	74
Example 5-25	Ag-TaN	17.6	73
Example 5-26	Cu-TaN	17.7	74
Example 5-27	Ru-TaN	17.9	73
Example 5-28	Rh-TaN	17.6	73

[Table 5B]

Example	Intermediate Under-layer	SNR _m [dB]	dPW ₅₀ [nm]
Example 5-29	Pt-Si ₃ N ₄	17.8	74
Example 5-30	Pd-Si ₃ N ₄	17.9	72
Example 5-31	Ir-Si ₃ N ₄	17.7	71
Example 5-32	Ag-Si ₃ N ₄	17.8	71
Example 5-33	Cu-Si ₃ N ₄	17.6	73
Example 5-34	Ru-Si ₃ N ₄	17.8	74
Example 5-35	Rh-Si ₃ N ₄	17.9	75
Example 5-36	Pt-TiC	17.9	75
Example 5-37	Pd-TiC	17.6	75
Example 5-38	Ir-TiC	17.7	73
Example 5-39	Ag-TiC	17.6	72
Example 5-40	Cu-TiC	17.7	74
Example 5-41	Ru-TiC	17.9	73
Example 5-42	Rh-TiC	17.9	72
Example 5-43	Pt-TaC	17.8	73
Example 5-44	Pd-TaC	17.8	74

Example 5-45	Ir-TaC	17.6	75
Example 5-46	Ag-TaC	17.6	75
Example 5-47	Cu-TaC	17.6	73
Example 5-48	Ru-TaC	17.8	74
Example 5-49	Rh-TaC	17.7	73
Comparative Example	(conventional medium)	15.4	109

(Example 6)

2.5 inch (about 6.4 cm) hard disk shaped nonmagnetic glass substrates were prepared and various magnetic recording media were fabricated using the fabricating procedure of Example 4 except that an orientation control layer was disposed between soft magnetic under-layer and grain diameter control layer. Then various magnetic recording media were obtained. As the orientation control layer, 5 nm thick NiAl layer was deposited in 0.7 Pa Ar atmosphere preparing and using NiAl targets. In addition, magnetic recording media having orientation control layer of MgO, NiO, MnAl, Ge, Si and TiN, respectively, are fabricated.

Table 6 shows the recording and reproducing characteristics of each magnetic recording medium having CoCrPt-SiO₂ magnetic recording layer and Pt-TiN under-layer. It was found that the SNR_m further increases by disposing the orientation control under-layer. Similar results were obtained for other magnetic recording media having other magnetic recording layer and under-layer combinations.

[Table 6]

Example	Orientation Control Under-layer	Diameter Control Under-layer	SNR _m [dB]	dPW ₅₀ [nm]
Example 6-1	None	Cu	17.7	73
Example 6-2	NiAl	Cu	18.1	71
Example 6-3	MgO	Cu	18.2	70
Example 6-4	NiO	Cu	18.3	70
Example 6-5	MnAl	Cu	18.1	71
Example 6-6	Ge	Cu	18.1	70
Example 6-7	Si	Cu	18.3	69
Example 6-8	TiN	Cu	18.2	69
Example 6-9	None	Ni	17.8	74
Example 6-10	NiAl	Ni	18.4	70
Example 6-11	MgO	Ni	18.2	70
Example 6-12	NiO	Ni	18.4	70
Example 6-13	MnAl	Ni	18.2	69
Example 6-14	Ge	Ni	18.2	70
Example 6-15	Si	Ni	18.3	71
Example 6-16	TiN	Ni	18.4	71
Example 6-17	None	Rh	17.5	75
Example 6-18	NiAl	Rh	18.0	69
Example 6-19	MgO	Rh	18.2	69
Example 6-20	NiO	Rh	18.2	70
Example 6-21	MnAl	Rh	18.3	71
Example 6-22	Ge	Rh	18.3	71
Example 6-23	Si	Rh	18.3	70
Example 6-24	TiN	Rh	18.2	69

(Example 7)

2.5 inch (about 6.4 cm) hard disk shaped nonmagnetic
5 glass substrates were prepared and various magnetic
recording media were fabricated using the fabricating
procedure of Example 5 except that an orientation control
layer was disposed between soft magnetic under-layer and
grain diameter control layer. Table 7 shows the recording
10 and reproducing characteristics of each magnetic recording
medium having CoCrPt-SiO₂ magnetic recording layer and Pt-TiN
under-layer. It was found that the SNR_m further increases by
disposing the orientation control under-layer. Similar
results were obtained for other magnetic recording media
15 having other magnetic recording layer and under-layer

combinations.

[Table 7]

Example	Orientation Control Under-layer	Diameter Control under-layer	SNR _m [dB]	dPW ₅₀ [nm]
Example 7-1	None	Cu	17.6	76
Example 7-2	NiAl	Cu	18.4	70
Example 7-3	MgO	Cu	18.3	71
Example 7-4	NiO	Cu	18.4	71
Example 7-5	MnAl	Cu	18.5	72
Example 7-6	Ge	Cu	18.2	71
Example 7-7	Si	Cu	18.3	69
Example 7-8	None	Ni	17.7	75
Example 7-9	NiAl	Ni	18.3	71
Example 7-10	MgO	Ni	18.3	69
Example 7-11	NiO	Ni	18.2	72
Example 7-12	MnAl	Ni	18.4	70
Example 7-13	Ge	Ni	18.2	71
Example 7-14	Si	Ni	18.3	70
Example 7-15	None	Rh	17.6	77
Example 7-16	NiAl	Rh	18.3	69
Example 7-17	MgO	Rh	18.2	68
Example 7-18	NiO	Rh	18.4	72
Example 7-19	MnAl	Rh	18.3	70
Example 7-20	Ge	Rh	18.2	69
Example 7-21	Si	Rh	18.4	71

5 Although the present invention has been shown and described with respect to best mode embodiments thereof, it should be understood by those skilled in art that the foregoing and various other changes in the form and detail without departing from the spirit and scope of the present invention.

CLAIMS:

1. A magnetic recording medium, comprising:
a substrate;
5 an under-layer formed on the substrate;
a magnetic recording layer on the under-layer; and
a protecting layer formed on the magnetic recording
layer,

wherein the under-layer including a grain diameter
10 control under-layer comprises crystalline grains of at least
one selected from the group consisting essentially of Cu, Ni,
Rh and Pt, and an deposited atom layer of at least one
selected from the group consisting of oxygen atoms and carbon
atoms on the grain diameter control layer surface.

15 2. The magnetic recording medium as set forth in claim
1,

wherein the deposited atom layer comprises the element
atoms in a range from 1×10^{13} atoms/cm² to 1×10^{15} atoms/cm² on the
average of areal density .

20 3. The magnetic recording medium as set forth in claims
1 or 2,

wherein the average grain diameter of the crystalline
grains of the grain diameter control under-layer is 50 nm or
larger.

25 4. The magnetic recording medium as set forth in any
one of the preceding claims,

wherein the grain diameter control under-layer comprises
crystalline grains of at least one selected from the group
consisting essentially of Cu, Ni and Rh orienting (100) planes
30 of the grains parallel to the substrate surface.

5. The magnetic recording medium as set forth in any one of the preceding claims,

wherein the magnetic recording layer comprises magnetic crystalline grains in an average areal density range from 1×10^{12} grains/cm² to 8×10^{12} grains /cm² held in plural on average on a crystalline grain of the large grain diameter under-layer.

6. The magnetic recording medium as set forth in any one of the preceding claims,

wherein the magnetic recording layer comprises magnetic crystalline grains arranged in a form of tetragonal lattice structure.

7. The magnetic recording medium as set forth in any one of the preceding claims,

wherein the grain diameter control under-layer comprises crystalline Pt grains orienting (111) planes of the grains parallel to the substrate surface.

8. The magnetic recording medium as set forth in claim 7, wherein the magnetic recording layer comprises magnetic crystalline grains in an average areal density range from 1×10^{12} grains/cm² to 8×10^{12} grains /cm² held in plural on average on a Pt crystalline grain of the large grain diameter under-layer.

9. The magnetic recording medium as set forth in claims 7 or 8,

wherein the magnetic recording layer comprises magnetic crystalline grains arranged in a form of hexagonal lattice structure.

10. The magnetic recording medium as set forth in any one of the preceding claims,

wherein the magnetic recording layer comprises granular structure comprising magnetic crystalline grains and grain

boundary regions enclosing each of the magnetic crystalline grains.

11. The magnetic recording medium as set forth in any one of the preceding claims,

5 wherein the magnetic recording layer comprises magnetic crystalline grains of at least one selected from the group consisting essentially of Co-Cr, Co-Pt, Fe-Pt and Fe-Pd.

12. The magnetic recording medium as set forth in any one of the preceding claims,

10 wherein the magnetic recording medium comprises at least one intermediate under-layer between the magnetic recording layer and the large grain diameter under-layer accompanied with the deposited atom layer.

13. The magnetic recording medium as set forth in claim 12,

wherein the intermediate under-layer comprises at least one granular structured layer comprising nonmagnetic crystalline grains and grain boundary regions enclosing each of the nonmagnetic crystalline grains.

20 14. The magnetic recording medium as set forth in claim 13,

wherein the granular structured intermediate under-layer comprises nonmagnetic crystalline grains of at least one selected from the group consisting essentially of Pt, Pd, Ir, 25 Ag, Cu, Ru and Rh.

15. The magnetic recording medium as set forth in any one of the preceding claims,

wherein the magnetic recording medium comprises a soft magnetic under-layer having soft magnetic characteristics 30 disposed between the grain diameter control under-layer and the

substrate.

16. The magnetic recording medium as set forth in claim 15,

wherein the magnetic recording medium comprises an under-layer having chemical composition of at least one selected from the group consisting essentially of NiAl, MnAl, MgO, NiO, TiN, Si and Ge disposed between the grain diameter control under-layer and the soft magnetic under-layer.

17. A method for producing magnetic recording medium, comprising:

a process for forming a grain diameter control under-layer comprising crystalline grains of at least one selected from the group consisting essentially of Cu, Ni, Rh and Pt on a substrate;

15 a process for forming an deposited atom layer of at least one element selected from the group consisting of oxygen and carbon atoms on the grain diameter control layer surface; and

a process for forming a magnetic recording layer on the deposited atom layer formed grain diameter control under-layer on the substrate.

18. The method for producing magnetic recording medium as set forth in claim 17,

wherein the deposited atom layer at least one element selected from the group consisting of oxygen and carbon atoms in an average areal density range from 1×10^{13} atoms/cm² to 1×10^{15} atoms/cm² is formed at the process for forming an deposited atom layer.

19. The method for producing magnetic recording medium as set forth in claims 17 or 18,

30 wherein the grain diameter control under-layer comprising

50 nm or larger than 50 nm crystalline grains of at least one selected from the group consisting essentially of Cu, Ni, Rh and Pt is formed at the process for forming a grain diameter control under-layer, and the element deposited atom layer at least one element selected from the group consisting of oxygen and carbon is formed on the grain diameter control under-layer surface at the process for forming an deposited atom layer.

20. The method for producing magnetic recording medium as set forth in any one of the claims 17 to 19,

wherein the grain diameter control layer comprising the crystalline grains of at least one selected from the group consisting essentially of Cu, Ni, and Rh oriented their (100) planes parallel to the substrate surface is formed at the process for forming a grain diameter control layer.

21. The method for producing magnetic recording medium as set forth in any one of the claims 17 to 20,

wherein the magnetic crystalline grains are arranged essentially in a form of tetragonal lattice structure in the magnetic recording-layer plane at the process of forming a magnetic recording-layer.

22. The method for producing magnetic recording medium as set forth in any one of the claims 17 to 21,

wherein the grain diameter control layer comprising the crystalline grains of Pt oriented their (111) planes parallel to the substrate surface is formed at the process for forming a grain diameter control layer.

23. The method for producing magnetic recording medium as set forth in claim 22,

wherein the magnetic crystalline grains are arranged essentially in a form of hexagonal lattice structure in the

magnetic recording-layer plane at the process of forming a magnetic recording-layer.

24. The method for producing magnetic recording medium as set forth in any one of the claims 17 to 23,

5 wherein the magnetic crystalline grains in the magnetic recording-layer are formed in an average areal density range from 1×10^{12} grains/cm² to 8×10^{12} grains /cm² at the process for forming a magnetic recording-layer.

25. A magnetic recording and reproducing apparatus,
10 comprising:

a substrate, an under-layer formed on the substrate, a magnetic recording layer on the under-layer, a protecting layer formed on the magnetic recording layer, the under-layer including a grain diameter control under-layer comprising
15 crystalline grains of at least one selected from the group consisting essentially of Cu, Ni, Rh and Pt, and an deposited atom layer of at least one selected from the group consisting of oxygen atoms and carbon atoms on the grain diameter control layer surface;

20 a recording medium driving mechanism, driving the magnetic recording medium;

a recording and reproducing head mechanism, recording information to the magnetic recording medium and reproducing from the magnetic recording medium;

25 a head driving mechanism, driving the recording and reproducing head; and

a recording and reproducing signal processing system, processing recording signals and reproducing signals.

26. A magnetic recording and reproducing apparatus as
30 set forth in claim 25,

wherein the recording and reproducing head mechanism comprises a single pole head.