

MAGNETIC RECORDING MEDIA WITH A SYNTHETIC NUCLEATION LAYER AND METHOD OF MANUFACTURE

FIELD OF THE INVENTION

This invention relates generally to magnetic recording media, and more particularly to a magnetic recording medium with a synthetic nucleation layer and a magnetic recording layer.

BACKGROUND OF THE INVENTION

Perpendicular magnetic recording media have been developed to provide higher recording density in data storage devices such as disk drives. A typical perpendicular magnetic recording medium includes a substrate and a magnetic recording layer formed over the substrate. A factor that determines the recording density of the perpendicular magnetic recording media is the size of the magnetic grains in the magnetic recording layer. Reduction of grain size can pack more grains in a bit, which may increase the storage density and the signal-noise ratio at a given density. Therefore, a key objective in the design of perpendicular magnetic recording media is to tailor the grain size.

Various attempts have been made to reduce the grain size in the magnetic recording layer, and to increase the recording density. In one approach, excessive oxygen is added during the deposition of a CoCrPt or CoCrPt:SiO₂ magnetic recording layer, in order to suppress the growth of the magnetic grains. When excessive oxygen is added during the deposition or as the oxide compound, such as SiO₂, in the target is introduced, oxide regions form and they prevent the formation of bigger magnetic grains. However, this approach may also result in oxygen getting into the magnetic grains. When this happens, the anisotropy constant of the magnetic grains is also reduced, which leads to the formation of superparamagnetic grains. In the magnetic recording layer, superparamagnetic grains are detrimental to the magnetic recording, hence are undesirable. This approach is therefore unable to provide a perpendicular magnetic recording medium with acceptable properties and performances.

Another approach has been to reduce the grain size of the magnetic recording layer without significantly affecting the thermal stability by tailoring the intermediate layer properties. In this scheme, the intermediate layer, which consists of two or more elements, is sputtered in the presence of oxygen, for example, with a RuCr alloy target. When the target is sputtered in the presence of oxygen, oxide regions, for example Cr oxide, form and separate the Ru grains from each other, reducing the growth of the grains in the intermediate layers. When the magnetic recording layer grows on these intermediate layers with smaller grain sizes, it also develops a smaller grain size. With this method, it has been possible to obtain a mean grain pitch, i.e., center-to-center distance between the grains, of 6.4 nm. However, in order to increase the data density, it is desirable to provide a magnetic recording layer having a grain size on a smaller scale than presently achievable, for example below 6.4 nm, without substantially compromising the recording performance of the perpendicular magnetic recording media.

Therefore, there is a need for alleviating problems associated with the current methods for controlling the grain size of crystalline magnetic grains in crystalline layers in magnetic recording layers of the magnetic recording media for achieving finer control and smaller grain sizes.

SUMMARY

In accordance with an aspect of the invention, a magnetic recording medium, comprises a base structure, a nucleation layer over the base structure, wherein the nucleation layer is primarily carbon by atomic weight, and a magnetic recording layer over the nucleation layer, wherein the nucleation layer provides nucleation sites that determine a grain size and a grain size distribution of magnetic grains in the magnetic recording layer.

In embodiments the nucleation layer is carbon based and provides nucleation sites that determine a grain size and a grain size distribution of magnetic grains in the magnetic recording layer. The nucleation layer can contact the magnetic recording layer, or alternatively, the nucleation layer can be spaced from the magnetic recording layer and

an intermediate layer such as ruthenium can contact and be sandwiched between the nucleation layer and the magnetic recording layer. The nucleation layer may be hydrogenated carbon or nitrogenated carbon. The grain size may have a mean of less than 6 nm, and the grain size distribution has a standard deviation of less than 15%. The magnetic recording media may be a disk that provides perpendicular magnetic recording for a disk drive.

In accordance with an aspect of the invention, a method of making a magnetic recording medium, comprises providing a base structure, depositing a nucleation layer that is primarily carbon by atomic weight formed over the base structure, and sputtering a magnetic recording layer over the nucleation layer, wherein the nucleation layer provides nucleation sites that determine a grain size and a grain size distribution of magnetic grains in the magnetic recording layer.

In an embodiment of the invention a magnetic recording medium comprises a substrate, a soft magnetic underlayer over the substrate, a seedlayer, a first or lower intermediate layer over the soft magnetic underlayer and a nucleation layer over the first intermediate layer, the nucleation layer may consist essentially of hydrogenated carbon or nitrogenated carbon and is primarily carbon by atomic weight, and a second or upper intermediate layer over the nucleation layer and a magnetic recording layer over the second intermediate layer, the nucleation layer provides nucleation sites that determine a grain size and a grain size distribution of the second intermediate layer which determines the size and distribution of magnetic grains in the magnetic recording layer, and the magnetic recording layer provides perpendicular magnetic recording for a disk drive.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that embodiments of the invention may be fully and more clearly understood by way of non-limitative examples, the following description is taken in conjunction with the accompanying drawings in which like reference numerals designate similar or corresponding elements, regions and portions, and in which:

FIG. 1 illustrates the structure of a magnetic recording medium in accordance with an embodiment of the invention;

FIG. 2 illustrates the structure of a magnetic recording medium in accordance with an embodiment of the invention;

FIGS. 3A-3D illustrates the case of random nucleation sites and the formation of grains in FIGS. 3A-3B, and the case of uniformly spaced nucleation sites and the formation of grains in FIGS. 3C-3D in accordance with an embodiment of the invention;

FIGS. 4A-4C illustrates the formation of a nucleation layer and the formation of clusters in accordance with an embodiment of the invention;

FIGS. 5A-5C are TEM images showing grain structure formed in an upper intermediate layer in accordance an embodiment of the invention;

FIG. 6 is a graph showing grain size and grain size distribution curves of a second intermediate layer according to embodiments of the invention, compared to those of a conventional magnetic recording medium; and

FIGS. 7A-7B are graphs showing the change of C-axis orientation ($\Delta\theta_{50}$), coercivity (H_c) and nucleation field ($-H_n$) upon insertion of a carbon-based nucleation layer in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

Grain size and grain size distribution in polycrystalline thin films, such as those utilized in recording media, are determined by the number and the arrangement of nucleation sites. In an embodiment of the invention, in view of conventional methods, the number of nucleation sites is increased to decrease the resulting grain size, and the nucleation sites are arranged uniformly to ensure that the grain size distribution is narrower. This also is to prevent varying distribution of the size of grains that is observed in the conventional methods of deposition where nucleation and film growth take place

simultaneously which has the implication that leads to an increased mean grain size. In an embodiment the number of nucleation sites and the arrangement of the nucleation sites are controlled in the formation of the nucleation layer. In this manner, the grain size can be tailored for the specific application. With this in mind, the dedicated synthetic nucleation layer is formed. When suitable materials are used as synthetic nucleation layer, the nucleation sites could be uniformly and densely distributed. This will lead to a reduction in the grain size and grain size distribution.

Referring to FIG. 1, a perpendicular magnetic recording medium 10 according to an embodiment of the invention includes a base structure 12, lower intermediate layer 14 disposed on the base structure 12, a synthetic nucleation layer 20 disposed between the lower intermediate layer 14, and an upper intermediate layer 16, and a magnetic recording layer 22 disposed on the upper intermediate layer 16. Base structure 12 includes a substrate 32, and an adhesion layer 34, a soft magnetic layer 36 and a seed layer or a growth inducing layer 38 sequentially formed on a substrate 32. The lower intermediate layer 14 is deposited at a pressure of about 0.1-1 Pa. By depositing at such a pressure, lower intermediate layer 14 possesses a relatively narrow dispersion of crystallographic orientation of the grains. Thereafter, a synthetic nucleation layer 20 is deposited on the lower intermediate layer 14. Subsequently, an upper intermediate layer 16 is formed on the synthetic nucleation layer 20, at a pressure higher than the pressure used to deposit lower intermediate layer 14. The lower intermediate layer 14 helps to improve the crystallographic texture, and the upper intermediate layer 16, acting as a template for separating the densely packed grains, helps to obtain segregated grain structure in the recording layer to improve signal to noise ratio from the magnetic recording layer 22. In this embodiment, the synthetic nucleation layer 20 is responsible for producing fine grains in upper intermediate layer 16, which controls the grain size in the recording layer 22.

The synthetic nucleation layer is deposited for a nominal thickness ranging from a quarter to two monolayers of material. Several materials or elements may be candidates for the nucleation layer, such as for example any one or combinations of C, Ta, W, Ru, Pt, Pd, Nb, Mo, Re, Os, Ir and the like. Additional element and/or elements may be included in the nucleation layer. For example, additional elements may be gasses such

as hydrogen, nitrogen, oxygen, and the like, or metals such as Cr, Ti, Zr, Ag, Au, In, Cu, Al, Mn, Mg and the like. The nucleation layer may be a hydrogenated carbon based layer. The nucleation layer may be a nitrogenated carbon based layer. Upon formation of synthetic nucleation layer 20 and the upper intermediate layer 16, subsequent deposition processes may be carried out in the deposition chamber, to form magnetic recording layer 22 on top of the upper intermediate layer 16.

Through the hetero-epitaxial growth, magnetic grains in layer 22 grow following the structure of grains in layer 16. From this process, magnetic recording layer having reduced grain size is successfully obtained. It should be appreciated, that since excessive oxygen, or other gases are not added during the formation of the magnetic layer, the magnetic recording layer is formed with less presence of these substances. As such, generation of superparamagnetic grains in the magnetic recording layer is successfully avoided by the solutions provided according to embodiments of the present invention.

Referring to FIG. 2, a perpendicular magnetic recording medium 30 according to another embodiment of the invention includes a base structure 12, lower intermediate layer 14 disposed on the base structure 12, a synthetic nucleation layer 20 disposed between the lower intermediate layer 14, and a magnetic recording layer 22. Base structure 12 includes a substrate 32, and an adhesion layer 34, a soft magnetic layer 36 and a seed layer 38 sequentially formed on a substrate 32. In this embodiment, the synthetic nucleation layer 20 is directly responsible for producing fine grains in the recording layer 22.

Referring to FIG. 1, in another embodiment, the perpendicular magnetic recording medium 10 includes a base structure 12, which may consist of amorphous or crystalline or a combination of soft magnetic underlayers 36. The layer 14 disposed on the base structure 12, could be magnetic or non-magnetic layer with an hcp(00.2) or fcc(111) texture or a derivative of these. According to this embodiment, a synthetic nucleation layer 20 is disposed on the lower intermediate layer 14, and a magnetic recording layer 22 could be disposed directly on synthetic nucleation layer 20 or on another intermediate layer 16 which is disposed on nucleation layer 20. Base structure 12 includes a

substrate 32, and an adhesion layer 34, a soft magnetic layer 36 and a seed layer 38 sequentially formed on a substrate 32. The lower intermediate layer 14 helps to improve the crystallographic texture, and upper intermediate layer 16, acting as a template for separating the densely packed grains, helps to obtain segregated grain structure in the recording layer to improve signal to noise ratio from the magnetic recording layer 22. If the lower intermediate layer 14 is made of a magnetic or metamagnetic layer, it also helps to direct the flux from the writing head, which helps in improving the writability.

In an embodiment, the soft magnetic layer 36, i.e. soft underlayers, may be a combination of one or several layers which may or may not necessarily be crystalline. The soft underlayers may be made of a material from one or more elements such as for example Fe, Co, Ni, B, Ta, Zr, Nb, Si, Ti, Ru, Cu, Pt, Pd, Cr, and the like. The soft underlayers may also be a combination of one or several layers which may or may not necessarily be antiferromagnetically coupled synthetically. The soft underlayers may be pinned by antiferromagnetic material such as for example IrMn, FeMn, NiO, IrMnCr, PtMn, and the like. The growth inducing layer may consist of one or a mixture of for example Ta, Cu, CrTi, Ag, Au, and the like. The lower intermediate layer may be formed from one or a mixture of elements such as for example Cr, Co, Fe, Ni, Cu, Ru, Pd, Pt, and the like. The upper intermediate layer may be of a material such as for example Ru, Cr, Co, Cu, Re, Os, alloys thereof, and the like. The upper intermediate layer may be sputtered in the presence of a reactive gas such as oxygen, nitrogen, hydrogen and the like. In forming the intermediate layers, the lower intermediate layer may be formed under lower pressure parameters to obtain more narrowly-dispersed grains than in forming the upper intermediate layer to obtain smaller-sized grains.

In an embodiment, the recording layer 22 is an alloy of two or more elements such as for example Co, Cr, Pt, B, Ta, Pd, Sm, Fe, Ni and the like. The recording layer may have an oxide based grain boundary to separate the grains from each other. The oxide based grain boundary may be obtained from one or more elements such as for example Si, Cr, Ta, Ti, Al, Mg and the like. The recording layer may be coated with a protective layer or a cover layer 42 such as for example carbon, nitrogenated carbon, hydrogenated carbon, silicon nitride and the like to improve resistance to corrosion. The recording layer 22 and the protective layer 42 may be coated with a lubricant material 44 such as

PFPE to improve wear resistance. Additionally, the magnetic recording media may be buffed or undergo other post-sputter treatments in order to achieve a smooth surface.

It will be appreciated that the base structure 12 shown in FIG. 1-2 may comprise of different configurations. For example, base structure may comprise a substrate 32. The base structure or may not include an adhesion layer 34 and/or growth inducing layer 38.

FIGS. 3A-3D shows two cases of nucleation and growth mechanisms in thin film deposition processes. In FIG. 3A, which represents the conventional deposition processes, nucleation sites 52 are formed randomly on the substrate 56. In FIG. 3B, when further deposition occurs, the grains 54 formed on nucleation sites 52 are of random sizes. FIG. 3C illustrates the case of more uniformly and densely arranged 82 nucleation sites 52 according to an embodiment of this invention. In FIG. 3D, when further deposition occurs, the grains 54 formed on nucleation sites 52 are of uniform and smaller sizes 84 than in FIG. 3B.

FIGS. 4A-4C shows a schematic illustration of the predicted mechanism of nucleation site formation. The layer shown in FIGS. 4A-4C is of the lower intermediate layer 14 shown in FIG. 1-2. On the lower intermediate layer 14, the material that would form the synthetic nucleation layer 20 is deposited. If there is no movement of atoms from the material of the nucleation layer 20, the material of the nucleation layer 20 would be scattered around lower intermediate layer 14, as shown in FIG. 4A showing the lower intermediate layer immediately after deposition 60. However, due to a competition between the atomic binding energy, the atom-substrate bonding energy, the kinetic energy of the atoms from the deposition, and the thermal energy from the substrate temperature, the material of the nucleation layer 20 moves around and forms clusters 58 within a short time after deposition 62. The clusters 58 of atoms from the material of the nucleation layer 20 act as the synthetic nucleation sites 52, as shown in FIG. 3C. When the upper intermediate layer 16 is deposited on base structure in FIG. 4B, intermediate layer grains 54 in the range of 5-6 nm with a grain boundary 54 are formed as shown 64 in FIG. 4C.

A comparison is shown in FIGS. 5A-5C between transmission electron microscope (TEM) images of upper intermediate layers 16 of magnetic recording media having nucleation layers and of a magnetic recording media without a nucleation layer. Specifically, TEM images 68,69 (FIG. 5B and 5C) of upper intermediate layers of magnetic recording medium residing on a nucleation layer 20 as discussed and shown in FIG. 1-3 in accordance with an embodiment of the invention, with a TEM image 66 (FIG. 5A) of an upper intermediate layer of a magnetic recording medium where the a nucleation layer is absent from the magnetic recording medium. The magnetic recording medium from which the TEM image 66 of intermediate layer is shown in FIG. 5A is not in accordance with an embodiment of the invention, and is provided only for illustrating the significance of the nucleation layer 20. It is clear that the images of samples 68 and 69 in FIG. 5B and 5C prepared with nucleation layer 20 show well-separated grains. The average grain size is smaller in the case of films with synthetic nucleation layer 20, as shown in FIG. 5B and 5C. The nucleation layers of FIG. 5B and 5C are of two different types -I and II. The difference between type I and type II is in the reactive gas used in the sputter deposition of the carbon layer, being for example hydrogen and nitrogen, respectively. It can be noticed that the insertion of nucleation layer of both types I and II helps to achieve segregation of grains in the intermediate layer.

To illustrate the effect of the nucleation layer, grain size was estimated by measuring the distance between the grain centers. FIG. 6 is a graph 70 showing grain size and grain size distribution curves 74, 76, 78 of the upper intermediate layer 16 according to embodiments of the present invention, compared to one curve 72 of the upper intermediate layer 16 of a conventional magnetic recording medium without nucleation layer. The magnetic recording media from which the grain size curves of intermediate layer of curve 72 as shown in FIG. 6 is not in accordance with an embodiment of the invention, and is provided only for illustrating the significance of the nucleation layer 20. Curve 74 is for 0.24nm nucleation layer, curve 76 is for 0.18nm nucleation layer, and curve 78 is for 0.08nm nucleation layer in accordance with embodiments of the invention. It can be noticed that, with the introduction of nucleation layer, the mean grain size is reduced by about 1 nm to below 6 nm and the grain size distribution also narrows. The distribution is also reduced to about 13 % in the case of upper intermediate layer 16 deposited on nucleation layer 20, as compared to about 15% for upper

intermediate layer 16 deposited without nucleation layer. These results clearly indicate the effectiveness of inserting a nucleation layer to reduce the grain size and distribution required for high-density recording media. It will be appreciated that this technique can be used in several applications that require small and uniform grains.

FIGS. 7A-7B are graphs showing the change of C-axis orientation ($\Delta\theta_{50}$), coercivity (H_c) and nucleation field ($-H_n$) upon insertion of a synthetic nucleation layer in accordance with an embodiment of the invention. For recording media applications, it is also essential to verify that the method used for grain size reduction does not deteriorate other properties, such as crystallographic orientation, magnetic and recording properties. FIG. 7A shows the dispersion in the perpendicular orientation of the Co-grains as measured from the full width at half maximum ($\Delta\theta_{50}$) of rocking curves using X-Ray Diffraction (XRD). It can be noticed that with the introduction of type II nucleation layer, $\Delta\theta_{50}$ increases by about 0.6° , which indicates a slight deterioration in the texture. With type I nucleation layer, the increase, is about 0.4° . However, this increase is not significant in affecting the performance of the media and may be overcome by using other methods that help improve the orientation. Indeed, measurements recorded indicated that the media with nucleation layer possess a signal to noise ratio significantly larger by about 1.5 dB than the media without the nucleation layers, which points towards the potential effectiveness of the proposed technique.

FIG. 7B shows the change in the coercivity (H_c) and nucleation field ($-H_n$) upon inserting the type II nucleation layer. It can be noticed that the coercivity and nucleation field decrease slightly, partly due to the reduction in grain size. As the magnetic grain size shrinks, the magnetic anisotropy energy $K_u V$ also reduces, which will lead to thermal stability issues. For other recording media, materials with higher K_u can be used to circumvent this problem. This problem can also be avoided by using different media structures, such as by stacking a small-grain layer below a slightly bigger grain layer or by using capping layers. These results indicate that the introduction of nucleation layer is an effective way to reduce the grain size and distribution, without significantly sacrificing the other properties.

A dedicated nucleation layer approach to reduce grain size in polycrystalline thin films is demonstrated. Empirical data obtained with the embodiments of the invention have shown that grain sizes below 5.5 nm with a standard deviation of 13% were obtained and signal to noise ratio improvement of about 1.5 dB has been observed. The embodiments of the invention can help to solve a major problem for high-density recording media and can also be applicable in several other fields requiring stringent grain size control.

It will be appreciated that the technology and application of embodiments of the invention may be applied to different magnetic recording media. For example the invention may be embodied in magnetic recording media materials such as CoCrPt, CoPt, FePt, CoPt₃, Co₃Pt, SmCo₅ and the like. Applied in different magnetic material media, it will be appreciated that different grain diameters may be achieved. For example in other recording media such as, CoCrPt media with 5-6 nm grain diameters, CoPt media with 4-5 nm grain diameters, FePt media with 3-4 nm grain diameters, CoPt₃ media with 4-5 nm grain diameters Co₃Pt media with 4-5 nm grain diameters, and SmCo₅ media with 3-4 nm grain diameters are needed while the desired thickness is in the range of 10-20 nm. The embodiments of the invention may be used to obtain these grain sizes with a standard deviation of 15%.

While embodiments of the invention have been described and illustrated, it will be understood by those skilled in the technology concerned that many variations or modifications in details of design or construction may be made without departing from the present invention.

CLAIMS:

1. A magnetic recording medium, comprising:
a base structure;
a nucleation layer over the base structure, wherein the nucleation layer is primarily carbon by atomic weight; and
a magnetic recording layer over the nucleation layer, wherein the nucleation layer provides nucleation sites that determine a grain size and a grain size distribution of magnetic grains in the magnetic recording layer.
2. The magnetic recording medium according to claim 1 wherein the base structure comprises a substrate.
3. The magnetic recording medium according to claim 1 wherein the base structure comprises a substrate with an adhesion layer over the substrate.
4. The magnetic recording medium according to claim 1 wherein the base structure comprises a substrate, an adhesion layer over the substrate and a soft magnetic underlayer over the substrate.
5. The magnetic recording medium according to claim 4 wherein the base structure further comprises a growth inducing layer over the soft underlayer.
6. The magnetic recording medium according to claim 4 or 5, wherein the soft magnetic underlayer comprises a combination of one or several crystalline or non-crystalline layers comprising of one or more elements selected from the group consisting of Fe, Co, Ni, B, Ta, Zr, Nb, Si, Ti, Ru, Cu, Pt, Pd and Cr.
7. The magnetic recording medium according to any one of claims 4 to 5, wherein the soft magnetic underlayer comprises a combination of one or several layers antiferromagnetically coupled synthetically and may be pinned by one or more of antiferromagnetic material selected from the group consisting of IrMn, FeMn, NiO, IrMnCr, and PtMn.

8. The magnetic recording medium according claim 5, wherein the growth inducing layer is selected from a group consisting of Ta, W, Ti, In, Ag, Cu or alloys thereof.
9. The magnetic recording medium according to any preceding claim further comprising a lower intermediate layer, the nucleation layer is spaced from the base structure, and the lower intermediate layer contacts and is sandwiched between the nucleation layer and the base structure.
10. The magnetic recording medium according claim 9, wherein the lower intermediate layer is ruthenium.
11. The magnetic recording medium according to claim 9, wherein the lower intermediate layer is selected from a group consisting of Ru, Cr, Co, Cu, Re, Os, Ni, Ir and alloys thereof.
12. The magnetic recording medium according to any one of the preceding claims, wherein the nucleation layer contacts the magnetic recording layer.
13. The magnetic recording medium according to any one of the preceding claims, wherein the nucleation layer comprises hydrogenated carbon.
14. The magnetic recording medium according to any one of the preceding claims, wherein the nucleation layer consists essentially of hydrogenated carbon.
15. The magnetic recording medium according to any one of the preceding claims, wherein the nucleation layer comprises nitrogenated carbon.
16. The magnetic recording medium according to any one of the preceding claims, wherein the nucleation layer consists essentially of nitrogenated carbon.

17. The magnetic recording medium according to any one of the preceding claims, wherein the nucleation layer comprises of a material selected from the group consisting of Ta, W, C, Re, Nb, Mo, Os, Ir, Pt, Pd and Ru.

18. The magnetic recording media according to any one of the preceding claims, wherein the nucleation layer comprises a material that is a gas selected from the group consisting of hydrogen gas, nitrogen gas, and oxygen gas.

19. The magnetic recording medium according to any one of the preceding claims, wherein the nucleation layer comprises a material that is a metal selected from the group consisting of Cr, Ti, Zr, Mn, Zn, Cu, Ag, Au, In, and Al.

20. The magnetic recording medium according to any one of claims 1-12, wherein the nucleation layer consists of hydrogenated carbon.

21. The magnetic recording medium according to any one of claims 1-12, wherein the nucleation layer consists of nitrogenated carbon.

22. The magnetic recording medium according to any one of the preceding claims, wherein the magnetic recording layer is a sputtered polycrystalline film.

23. The magnetic recording medium according to any one of the preceding claims, wherein the magnetic recording layer includes cobalt and platinum.

24. The magnetic recording medium according to any one of the preceding claims, wherein the magnetic recording layer is an alloy of two or more elements selected from the group consisting of Co, Cr, Pt, B, Ta, Pd, Sm, Fe and Ni.

25. The magnetic recording medium according to any of the preceding claims, wherein the magnetic recording layer comprises an oxide based grain boundary to separate the grains, the oxide based grain boundary obtained from one or more elements selected from the group consisting of Si, Cr, Ta, Ti, Al, and Mg.

26. The magnetic recording medium according to any of the preceding claims further comprising a protective layer above the magnetic recording layer, the protective layer coating the magnetic recording layer to prevent corrosion, the protective layer comprising a material selected from the group of carbon, nitrogenated carbon, hydrogenated carbon, silicon nitride.

27. The magnetic recording medium according to any one of the preceding claims, wherein the grain size has a mean of less than 6 nm.

28. The magnetic recording medium according to any one of claims 1-26, wherein the grain size has a mean in the range of 4.5 to 5.5 nm.

29. The magnetic recording medium according to any one of claims 1-26, wherein the grain size has a mean of about 5.0 nm.

30. The magnetic recording medium according to any one of the preceding claims, wherein the grain size distribution has a standard deviation of less than 15%.

31. The magnetic recording medium according to any one of claims 1-29, wherein the grain size distribution has a standard deviation in the range of 8 to 15%.

32. The magnetic recording medium according to any one of claims 1-26, wherein the grain size has a mean of less than 6 nm, and the grain size distribution has a standard deviation of less than 0.8 nm.

33. The magnetic recording medium according to any one of the preceding claims, wherein the magnetic recording media is a disk and provides perpendicular magnetic recording for a disk drive.

34. The magnetic recording medium according to any one of the preceding claims further comprising an upper intermediate layer, the nucleation layer is spaced from the magnetic recording layer and the upper intermediate layer contacts the nucleation layer and is sandwiched between the nucleation layer and the magnetic recording layer.

35. The magnetic recording medium according claim 34, wherein the upper intermediate layer is ruthenium.
36. The magnetic recording medium according to claim 34, wherein the upper intermediate layer comprises a material selected from a group consisting of Ru, Cr, Co, Cu, Re, Os, and alloys thereof.
37. The magnetic recording medium according to any one of claims 34-36, wherein the upper intermediate layer is sputtered in the presence of a reactive gas such as oxygen, nitrogen or hydrogen.
38. A method of making a magnetic recording medium, comprising:
providing a base structure;
depositing a nucleation layer that is primarily carbon by atomic weight formed over the base structure; and
sputtering a magnetic recording layer over the nucleation layer, wherein the nucleation layer provides nucleation sites that determine a grain size and a grain size distribution of magnetic grains in the magnetic recording layer.
39. The method according to claim 38, wherein the nucleation layer contacts the magnetic recording layer.
40. The method according to claim 38 or 39, wherein the nucleation layer comprises of a material selected from the group consisting of Ta, W, C, Re, Nb, Mo, Os, Ir, Pt, Pd and Ru.
41. The method according to any one of claims 38-40, wherein the nucleation layer comprises a material that is a gas selected from the group consisting of hydrogen gas, nitrogen gas, and oxygen gas.

42. The method according to any one of claims 38-41, wherein the nucleation layer comprises a material that is a metal selected from the group consisting of Cr, Ti, Zr, Mn, Zn, Cu, Ag, Au, In, and Al.
43. The method according to any one of claims 38-42, wherein the nucleation layer comprises hydrogenated carbon.
44. The method according to any one of claims 38-43, wherein the nucleation layer comprises nitrogenated carbon.
45. The method according to any one of claims 38-44, wherein the nucleation layer is spaced from the magnetic recording layer, and an upper intermediate layer contacts and is sandwiched between the nucleation layer and the magnetic recording layer.
46. The method according to claim 45, wherein the upper intermediate layer comprises ruthenium.
47. The method according to claim 45 or 46, wherein the upper intermediate layer is selected from a group consisting of Ru, Cr, Co, Cu, Re, Os, and alloys thereof.
48. The method according to any one of claims 45-46, wherein the upper intermediate layer is sputtered in the presence of a reactive gas selected from the group consisting of oxygen, nitrogen and hydrogen.
49. The method according to any one of claims 38-48, wherein the grain size has a mean in the range of 4.5 to 7.5 nm and the grain size distribution has a standard deviation in the range of 8 to 15%.