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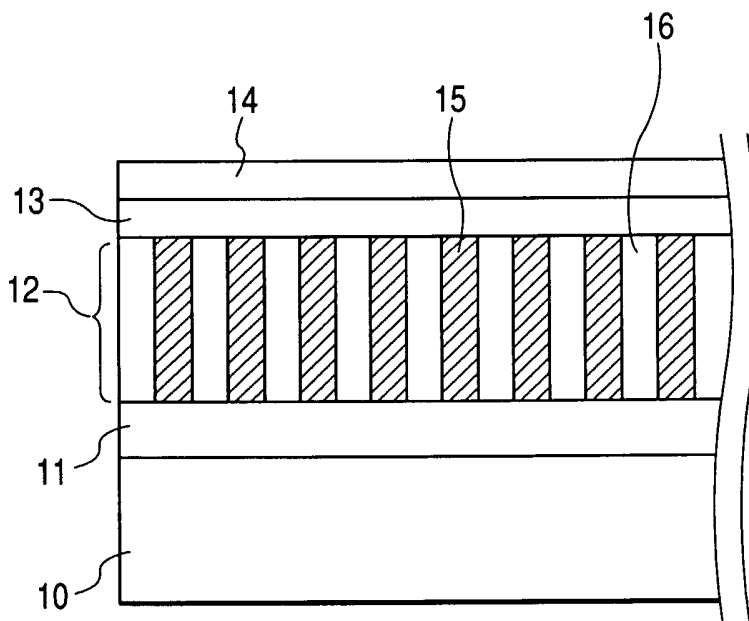
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(54) Title: PLATING SOLUTION, PROCESS FOR PRODUCING A STRUCTURE WITH THE PLATING SOLUTION, AND APPARATUS EMPLOYING THE PLATING SOLUTION



(57) Abstract: A stable FePt plating solution is provided. Further a process for electroplating is provided for producing an FePt magnetic material having especially strong coercive force and excellent properties by use of the plating solution. The plating solution contains ionic Fe, ionic Pt, and a complex agent, at a molar ratio (Fe/Pt) of the ionic Fe to the ionic Pt ranging from 0.75 to 3.



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## DESCRIPTION

PLATING SOLUTION, PROCESS FOR PRODUCING A STRUCTURE  
WITH THE PLATING SOLUTION, AND APPARATUS EMPLOYING  
5 THE PLATING SOLUTION

### TECHNICAL FIELD

The present invention relates to a plating  
solution, a process for producing a structure with  
10 the plating solution, and an apparatus employing the  
plating solution.

### BACKGROUND ART

A recording density of a hard disk (HDD), a  
15 main recording assembly of a personal computer, is  
being made higher and higher at a remarkable rate,  
100-fold or more in 10 years. In recent years, HDDs  
are being developed for digital household electric  
appliances and portable information stations, not  
20 only for personal computers, so that a further higher  
recording density is wanted for the uses.

At the moment, conventional HDDs employ  
longitudinal recording systems in which magnetization  
is kept in the direction of the disk plane. In the  
25 longitudinal recording system, the magnetic recording  
layer should be made thinner to suppress diamagnetism  
in the magnetic domains and to form strong magnetic

field above the medium. The individual magnetic particles in the magnetic layer constituting the thinner magnetic recording layer are smaller in size, and magnetic energy held by the smaller magnetic particles is affected significantly by a thermal energy. Consequently, the effect of superparamagnetism (thermal fluctuation) becomes remarkable, which causes loss of the recorded magnetization.

10           On the other hand in the vertical recording system in which the magnetization is kept in a direction perpendicular to the disk plane, with increase of the recording density, demagnetization is decreased and the magnetization is stabilized in principle, being different from the longitudinal recording system, and the superparamagnetism would be less liable to occur. Therefore, the vertical magnetic recording system is attracting attention as a technique for increasing the density of the magnetic recording.

          At present, CoCr alloys are mainly studied as the material of the recording layer of the vertical magnetic recording medium. For more effective suppression of the superparamagnetism, FePt alloys are attracting attention which has an L10 ordered alloy structure and is capable of generating a strong anisotropic magnetic field of  $7 \times 10^7$  erg.cm<sup>-3</sup> and of

achieving a greater coercive force, as a new-generation recording film material.

For production of the FePt alloy, many investigations are made regarding a vapor-quenching process such as sputtering, and vapor deposition. In the FePt alloy production by the vapor-quenching process, an fcc phase as an irregular phase is formed firstly, and then is transformed into an L10 structure with crystal grain growth by high temperature treatment at 600°C or higher. However, for lower noise in the magnetic recording medium, the crystal grains should be made finer. Further, the high temperature treatment in the magnetic recording medium production process is not suitable because of undesired melting of the substrate and other disadvantages.

For formation of an ordered phase of an L10 structure of FePt by heat treatment below 600°C, methods are disclosed: a method of alternate lamination of monoatomic layers of Fe and Pt (001) by molecular beam epitaxy (MBE) or a like process to prepare an FePt magnetic material having a strong coercive force, and a method of production of an FePt magnetic material having a coercive force of about 5000 Oe by addition of a third element such as Cu and Ag.

As another process, a liquid phase process of

electrolytic plating is disclosed for the FePt magnetic material production. The electrolytic plating process, which does not use an expensive vacuum apparatus such as a sputtering apparatus and a  
5 vapor deposition apparatus, is suitable for industrial mass production (Japanese Patent Application Laid-Open No. 2002-180259).

A production process for an FePt magnetic material by electrolytic plating is disclosed in  
10 which an FePt electric deposition film is produced from iron sulfate and hexachloroplatinate(IV) salt (intermag 2003 "electrodeposited FePt film").

However, in the conventional plating solution, the ionic Fe and the ionic Pt are instable, tending  
15 to form more stable precipitates. Thereby, the intended FePt is not readily obtainable. A stable plating solution is wanted for the FePt plating.

With the above background, the present invention provides a plating solution for FePt  
20 plating.

The present invention provides also a process for producing a structure by use of the plating solution for FePt plating.

The present invention provides further an  
25 apparatus which employs the plating solution for FePt plating.

The aforementioned problems are solved by the

means described below.

According to an aspect of the present invention, there is provided a plating solution which contains ionic Fe, ionic Pt, and a complex agent, at a molar  
5 ratio of the ionic Fe to the ionic Pt ranging from 0.75 to 3.

The complex agent preferably contains tartrate ions or citrate ions.

The concentration of the ionic Fe preferably  
10 ranges from 0.005 mol/L to 0.1 mol/L.

The plating solution preferably has a pH ranging from 5.0 to 10.5.

The ionic Fe and the ionic Pt preferably form a double complex constituted of an Fe complex and a Pt  
15 complex.

The plating solution preferably contains ionic Cu and a complex agent for the ionic Cu.

According to another aspect of the present invention, there is provided a process for producing  
20 a structure comprising steps of:  
providing an electrode and an object to be plated in a vessel containing the plating solution, and  
plating the object with a magnetic material containing FePt from the plating solution by applying  
25 voltage to the electrode to form a structure.

The structure formed in the process is preferably heat-treated further at a temperature

ranging from 450°C to 750°C.

The structure in the process is preferably heat-treated further in the presence of hydrogen.

The object to be plated in the process is  
5 preferably a structure having holes, and the step of plating the object to form the structure is deposition of the magnetic material containing FePt into the holes.

According to still another aspect of the present  
10 invention, there is provided an apparatus, having the plating solution, a vessel for holding the plating solution, and electrodes, for conducting plating by application of a voltage to the electrodes.

According to the present invention, the plating  
15 solution for FePt plating is stabilized by adjusting the molar concentration ratio of the ionic Fe to the ionic Pt within the range from 0.75 to 3 in the plating solution (the ratio is referred to occasionally as a "FePt ratio"). The use of this  
20 plating solution enables formation of an FePt plating layer having a strong coercive force. A structure having holes filled with the FePt is useful for forming a magnetic recording medium for high-density recording.

25

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic drawing of an example of



embodiment of a magnetic recording medium employing a magnetic material produced by the present invention.

Figs. 2A and 2B are schematic drawings of a structure having fine holes.

5

#### BEST MODE FOR CARRYING OUT THE INVENTION

The mode for carrying out the present invention is explained below.

An FePt alloy having an L10 ordered alloy phase  
10 contains Fe at a composition ratio of about 50 at.%.  
In the present invention, however, the FePt magnetic material is not limited to alloys containing Fe-Pt at a composition ratio of 1:1. The FePt magnetic material in the present invention includes FePt  
15 alloys containing Fe at a content ranging from 40 at.% to 60 at.%.

The FePt magnetic material in the present invention is formed from a plating solution containing metallic ions of Fe and Pt and  
20 additionally a complex agent capable of stabilizing the metal ions in the solution.

Usually the ionic Fe in the Fe ion-containing plating solution is fed as bivalent ions to an aqueous source solution. In the present invention,  
25 ferrous sulfate and ferrous chloride are useful as the source material of the bivalent ionic Fe in the plating solution, but another bivalent ionic Fe

compound may be used as the source material.

The bivalent ionic Fe is readily oxidized to be tervalent, and this tervalent ionic Fe reacts with hydroxide ions to form precipitate of  $\text{Fe}(\text{OH})_3$ . That  
5 is, the plating solution containing ionic Fe is instable and tends to form precipitate. The formation of the precipitate can be prevented by complexing the ionic metal for stabilization in the solution. However, the addition of the complex agent  
10 should be carefully investigated, since the reduction potential of the ionic metal is different from that of the metal complex and the addition of a complex agent can prevent deposition of the metal. Further, an impurity contained in the complex agent may become  
15 included in the formed film. Furthermore, stability of the metal complex to the temperature and pH of the bath should be taken into account. The FePt magnetic material of the present invention should contain the Fe at a content around 50 at.% to form the L10  
20 ordered alloy phase. Therefore the complex agent should be selected to be controllable to obtain the above composition. The complex agent may be the one which is capable of forming a complex containing plural kinds of ionic metals, such as a complex agent  
25 capable of forming a double complex composed of an Fe complex and a Pt complex formed from ionic Fe and ionic Pt.

The complex agent to be added to the plating solution includes tartaric acid, citric acid, succinic acid, malonic acid, malic acid, and gluconic acid; and salts thereof. The inventors of the present invention have found that a complex agent is particularly effective which contains at least the one selected from the group consisting of tartaric acid and salts thereof, citric acid and salts thereof. Especially, sodium tartrate and ammonium tartrate are preferable. For instance, sodium tartrate or ammonium tartrate added to ionic Fe is considered to react with the ionic Fe to form iron tartrate. In a plating solution containing hexachloroplatinate(IV) as an ionic Pt material, the iron tartrate bonds to the hexachloroplatinate(IV) to stabilize, which is shown by analysis by ESI-MS (electrospray ionization mass spectroscopy). This ESI-MS is an analysis method in which a liquid flow from liquid chromatogram (LC) is ejected from a capillary into an atmospheric pressure under application of a high voltage for ionization and the components of the ions are analyzed by mass spectroscopy.

When a complex agent for supplying tartrate ions is selected and is added to the plating solution, the bivalent Fe ions and the tartrate ions form iron tartrate. The concentration of the tartrate ions and the concentration of the Fe ions are preferably

equivalent.

An excess of the iron tartrate is instable in the plating solution and forms precipitate. For dissolution of the iron tartrate in the solvent water, the concentration of ionic Fe in the plating solution should be not higher than 0.1 mol/L, preferably not higher than 0.05 mol/L. At the Fe ion concentration of not higher than 0.05 mol/L, the plating solution is highly stable, whereas at an extremely low Fe ion concentration, allowable ranges of conditions in the plating process are narrow to lower the reproducibility of the FePt composition ratio. Therefore, the Fe ion concentration is preferably not less than 0.005 mol/L.

As the source material for the ionic Pt, a hexachloroplatinate(IV) salt is useful in the present invention. The hexachloroplatinate(IV) salt is known to change by substitution of the chloride ions coordinating to the Pt atom by H<sub>2</sub>O and -OH under influence of the pH or other conditions during lapse of time. The inventors of the present invention disclosed that presence of excess chloride ions is preferred in the plating solution for stabilization of the hexachloroplatinate(IV) in the plating solution of the present invention. The chloride ion concentration should be not lower than the molar concentration equivalent to the

hexachloroplatinate(IV) salt. The presence of excess quantity of the chloride ions is desirable for stabilization of the plating solution. The chloride ions are preferably present in an amount of up to 15 times the quantity equivalent to the Pt in consideration of the properties of the formed FePt film.

In controlling the content of Fe in the FePt magnetic material to be at about 50 at.%, the composition ratio of the magnetic material depends largely on the ratio of the source compounds in the plating solution and the set potential in the plating. Variation of the potential causes variation of the current density per area of the working electrode, and the current density affects the composition ratio. The stirring condition and the temperature also affect the composition ratio. Further, the potential causing actually the reducing reaction is affected by the electrode and the solvent. Therefore, potential more negative than the reduction potential of the metal, namely an overvoltage, should be applied. However, excessive negative overvoltage will cause generation of hydrogen by reduction of hydrogen ions on the working electrode to affect the electrodeposition rate and to deteriorate the quality of the plated film. Therefore, the potential should be set suitably.

For production of an intended FePt magnetic material with high reproducibility under the above-mentioned conditions from a stable plating solution, it has been found in the present invention that the  
5 ratio of Fe to Pt in the plating solution is preferably in the range from 0.75 to 3. At the ratio  $\text{Fe/Pt} < 0.75$ , the intended FePt alloy of 50 at.% Fe is not obtained, whereas at the ratio  $\text{Fe/Pt} > 3$ , the plating solution is instable, being liable to cause  
10 precipitation.

Further, in view of the solubility of iron tartrate, the stability of the formed FePt thin film, and other problems, the Fe ion concentration should be in the range from 0.005 mol/L to 0.1 mol/L,  
15 particularly preferably in the range from 0.01 mol/L to 0.05 mol/L in the present invention.

The properties of the electroplated FePt magnetic material such as appearance, stress and other physical properties, and magnetic properties  
20 depend on the composition, particle size, orientation, and other properties of the deposited FePt, which are determined by the plating solution conditions, plating conditions, and various factors.

The plating solution of the present invention  
25 becomes instable at the pH of the solution lower than 5.0 and at the pH higher than 10.5. Therefore the pH of the plating solution is preferably in the range

from pH 5.0 to pH 10.5, more preferably from pH 7 to pH 9. Any pH controlling agent may be used without limitation. However, an excessive quantity of ammonia may cause precipitation of ammonium  
5 hexachloroplatinate(IV) by reaction of the hexachloroplatinate(IV) salt and the ammonia. Therefore, use of sodium hydroxide or the like is preferred for the pH adjustment to avoid excess ammonium ions.

10 The above plating solution may contain an additive such as a supporting electrolyte like sodium sulfate, a buffering agent like ammonium chloride, and a surfactant like sodium dodecylsulfate.

The temperature of the plating solution is in  
15 the range preferably from 15°C to 70°C, more preferably from 25°C to 50°C. At a higher bath temperature, the bath is instable to cause precipitation and other disadvantages. Since the amount of Pt  
electrodeposition increases with elevation of the  
20 bath temperature, the potential and the Fe/Pt ratio should be controlled corresponding to the bath temperature.

From the above FePt plating solution, an FePt magnetic material can be prepared which contains Fe  
25 at a content of 40 to 60 at.%. The FePt composition can be determined by X-ray fluorometry (XRF) and high frequency-induced plasma coupling analysis (ICP), or

a like method.

The FePt magnetic material produced as above, immediately after the plating, is an alloy having an fcc phase not having a high coercivity ( $H_c$ ) for a magnetic recording material. The transformation from the formed magnetic material to an L10 structure is made to begin by heat treatment at 400°C. Heat treatment at 450°C or higher gives a coercive force of 4000 Oe or more to the magnetic material. The heat treatment temperature is preferably in the range from 450°C to 750°C.

Heat treatment of the formed magnetic material in the presence of hydrogen at 350°C or higher makes the material to transform into the L10 structure to have a coercive force exceeding 4000 Oe.

The underlayer under the plated FePt film should have electroconductivity. Further the underlayer is preferably a thin film or films of Ag and/or Cu for forming an ordered structure of the FePt magnetic material by diffusion during the heat treatment.

At the Fe content of higher than 60 at.% or lower than 40 at.%, the intended FePt magnetic material of strong coercive force cannot be obtained by the heat treatment. The FePt magnetic material may contain a trace amount of hydrogen or carbon as an impurity. However, a larger amount of impurity



deteriorates the properties of a magnetic recording material employing the FePt magnetic body. Therefore the content of impurity is preferably lower.

Next, a magnetic recording medium will be  
5 explained which has holes of 100 nm or less in diameter filled with an FePt magnetic material of the present invention.

Fig. 1 illustrates schematically constitution of a magnetic recording medium which has fine holes  
10 filled with an FePt magnetic material of the present invention.

In Fig. 1, the numerals denote the followings:  
10, a substrate; 11, an underlying electrode layer;  
12, a recording layer; 13, a protection layer; 14, a  
15 lubrication layer; 15, a magnetic material; and 16, a recording layer base.

Substrate 10 is a flat plate made of glass, quartz, silicon, or the like.

Recording layer 12 is constituted of recording  
20 layer base 16 having fine holes filled with magnetic material 15 of the present invention as shown as an example in Figs. 2A and 2B. In this embodiment, the filled magnetic material is an L10 ordered alloy, and the c-axis thereof is oriented preferably to be  
25 perpendicular to the substrate.

Recording layer base 16, as shown in Fig. 2A, has fine holes 20 partitioned by base material 21 and

arranged therein. The holes are characterized by hole diameter 22 and hole interval 23. The recording layer base 16 can be produced by any of the following processes: formation of holes by anodic oxidation of  
5 aluminum (hereinafter referred to as a "anodic oxidation process"); and formation of holes by use of a working object constituted of aluminum columns and surrounding material composed of silicon, germanium, or silicon-germanium such as AlSi, AlGe, and AlSiGe  
10 (hereinafter referred to as a "column removal process"). The processes are explained below in detail. A structure made of a block copolymer is also useful therefor.

Firstly, features of the recording layer base  
15 obtained by anodic oxidation process are described.

An aluminum film is placed on substrate 10. The portion of the film where fine holes 20 are to be formed is immersed in aqueous solution of phosphoric acid, oxalic acid, sulfuric acid, or the like. A  
20 voltage is applied to the immersed film portion employing this portion as the anode, whereby holes are formed by self-organization. The intervals 23 between the formed holes depend on the applied voltage, in the known relation :  $2.5 \times (\text{voltage (V)})$   
25 nm. The minimum period of hole intervals 23 is about 10 nm, and the minimum the hole diameter 22 of is about 8 nm.

By forming dents regularly on the surface of the aluminum film, holes can be formed regularly at the dent positions as the original points in a honeycomb state or a square state. This is a feature  
5 of the present invention, providing high possibility for production of patterned media.

Specific examples of the structures having fine holes prepared by anodic oxidation of aluminum as described above are shown in Japanese Patent  
10 Application Laid-Open No. H11-200090.

Next, the recording layer base prepared by a column removal process is explained below. Si is used as the base material as an example, but Ge and SiGe are also useful.

15 A working object is provided in which Al columns stand straight in the direction perpendicular to the substrate, and an Si portion as base material  
21 surrounds the columns. Si penetrates slightly into the Al portions and Al penetrates slightly into  
20 the Si portion. This working object is preferably formed by simultaneous film formation under nonequilibrium state between Al and Si.

The working object is immersed into an acid such as phosphoric acid, and sulfuric acid, or into  
25 an alkali such as an aqueous ammonia solution to dissolve and remove the Al columns. Otherwise, the Al columns can be removed by anode oxidation of the

AlSi working object in an aqueous solution of sulfuric acid or the like. During the anodic oxidation, the Si portion is oxidized to  $(\text{Al}_x\text{Si}_{1-x})_z\text{O}_{1-z}$ , where  $0 < x \leq 0.2$ , preferably  $0 < x \leq 0.1$ . In the range of  
5  $0.334 \leq z \leq 1$ , the portion is in an oxidation state. After the oxidation step, the recording layer base material contains non-oxidized portions also. The anodic oxidation is preferably stopped at a time of 30 to 60 seconds after the holes has reached  
10 underlayer 11 as shown in Fig. 2B, a sectional view at 2B-2B in Fig. 2A. Otherwise the anodic oxidation may be stopped at the time when the anodic oxidation current has reached the minimum level. The oxidation may be conducted by annealing in an oxygen atmosphere.

15 The columnar Al is removed in such a manner to obtain a recording layer base. Depending on the composition of the base material portion, diameters 22 of the holes range preferably from 1 nm to 15 nm, and hole intervals 23 range preferably from 3 nm to  
20 20 nm.

Specific examples of the aforementioned structure containing Si, Ge, or SiGe are described in Japanese Patent Application Laid-Open No. 2004-237431.

25 In the case where the magnetic material of the present invention is an L10 ordered alloy layer, the underlying electrode layer 11 has preferably crystal arrangement in a square parallel to the substrate

face in order to orient the c-axis in a direction perpendicular to the substrate. The (111) or (001) orientation of the crystal arrangement is preferably utilized: particularly the (001) orientation of the fcc structure is utilized. Specifically, for example, MgO having (001) orientation is inserted as the underlying electrode layer 11.

In the case where Al is used as substrate 10, an NiP film is preferably formed by plating or a like method as the underlying layer for obtaining the hardness.

Between substrate 10 and underlying electrode layer 11, a soft-magnetic underlayer is formed. The soft-magnetic film is mainly constituted of  $\text{Ni}_t\text{Fe}_{(1-t)}$ , where  $t$  is in the range preferably from 0.65 to 0.91. The film may contain additionally Ag, Pd, Ir, Rh, Cu, Cr, P, B, or the like. The soft-magnetic underlayer such as FeCo, FeTaC, and amorphous materials may be formed.

The surface of the recording layer of the magnetic recording medium is finely polished by use of diamond slurry or the like. The rms (root mean square: square root of the arithmetic means of the squares) of projection-depression of the surface is not larger than 1 nm. The surface of the recording layer is preferably protected by protection layer 13. An effective protection layer is formed from a non-

magnetic material of high hardness such as carbon, carbides, and nitrides for abrasion resistance against the friction with the head.

Lubrication layer 14 is preferably provided as  
5 the outermost layer of the magnetic recording medium. The lubrication layer is preferably formed by application of PFPE (perfluoropolyether).

The filling of the magnetic material into the fine holes can be conducted by electro-deposition  
10 with an electrode placed at the hole bottom.

The filled magnetic material can be transformed into an L10 ordered alloy by annealing at a temperature not higher than 500°C.

The magnetic recording medium of the present  
15 invention is useful as a vertical magnetic recording medium.

#### EXAMPLES

The present invention is explained by reference to Examples.

#### 20 Example 1

This Example describes preparation of FePt plating solutions.

Plating Solution A was prepared which contained 0.015 mol/L of hexachloroplatinate(IV) and 0.02 mol/L  
25 of iron chloride (i.e., hexachloroplatinate(IV): iron chloride (Pt:Fe) = 2:3). Thereto, 0.02 mol/L of ammonium tartrate was added as a complex agent, and

further 0.1 mol/L of NaCl was added. The plating solution was kept at a temperature of 25°C. The pH of the plating solution was adjusted to pH 8 by addition of sodium hydroxide to prepare Plating Solution A.

- 5 For comparison, Plating Solution B was prepared by adjusting the pH to 3. Plating solution C was prepared by adjusting the pH to 11.

Plating Solution A was in a good state, being stable for a long time. On the other hand, Plating  
10 Solutions B and C were instable, forming precipitate on standing for some time.

Plating Solution D was prepared which contained 0.01 mol/L of hexachloroplatinate(IV) and 0.01 mol/L of iron chloride (i.e., hexachloroplatinate(IV): iron  
15 chloride = 1:1). Thereto, 0.01 mol/L of ammonium tartrate was added as a complex agent. The plating solution was kept at a temperature of 25°C. The pH of the plating solution was adjusted to pH 8 by addition of sodium hydroxide to prepare Plating Solution D.

20 Plating Solution E was prepared which contained 0.01 mol/L of hexachloroplatinate(IV) and 0.03 mol/L of iron chloride (i.e., hexachloroplatinate(IV): iron chloride = 1:3). Thereto, 0.03 mol/L of ammonium tartrate was added as a complex agent. The plating  
25 solution was kept at a temperature of 30°C. The pH of the plating solution was adjusted to pH 8 by addition of sodium hydroxide to prepare Plating Solution E.

Plating Solution F was prepared which contained 0.01 mol/L of hexachloroplatinate(IV) and 0.05 mol/L of iron chloride (i.e., hexachloroplatinate(IV): iron chloride = 1:5). Thereto, 0.05 mol/L of ammonium  
5 tartrate was added as a complex agent. The plating solution was kept at a temperature of 30°C. The pH of the plating solution was adjusted to pH 8 by addition of sodium hydroxide to prepare Plating Solution F.

The above Plating Solutions D, E, and F  
10 contained respectively iron chloride and ammonium tartrate at the same concentration ratio, but contained hexachloroplatinate(IV) and iron chloride at different concentration ratios. Plating Solutions D and E were in a good state and stable for a long  
15 time, but Plating Solution F was instable.

Plating Solution G was prepared which contained 0.02 mol/L of hexachloroplatinate(IV) and 0.04 mol/L of iron chloride (i.e., hexachloroplatinate(IV): iron chloride = 1:2). Thereto, 0.04 mol/L of ammonium  
20 tartrate was added as a complex agent. The plating solution was kept at a temperature of 25°C. The pH of the plating solution was adjusted to pH 8 by addition of sodium hydroxide to prepare Plating Solution G.

Plating Solution H was prepared which contained  
25 0.02 mol/L of hexachloroplatinate(IV) and 0.05 mol/L of iron chloride (i.e., hexachloroplatinate(IV): iron chloride = 1:2.5). Thereto, 0.05 mol/L of ammonium



tartrate was added as a complex agent. The plating solution was kept at a temperature of 25°C. The pH of the plating solution was adjusted to pH 8 by addition of sodium hydroxide to prepare Plating Solution H.

5           The above Plating Solutions G and H contained hexachloroplatinate(IV) at the same concentration of 0.02 mol/L. Plating Solutions G and H were both in a good state, being stable for a long time.

          A solution containing hexachloroplatinate(IV)  
10 and iron chloride at a molar ratio of 1:0.74 was prepared for preparation of Plating Solution I. Another solution containing hexachloroplatinate(IV) and iron chloride at a molar ratio of 1:3.1 was prepared for preparation of Plating Solution J. To  
15 the respective solutions, ammonium tartrate was added as a complex agent in an amount equimolar to the iron chloride. The solutions were kept at a temperature of 25°C. The pH levels of the solutions were adjusted respectively to pH 8 by addition of sodium hydroxide  
20 to prepare Plating Solutions I and J. Plating Solution I was stable for general use as a plating solution, but was not suitable for FePt Plating. Plating solution J was unstable.

          For comparison, Plating Solutions A1 to G1 were  
25 prepared in the same manner as preparation of Plating Solutions A to G except that ammonium tartrate was not added. Plating Solutions A1 to G1 were

relatively unstable, causing precipitation during storage. In particular, the plating solutions of a high pH were highly instable.

For further comparison, Plating Solutions A2 to  
5 H2 were prepared in the same manner as in preparation of Plating Solutions A to H except that the pH of the respective solutions was adjusted to pH 4.9; and Plating Solutions A3 to H3 were prepared in the same manner as above except that the pH of the respective  
10 solutions was adjusted to pH 10.6. These Plating solutions A2 to H2, and A3 to H3 were instable and formed precipitate during storage.

Plating Solution K was prepared which contained 0.01 mol/L of hexachloroplatinate (IV) and 0.02 mol/L  
15 of iron chloride. Thereto, 0.02 mol/L of ammonium tartrate was added as a complex agent. The plating solution was kept at a temperature of 25°C. The pH of the plating solution was adjusted to pH 8 by addition of sodium hydroxide to prepare Plating Solution K.  
20 This Plating Solution K was satisfactory. To fractions of Plating Solution K, NaCl was added at concentrations of 0.03, 0.10. and 0.12 mol/L, respectively. The addition of NaCl improved further the long term stability as the plating solution.

25 Presumably, this improvement is caused by suppression of substitution reaction of chloride ions as ligands of the hexachloroplatinate(IV) with H<sub>2</sub>O as

the solvent and  $\text{OH}^-$  owing to the increased amount of the chloride ions.

#### Example 2

In this Example, an FePt magnetic material was  
5 produced from a stable FePt plating solution.

A plating solution of this Example was prepared by adding, to Plating Solution A prepared in Example 1, 0.03 mol/L of ammonium chloride as a buffering agent and 0.0001 mol/L of sodium dodecylsulfate as a  
10 surfactant. The above additives contribute to stabilization of pH of the plating bath during the plating and to improvement of the plated film quality. The amount of the additives may be changed suitably corresponding to the uses.

15 An FePt magnetic material was prepared from the above plating solution. The working electrode employed was an Si substrate covered with a film of Ag and Cu of 50 nm thick formed by sputtering as an underlying electrode layer. The auxiliary electrode  
20 employed was a platinum plate. The reference electrode employed was Ag/AgCl. Plating was conducted at a potential of -1.5 V to obtain an FePt magnetic material having a composition of  $\text{Fe}_{50}\text{Pt}_{50}$ .

The formed FePt magnetic material film after  
25 annealing at 400°C had a coercive force of 1000 Oe. Further annealing of the film at 450°C increased the coercive force up to 4000 Oe or more. The greater

coercive force is considered to be due to the higher ordered state of the FePt. The coercive force was measured by an AGM (Altemating Gradient Magnetometer).

The FePt magnetic film of the present invention  
5 having a composition of Fe<sub>50</sub>Pt<sub>50</sub> formed on the Ag and Cu underlayer transformed into an L10 ordered alloy structure at a relatively low temperature of 450°C, and exhibited a coercive force of 4000 Oe or more.

With any of the stable plating solutions  
10 prepared in Example 1 except the one employed in Example 2, an FePt magnetic material having the composition of Fe<sub>50</sub>Pt<sub>50</sub> can be produced, which can be transformed into L10 structure by annealing at 450°C to exhibit the coercive force of 4000 Oe or more.

15 Example 3

In this Example, a recording medium was produced by use of the magnetic material of the present invention.

On a glass substrate for a doughnut-shaped 2.5-  
20 inch HDD, were formed, by sputtering, successively an MgO film of 10 nm in (001) orientation perpendicular to the substrate, an Ag film of 20 nm as an underlying electrode layer, and an AlSi structure of 30 nm formed from a sputtering target of Al<sub>56</sub>Si<sub>44</sub>. The  
25 AlSi structure employed in this Example was constituted characteristically of columnar aluminum portions and a surrounding Si portion.

The above film-coated substrate was immersed in an aqueous 2.8 wt.% ammonia solution at room temperature for 10 minutes to remove the aluminum portions from the AlSi structure to form fine holes. Thereby, at the bottom portions of the fine holes, the face of the Pt in (001) orientation state was bared. By the removal of the aluminum portions, the structure was obtained as shown in Figs. 2A and 2B. In this Example, the diameter of the holes was 8 nm, and the interval between the holes was 10 nm.

The holes were filled with the magnetic material of the present invention as below. The plating solution therefore contained 0.015 mol/L of hexachloroplatinate(IV) salt, 0.02 mol/L of iron sulfate, 0.02 mol/L of ammonium tartrate and 0.1 mol/L of sodium chloride. The plating bath was kept at 30°C, and the pH of the solution was adjusted with sodium hydroxide to pH 8. Thereto ammonium chloride was added at a concentration of 0.03 mol/L as a buffering agent, and sodium dodecylsulfate was added at a concentration of 0.001 mol/L as a surfactant. Plating was conducted with this plating solution. The formed FePt magnetic material filling the holes was found to have a composition of Fe<sub>50</sub>Pt<sub>50</sub> by analysis. The obtained magnetic material was annealed in vacuum at 500°C for 30 minutes to obtain an ordered alloy structure of the magnetic material.

The resulting FePt magnetic material filled in the holes had an L10 ordered alloy structure. The magnetic material had a coercive force of 4000 Oe in the direction perpendicular to the substrate. By  
5 observation of the structure, it was confirmed that the FePt magnetic material portions had a diameter of 8 nm with intervals of 10 nm in average and the magnetic material portions were partitioned by a nonmagnetic material mainly composed of Si.

10 Accordingly, the structure having a hard magnetic material dispersed uniformly was found to be suitable as a magnetic recording medium.

#### Example 4

In this Example, an FePt magnetic material  
15 having a composition of Fe<sub>50</sub>Pt<sub>50</sub> was heat-treated in the presence of hydrogen at one atmospheric pressure at 350°C to form an L10 ordered alloy structure to obtain a coercive force of 4000 Oe or more.

Firstly, a copper ammonium tartrate solution  
20 was prepared which contained 0.001 mol/L of ammonium chloride, and 0.002 mol/L of ammonium tartrate, and 0.002 mol/L of anhydrous copper sulfate added thereto. Then an FePt plating solution was prepared which contained 0.014 mol/L of hexachloroplatinate(IV) salt,  
25 0.02 mol/L of iron chloride, 0.02 mol/L of ammonium tartrate as a complex agent, and 0.1 mol/L of NaCl. To this FePt plating solution, there was added the

above ammonium copper tartrate solution to prepare a Cu-containing FePt plating solution. The added Cu did not impair the plating solution stability. Incidentally, FePtCu plating solutions can be  
5 prepared by use of any of the FePt plating solutions shown in Example 1.

An FePtCu alloy was prepared by plating with the above plating solution. The working electrode employed was an Si substrate covered with a film of  
10 Ag and Cu of 50 nm thick as an underlying electrode layer formed by sputtering. The auxiliary electrode was a platinum plate. The reference electrode was Ag/AgCl. Plating was conducted at a potential of -1.0 V to obtain an FePt alloy having a composition  
15 of Fe<sub>45</sub>Pt<sub>45</sub>Cu<sub>10</sub>.

The formed FePtCu magnetic material after heat treatment at 400°C had a coercive force of 4000 Oe or more. Further, the film annealed at 350°C in the presence of hydrogen at one atmospheric pressure had  
20 a coercive force of not less than 5000 Oe. Thus annealing at 300°C in the presence of hydrogen increased the coercive force. The composition of the plated matter depends on the stirring rate, the pH of the plating solution, the temperature, and the  
25 applied voltage. With the FePtCu alloy, a greater coercive force can be obtained by forming an ordered alloy phase by heat treatment at a temperature lower

than that of the no-Cu-containing FePt alloy.

As shown in this Example, an FePtCu alloy composed of FePt as main components and Cu as a minor component can be produced by adding Cu to the FePt  
5 plating bath. In particular, a stable plating solution can be obtained by addition of the Cu in a form of copper ammonium tartrate, and with this plating solution, an FePtCu alloy containing 25 at.% Cu can be produced. The Cu content of the FePtCu  
10 alloy can be changed by changing the concentration of the copper ammonium tartrate. At a Cu content in the alloy of higher than 25 at.%, the quality of the alloy film is significantly deteriorated, so that the concentration of the copper ammonium tartrate is  
15 preferably not higher than 0.05 mol/L. The Cu content in the FePtCu alloy depends also on the electrodeposition potential, pH of the plating bath, the stirring rate, and other conditions.

The FePtCu alloy can be transformed, after film  
20 formation, into an L10 structure by heat treatment at 400°C or higher to obtain a coercive force of more than 4000 Oe, and the coercive force can further be increased by heat treatment in the presence of hydrogen at a temperature of higher than 300°C.

25

#### INDUSTRIAL APPLICABILITY

The present invention relates to a plating



solution, a process for producing a structure by use of the plating solution, and an apparatus for using the plating solution. A magnetic recording medium can be provided by use of the plating solution.

5

This application claims priority from Japanese Patent Application Nos. 2004-009238 filed on January 16, 2004, and 2004-271466 filed on September 17, 2004,  
10 which are hereby incorporated by reference herein.

## CLAIMS

1. A plating solution which contains ionic Fe,  
ionic Pt, and a complex agent, at a molar ratio of  
5 the ionic Fe to the ionic Pt ranging from 0.75 to 3.

2. The plating solution according to claim 1,  
wherein the complex agent contains tartrate ions or  
citrate ions.

3. The plating solution according to claim 1,  
10 wherein the concentration of the ionic Fe ranges from  
0.005 mol/L to 0.1 mol/L.

4 The plating solution according to claim 1,  
wherein the plating solution has a pH ranging from  
5.0 to 10.5.

15 5. The plating solution according to claim 1,  
wherein the ionic Fe and the ionic Pt form a double  
complex constituted of an Fe complex and a Pt complex.

6. The plating solution according to claim 1,  
wherein the plating solution contains ionic Cu and a  
20 complex agent for the ionic Cu.

7. A process for producing a structure  
comprising steps of:  
providing an electrode and an object to be plated in  
a vessel containing a plating solution set forth in  
25 any of claims 1 to 6, and  
plating the object with a magnetic material  
containing FePt from the plating solution by applying

voltage to the electrode to form a structure.

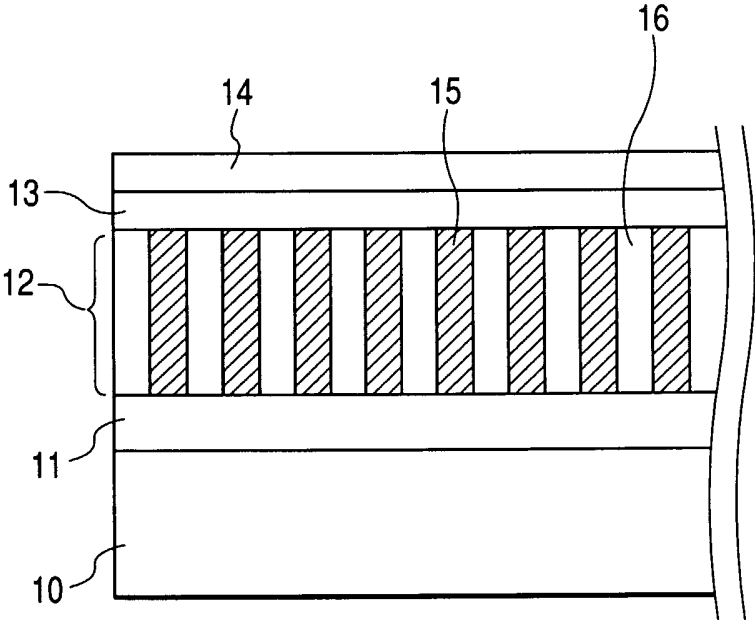
8. A process for producing a structure,  
wherein the structure formed in claim 7 is heat-  
treated further at a temperature ranging from 450°C to  
5 750°C.

9. A process for producing a structure,  
wherein the structure set forth in claim 7 is heat-  
treated further in the presence of hydrogen.

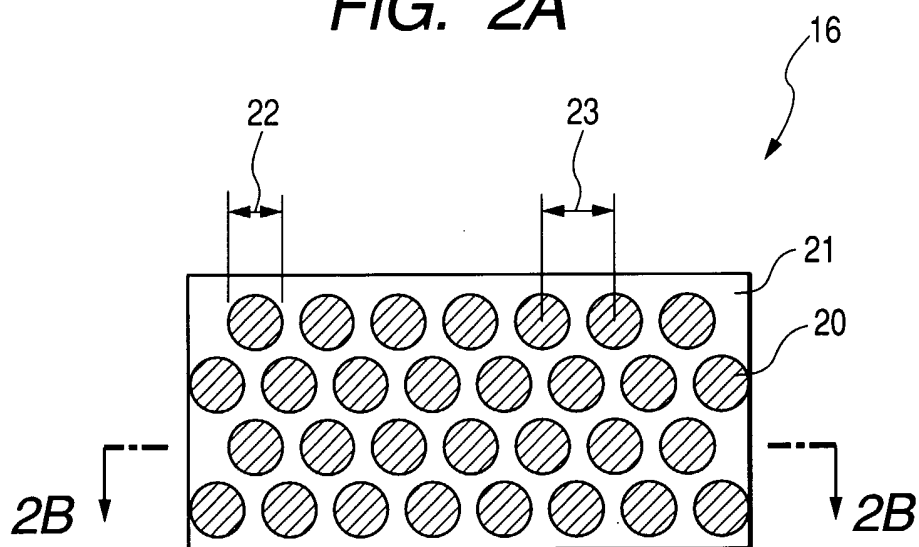
10. The process for producing a structure  
10 according to claim 7, wherein the object to be plated  
is a structure having holes, and the step of plating  
the object to form the structure is deposition of the  
magnetic material containing FePt into the holes.

11. An apparatus, having a plating solution as  
15 set forth in any of claims 1 to 6, a vessel for  
holding the plating solution, and electrodes, for  
conducting plating by application of a voltage to the  
electrodes.

FIG. 1



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*FIG. 2A**FIG. 2B*