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DISK TEXTURING METHOD FOR IMPROVED FEATURE ELEVATION UNIFORMITY

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The present invention relates to the field of magnetic recording disk manufacturing, and more particularly to a method for creating a desired surface texture of uniform elevation on selected regions of a magnetic recording disk.

Methods and apparatus for creating texture features on the surface of magnetic recording disks using laser energy are known. See, for example, U.S. patents 5,062,021 and 5,108,781 to Ranjan et al., and published European Patent Application number 94308034.1.

As is known from these references, the beam of a pulsed laser is focused onto the surface of one layer of a magnetic recording disk or substrate with sufficient intensity to locally melt a portion of that layer and/or sublayers. Following incidence of the laser pulse, the melted region resolidifies, leaving a topographic variation (referred to herein as a "laser texture feature") in the surface of the targeted layer and/or sublayers. The geometrical characteristics of the laser texture features are a function of many parameters, including laser pulse width, spot size and shape, spot energy, substrate composition, etc.

Most commonly, these laser texture features are either depressions (e.g., "craters", having a single rim, as shown in Figs. 2A and 2B, and described further below, or multiple rims, as shown in Fig. 2C and 2D) or bumps (e.g., "sombreros", as shown in Figs. 3A and 3B, and described further below) formed in a planar, highly polished nickel phosphate (NiP) layer on an aluminum base material (in the case of the aforementioned published European Patent Application, the texture features are formed directly on the surface of a glass substrate). The layer having the laser texture features is referred to herein as the "textured layer". The rims of the craters or tops of the bumps rise above the plane of the textured layer. Subsequent layers deposited on the textured layer carry forward the topography of the laser texture features so that the outermost layer of the finished multi-layered magnetic recording disk has approximately the same topography as the textured layer (e.g., shape, depth/elevation, radius, density, etc. of the laser texture features). A magnetic recording disk having variation in its surface topography formed by this process is referred to herein as a laser textured disk.

As well known, a magnetic recording disk having a smooth, highly polished surface is preferred in the art to permit a transducer to fly as close to the disk surface as possible. However, as also known, some degree of roughness of the disk surface is necessary to reduce stiction (static friction) between the disk surface and the head. In advanced magnetic

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media, this roughness is applied only to a special region of the disk surface referred to as a landing or contact-start-stop ("CSS") zone over which the head parks during start-up and slow-down (when the disk's rotational speed is insufficient to maintain the air bearing on which the head flies) and when the disk is at rest. The remainder of the disk surface over which the head flies during operation is relatively much smoother than the CSS zone, and is referred to as the data zone. Therefore, particular attention has been paid to zone texturing processes for forming a texture in the CSS zone.

Prior zone texturing methods have involved primarily mechanical application of texture, such as taught by Fukuda et al. in U.S. Patent 4,698,251. However, such mechanical zone texturing methods have proven to lack the required precision and control, e.g., in formation of the transition zone between the CSS and data zones. Laser-based methods have shown promise in improving such precision and control, for example as taught by Ranjan et al. in U.S. patents 5,062,021 and 5,108,781.

However, methods for forming laser texture features known in the art all suffer from the disadvantage that they do not recognize the importance of uniform feature elevation, and consequently do not specifically teach methods to obtain uniform feature elevation.

For example, the high point of the crater-type laser texture features is the rim of the crater. Our studies show

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that the rim of each such laser texture feature varies in elevation around its circumference by up to 100Å, depending sensitively on the intensity distribution at the focal point of the laser, as well as depending on the uniformity of the disk surface material, etc. This variation is referred to as intra-feature elevation variation.

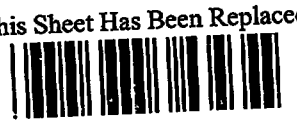
Furthermore, our studies show that as between a number of such crater-type laser texture features formed by virtually the identical process within a disk, the highest point of the features vary. This variation is referred to as inter-feature elevation variation.

The high point of the sombrero-type laser texture feature is generally the single point at its center, and thus this type of laser texture feature generally does not suffer from intra-feature elevation variations. However, our studies show that as between a number of such sombrero-type features, there is a great deal of inter-feature elevation variation.

A clear disadvantage of the presence of such intra- and inter-feature interference is that high points of the features are presented to the read/write head. As this is a relatively few number of points, the pressure from resulting impact will be high, causing wear and generation of debris.

One conclusion that may be drawn from the degree of both intra- and inter-feature elevation variation we have seen is that the final topography of both the crater- and sombrero-type laser texture feature is extremely sensitive to operating conditions such as the laser's pulse width, pulse spot energy,

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shape, size, and starting surface conditions of the layer or substrate to be textured. In addition, as the density of the texture features increases, and the size of the features decreases, the numerical aperture of the lens system focusing the laser spot on the disk must increase. This implies that laser spot power, and hence texture feature elevation, becomes more sensitive to variation in the focal point of the laser beam, such as variation resulting from wobble of the disk in the laser texturing apparatus.

One very important criterion for laser textured disks is that the fluctuation in elevation of the laser texture features be very small (i.e., that the high points of the features be as close to the same elevation above the plane of the magnetic recording disk surface as possible). If the elevations of certain features, or portions of features, are greater than others, those taller features or portions of features will essentially appear as asperities with which a read/write head will collide. Repeated collisions with these high points result in excessive wear of the hard overcoat at these points protecting the relatively soft metal underlayers of the disk. Once this protective overcoat is worn away by the head, further collisions between the head and the disk result in generation of debris from the worn regions of the disk. This debris enhances further wear, smoothing the disk/head interface and increasing stiction, quickly degrading the CSS performance of the disk/head combination.

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In addition, we have discovered that a region of laser texture features of uniform elevation and appropriate density will provide an air bearing at lower disk rotation speeds, preventing the head from prematurely colliding with the texture features, as compared to a region of features of varying elevations. This is important in minimizing damage, generation of debris, wear, and stiction over the surface of a magnetic recording disk, especially the landing zone of a zone textured disk, during start-up and spin-down of the disk.

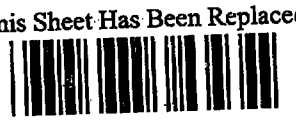
It is an object of the present invention to provide a method for producing laser texture features having uniform elevations by accommodating fluctuations in laser power during laser texturing.

Summary of the Invention

The present invention is a method for operating a laser texturing apparatus such that the feature elevation of laser texture features produced thereby are uniform, despite inherent variation in laser operating conditions.

Associated with each laser texture feature forming process there is what we refer to as a "process window". The process window is the range of operating parameters for a given process which produces laser texture features within a predetermined desired range of elevations. Once a target range of feature elevations is selected, a process may be selected which produces features within that range of

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elevations. Operation of that process within its process window will yield laser texture features within the desired range of elevations; operation of the process outside of its process window will yield laser texture features outside the desired range of elevations.

We have discovered that there is a certain degree of inherent fluctuation in the operating performance of practical laser texturing apparatus, notably in the laser itself. This fluctuation, which is typically manifested by fluctuation in pulse energy, pulse width, and shape of a laser spot forming a laser texture feature, results, *inter alia*, in variation in the elevation of the laser texture feature. Thus, attempts to control variation in laser texture feature elevation must address this fluctuation in laser performance.

The average laser pulse energy, pulse width, and spot shape, as they affect feature elevation, are generally practically controllable. However, pulse-to-pulse fluctuations in pulse energy and pulse width are generally inherent in the system and difficult to control.

We have discovered that preliminary evaluation of a laser texturing system to determine its optimal process window, and operation within that optimal process window permits accommodation for the inherent fluctuations in laser performance. We have determined that a laser texturing system may have multiple process windows, and selection of the optimal process window maximizes the accommodation for such power fluctuations. Thus, for purposes of the present

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invention, an optimal process window is that window accommodating the greatest fluctuation in power while producing features within the range of desired elevations.

For sombrero-type laser texture features, a plot of feature elevation versus power for certain operating conditions exhibits a maximum feature elevation at a single value for power.

We have discovered that there exists a family of such dome-shaped curves whose peak heights can be selected by proper choice of operating conditions, such as pulse width, spot size, etc. Matching the target feature elevation to the maximum feature elevation for such a curve can be used to select the optimal operating conditions for producing features at the target feature elevation, while accommodating the widest variation in laser power.

Our research confirms that a higher rotational velocity of the disk is required to maintain the air bearing which supports the flying head over the crater-type laser texture features as compared with the sombrero-type features. Also, our research indicates that for crater-type laser texture features, increasing laser spot power increases feature height -- the curves of feature height versus spot power are not dome-shaped as they are for the sombrero-type features. Thus, the present invention is described principally from the perspective of forming and using the sombrero-type texture feature.

In general, the magnetic recording disk typically

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comprises an aluminum alloy base material onto which numerous layers are formed. Initially, a plated layer of NiP is plated onto the aluminum alloy base material. Commonly, these two layers are referred to together as the substrate. The plated NiP layer is highly polished and extremely well cleaned by techniques known in the art. Typically, laser energy is then focused onto the surface of the plated NiP layer, forming the laser texture features.

Subsequent to forming the laser texture features, additional layers are formed on the substrate, such as layers of magnetic material and layers of hard and corrosion resistant protective material. These subsequent layers, deposited on the textured layer, carry forward the laser texture features so that the finished multi-layered magnetic recording disk has approximately those same laser texture features (e.g., shape, depth/elevation, density, etc.) in its outermost layer.

According to another embodiment, the laser energy is focused on the well-cleaned surface of the aluminum alloy base material layer or some other layer, and the laser texture features are formed in that layer. Formation of subsequent layers proceeds as otherwise described.

Brief Description of the Drawings

The present invention will be described in greater detail below, including specific examples thereof, with regard to the

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figures, in which:

Fig. 1 is a schematic illustration of an apparatus for producing laser texture features in a magnetic hard disk substrate of the type known in the art.

Fig. 2 is a cross section of a magnetic recording disk illustrating the layered composition and the cross section of laser texture features through the various layers.

Figs. 3A and 3B are perspective and cross-sectional views, respectively, of a single-ridge crater-type laser texture feature.

Figs. 3C and 3D are perspective and cross-sectional views, respectively, of a multiple-ridge crater-type laser texture feature.

Figs. 4A and 4B are perspective and cross-sectional views, respectively, of a sombrero-type laser texture feature.

Fig. 5 is a family of operating curves (laser power vs. feature elevation) illustrating different process windows.

Fig. 6 is another family of operating curves illustrating a range of producible texture feature elevations.

Detailed Description

For purposes of illustration, the present invention will be described by way of selected embodiments. It will be apparent to one skilled in the art that the embodiments, and the environment in which they are developed, demonstrate the functionality and features of the present invention. It will also be apparent that certain variations, additions, deletions, modifications, etc., to the embodiments, although

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not specifically discussed herein, are contemplated and within the scope of one skilled in the art given the present disclosure. Therefore, recitation of embodiments is not intended as, nor should be read as, limiting the scope of the invention claimed herein.

Fig. 1 is a schematic illustration of a laser texturing apparatus 10 for creating laser texture features in a layer of a magnetic recording disk. Apparatus 10 consists of a pulsed laser 12, for example a Q-switched (pulsed) YLF, YAG or YVO_4 laser. Laser 12 produces a coherent laser beam 20, which is directed toward focusing optics (e.g., a lens or a combination of lenses) 22. Optionally, the diameter of the beam 20 may be controlled by beam expander 23 and/or iris 27. Beam 20 may be incident off-center on optics 22 so as to facilitate elimination of feedback of reflected beam 21 into the cavity of laser 12, reducing variation of laser power as described in copending application, attorney docket number K9405 (serial number not yet assigned), of common assignee herewith, incorporated by reference herein.

As shown in Fig. 2, magnetic recording disk 25 is typically a layered structure consisting of a substrate having a base material layer 42, such as an aluminum alloy, and a plated underlayer 44, for example plated NiP. Typically, additional layers are deposited by vacuum deposition, such as sputtering. For example, a sputtered underlayer 46, such as NiP, a magnetic layer 48, such as an alloy of cobalt, nickel, and platinum, and a protective overcoat layer 50, such as

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carbon may then be deposited onto the substrate layers. Variations in the order, methods of deposition, and materials of these layers, and the inclusion of fewer or greater numbers of layers will not, *per se*, change the nature of the present invention.

Following plating, the plated underlayer 44 is polished to a mirror finish and thoroughly cleaned. Magnetic disk 25 is then located in disk receiving region 29. Laser beam 20 is focused by focusing optics 22 to a spot on the surface (referred to as the target surface 24) of plated underlayer 44. Alternatively, target surface 24 may be base material layer 42 or another selected layer of magnetic disk 25. As will be described in further detail below, the incident laser beam causes a local melting of the target surface 24, which rapidly solidifies, leaving a texture feature. The shape, size, etc. of the texture feature is carried up through subsequently formed layers.

As the laser texture features are being formed, motor 26 causes magnetic recording disk 25 to rotate. Thus, as the laser 12 is pulsed, each pulse of beam 20 may be made incident on a different circumferential region of target surface 24. In addition to rotation, magnetic recording disk 25 is translated roughly perpendicular to the path of beam 20, for example by a motor 28, so that the radial location of incidence of laser beam 20 on target surface 24 may be varied. Alternatively, rotating mirrors or other optical techniques may be used to scan the beam radially and/or circumferentially

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across the target surface 24.

The incidence of laser beam 20 on target surface 24 generally forms one of two types of laser texture features, as determined by the parameters of the laser and material comprising the target surface 24. A first of these representative features is referred to as a "crater". A single-ridge crater 30 is shown in Fig. 3A in perspective and Fig. 3B in cross-section. A multiple-ridge crater 31 is shown in Fig. 3C in perspective and Fig. 3D in cross-section. Crater 30 of Figs. 3A and 3B (and crater 31 of Figs. 3C and 3D) has a raised rim 32 (or first and second rims 33, 34 in the case of crater 31), which rises above the plane of target surface 24. The elevation of the crater-type laser texture feature is the elevation h of the rim 32 (or 33, 34) above the plane of target surface 24. The width of the crater-type laser texture feature 30 (or 31) is the diameter d of the roughly circular rim 32 (or 33).

The second representative feature is referred to as a "sombrero" (so-called since in cross section it resembles this type of hat), and is shown at 36 in Fig. 4A in perspective and Fig. 4B in cross-section. Sombrero 36 has a raised rim 38 as well as a central crown 40, which both generally rise above the plane of target surface 24. The raised rim 38 surrounds an annular depression, which in turn surrounds the central located crown 40. The elevation of the sombrero-type laser texture feature is either the elevation h_1 of the rim 38 or the elevation h_2 of the crown 40, whichever is greater, above the

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plane of target surface 24. Preferably, $h_2 > h_1$. The width of the sombrero-type laser texture feature 36 is the diameter d of the roughly circular rim 38.

Associated with each laser texturing process is an operating curve. Fig. 5 shows two such operating curves for two different processes. These curves plot the elevation of laser texture features as a function of laser power for different process parameters. For example, a process A including a certain pulse width, and spot size will produce a curve A. Likewise, a process B including a certain pulse width, and spot size, one or both of which are different from process A, will produce a curve B. For sombrero-type texture features, we have found that each curve will generally be dome-shaped, and will have a maximum feature elevation for a single value of laser spot power.

A laser operated between powers P_1 and P_2 will produce feature elevations between E_1 and E_2. The range of power between P_1 and P_2 is referred to as the process window W_A for process A. Changing, for example, the pulse width of the laser produces a new operating curve B, which produces feature elevations between E_1 and E_2 for laser powers between P_3 and P_4. The range of power between P_3 and P_4 is referred to as process window W_B for process B.

One goal of the present invention is to provide a technique for repeatably producing laser texture features having elevations within a predetermined range. This means that the optimal process window accommodates as wide a

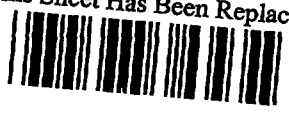
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fluctuation in laser power as possible so as to allow for such fluctuations as are inherent in operation of the laser. With the information provided by Fig. 5, it is possible to select operating conditions (as represented by an operating curve) providing an optimal process window for the production of laser texture features having an elevation as close as possible to a selected elevation, for example E_2.

Specifically, assume we wish to obtain feature elevations as close to E_2 as possible (with some degree of tolerance for system variations). If we know a process is capable of a maximum feature elevation of E_2, for example as shown by curve A, then any variation in elevation will be between some lower limit, for example E_1, and the selected elevation E_2. Now, compare two process for producing a texture feature with elevation between E_1 and E_2, for example process A which, process produces curve A, and process B, which produces curve B. As can be seen from Fig. 5, the process window W_B is much narrower than the process window W_A for the range of selected feature elevations. This means that process A can accommodate a wider variation in laser spot power, such as the aforementioned inherent variations, than can process B for the selected range of feature elevations. The conclusion is that for any desired feature elevation, that process providing the selected feature elevation as the maximum point on the plot of feature elevation versus laser power will accommodate the widest variation in laser power, and from the perspective of producing uniform feature elevation in light of fluctuations

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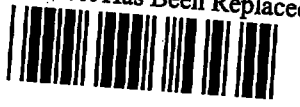


in laser power, is the preferred process over all other process capable of producing features at the desired elevation.

Thus, formation of laser texture features by practice of the present invention begins by referring to a matrix of feature elevation data and associated process parameters specific to the substrate composition in which the laser texture features are to be formed. Such a matrix will typically be constructed by performing multiple test runs of the laser texturing apparatus on the specific target surface composition (e.g., the substrate), keeping all operating parameters constant, monitoring the inherent fluctuations in laser power over time, and plotting the resulting laser texture feature elevations against laser powers to arrive at an operating curve. Next, one or more parameters of the laser texture process are adjusted (for example, spot size and/or pulse width), and the process of correlating feature elevation and laser power repeated to produce a new operating curve.

Once the feature elevation versus process parameter matrix is assembled, a target feature elevation is selected. Selection of this elevation will be a function of desired flying height, and other parameters relating to integration of the magnetic recording disk into a disk drive. A process is then selected having a maximum feature elevation equal to (or within a set percentage of) the target feature elevation. This requires that it is possible to develop processes for arbitrarily selected feature elevations. We have verified

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this is the case for feature elevations at least in the range between 150Å and 500Å.

For example, three curves having arbitrarily selected peak elevations are shown in Fig. 6. These three curves represent processes 1, 2, and 3 for forming laser texture features in a plated NiP layer on an aluminum alloy base. The conditions for each process are shown in Table 1. The focal length for each process was 25.8 mm, and the beam offset from the center of optics 22 was 1.5 mm:

	pulse width	beam size at lens (full width at half maximum)	laser type and model	iris diameter
Process 1	10 nsec	2.0 mm	YLF laser, Spectra Physics 7960-L4-E	3.77 mm
Process 2	35 nsec	1.3 mm	YVO_4 laser, Spectra Physics T20-V70-106Q	3.03 mm
Process 3	35 nsec	0.7 mm	YVO_4 laser, Spectra Physics T20-V70-106Q	3.03 mm

Table 1

As can be seen from Table 1, the various curves of Fig. 6 are selected by varying the beam size, either at a beam expander (as in the exemplary processes 1-3 above), at an iris or by another technique known in the art, and/or by varying the pulse width of the laser. Thus, processes 1-3 illustrate that one skilled in the art may select process conditions

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providing a desired texture feature elevation, for example from within the range of elevations between 150Å and 500Å.

In general, to those skilled in the art to which this invention relates, many changes in construction and widely differing embodiments and applications of the present invention will suggest themselves without departing from its spirit and scope. For example, the present invention has been described from the perspective of forming laser texture features in metal layers. However, there are numerous disclosures in the art relating to the formation of laser texture features in nonmetallic materials, such as glass, which would benefit from the teachings of the present invention.

Furthermore, the present invention has been described in terms of two common cross sections of laser texture feature - the crater and the sombrero. However, these shapes are merely illustrative, and the present invention is not limited to formation of laser texture features of any particular cross-section.

Still further, lasers having frequency multipliers ("frequency multiplied laser") may be used for laser texturing according to the present invention such that the wavelengths employed are 1/2, 1/4, etc. of the natural wavelength of the laser.

In addition, a laser has exemplified the radiation source used to form the texture features. However, other sources of radiation may be employed to form texture features. Principal

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other sources include radiation outside the visible spectrum, such as infrared radiation. Thus, the disclosures and descriptions herein are illustrative, and are not intended and should not be read to be in any sense limiting.

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What is claimed is:

1. A method for forming texture features of uniform and desired elevation in a selected layer of a magnetic recording disk, said method employing a radiation source, comprising the steps of:

selecting a target elevation for said texture features, said target elevation being between 150Å and 500Å;

selecting process parameters, including at least a pulse width of said radiation source and a diameter of a spot representing the incidence of a radiation beam produced by said radiation source on a target surface of said selected layer, said selected process parameters capable of forming texture features at a maximum elevation approximately equal to said target elevation; and

causing said radiation beam to be incident on said target surface with said selected pulse width and said selected spot diameter so as to form texture features having said selected target elevation.

2. A method for forming laser texture features of uniform elevation in a selected layer of a magnetic recording disk, said method employing a laser, comprising the steps of:

selecting a target elevation for the laser texture features, said target elevation being between 150Å and 500Å;

selecting process parameters, including at least a pulse width of said laser and a diameter of a spot representing the incidence of a laser beam produced by said laser on a target

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surface of said selected layer, said selected process parameters forming laser texture features at a maximum elevation approximately equal to said target elevation; and

causing said laser beam to be incident on said target surface with said selected pulse width and said selected spot diameter so as to form laser texture features having said selected target elevation.

3. The method of claim 2, wherein said laser is a YLF laser.

4. The method of claim 3, wherein said laser is frequency multiplied.

5. The method of claim 2, wherein said laser is a YVO_4 laser.

6. The method of claim 5, wherein said laser is frequency multiplied.

7. The method of claim 2, wherein said laser is a YAG laser.

8. The method of claim 7, wherein said laser is frequency multiplied.

9. The method of claim 2, wherein the laser texture features produced have an annular depression surrounding a centrally located crown, said crown being the only part of said laser texture features having the target elevation.

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10. The method of claim 2, wherein said laser texture features are formed only in a selected CSS zone.

11. The method of claim 2, wherein said selected layer is a polished layer of nickel phosphate plated onto an aluminum alloy base.

12. A method for manufacturing a magnetic recording disk of the type having laser texture features of uniform elevation formed in a selected layer thereof, said method employing a laser, comprising the steps of:

selecting a target elevation for the laser texture features, said target elevation being between 150Å and 500Å;

selecting process parameters, including at least a pulse width of said laser and a diameter of a spot representing the incidence of a laser beam produced by said laser on a target surface of said selected layer, said selected process parameters forming laser texture features at a maximum elevation approximately equal to said target elevation;

causing said laser beam to be incident on said target surface with said selected pulse width and said selected spot diameter so as to form laser texture features having said selected target elevation;

depositing by sputter deposition process onto said selected layer a layer of magnetic recording material such that the topography of the laser texture features formed in the selected

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layer is also present in the layer of magnetic recording material; and

depositing by sputter deposition process onto said layer of magnetic recording material a layer of impact and corrosion protection material such that the topography of the laser texture features present in the layer of magnetic recording material is also present in the layer of impact and corrosion protection material.

13. The method of claim 12, further comprising the step of, following formation of the laser texture features and prior to depositing the layer of magnetic recording material, depositing by sputter deposition process onto said selected layer an underlayer of nickel phosphate.

14. The method of claim 12, wherein said laser is a YLF laser.

15. The method of claim 14, wherein said laser is frequency multiplied.

16. The method of claim 12, wherein said laser is a YVO_4 laser.

17. The method of claim 16, wherein said laser is frequency multiplied.

18. The method of claim 12, wherein said laser is a YAG laser.

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19. The method of claim 18, wherein said laser is frequency multiplied.

20. The method of claim 12, wherein the laser texture features produced have an annular depression surrounding a centrally located crown, said crown being the only part of said laser texture features having the target elevation.

21. The method of claim 12, wherein said laser texture features are formed only in a selected CSS zone.

22. The method of claim 12, wherein said selected layer is a polished layer of nickel phosphate plated onto an aluminum alloy base.



