

METHOD OF MANUFACTURING A MAGNETIC RECORDING MEDIUM

CROSS-REFERENCE TO RELATED APPLICATION

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This application is based on, and claims priority to, Japanese Application No. 2004-066422, filed March 09, 2004.

BACKGROUND OF THE INVENTION

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1. Field of the Invention

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The present invention relates to a method of manufacturing a magnetic recording medium used in an information recording device of information processing apparatuses such as computers, or in a recording device (especially a hard disk drive) mounted on consumer products, and in particular to a method of manufacturing a magnetic recording medium having a liquid lubricant layer with high coverage even being a thin film.

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2. Description of the Related Art

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With increase of quantity of information treated by an information processing apparatus such as a computer and miniaturization of the information processing apparatus in recent years, efforts have been made for enhancing recording capacity of the

information recording devices. Accordingly, recording capacity required by a magnetic recording medium (hereinafter also called “a magnetic disk”) used in the information recording devices is consistently increasing. To enhance recording capacity and improve recording performance of a magnetic recording medium, the flight height of the magnetic head must be lowered. In particular, a perpendicular magnetic recording system, drawing attention these days, with the magnetic flux flowing out perpendicularly to the surface of the magnetic recording medium, is expected to narrow the magnetic spacing by positioning the magnetic head and the medium surface as close as possible. Recently, flight height of the magnetic head has been decreased as low as below 10 nm.

A common magnetic disk comprises a substrate, an underlayer, a magnetic layer, and a protective layer, on which a liquid lubricant layer is further provided to improve durability. The thickness of the liquid lubricant layer is generally in the range of 1 nm to 2 nm. In that range of film thickness, actual feature of the lubricant molecules are considered to be an island-like distribution scattered in the surface of the protective layer, and not to form one complete thin film layer. The lower layer, the protective layer, exposes in the area between the lubricant molecules scattering in the island-like distribution (the area absent from the lubricant), which causes several problems as described below.

A protective layer of a magnetic disk used in general is a carbon

film formed by a sputtering method or a CVD method. The surface of the carbon film, being in an active state, is liable to adsorb surrounding gases or contaminants. Some types of the adsorbed gases cause corrosion together with surrounding moisture. Corrosion of the magnetic disk seriously deteriorates electromagnetic conversion characteristics and significantly degrades reliability of the HDD.

A manufacturing process for a magnetic disk in the present day technology commonly includes a tape burnishing step using a working tape after a lubricant coating step. In this step, contaminants attached in the previous steps are removed to ensure stable flight of the magnetic head. Since the usually employed thickness of the liquid lubricant layer is hard to completely cover the protective layer as described earlier, the tape burnishing step causes direct contact between the protective layer and the working tape. This generates frictional electric charges, which accumulate on the surface of the magnetic disk. This accumulation of frictional electric charges on the surface of the magnetic disk causes a problem of flight interruption of a glide test head or a magnetic head. If pressure at the tape working step is increased to ensure contaminant elimination in the tape burnishing step, the surface of the magnetic disk suffers from occurrence of flaws.

The above problem can be solved by wholly covering the protective layer with lubricant, that is, by forming one complete thin

film of lubricant layer on the protective layer. A liquid lubricant layer having a thickness of as thick as 10 nm to 100 nm would completely cover the protective layer. However, such a thick liquid lubricant layer is not appropriate for a magnetic disk in the present
5 days when the lowering of the flight height of a magnetic head is required. A next generation magnetic recording system, in which a head slides in contact with a disk, is required to raise reliability of the magnetic disk by making use of thorough function of a liquid lubricant layer and avoiding friction between the protective layer and
10 the magnetic head. Therefore, a liquid lubricant layer with high coverage while keeping an appropriate thickness (of about 1 nm to 2 nm) is required for obtaining a magnetic recording medium of high reliability and high performance.

15 A typical method of forming a liquid lubricant layer is coating of a lubricant on the surface of the magnetic disk. The liquid lubricant is coated generally to an average thickness of the liquid lubricant layer of about 1 to 2 nm. It is however difficult to sufficiently cover the protective layer by simply coating a lubricant and forming a film
20 of about 1 to 2 nm thickness, as described previously. In a magnetic disk provided with protrusions and dents (or a texture), in particular, the dents may not be coated enough. Some attempts have been made for improving homogeneity of the lubricant distribution occurring in the process of lubricant layer formation. For example, Japanese
25 Unexamined Patent Application Publication No. 2003-006849 discloses a method in which a buffing process is conducted with

rather high contact pressure after coating of a lubricant to make the lubricant distribution homogeneous. There is another method in which a lubricant is diluted producing a solution with homogeneous concentration using an appropriate high solubility solvent to obtain
5 homogeneous lubricant distribution in the liquid lubricant layer obtained after volatilization of the solvent.

SUMMARY OF THE INVENTION

10 However, a satisfactory result has not been achieved by the methods of forming a liquid lubricant layer described above in which the buffing process or the coating of diluted lubricant is conducted. Satisfactory lubricating effect cannot be obtained by a present technology with a mean film thickness of the liquid lubricant layer in
15 a range of 1 to 2 nm. In the case a buffing process is conducted under high pressure, friction occurs between the buff and the protective layer such as a thin film of carbon, raising risk of generating flaws on the magnetic disk. Accordingly, the buffing process imposes severe limitation on applicable contacting material and exerting pressure in
20 the buffing process. In the case a lubricant is coated using a high solubility solvent, although the distribution of the lubricant remained on the disk surface after volatilization of the solvent can be pretty homogeneous, a complete thin film is not formed with such a quantity of coated lubricant that results a film thickness of 1 to 2 nm, thus, the
25 island-like distribution of lubricant still remains. Therefore, a problem to be solved by the present invention is to provide a method

of manufacturing a magnetic recording medium, the method allows to form a liquid lubricant layer preserving a desirable film thickness (about 1 to 2 nm) and ensuring high coverage, and as a result, to provide a magnetic recording medium exhibiting high performance
5 and high reliability.

A desirable coating method for preventing the liquid lubricant layer from the island-like distribution of lubricant would be, in principle, to extend the stock solution of the lubricant without
10 dilution over the surface of the protective layer in an extremely thin and homogeneous condition. The coating method is, however, unfavorable because the method wastes excessive raw liquid, and the raw liquid available for use in a hard disk at present is expensive. The inventors of the present invention have made extensive studies
15 on formation of a liquid lubricant layer and noticed the fact that in the coated lubricant onto the protective layer of a carbon film, only one or two molecular layers in the bottom layers tightly adhere to the carbon film and the lubricant molecules in the upper layers exhibit relatively weak adhesion force and are easily removed. Even if a
20 thick lubricant layer is formed by lubricant coating to a thickness of several tens to several hundreds of nanometers, the fraction of the lubricant tightly adhering to the protective layer principally depends on the roughness of the substrate, the quality of the carbon film, and the polar end groups of the liquid lubricant, and thus is confined
25 within a certain range. The film thickness left after removing the lubricant to the extent that is easily removed by a solvent falls within

a range of about one to two nanometers, which corresponds with the thickness of a practical liquid lubricant layer. Although the bonded component that adheres tightly to the protective layer is dominant in the liquid lubricant layer made thin by the solvent, a component that
5 moves relatively freely still remains. Therefore, such a thin film described above can be utilized as a liquid lubricant layer of a magnetic disk as it is.

From this point of view, the inventors have found that a liquid
10 lubricant layer without island-like distribution of lubricant and well covering the protective layer even though a thin film, can be provided by forming through a series of processes comprising processes of forming a thick film of a liquid lubricant layer, homogenizing the lubricant distribution in the liquid lubricant layer and making the
15 lubricant tightly adhering to the protective layer, and diminishing thickness of the thick liquid lubricant layer with a rinsing solvent. Thus, the invention has been accomplished.

The present invention directs to a method of manufacturing a
20 magnetic recording medium comprising at least an underlayer, a magnetic layer, and a protective layer sequentially laminated on a substrate, and further a liquid lubricant layer formed on the protective layer. The method of the invention is characterized in that the process of forming the liquid lubricant layer comprises a first step
25 of forming a liquid lubricant layer on the protective layer by applying a liquid lubricant diluted with a solvent to a thickness of at least a

surface roughness R_{max} of the protective layer, a second step of making adhesion of the liquid lubricant to the protective layer by pressing a slidable member against a surface of the liquid lubricant layer while rotating the magnetic recording layer, and a third step of
5 diminishing the thickness of the liquid lubricant layer by ejecting a solvent that can dissolve the liquid lubricant on the surface of the liquid lubricant layer while rotating the magnetic recording medium.

To adjust the film thickness of the liquid lubricant layer to a
10 desired value, the thickness of the liquid lubricant layer can be increased by repeating a process of liquid lubricant coating using a liquid lubricant that is same as or different from the liquid lubricant after the third step or in the first step. In the third step, the thickness of the liquid lubricant layer can be further diminished by
15 repeating a process of removing the liquid lubricant using a solvent that is same as or different from the solvent that can dissolve the liquid lubricant.

The slidable member used for enhancing adhesion of the
20 lubricant in the manufacturing method preferably has a shape of a tape, a pad, or a sponge, and is preferably made of a woven fabric, a nonwoven fabric, or a resin.

Advantageously, the manufacturing method further comprises a
25 step of recovering the liquid lubricant removed in the third step.

Advantageously, the magnetic recording medium is used in a head contact type perpendicular magnetic recording system.

BRIEF DESCRIPTION OF THE DRAWINGS

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Fig. 1 is a schematic sectional view of a structure of a magnetic recording medium manufactured by the method of the invention;

Fig. 2 is a flow chart of the method of manufacturing a magnetic
10 recording medium according to the invention;

Fig. 3 shows structures of a magnetic recording medium in the process of forming a liquid lubricant layer, in which (a) shows the medium before applying liquid lubricant, (b) the medium after
15 forming a thick film liquid lubricant layer, and (c) the medium after diminishing the thickness of the thick film liquid lubricant layer;

Fig.4 schematically illustrates movement of the disk and the ejection nozzle in the step of applying a liquid lubricant;

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Fig.5 schematically illustrates movement of the disk and the slidable member in the process of enhancing adhesion of the liquid lubricant;

25 Fig. 6 schematically illustrates an example of a liquid receiving structure in the process of removing the liquid lubricant with a

rinsing solvent; and

Fig. 7 is a graph showing durability during contact running (sliding) of magnetic disks obtained in Embodiment Example 1 and Comparative Example 1.

DETAILED DESCRIPTION OF THE INVENTION

Detailed description of the invention will be made in the following. The invention relates to a method of manufacturing a magnetic recording medium 10 having at least an underlayer 2, a magnetic layer 3, a protective layer 4, and a liquid lubricant layer 5 sequentially formed on a substrate 1, as shown in Fig. 1. The method of the invention of manufacturing a magnetic recording medium comprises steps of sequentially laminating at least an underlayer, a magnetic layer, a protective layer, and a liquid lubricant layer on a substrate. The method of the invention is characterized in that the process for forming the liquid lubricant layer comprises, as shown in Fig. 2, a first step (S201) of forming a thick film liquid lubricant layer on the protective layer by coating a liquid lubricant diluted with a solvent to a thickness of at least a surface roughness R_{max} of the protective layer, a second step (S202) of adhesion of the liquid lubricant to the protective layer by pressing a slidable member against a surface of the liquid lubricant layer while rotating the magnetic recording medium, and a third step (S203) of diminishing the thickness of the liquid lubricant layer by ejecting a solvent that is

capable of dissolving the liquid lubricant on the surface of the liquid lubricant layer while rotating the magnetic recording medium. Fig. 3 shows schematic structures of the magnetic recording medium in the process of forming the liquid lubricant layer. Fig. 3(a) shows the medium before applying liquid lubricant; Fig. 3(b) shows the medium after forming a thick film liquid lubricant layer by coating a liquid lubricant (corresponding to S202); and Fig. 3(c) shows the medium after diminishing the thickness with a rinsing solvent (corresponding to S203). By forming the liquid lubricant layer through the series of steps of forming a thick film liquid lubricant layer, homogenizing the lubricant distribution and making adhesion of the lubricant onto the protective surface, and diminishing the thickness of the thick film liquid lubricant layer with a rinsing solvent, an effect is achieved that is almost equivalent to the effect obtained by a method to rub lubricant molecules directly onto the carbon surface. By this method of the invention, a liquid lubricant layer is formed in which the lubricant density is high and most of the principal chains of the lubricant molecules are aligning parallel to the plane of the lubricant layer. As a result, the surface of the protective layer of carbon film is covered with a high ratio, without disturbing flight of the magnetic head even though the lubricant layer is a thin film having a thickness of 1 to 2 nm that is an appropriate thickness to a liquid lubricant layer.

The method of the invention for manufacturing a magnetic recording layer does not impose any special limitation on a structure

of the magnetic recording medium, or on materials and deposition conditions of the layers of the medium. Commonly used techniques in the art can be employed except that the liquid lubricant layer is formed through the steps specified above. The structure of a

5 magnetic recording medium of the invention basically comprises a substrate, an underlayer, a magnetic layer, a protective layer, and a liquid lubricant layer, and may be further provided with additive layers such as an intermediate layer, as required.

10 The substrate can be made of a material selected from aluminum alloy, strengthened glass, crystallized glass, ceramics, silicon, polycarbonate, and polymer resin; and not limited to these materials. A substrate surface is preferably subjected to texturing for improving stability of head flight and magnetic alignment.

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The underlayer can be formed of a nonmagnetic material such as Ni-P, CoZrNb, or FeTaC according to a known deposition method such as a sputtering method or a plating method.

20 The magnetic layer can be formed of a magnetic material selected from CoCrPt, CoCrTa, CoCrPtB, CoPt-SiO₂, and CoCrPt-SiO₂, for example, by depositing the material according to a deposition technique such as a sputtering method.

25 The protective layer can be composed of a thin film of SiO₂ or carbon; the latter is particularly favorable for a protective layer. The

carbon thin film can be formed by applying a CVD method (of ion beam system using ethylene gas, for example) or a sputtering method (of DC magnetron system using an argon + nitrogen gas and a target of graphite, for example).

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The following describes a process for forming a liquid lubricant layer in detail. Formation of a liquid lubricant layer is performed through a series of steps of forming a thick film liquid lubricant layer, homogenizing lubricant distribution and making adhesion onto a protective layer of the liquid lubricant layer, and diminishing thickness of the thick liquid lubricant layer with a rinsing solvent. These specified steps can be applied without depending on the property of the protective layer and to any type of protective layer.

10 (First step: forming a thick film liquid lubricant layer)

A thick film liquid lubricant layer is formed by coating a liquid lubricant diluted by a solvent on a protective layer. A practicable liquid lubricant in the invention can be a fluorine-containing lubricant such as perfluoropolyether including Fomlin-Z-DOL, AM3001, and Z-Tetraol (all being trade names of products manufactured by Solvay Solexis K.K.), which are commonly used for lubricant of a magnetic recording medium. A solvent to dilute the liquid lubricant only needs compatibility with the lubricant and property to form a homogeneous solution, and is not limited to a special solvent. The solvent can be an organic solvent of fluorocarbon, specific examples of which include HFE7200 (a product of Sumitomo

3M Limited) and VERTREL (supplied from Du Pont Kabushiki Kaisha). Dilution of the lubricant is conducted corresponding with the quality and the surface roughness R_{max} of the protective film. Concentration of the lubricant solution in the invention is favorably
5 higher than the concentration of a solution commonly used in the art. The concentration of a lubricant solution used in the invention is determined in a range of about 1 wt% to 5 wt%. If the solution concentration is higher than 5 wt%, dissolution of the lubricant becomes insufficient and undissolved components aggregate,
10 resulting fluctuation of thickness of the film coated in the first step and, in addition, causing choking of a nozzle in a spin coating apparatus, for example, used in the coating process. If the solution concentration is lower than 1 wt%, a thick film having a required thickness of 10 to 20 nm becomes hard to be formed.

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The liquid lubricant can be conducted by means of a known method such as dipping or spin coating. A dipping method, however, occasionally attaches a large amount of lubricant onto the end region of the disk surface and hinders adequate removal of the thick film of
20 lubricant on the innermost part of the disk. Therefore, a spin coating method is preferably employed, which can control the coated area. The spin coating method allows using a technique in which a region of about 1 mm from the innermost part of the disk can be left uncoated considering the following step of diminishing thickness with
25 a rinsing solvent. In the process of diminishing thickness with a rinsing solvent, excessive lubricant is securely removed by ejecting

the solvent from the inner region than this region of the disk surface by means of the spin-coating method, and the diminishing of the thick film liquid lubricant layer can be performed. The control of the coated region in the spin-coating method can be accomplished, as shown in Fig. 4, by appropriately adjusting the rotating speed of the magnetic disk 10 and the seeking speed of the ejecting nozzle 41. Regarding details of the control of the coated region, please see Japanese Unexamined Patent Application Publication No. H5-266467.

According to the manufacturing method of the invention, the amount of the liquid lubricant coated in the first step must be enough to cover from the depth of concave to the height of convex of the surface, that is, enough to form a film thickness at least R_{max} . The “ R_{max} ” in this specification is the one specified in JIS (Japanese Industrial Standards) B0601-1982. A film thickness required in the invention is roughly in a range of 10 to 20 nm depending on the surface property of the protective layer. A desired thickness of the lubricant can be coated either at one time or in separated plural times. In case the film thickness of the liquid lubricant needs to be further increased after the third step, the increase can be attained by repeating the process of liquid lubricant application using the same liquid lubricant or a different liquid lubricant.

(Second step: homogenizing lubricant distribution and making adhesion onto the protective layer of the lubricant layer)

The step of homogenizing lubricant distribution and making

adhesion onto the protective layer of the thick film lubricant layer can be conducted, as shown in Fig. 5, by pressing a slidable member onto the surface of the thick film liquid lubricant layer 5' formed in the previous step while rotating the magnetic disk 10 having the liquid lubricant layer (for example, by pressing a wiping tape 51 by a solid pad 52 and moving the wiping tape along the surface of the thick film liquid lubricant layer 5'). In the previous application step of the invention, such an amount of lubricant that saturates on the disk surface has been coated to form a thick film of the liquid lubricant layer and lubricity is sufficiently secured when the member of a tape or the like is slid on the lubricant layer. Therefore, the process of the invention completely eliminates the problems of generation of flaws or break away of fibers of the tape in the tape working process. The contacting member applicable in the invention is not limited to a fibrous tape, but any member can be used that has little concave and convex and is smooth, to spread out the lubricant uniformly on the disk surface.

The member usable in the invention can be made of woven fabric, nonwoven fabric, and resins of polyethylene terephthalate or urethane, and can have a shape of tape, pad, or sponge.

The pressure exerted on the disk surface on the working process must be a proper pressure to attain an expected effect. If the pressure of the member against the disk surface is too low, the lubricant would not be rubbed in over the disk surface that has a

certain roughness. If the pressure is too high, the pressure pushes away the lubricant between the disk and the member and lowers the lubricating ability during the working process causing generation of flaws on the disk surface. The pressure exerted on the disk surface during the working process is approximately in a range of 0.01 to 2.0 kgf/cm², depending on the film quality and surface roughness R_{max} of the protective layer. Rotating speed of the disk during the working process has no limitation in the low speed side. On the other hand, high rotating speed may scatter the thick lubricant due to the centrifugal force during the working process and causes insufficient lubricating ability during the working process as in the case of too high pressure. A proper rotating speed of a disk is at most about 4,000 rpm, depending on the film quality and surface roughness R_{max} of the protective layer.

To make adhesion of the lubricant layer to the protective layer and raise the bonded ratio between the two is an important technology for preventing scattering of the lubricant during the disk rotation and transfer of the lubricant to the magnetic head. To raise the bonded ratio, the lubricant is generally heated or UV irradiated after coating. A sufficiently high bonded ratio can be achieved by the invention without heating or UV irradiation. However, heating process or UV irradiation process may be added as required for further raising the bonded ratio.

(Third step: diminishing thickness of the lubricant layer with a

rinsing solvent)

Diminishing the thickness of the thick film liquid lubricant layer is conducted using a rinsing solvent. Specifically, a solvent that can dissolve the lubricant is ejected onto the lubricant layer surface and
5 excessive lubricant is removed while rotating the magnetic disk 10. Rotating speed of the disk on rinsing with solvent is preferably at least 500 rpm, since a too low speed of rotation lowers removing effect by a centrifugal force and is liable to generate uneven removal. The seeking speed of the ejecting nozzle is preferably at most about 50
10 mm/s.

Usable solvents for diminishing the lubricant are the same as those exemplified for the solvents of dilution of the lubricant. The solvent used in the step is selected from the solvents exhibiting high
15 dissolving ability (high removing effect for the lubricant) and the solvents with low dissolving ability corresponding to the degree of thickness reduction, considering parameters at the process of ejecting the solvent by the spin-coating method. The thickness of the lubricant layer can be diminished to a desired target thickness
20 repeating the steps of removing liquid lubricant using the same or different solvent under appropriately selected parameters.

Diminishing thickness of the lubricant layer could be conducted, besides the above method, by a vapor method or a dipping method.
25 The vapor method, however, is liable to generate uneven removal and needs unacceptably large quantities of solvent. The dipping method

accumulates the removed lubricant in the dipping bath. So, a removing effect and a re-coating effect become coexisting in the course of repeating the steps. Thus, the two methods are not suited for mass production.

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As described above, the manufacturing method of the invention provides a magnetic recording medium exhibiting high quality and high reliability having a lubricant layer that has a desirable thickness and high coverage. When the manufacturing method of the invention is applied to manufacturing a magnetic recording medium of a contact type perpendicular magnetic recording system, lubricating characteristic in disk operation is remarkably improved. Although the method of the invention would be assumed costly because of the use of larger amount of liquid lubricant than usual methods, the problem can be dissolved by providing a step of recovering the liquid lubricant removed with the rinsing solvent and recycling the lubricant. The recovering of the liquid lubricant can be conducted, as shown in Fig. 6, by providing a liquid receiving structure (for example, a liquid receiving cover 61 and a transfer tube 62 to a recovery tank) around periphery of the disk 10.

The following specifically describes the present invention referring to examples. The examples shall not limit the invention, and needless to say, various modifications are possible within the spirit and scope of the invention.

(Embodiment Example 1) (EEx 1)

An underlayer, a perpendicular magnetic layer, and a protective layer were sequentially formed on an aluminum substrate with a 3.5 inch diameter (and a thickness of 1.27 mm) for a magnetic disk. The surface roughness R_{max} of the substrate was 7.8 nm. The underlayer 200 nm thick was deposited by a DC sputtering method of argon gas using a CoZrNb target. The perpendicular magnetic layer 10 nm thick was deposited by an RF sputtering method of argon gas using a CoCrPt-SiO₂ target. The protective layer 3 nm thick of a carbon thin film was formed by CVD of ion beam system using ethylene gas. The surface roughness of the carbon thin film was 7.8 nm.

On the magnetic disk sequentially laminated as described above up to the protective layer, a liquid lubricant layer was formed (on the protective layer) as follows. Initially, a liquid lubricant, Fomblin-Z-DOL (manufactured by Solvay Solexis K.K.) was diluted with an organic solvent of fluorocarbon, Fluorinert FC77 (manufactured by Sumitomo 3M Limited) to prepare a solution with a concentration of 3 wt%. The prepared lubricant solution was coated to a surface of the disk (the protective layer) to a film thickness of 10.4 nm according to a spin-coating method. In the spin-coating process, the rotating speed of the disk was 1,500 rpm and the seeking speed of the nozzle was 10 mm/s.

Then, a wiping tape (TORAYSEE, a product of Toray Industries,

Inc.) was pushed onto the disk with a pressure of 0.03 kgf/cm² at a disk rotation speed of 100 rpm. The tape of a half inch wide was sought one round from outer to inner circumference and from inner to outer circumference at a seeking speed of 150 mm/min, to rub the lubricant into the disk surface and make the lubricant to adhere to the disk surface. At this moment, the thickness of the lubricant layer was 4.3 nm.

Then, a rinsing solvent of an organic solvent of fluorocarbon, Fluorinert FC77 (a product of Sumitomo 3M Limited) was ejected while rotating the disk at a rotating speed of 1,500 rpm and moving the nozzle from inner to outer circumference of the disk at a seeking speed of 10 mm/s, thereby removing excessive lubricant and diminishing thickness of the lubricant layer to form a thin film of lubricant layer on the disk. At this moment, the thickness of the lubricant layer was 1.8 nm.

(Comparative Example 1) (CEx 1)

A magnetic disk was manufactured in the same manner as in Embodiment Example 1 except that a lubricant layer having the same thickness as in Embodiment Example 1 was formed without the step of forming a thick film liquid lubricant layer and the step of homogenizing lubricant distribution and making adhesion of the lubricant onto the protective layer using a tape. After sequentially forming an underlayer, a perpendicular magnetic layer, and a protective layer on a substrate as in Embodiment Example 1, a

lubricant layer was formed by coating a lubricant solution with a concentration of 0.02 wt% on the surface of the disk (on the protective layer) by a spin-coating method. The thickness of the obtained lubricant layer was 1.8 nm. The surface roughness $R_{\max}$ of the protective layer was 7.8 nm.

(Embodiment Example 2) (EEEx 2)

A magnetic recording medium was manufactured in the same manner as in Embodiment Example 1 except for alteration of the surface roughness of the protective layer (surface roughness of the substrate) and accompanied alteration of thickness of the thick film. An underlayer, a perpendicular magnetic layer, and a protective layer were sequentially formed as in Embodiment Example 1 on a substrate with a surface roughness $R_{\max}$ of 3.9 nm, and then a lubricant layer was formed. The surface roughness of the protective layer $R_{\max}$ was 3.9 nm. The lubricant layer was formed by coating a lubricant solution with a concentration of 3 wt% on the protective layer to a film thickness of 11.2 nm, tape processing (the film thickness at this moment was 4.0 nm), and then diminishing the film thickness using a rinsing solvent, to obtain a lubricant layer 1.6 nm thick.

(Embodiment Example 3) (EEEx 3)

A magnetic recording medium was manufactured in the same manner as in Embodiment Example 1 except for alteration of a method of depositing a protective layer. The protective layer was

formed by sputtering a target material of graphite according to a sputtering method of DC magnetron type using argon gas and nitrogen gas. The surface roughness $R_{\max}$ of the protective layer was 7.8 nm. A lubricant layer was formed by coating a lubricant solution with a concentration of 3 wt% on the protective layer to a film thickness of 9.8 nm, tape processing (the film thickness at this moment was 3.9 nm), and then diminishing the film thickness using a rinsing solvent, to obtain a lubricant layer 1.5 nm thick.

10 (Comparative Example 2) (CEx 2)

A magnetic recording medium was manufactured in the same manner as in Embodiment Example 1 except that the thickness of the thick film lubricant layer formed on the protective layer was less than $R_{\max}$. After sequentially forming an underlayer, a perpendicular magnetic layer, and a protective layer as in Embodiment Example 1, a lubricant layer was formed as follows. The lubricant layer was formed by coating a lubricant solution with a concentration of 0.1 wt% on the protective layer to a thickness of 3.5 nm, tape processing (the film thickness at this moment was 3.2 nm), and then diminishing the film thickness using a rinsing solvent, to form a lubricant layer 1.8 nm thick. The surface roughness of the protective layer was 7.8 nm.

Bonded ratio, which represents adhesive force between the lubricant and the protective layer, was measured on the obtained magnetic disks. The results are shown in Table 1. The bonded ratio

was defined by a ratio of an absorption coefficient of the lubricant component (a C-F peak) in an FT-IR (Fourier transform infrared spectroscopy) after immersion in FC77 solution for 5 minutes and absorption coefficient before the immersion. Slide durability was then studied on the magnetic disks of Embodiment Example 1 and Comparative Example 1.

The slide durability was evaluated by a pass number (rotated number of the disk) until fracture of the carbon protective layer after contact running under a magnetic head with a load of 0.5 gf in a vacuum of 10 Torr. The rotating speed of the disk was fixed to 5,400 rpm, and the radius of the contact running was also fixed at 25 mm. The results are shown by the graph in Fig. 7. The graph of Fig. 7 shows the data on 3 sheets of disks randomly selected from the studied plurality of disks. Fig. 7 clearly demonstrates that the sample of Embodiment Example 1 exhibits better durability than the sample of Comparative Example 1. This is brought about from contributions of high coverage and strong adhesion force with the carbon protective layer.

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Further, occurrence of flaws on the disk surface was evaluated by conducting tape burnishing with high contact pressure on every magnetic disk of Embodiment Examples and Comparative Examples. The tape burnishing was conducted by a roller contact method for ten seconds with a roller hardness of 40° using a polishing tape (WA8000) under conditions of a pressure of 1.0 kgf/cm² and 1,000 rpm.

25

Then, observation was made on the degree of occurrence of flaws due to working process using a surface inspection apparatus. The results are shown in Table 1.

5 Table 1 Variation of lubricant layer thickness, bonded ratio, and flaws due to tape working process

Example	Rmax (nm)	deposition method of protective layer	liquid lubricant layer thickness			bonded ratio (%)	flaws due to working
			after thick layer coating (nm)	after tape processing (nm)	after rinsing with solvent (nm)		
EEx 1	7.8	CVD	10.4	4.3	1.8	70	none
EEx 2	3.9	CVD	11.2	4.0	1.6	75	none
EEx 3	7.8	nitriding sputtering	9.8	3.9	1.5	65	none
CEx 1	7.8	CVD	—	—	1.8	20	observed
CEx 2	7.8	CVD	3.5	3.2	1.8	25	observed

Table 1 clearly shows that the liquid lubricant layer formed according to the method of the invention (Embodiment Examples 1 through 3) exhibit higher adhesion rate than the lubricant layer (Comparative Example 1) formed by only usual spin coating process of the same lubricant to the same thickness as in the Embodiment Examples. In the magnetic disks provided with a liquid lubricant layer according to the invention (Embodiment Examples 1 through 3), occurrence of flaws during tape burnishing process is prevented and good durability against polishing tape is achieved. It has been also found that the flows due to working process are generated when the film thickness at the thick film formation is less than Rmax even

though adhesion of lubricant by tape processing is conducted after the thick film formation. This fact shows that a satisfactory liquid lubricant layer can not be obtained unless the thick film after lubricant coating stage has a sufficient thickness, even if the
5 thickness of the lubricant layer at the final stage is in the same level.

According to the invention, a liquid lubricant layer is formed securing high coverage while retaining thin layer of the liquid lubricant, and thus, a magnetic recording medium with high
10 performance and high reliability is provided.

CLAIMS

What is claimed is:

- 5 1. A method of manufacturing a magnetic recording medium comprising at least an underlayer, a magnetic layer, and a protective layer sequentially formed on a substrate, and further a liquid lubricant layer formed on the protective layer, characterized in that a process for forming the liquid lubricant layer comprises:
 - 10 a first step of forming a liquid lubricant layer by coating a liquid lubricant diluted by a solvent on the protective layer to a thickness of at least a surface roughness R_{max} of the protective layer,
 - a second step of making the liquid lubricant to adhere onto the protective layer by pressing a slidable member against the surface of
 - 15 the liquid lubricant layer while rotating the magnetic recording medium; and
 - a third step of diminishing thickness of the liquid lubricant layer by ejecting a solvent that can dissolve the liquid lubricant to the surface of the liquid lubricant layer while rotating the magnetic
 - 20 recording medium.
2. The method of manufacturing a magnetic recording medium according to claim 1, wherein thickness of the liquid lubricant layer is increased after the third step by repeating a process of coating a
- 25 liquid lubricant that is same as or different from the liquid lubricant of the liquid lubricant layer.

3. The method of manufacturing a magnetic recording medium according to claim 1, wherein thickness of the liquid lubricant layer is further diminished in the third step by repeating a process of removing the liquid lubricant using a solvent that is same as or
5 different from said solvent that can dissolve the liquid lubricant.

4. The method of manufacturing a magnetic recording medium according to claim 1, wherein the slidable member is composed of a woven fabric, nonwoven fabric, or a resin and has a shape of a tape, a
10 pad, or a sponge.

5. The method of manufacturing a magnetic recording medium according to claim 1, further comprising a step of recovering the liquid lubricant that is removed in the third step.
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6. The method of manufacturing a magnetic recording medium according to claim 1, wherein the magnetic recording medium is applied to a head contact type perpendicular magnetic recording system.
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7. The method of manufacturing a magnetic recording medium according to claim 1, wherein an aimed thickness of the liquid lubricant layer is attained in the first step by repeating a process of coating a liquid lubricant or liquid lubricants that are same as or
25 different from each other.