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PATTERNED MAGNETIC MEDIA FOR MAGNETIC RECORDING

5 BACKGROUND

Data storage devices encode data on a magnetic recording media. Data is encoded on the magnetic recording media in longitudinal or perpendicular recording patterns. Magnetic media for a perpendicular recording pattern typically include a magnetic recording layer and a soft magnetic underlayer. The soft magnetic underlayer provides a magnetic flux path to enhance the magnetic field in the magnetic recording layer. Form factors for data storage devices are becoming smaller and more compact thereby increasing demand for higher recording densities. With higher recording densities, magnetic recording widths are becoming smaller and consequently the width of the write pole W_{pole} is narrower to accommodate smaller recording widths. The narrow width of the write pole limits the magnitude flux generated by the write pole and thus the magnetic field in the magnetic recording layer. Embodiments of the present invention provide solutions to these and other problems, and offer other advantages over the prior art.

20 SUMMARY

The application relates to a patterned magnetic media for a magnetic storage device. The patterned media includes etched recording portions, which include etched portions of a soft magnetic underlayer. In illustrated embodiments, the soft magnetic layer of the media is etched to form radially and circumferentially spaced recording bits including a soft magnetic segment. In illustrated embodiments, the soft magnetic segment enhances magnetic field strength of the magnetic recording layer. In other embodiments, soft magnetic layers are deposited in etched regions or areas of the media. Other features and benefits that characterize embodiments of the present invention will be apparent upon reading the following detailed description and review of the associated drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of a data storage device.

FIG. 2 is schematic illustration of a write element of a data storage device configured to record data to a data storage media.

5 FIG. 3 is a schematic illustration of a write pole and data storage media having raised recording portions.

FIG. 4 is a schematic illustration of a write pole and data storage media having raised recording portions including a magnetic recording segment, an intermediate segment and soft magnetic segment etched from a magnetic
10 recording layer, intermediate layer and soft magnetic underlayer.

FIG. 5 is a schematic illustration of a data storage media including a plurality of raised recording bits.

FIG. 6 is a schematic illustration of a magnetic recording media having raised recording bits including a magnetic recording bit segment, an intermediate
15 bit segment and soft magnetic bit segment.

FIG. 7 is a flow chart illustrating fabrication steps for a data storage media.

FIG. 8 illustrates an embodiment of a data storage media including radially and circumferentially spaced recording bits having a magnetic recording bit segment and radially spaced recording tracks including soft magnetic track
20 segments.

FIG. 9 illustrates an embodiment of a data storage media including etched recording portions including a soft magnetic segment between a magnetic recording segment and non-magnetic segment.

FIG. 10 is a schematic illustration of a data storage media including etched
25 recording portions including a soft magnetic segments and an anti-ferromagnetic segment between the soft magnetic segments.

FIG. 11 is a flow chart including processing steps for fabricating a data storage media.

FIGS. 12-14 schematically illustrate embodiments of a data storage media including etched recording portions having a magnetic recording segment and soft magnetic segment and intermediary regions between the recording portions including one or more intermediary layers.

5 FIG. 15 is a flow chart including processing steps for fabricating a data storage media.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

FIG. 1 is a schematic illustrates of a data storage device 100 including a magnetic media 102 for storing digital information or data. In the illustrated
10 embodiment, the media 102 is a disc, which rotates as illustrated by arrow 104 via operation of a spindle motor (not shown). The device 100 includes a head 106 to read data from and/or write data to the magnetic disc or media 102. As shown, the head 106 is carried on a suspension arm 108 coupled to an actuator assembly 110 (illustrated schematically) which moves the head relative to concentric tracks on the
15 disc or media for read/write operations. In an illustrated embodiment the actuator assembly 110 includes a voice coil motor (not shown) which is energized to radially move the head 106 to position the head 106 relative to the concentric data tracks for read/write operations.

The head 106 includes an inductive write element 120 as shown in FIG. 2 to
20 encode data on the disc or media 102. Data is encoded in a parallel (longitudinal) recording pattern or a perpendicular recording pattern. In the illustrated embodiment shown in FIG. 2, the write element 120 is configured to encode data in a perpendicular recording pattern. As shown, the write element 120 shown in FIG. 2 includes a write pole 122, a return pole or shield 124 and coil 126. For write
25 operations, the coil 126 is energized to generate a magnetic flux path between the write pole 122 and the return pole 124. For perpendicular recording, the magnetic media 102 includes a magnetic recording layer 130, an intermediate or non-magnetic layer 132 and a soft magnetic underlayer 134 ("SUL"). The magnetic recording layer 130 is formed of a hard magnetic material that has low permeability and high

coercivity for recording data. The soft magnetic underlayer is formed of a weaker or soft magnetic material relative to the magnetic recording layer 130. The soft magnetic layer has a relatively high permeability and relatively low coercivity to provide a magnetic flux path for the magnetic recording layer. Example soft magnetic materials includes NiFe or CoZrNb.

Upon energization of the coil 126, the soft magnetic underlayer 134 provides a mirror image of write pole 122 to provide a magnetic flux path that focuses the magnetic field of the write pole 122 through the magnetic recording layer 130 to the return pole 124. Intermediate layer 132 is a non-magnetic layer formed of a material, such as CrTa or NiAl and is used to enhance crystallographic properties of the magnetic recording layer 130 to control segregation and crystallography of the grains in the recording layer 130.

As previously discussed, the coil 126 is energized to generate a flux path through the magnetic recording layer 130 to record data to the magnetic recording layer 130. The direction of current through the coil 126 is altered to change the polarity of the write pole 122 and thus alter the recording direction or polarity of the recording layer 130. In particular, the coil 126 is energized in a first direction to provide a magnetic flux path from the write pole 122 in a downward recording direction. The coil 126 is energized in a second direction to provide a magnetic flux path toward the write pole 122 in an upward recording direction.

As shown in FIG. 2, the magnetic recording layer 130, intermediate layer 132 and soft underlayer 134 are fabricated on a substrate 136 of a disc or other media (e.g.magnetic tape). Example substrate materials include aluminum, glass, ceramic or other materials as will be appreciated by those skilled in the art.

In the illustrative embodiment shown in FIG. 3, the media or disc 102 is patterned to form raised or etched recording portions 140. During write operations as shown in FIG. 3, the write pole 122 is positioned proximate to the recording portions 140. Upon energization, the write pole 122 provides a flux path focused in a subtended angle 142. The pole image in the soft underlayer 134

provides a contrast image angle 144 to focus the magnetic flux in the recording layer or portions 130 and provide a closed flux path between write pole 122 and return pole 124. The subtended angle 142 of the write pole 122 and pole image angle 144 of the soft magnetic underlayer 134 define the magnetic field B in the recording layer or portion. For an infinitely thick write pole 122, the magnitude of the magnetic field B in the center of the recording layer or portion is proportional to:

$$B \approx (B_{sat} / \pi)(\tan^{-1}[W_{pole}/D_{SUL}] + \tan^{-1}[W_{pole}/3D_{SUL}])$$

where B is the magnetic field in the center of the magnetic recording layer;

B_{sat} is the saturation flux of the write pole 122;

W_{pole} is the width of the write pole 122;

D_{SUL} is the distance of the write pole to the top of the soft magnetic underlayer 134.

The above equation assumes that the center of the media is half the distance from the write pole 122 to the top of the soft magnetic underlayer 134 ($D_{SUL}/2$). In the above equation W_{pole}/D_{SUL} represents the subtended angle 142 of the write pole 122 and $W_{pole}/3D_{SUL}$ represents the image angle 144 from the soft magnetic underlayer 134. Thus as illustrated, the magnetic field strength B is proportional to the subtended angle 142 of write pole 122 and image angle 144 of the soft magnetic underlayer 134. Form factors for data storage devices are becoming smaller and more compact thereby increasing demand for higher recording densities. With higher recording densities, the recording widths are becoming smaller and consequently the width of the write pole W_{pole} is narrower to accommodate the smaller recording widths.

As illustrated by the equation above, the narrow pole width W_{pole} reduces the subtended angle 142 and image angle 144 of the recording media. This reduces the magnetic field in the recording layer for a give magnetic flux

saturation B_{sat} of the write pole 122. In illustrated embodiments described herein, the soft magnetic underlayer 134 is etched to enhance the magnetic pole image 144 to increase the magnetic field in the magnetic recording layer 130.

In particular, in an illustrated embodiment shown in FIG. 4, the recording
5 layer 130 and etched soft magnetic underlayer 134 are etched to form raised recording portions 150 including an etched magnetic recording segment 152, an intermediate non-magnetic segment 154 and a soft magnetic segment 156. The recording portions 150 as shown in FIG. 4 provide an etched soft magnetic segment 156 which increases contribution of the soft magnetic underlayer to the
10 magnetic field generated in the recording layer 130. In particular, the etched soft magnetic underlayer 134 reduces flux leakage in the etched regions 156 of the media. Flux leakage is inversely proportional to the distance of the soft magnetic underlayer 134 from the write pole 122 and thus the etched soft magnetic underlayer regions increase the distance of the soft underlayer in the etched
15 regions 158 from the write pole 122 thereby reducing leakage.

FIG. 5 illustrates a recording media where the etched recording portions include a plurality of radially and circumferentially spaced recording bits 160 elevated above recessed or etched portions 162 on the media. As shown in FIG. 5, the raised recording bits 160 are generally oval or elliptically shaped and are sized
20 to store a bit of data recorded on the magnetic media. In the illustrated embodiment of FIG. 6, the plurality of recording bits 160 having an etched magnetic recording segment 164, a non-magnetic segment 166 and soft magnetic segment 168 formed of etched portions of the magnetic recording layer 130, intermediate layer 132 and soft magnetic underlayer 134. In the illustrative
25 embodiment, the raised recording bits 160 cover approximately 25% of the media area and the recessed or etched regions 162 cover approximately 75% of the media area. Thus, in 75% of the media area, flux leakage is reduced via the etched regions of the soft magnetic underlayer 134. Also, there is no loss of magnetic field in the recording portion or bits 160 since the soft magnetic underlayer is

etched in the intermediary region between recording portions or bits and the distance of the soft magnetic underlayer or segment from the write pole 122 is the same as in the embodiment illustrated FIG. 3.

FIG. 7 illustrates a flow chart illustrating an embodiment for
5 fabricating a recording media including recording portions having a soft magnetic segment as previously described. As shown in FIG. 7, in step 170, a soft magnetic layer is deposited on substrate 136. The soft magnetic layer 134 is deposited using known deposition or sputtering techniques. In step 172, a non-magnetic layer 132 is deposited on the soft magnetic underlayer 134. As shown, in step 174, the
10 magnetic recording layer 130 is deposited on the non-magnetic layer 132. Thereafter in step 176, the magnetic recording layer 130, non-magnetic layer 132 and soft magnetic underlayer 134 are etched to form the raised recording portions having a magnetic recording segment and soft magnetic segment as previously described. Layers are etched using photolithographic techniques or other
15 patterning and etching techniques, such as reactive ion etching (REI), chemical etching or laser etching. Although illustrative steps are shown in FIG. 7, additional or intermediate steps can be utilized to process the magnetic media as described.

The etched depth of soft underlayer 134 can be optimized using finite
20 element modeling (FEM). The FEM is used to balance magnetic properties of magnetic underlayer 134 relative to flux leakage of the soft magnetic underlayer 134. For example, if the etched depth is too deep, the flux path between the write pole 122 and the return pole 124 is degraded. In contrast if the etched depth is not deep enough, flux leakage limits magnetic field strength in the recording layer for
25 a given write pole saturation B_{sat} . Based upon FEM, it has been found that an optimum depth is provide based upon a ratio of the pole width W_{pole} relative to etch depth. Optimally, the depth to pole width W_{pole} ratio D/W_{pole} is in the range of 0.5-1.0.

FIG. 8 illustrates an alternate embodiment of a patterned media structure. As shown, the media structure illustrated in FIG. 8 includes an array of radially and circumferentially spaced recording bits 170 and a plurality of radially spaced recording tracks 172. As shown, the recording bits 170 include etched magnetic bit segments 176 and the radially spaced recording tracks 172 include an etched non-magnetic track segment 177 and soft magnetic track segment 178. The illustrated pattern reduces the tendency of the magnetization of the soft magnetic segment to orient in a vertical direction which can introduce read back noise and write process variability. The recording bits and tracks are formed by etching the magnetic recording layer 130 in a first etching step and etching the non-magnetic layer 132 and soft magnetic layer 134 in a second etching step. Alternatively, in the embodiment illustrated in FIG. 6, the etched depth of the soft magnetic layer or segments 168 is less than width dimensions of the raised recording bits to reduce the propensity of a vertical remnant magnetization in the soft magnetic segments 168.

FIG. 9 illustrates another patterned media embodiment. In the embodiment illustrated in FIG. 9, the media includes recording portions 180, which have a soft magnetic segment 156 disposed between the magnetic recording segment 152 and the non-magnetic segment 154. The soft magnetic segment 156 is disposed between the magnetic recording segment 152 and non-magnetic segment 154 to boost the magnetic field in the recording layer or segment 152. The soft magnetic segment 156 is formed between the recording segment 152 and non-magnetic segment 154 by depositing a soft magnetic layer 182 on the non-magnetic layer 132 prior to depositing the magnetic recording layer 130. Thereafter, the magnetic recording layer 130, soft magnetic layer 182 and non-magnetic layer 132 are etched as previously described to form the illustrated recording portions 160 as shown in FIG. 6.

FIG. 10 illustrates another embodiment wherein the raised recording portions 190 includes multiple soft magnetic segments 192, 194 separated by an

anti-ferromagnetic segment 196 to force a horizontal rest magnetization as illustrated by arrows 198. In particular, as shown, the etched or raised recording portions 190 include magnetic recording segment 152, non-magnetic segment 154, a first soft magnetic segment 192, a second soft magnetic segment 194 and an anti-ferromagnetic segment 196 between the first and second soft magnetic segments 192, 194. In the illustrated embodiment the anti-ferromagnetic segment 196 to provide flux closure to remove flux leakage from the soft magnetic underlayer or segment to a read sensor of the head 106.. An example of an anti-ferromagnetic layer includes Ruthenium Ru having a thickness in a range of 0.4-1.2nm, however other thickness dimensions can be used. In one embodiment the thickness of the Ru layer is 0.45nm.

FIG. 11 is a flow chart illustrating fabrication steps for fabricating a soft magnetic segment having anti-ferromagnetic layer as illustrated in the embodiment shown in FIG. 10. In step 200, a soft magnetic layer is deposited on a substrate or media surface. An anti-ferromagnetic layer is deposited on the soft magnetic layer in step 202. In step 204 an anti-ferromagnetic layer is deposited on the soft magnetic layer of step 202. Thereafter a second soft magnetic layer is deposited in the anti-ferromagnetic layer in step 206. A non magnetic intermediate layer is deposited in step 208 and the magnetic recording layer is deposited on the intermediate layer in step 210. The magnetic recording layer, intermediate layer, soft magnetic layers and anti-ferromagnetic layer are etched as illustrated in FIG. 10 to form the raised recording portions as described using known etching and masking processes and techniques.

FIGS. 12-14 illustrate embodiments of a patterned media having raised recording portions 220 including etched soft magnetic segments as previously described. The etched recording portions 220 are elevated above etched or intermediary regions 222. In each of the embodiments shown, the etched or intermediary regions 222 include an intermediary layer or portion to enhance magnetic properties of the recording portions 220. In the embodiment illustrated

in FIG. 12, the etched or intermediary regions 222 include a non-magnetic layer or portion 224 to limit fringe fields in the intermediary regions 222. The non-magnetic segment or portion 224 controls write fringe fields to minimize the loss of on track write fields and the strength of erase fields on adjacent tracks of the recording portions 220.

In another embodiment illustrated in FIG. 13, the etched or intermediary regions 222 include a non-magnetic layer 224 and a soft magnetic layer 226. As shown, the non-magnetic layer 224 separates the soft magnetic underlayer 134 of the media from the soft magnetic layer 226 in the intermediary regions or portion 222. The soft magnetic layer 226 absorbs fringe fields or flux in the intermediary region or portions 222 to enhance magnetic properties of the recording portions 220. In the embodiment illustrated in FIG. 13, the height of the non-magnetic layer 224 is preferably above the soft magnetic segment 156 to limit flux path or leakage from the write pole 122 through the intermediary regions or portions 222 to the soft magnetic underlayer 134. In alternate embodiments, not shown in FIG. 13, the recording portions 220 or recording bits are formed of etched segments of the magnetic recording layer 130 or etched segments of the magnetic recording layer 130 and non-magnetic layer 132, but not the soft magnetic layer 134. In these embodiments, the intermediary regions or portions 222 formed by the etched segments include a soft magnetic layer 226 or non-magnetic layer 224 and soft magnetic layer 226 to confine magnetic flux to the recording portions 220 or bits as illustrated in FIG. 13.

FIG. 14 illustrates an embodiment where the intermediary regions or portions 222 include a non-magnetic layer 224 proximate to the soft magnetic underlayer 134. As previously described, height of the non-magnetic layer 224 is preferably above the soft magnetic segment 156 to limit flux path or leakage from the write pole 122 through the intermediary regions or portions 222. In the illustrated embodiment, the intermediary regions or portions 222 also include a first soft magnetic layer 230, second soft magnetic layer 232 and an anti-

ferromagnetic layer 234 disposed between the first and second soft magnetic layers 230 and 232 to enhance magnetic recording properties of the media. Although a particular recording portion structure is shown in FIGS. 12-14, application is not limited to the particular embodiment shown and the recording portion can have alternative structures as illustrated in FIGS. 9-10.

In other embodiments of FIG. 14, intermediary regions 222 are formed by etched segments or bits of the magnetic recording layer 130 or the magnetic recording layer 130 and non-magnetic layer 132, and not the soft magnetic layer 134. In these embodiments, the intermediary regions 222 include a first soft magnetic layer 230, second soft magnetic layer 232, and anti-ferromagnetic layer 234 in the etched regions of the magnetic recording layer 130; or a first soft magnetic layer 230, second soft magnetic layer 232, anti-ferromagnetic layer 234 and non-magnetic layer 224 in etched regions of the magnetic recording layer 130 and non-magnetic layer 132.

FIG. 15 is a flow chart illustrating steps for fabricating raised recording portions and intermediary regions 222 including one or more layers as previously described. As shown, in step 240, a soft magnetic underlayer 134 is deposited on substrate 136. A non-magnetic layer 132 is deposited on the soft magnetic underlayer 134 in step 242. In step 244, the magnetic recording layer is deposited. In step 246 a pattern mask is deposited and the magnetic recording layer 130, non-magnetic layer 132 and soft magnetic underlayer 134 are etched to form raised recording portion including an etched soft magnetic segment and intermediary regions 222. Thereafter in step 250 layers are deposited in the intermediary regions 222 and thereafter, the mask is removed in step 252 and an overcoat layer is deposited on the patterned media .

Although various embodiments are illustrated in the FIGS, application is not limited to the particular embodiments shown and alternate embodiments include selected attributes and features of the various embodiments shown in the FIGS.

It is to be understood that even though numerous characteristics and advantages of various embodiments of the invention have been set forth in the foregoing description, together with details of the structure and function of various embodiments of the invention, this disclosure is illustrative only, and
5 changes may be made in detail, especially in matters of structure and arrangement of parts within the principles of the present invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed. For example, the particular elements may vary depending on the particular application while maintaining substantially the same
10 functionality without departing from the scope and spirit of the present invention. In addition, although the preferred embodiments described herein are directed to a particular recording media, it will be appreciated by those skilled in the art that the teachings of the present invention can be applied to other recording media, without departing from the scope and spirit of the present invention.

WHAT IS CLAIMED IS:

1. A recording media comprising;
a plurality of etched recording portions including an etched soft magnetic segment and an etched magnetic recording segment above the etched soft magnetic segment.
2. The recording media of claim 1 wherein the plurality of recording portions include an etched non-magnetic segment.
3. The recording media of claim 2 wherein the etched soft magnetic segment is between the etched magnetic recording segment and the etched non-magnetic segment.
4. The recording media of claim 1 wherein the plurality of recording portions include a plurality of spaced recording bits including a soft magnetic bit segment and a magnetic recording bit segment.
5. The recording media of claim 1 wherein the plurality of recording portions includes a plurality of recording bits including etched magnetic recording bit segments and a plurality of recording tracks including etched soft magnetic track segments.
6. The recording media of claim 1 wherein the plurality of recording portions include a first soft magnetic segment and a second soft magnetic segment and an anti-ferromagnetic segment between the first and second soft magnetic segments.

7. The recording media of claim 1 and comprising a non-magnetic layer in an intermediary region between the etched recording portions.
8. The recording media of claim 7 and comprising a soft magnetic layer in the intermediary region between the etched recording portions.
9. The recording media of claim 8 and comprising a first magnetic layer, a second magnetic layer and an anti-ferromagnetic layer in between the first and second magnetic layers in the intermediary region between etched recording portions.
10. A recording media comprising:
 - a plurality of radially and circumferentially spaced recording bits and the plurality of spaced recording bits including a magnetic recording bit segment and a soft magnetic bit segment.
11. The recording media of claim 10 wherein the magnetic recording bit segment and the soft magnetic bit segment are etched segments of a magnetic recording layer and soft magnetic underlayer.
12. The recording media of claim 10 wherein the magnetic recording bits include a non-magnetic bit segment.
13. The recording media of claim 12 wherein a depth of the soft magnetic bit segments is smaller than width dimensions of the magnetic recording bits.
14. The recording media of claim 10 and comprising a first soft magnetic bit segment, a second soft magnetic bit segment and an anti-ferromagnetic segment in between the first and second soft magnetic bit segments.

15. A method comprising:
 - depositing a soft magnetic layer on a substrate;
 - depositing a magnetic recording layer; and
 - etching the soft magnetic layer and the magnetic recording layer to form raised recording portions.
16. The method of claim 15 and further comprising
 - depositing a non-magnetic intermediate layer; and
 - etching the non-magnetic intermediate layer to form the raised recording portions.
17. The method of claim 15 wherein the magnetic recording layer and the soft magnetic layer are etched to form a plurality of radially and circumferentially spaced recording bits.
18. The method of claim 15 and comprising
 - depositing a soft magnetic layer in etched regions of the magnetic recording layer or soft magnetic layer.
19. The method of claim 15 and comprising:
 - depositing a non-magnetic layer in etched regions of the magnetic recording layer or soft magnetic layer.
20. The method of claim 15 and comprising
 - depositing a first soft magnetic layer;
 - depositing an anti-ferromagnetic layer on the first soft magnetic layer;
 - depositing a second soft magnetic layer; and

etching the first soft magnetic layer, the anti-ferromagnetic layer and the second soft magnetic layer to form the raised recording portions.