SLIDER FOR DISC STORAGE SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to disc storage systems for storing information. More specifically, the present invention relates to sliders used in such systems.

Disc drives are used for storing information, typically as magnetically encoded data, and more recently as optically encoded data, on a disc surface. A transducing head is carried on a air-bearing slider that rides on a bearing of air above the disc surface as the disc rotates at high speed. In another technique, the slider contacts the disc surface with no air bearing interface such as is shown in U.S. Patent Nos. 5,453,315 and 5,490,027. The head is then positioned radially over the disc to read back or write at a desired location. Benefits associated with an air bearing design are lost in such "contact" sliders.

In an air bearing design, the air bearing provides an interface between the slider and the disc which prevents damage to the disc over the life of the system, provides damping if the disc drive system undergoes shock due to external vibrations. The air bearing is also used to provide a desired spacing between the transducing element and the disc surface. A bias force is applied to the slider by a flexure armature in a direction toward the disc surface. This bias force is counteracted by lifting forces from the air bearing until an equilibrium is reached. The slider will contact the disc surface if the rotating speed of the disc is insufficient to cause the slider to "fly." This contact typically occurs during start up or shut down of the disc. If the slider contacts a region of

the disc which carries data, the data may be lost and the disc permanently damaged.

In many disc drive systems, a lubricant is applied to the disc surface to reduce damage to the head and the disc surface during starting and stopping. Air or gas also acts as a lubricant. However, a phenomenon known as "stiction," which is caused by static friction and viscous shear forces, causes the slider to stick to the disc surface after periods of non use. The lubricant exasterbates the stiction problem. The stiction can damage the head or the disc when the slider is freed from the disc surface. Additionally, the spindle motor used to rotate the disc must provide sufficient torque to overcome the stiction.

One technique used to overcome the problem associated with stiction is to provide texturing to at least a portion of the disc surface. However, this reduces the effective recording area of the disc. Additionally, various attempts have been made to provide texturing on the air bearing surface of the slider. For example, U.S. Patent Nos. 5,079,657 and 5,162,073 describes a technique for forming recesses in a slider surface. Another technique which is described in U.S. Patent No. 5,418,667 includes providing large pads which provide a pitch to the slider to allow air flow between the air bearing surface and the disc.

SUMMARY OF THE INVENTION

A disc storage system includes a rotating disc and a transducer. The transducer is carried on a slider which is supported by an armature. The armature is used to move the slider radially across the disc surface whereby information may be read from or written to the disc surface of the transducer. The slider includes an air bearing surface which faces the disc surface. As

the disc rotates, the air bearing surface causes the slider to "fly" over the disc surface. Pads are provided on the air bearing surface to improve operational characteristics of the system. For example, the pads may be used to reduce the stiction or improve flying characteristics. Further, one aspect of the present invention includes techniques for fabrication of such pads.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a simplified diagram of a storage disc system in accordance with the present invention.

Figure 2A is a graph of stiction as a function of height of landing pads of various sizes.

Figure 2B is a graph of stiction as a function of lubrication thickness.

Figures 3A-3D are side cross-sectional views of steps in a process in accordance with one embodiment of the present invention for forming landing pads.

Figure 3E is a bottom plan view of a slider including landing pads made in accordance with the steps of 3A-3D.

Figure 3F is a side view of a mask in accordance with one embodiment of the invention.

Figure 3G is a side plan view of a landing pad formed using the mask of Figure 3F.

Figure 3H is a side view of a mask in accordance with one embodiment of the invention.

Figure 3I is a side plan view of a landing pad formed using the mask of Figure 3H.

Figure 4A is a bottom of a slider in accordance with another embodiment of the present invention.

Figure 4B is a side cross-sectional view of a rail of the slider of Figure 4A.

Figure 4C is a side plan view of a rail of a slider in accordance with another embodiment of the present invention.

Figure 5A is a bottom plan view of a slider in accordance with another embodiment of the present invention.

Figure 5B is a bottom plan view of a slider in accordance with another embodiment of the present invention.

Figure 6A is a bottom plan view of a slider in accordance with another embodiment of the present invention.

Figure 6B is a bottom plan view of a slider in accordance with another embodiment of the present invention.

Figure 6C is a bottom plan view of a slider in accordance with another embodiment of the present invention.

Figure 6D is a side plan view of a slider in accordance with another embodiment of the present invention.

Figure 6F is a side plan view of a slider in accordance with another embodiment of the present invention.

Figure 7A is a bottom plan view of a slider in accordance with another embodiment of the invention including kick pads.

Figure 7B is a side plan view of the slider of Figure 7A.

Figures 8A, 8B and 8C are side cross-sectional views of pads in accordance with embodiments of the invention.

Figure 8D is a side plan view of a slider having an air bearing surface formed in accordance with the embodiments of Figures 8A-8C.

Figure 9A is a side plan view of a slider in accordance with one embodiment of the invention shown relative to a medium surface.

Figure 9B is a graph of stiction versus belly clearance for a slider.

Figure 9C is a bottom plan view of a slider in accordance with another embodiment of the invention.

Figure 10 is a bottom plan view of a slider in accordance with another embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a top view of a disc drive 10 including a slider in accordance with the present invention. Disc drive 10 includes a magnetic disc 12 mounted for rotational movement about and axis defined by spindle 14 within housing 16. Disc drive 10 also includes an actuator 18 mounted to a base plate 20 of housing 16 and pivotally moveable relative to disc 14 about axis 22. A cover 24 covers a portion of actuator 18. Drive controller 26 is coupled to actuator 18. In the preferred embodiment, drive controller 26 is either mountable within disc drive 10, or is located outside of disc drive 10 with suitable connection to actuator 18. Actuator 18, includes an actuator arm assembly 28, a rigid support member 30, and a head gimbal assembly 32. Head gimbal assembly 32 includes a load beam or flexure arm 34 coupled to rigid member 30, and a slider 36 coupled by a gimbal (not shown) to load beam 34. Slider 36 operates in accordance with the embodiments set forth herein and supports a transducer for reading information from and encoding information on disc 12.

During operation, drive controller 26 receives position information indicating a portion of disc 12 to be accessed. Drive controller 26 receives the position information from an operator, from a host computer, or from another suitable controller. Based on the position information, drive controller 26 provides a position signal to actuator 18. The position signal causes actuator 18 to pivot about axis 22. This, in turn, causes actuator 18 to pivot about axis 22. This, in turn, causes slider 36 (and consequently the transducer mounted on slider 36) to move radially over the surface of disc 12 in a generally arcuaic path indicated by arrow 38. Drive controller 26 and actuator 18 operate in a known closed loop, negative feedback manner so that the transducer carried by slider 36 is positioned over the desired portion of disc 12. Once the transducer is appropriately positioned, drive controller 26 then executes a desired read or write operation.

Recording density can be increased by reducing the fly height of slider 36. Close proximity of slider 36 with disc 12 allows greater accuracy in reading and writing information onto disc 12.

Stiction and fly/stiction are two major phenomena that impair the use of ultra-low flying recording heads to increase recording areal density. The solution to these problems has been to generate, in a controlled fashion, some asperities, or texture, on the media surface to reduce the area of contact at the head-media interface. The presence of these asperities on the media surface, although they can be confined to only within a small dedicated zone (i.e., a "landing zone"), enhances the chance of head-media contact during operation and thereby sets the limit to the true attainment of ultra-low flying. In most cases, due to

the shape of the asperity, the nature of contact is called Hertzian contact, in which elastic deformation can occur locally. Consequently, the number of asperities on the media surface to support the head cannot be arbitrarily reduced, otherwise the interface will collapse leading to excessive stiction. In addition, this type of contact is prone to collapsing when an excessive amount of liquid lubricants are present in the interface. For example, the lubricant applied on the media to prevent wear during head-disc contact, as well as other outgassing materials from various drive components, may accumulate on the heads, and transfer to the interface thereby leading to excessive fly/stiction.

One aspect of the invention includes modeling the stiction to provide a desired texturing to the air bearing surface, as opposed to the medium surface. If the tip of the asperity in contact can be described as semi-spherical, a stiction model has predicted that head-disc interface could become unstable when the asperity density becomes too small or lube thickness too high. One stiction model is described in an article in J. Appl. Phys. 78, 4206 (1995) by J. Gui and B. Marchon. However, if the shape of asperity is a column or a step, the elastic deformation does not occur locally. This "non-Hertzian" contact has a much higher rigidity in comparison to a spherical type of contact. Consequently, the number of contacting points at the interface may be reduced to control stiction without worrying about the possibility that the interface may collapse. Under this contact condition, fly/stiction will not occur, and stiction is mainly a function of the contacting area (or bearing area), which can be modelled rather readily. A

stiction model can be used to predict stiction level as a function of texture geometries.

Texture features may be placed on either media or sliders. However, if this kind of texture is put on a media surface, the density of these texture features still has to meet a minimum requirement imposed by the fact that if the texture features are too far apart, the slider could fall in between the texture features and directly contact the smooth media surface, leading to high stiction. One aspect of the invention that can ensure the contacts between sliders and a disc are always made on texture is to put these texture features on the sliders. Kasamatsu et. al. from Fujitsu has reported low stiction from smooth disks using heads that had small pads on the sliders in the article at IEEE Trans. Magn. 31, 2961 (1995).

The present invention includes small column-like texture features, i.e., landing pads, on the rails of a flying head to control stiction. For example, four such pads may be used. Sliders with such landing pads can be used on substantially smooth discs. The size and height of these landing pads must be controlled such that the pads can effectively reduce stiction during take-off yet provide enough clearance to prevent interference during normal flying. The following equations can be used to calculate the size and height of the pads based on the stiction requirement of a drive design:

$$S=\mu Ea\frac{H-h}{H} \qquad \text{Eq. 1}$$

$$\frac{2\gamma A}{h}\frac{d-(h/\alpha)^{1/3}}{h-(h/\alpha)^{1/3}}+\frac{2\gamma a}{h}+W=aE\frac{H-h}{H} \qquad \text{Eq. 2}$$

where S is stiction, μ is coefficient of friction, E is the Young's modulus, a is the total surface area of all pads, H is the pad height, h is the head-disc separation at contact, W is the head pre-load, A is the air bearing surface area, and α is a constant defined by $(12\pi\gamma/A_H)$ where γ is the surface tension and A_H is the Hamaker constant.

Figure 2A is a graph of stiction as a function of the heights of the landing pads of various sizes. These curves are generated from above two equations. Based on these curves, if one chooses the total area of landing pads to be between about 0.002 to 0.003 mm^2, and height to be about 300 Å, stiction is between about 2 to 3 gram-force, which is well within current disc drive design requirement.

Figure 2B shows stiction as a function of lubrication thickness for both landing pad design and a laser zone texture media design. As lube thickness increases, stiction increases. However, stiction increases much more rapidly in the case of the laser zone textured media, eventually stiction diverges at still higher lube thickness. This interface instability is the fundamental cause of fly/stiction. In the case the landing pad texture, on the other hand, stiction exhibits a well defined linear relationship with lube thickness. It does not diverge as lube thickness continues to increase. In other words, the fly/stiction problem does not occur for landing pad texture.

The modeling technique set forth herein may be used with other aspects of the present invention. The shape, density and placement of the pads may be modified as desired. Further, the pads may be formed using any appropriate technique. Such formation techniques are not limited to those specifically set forth herein.

One aspect of the present invention includes various techniques for forming landing pads. Figure 3A is a cross-sectional view of one embodiment of a slider 110 in an area on which landing pads are to be formed on surface 112. The slider body is coated with a vacuum compatible negative photoresist and the resist 114 is patterned as shown in Figure 3B. Next, a landing pad material is deposited anisotropically, typically using an ion beam to deposit, for example, diamond-like carbon (DLC) to form DLC layer 116. The photoresist 114 and its overcoat of DLC are removed using any appropriate technique such as sodium bicarbonate blasting followed by a cleaning step such as a deionized water rinse and a dry to form pad 118 as shown in the cross section of Figure 3D.

This process offers a number of advantages over other techniques. For example, using this embodiment the edges of pad 118 are automatically deposited such that they blend smoothly into the slider body surface. This advantages arises from the "penumbral" shadowing of the anisotropic deposition process. Further, the landing pad material can be deposited over a previously deposited protective layer of the same material. This provides some protection from corrosion and electrostatic discharge (ESD) hazard to sensitive material used in the magnetic transducer early in the fabrication process. No additional adhesion layer, such as silicon, is required. The mechanical removal process makes any deviations which result from a landing pad material adhesion failure immediately and obviously detectable thereby providing improved reliability. This technique is also less expensive than reactive ion etching techniques and the pad can be deposited relatively quickly. The increased

speed provides improved manufacturability and reduced costs by minimizing work in process. The process is also compatible with current techniques used for processing arrays of slider bars as they are lappēd to their final surface finish. This is less expensive than attempting to deposit pads on individual sliders. Further, the process is compatible with materials that are difficult or impossible to remove from the substrate using etching or milling processes. Such materials include hard materials such as cathodic arc diamond films. Figure 3E is a bottom plan view of slider 110 showing four pads 118 carried on rails 120. Using a four to eight pad design such as shown in Figure 3E, in one preferred embodiment of the invention the pads have a area of between about 100 μm^2 to about 12,000 μm^2. The pads may provide any shape such as square or elliptical with an aspect ratio of about 2 to 1. Any other shape may be used such as round, tear drop, etc.

One aspect of the present invention includes controlling the angle of deposition relative to the plane of the substrate to form a desired surface on the landing pad. Figure 3F shows one embodiment in which mask 114 has a thickness of 2.6 μm and a width of 5 μm. The ion beam 126 used for deposition is angled such that there is a 2.2 μm shadow. The substrate is rotated during deposition such that a convex contacting surface 122 as shown in Figure 3G is formed on pad 118. Figure 3I shows a concave contacting surface 124 on pad 118. Such a concave surface may be formed using the mask 114 shown in Figure 3H having a thickness of 4.8 μm and a width of 5 μm. This provides the 4 μm shadow which, as the substrate rotates, causes the contact area of the pad 118 to have the concave shape. Such concave or convex shapes are particularly advantageous because the

reduce the size of the contact area. Further, such shapes may have desirable hydrodynamic properties.

The above processing steps may be used to form any of the pads set forth herein, or other pads which are not explicitly set forth herein, as desired. The particular shape, height, placement and density of the pads may be in accordance with any particular design to achieve desired slider characteristics.

The present invention includes a novel technique for creating pads on the air bearing surface. As used herein, the term "pad" includes the structure formed by forming grooves in the air bearing surface of the slider. In one aspect of the invention, such pads or grooves are created using a laser beam, such as a pulsed continuous laser, at preferred locations along the air bearing surface. The dimensions of the features may be adjusted by varying the laser power, the pulse duration, the laser wavelength, etc. Instead of using diamond-like carbon, in this aspect of the invention the contact surface is the same as the slider, for example, AlTiC. This reduces the concern of wear of the DLC due to repeated landings and take offs. Further, the real area of contact between the disc and the head is reduced in comparison to "feet" type bumps in that the contact area is a line contact rather than an area contact. Further still, application of such a laser is easily integrated into current manufacturing techniques which use a laser to form the crown on a slider.

Diamond-like carbon is not considered advantageous for the formation of the pads in all embodiments of the invention. For example, DLC tends to wear with time and requires additional processing steps.

In another aspect of the invention, pads or feet are formed of AlTiC. For example, such feet may be

formed through the application of a photoresist at selected locations on the slider followed by a subsequent etch such as an extended etch milling process. The photoresist is then removed revealing raised areas in the AlTiC slider body. For example, in Figure 3B, ion milling may be applied to slider 110 thereby removing exposed portions of slider 110.

These techniques may be used to form pads of any shape, position, density, or other desired characteristics whether or not specifically set forth in the present disclosure.

Figure 4A is a bottom plan view of a slider 150 in accordance with another embodiment of the present invention. Slider 150 includes rails 152 carrying pads 154. Furthermore, in accordance with one aspect of the present invention, depressions or recesses 156 are formed on rails 152. Figure 4B is a cross-sectional view of rail 152 taken along the line labeled 4B--4B shown in Figure 4A and shows a cross-sectional view of recesses 156.

The invention as set forth in Figures 4A and 4B is particularly advantageous because depressions 156 produce a hydrodynamic effect providing additional lift. Furthermore, as illustrated in Figure 4C which is a side plan view of rail 152, rail 152 typically includes a curvature between the leading and trailing edges. This curvature is referred to as a crown and may be on the order of 20 nm. Curvature along the outer rail and inner rail is referred to as camber and is on the order of 8 nm. If pads 154 have a height of 20 to 30 nm, the crown of rail 152 may be sufficient to interfere and cause contact to occur to the center region 160 of slider 152 and the disc surface. Recesses 156 provide additional lift to prevent such contact.

This aspect of the present invention is particularly advantageous because it does not require additional protrusions yet provides increased hydrodynamic effects during flying. This allows the slider to achieve a lower flying height by decreasing the air bearing effect. This "micro-hydrodynamic" effect improves flying characteristics when the slider transitions from a stationary position to a sliding position and vice versa. Recesses 156 may be optimized both in size, depth and shape. Recesses 156' in Figure 4A show four example shapes which may be used for recesses 156. Similarly, recesses 156 and 156" shown in Figure 4B are various examples of cross-sectional shapes. The specifications for recesses 156 may be optimized by modeling using, for example, Reynold's Equation and/or by performing experiments. In some embodiments, it may be possible to eliminate the crown on the rails 152. However, in another aspect of the invention, additional pads 162 may be added near the center line on the rail 152 as shown in Figure 4C. Pad 162 may hit a height which is less than the height of pads 154. In one embodiment, the height of pads 154 should be slightly larger than the tallest asperity present in the media, typically around 10 nm for a very smooth media in which the roughness Ra is about 1 nm.

Furthermore, recesses 156 can be designed to provide additional damping to the air bearing for load/unload applications in which the quick formation of an air bearing between the slider and the disc is critical. Such air bearing damping is very advantageous for establishing the air bearing. The recesses 156 may also be used to provide additional damping should slider 150 contact an asperity on the disc surface. One aspect of the invention includes an air bearing surface

including such recesses but without the use of landing pads. This is particularly advantageous for load/unload as there are no zero speed/stiction issues. Thus the recesses provide additional damping and reduced flying characteristics.

Another aspect of the present invention may be employed with pads in accordance with other aspects of the invention, or other pads which are not specifically set forth herein. Further, the recesses may be of any desired shape, form, depth, density to achieve desired air bearing characteristics.

In another aspect of the present invention, rails 200 of slider 202 as shown in Figure 5A includes a large plurality of pads 204 formed thereon. This configuration of the invention is particularly advantageous. With the present invention, numerous small pads are fashioned over a majority of the air bearing surface of the slider. As discussed above, the head to disc spacing during the read and write operations is critical to recording densities. Therefore, the textured pads 204 stop at a position which is spaced apart from the trailing edge 208 of the slider 202 and the transducer 210.

By placing numerous pads 204 across a relative large area, the interface between the slider 202 and the disc surface is less sensitive to changes in the crown or flatness of the slider. Further, the use of numerous pads 204 is advantageous because it provides improved reliability as a single defective pad will not cause a catastrophic failure. Further still, this aspect of the present invention provides a head/disc interface which may be studied based upon studies performed on head/disc interfaces in which the disc surface is textured and the slider is smooth.

During take-off, slider 202 tends to rock back and forth, and/or side to side. The use of multiple pads 204 allows the load to be distributed over numerous pads, even during this rocking motion. The pads 204 are also relatively easy to align with the air bearing surfaces during manufacture. Further, the use of numerous pads to provide a fully textured air bearing surface provides reduced friction and stiction relative to a design with four pads.

Experiments conducted in accordance with the present invention showed that the fully textured configuration provided an average dwell stiction of about 5 grams whereas a design using four pads yielded a dwell stiction of about 15 grams. In one preferred embodiment for the fully textured air bearing surface, the pads have a height of between about 100 and about 1000 Å, an area of between about 10 and 100 μm^2, a density of about 1 pad per about 100 μm^2 to about 10,000 μm^2. The pads may be distributed across anywhere from about 10% to about 100% of the air bearing surface, in one preferred embodiment, the full texturing is confined to an area in about the middle 2/3 of the rails. Further still, in some designs it may be desirable to have pads positioned differently on an inner rail of the slider versus an outer rail. For example, the relationship between pads on the rails may be such that pads on one rail are closer to a leading edge while pads on the other rail are closer to a trailing edge. However, these parameters may be adjusted as appropriate based upon the particular configuration and desired specifications.

Figure 5B is a bottom plan view of slider 202 showing rails 200 with various configurations for pads 204. As shown in Figure 5B, pads 204 may by circular

(204A), rectangular (204B), angled rectangles (204C), squares (204D), etc. the shape and placement of pads 204 may be predefined using masking techniques or may be random.

Figure 6A is a bottom plan view of a slider 230 having rails 232 in accordance with another embodiment. Rails 232 carry pads having heights which vary with position. In this example of the invention, pads 234 have a height which is different than pads 236. Varying the height of the pads can be used to further reduce fly stiction and dwell stiction. In the present example, pads 236 have a greatest height which is greater than about 200 Å and pads 234 have a lowest height which is about 200 Å. The greater height of pads 200 improves the margin for stiction and wear of the pads. Further, the lower height pads 234 help avoid contact between the trailing edge 238 of slider 230 and the disc during operation. Furthermore, as illustrated in Figure 6A the location of the pads can be randomized. Such randomization reduces the chance that the pads will contact the disc along the same track during repeated operation. This reduces unbalanced wear on the disc surface.

In another aspect of the invention, the area of the pads can be varied either randomly or as a function of position. Figure 6B is a bottom plan view of slider 240 having rails 242 carrying pads 244 and 246. As illustrated in Figure 6B pads 244 which are near the leading edge 248 of slider 240 provide a larger area in comparison to pads 246. This configuration is advantageous because pads near the leading edge 248 of slider 240 tend to experience increased wear and stress relative to pads closer to the trailing edge. The large

front pads 244 exhibit improved wear behavior and are less likely to be broken during operation.

Figure 6C is a bottom plan view of a slider 250 in accordance with another embodiment having rails 252. Rails 252 include pads 254 and 256. Preferably, there are a plurality of pads 256 positioned near the crowned portion of a crowned rail 252. Pads 256 may be of number, density, height and shape, etc. as desired to reduce contact between the crowned portion of rails 252 in the medium.

Figure 6D is a side view of a slider 260 in accordance with another embodiment shown relative to storage disc 262. In the embodiment of Figure 6D, pads 264 positioned near the leading edge 266 of slider 260 have a height which is greater than pads 268 positioned closer to the trailing edge. Pads 264 extend from the leading edge to the mid section of slider 260. This is particularly advantageous for heads in which the leading edge may experience increased wear in comparison to the trailing edge due to a negative pitch of the slider during initial operation.

Pads 268 may be formed using a second mask, or other technique set forth herein, for example, and disposed with a height to avoid contact with medium 262 during normal operation. Further, pads 264 reduce stiction during normal operation and are capable of absorbing any contact or wear should the slider 260 pitch forward.

Figure 6F is a side view of a slider 270 shown flying over disc 262 in accordance with another embodiment. Slider 270 includes bumps 272 in accordance with the present invention. In the embodiment of Figure 6F, bumps 272 have are tallest near the leading edge 274 of the slider which is progressively shorter in a

direction toward the trailing edge 276. This may be a relatively continuous change or may be through a series of steps. The geometry may be obtained through an desirable technique. For example, through the use of shadowing during the deposition and formation processes.

Another aspect of the present invention includes the recognition that placement of pads on the air bearing surface may be used to optimize performance.

For example, placing pads closer to the trailing edge of the slider can improve contact start/stop (CSS) performance because the slider is less likely to tip backwards thereby contacting the trailing edge of the air bearing surface which would lead to stiction with the polished media. However, slider flyability is improved by moving the rear pads toward the leading edge of the slider. Placing the rear pads near the leading edge of the slider reduces the likelihood that the pads will contact the media surface due to changes in altitude, roll sensitivity and access fly height losses.

The present invention also provides a technique to overcome the tradeoff between CSS and flyability performance. Figure 7A is a bottom plan view and Figure 7B is a side plan view of slider 300 in accordance with another embodiment of the invention. Slider 300 includes rails 302 and pads 304. Further, slider 300 includes kick pads 306 positioned behind pads 304, closer to trailing edge 308 of slider 300. Kick pads 306 prevent slider 300 from tipping during operation in a manner which would cause the trailing edge of slider 300 to contact the medium surface. This will avoid a high stiction orientation during operation. Further, kick pads 306 allow pads 304 to be placed closer to the leading edge of slider 300 thereby

improving flyability of slider 300. Preferably, kick pads 306 have a height which is less than the height of pads 304 such that pads 306 do not contact the media surface during normal flying. The design of pads 304 and 306 is preferably such that they may be easily integrated into the manufacturing process and have size, shape and positioning to achieve the desired flying and start/stop characteristics for a particular slider, media, lubrication, speed, etc. The kick pads 306 may be of appropriate size, shape or density as desired.

One aspect of the use of pads on sliders in accordance with the present invention is that the pads may become smooth as the surface is worn over time. This tends to reduce the compatibility of the pads with a very smooth media surface. The smooth pad may increase the dynamic friction.

One aspect of the invention includes texturing the pads to thereby provide a rough surface on the pad to further reduce contact area and thereby reduce friction. The texturing may be in accordance with any technique. However, one technique which may be integrated in a diamond-like carbon pad is through the introduction of small particles, such as silicon dioxide, slightly below the diamond-like carbon. For example, the smallest particles may be 3 to about 20 nm below the DLC. The total thickness is in one embodiment, between about 30 nm and about 50 nm. The texture may be applied directly to the air bearing surface, (for example, using a mask to form a pad) on a DLC pad, on adhesion layer, or in multiple layers of particles and DLC. Such particles may provide a height of between about 0.1 micro inches to about 10 micro inches.

Figure 8A is a side cross-sectional view of a rail 320 of an air bearing surface carrying a pad 322. Pads 322 include particles 324, such as silicon dioxide, coated with a DLC layer 326. As illustrated in Figure 8A, the particles 324 provide a texturing to the surface of the DLC layer 326.

Figure 8B is a cross-sectional view of an air bearing surface 328 of a rail 328 in accordance with another embodiment in which a pad 330 is formed on an intermediary layer 332 which carries particles 324 and DLC layer 326 thereon. Intermediary layer 332 may, for example, comprise a DLC layer or an adhesion layer with particles 324 deposited thereon.

Figure 8C is a cross-sectional view of a pad 338 in accordance with another embodiment deposited on the air bearing surface 340 of a rail. Pad 338 is formed using any desired number of multiple layers of particles 342 and DLC layers 344. This provides multiple layers of texturing which may be exposed as head 338 wears over extended use.

The particles may be deposited on the air bearing surface or landing pads to provide desired texturing. The DLC, or other layer, is applied to encapsulate the texture into the substrate. This layer also preferably provides a good tribological material. Tall structures may be obtained using multiple layers. Figure 8D is a side plan view of a slider 350 including air bearing surfaces 352 which are formed using a texturing technique in accordance with this aspect of the invention in which a plurality of small particles are injected into layers of material during fabrication.

As set forth herein, pads on sliders in accordance with the present invention allow the slider to fly closer to the medium and thereby provide higher

areal recording density. Further, the need for zone texture on the medium is eliminated. Figure 9A is a side plan view of a rail 370 of a slider in accordance with one embodiment of the present invention. RaiI 370 includes a crown in which the middle portion 372 of the rail is closer to the medium 374 in comparison to end portions 376. This four pad design (two pads on each rail) may, in some embodiments, be susceptible to high stiction because of the interface between crown portion 372 and medium 374. As illustrated in Figure 9A, the minimum separation distance between the air bearing surface of rail 370 and the surface of medium 374 is defined by the clearance at crown portion 372 rather than by the height of pads 378. As the crown may be substantial, especially in 50% slider designs in which the clearance between crown portion 372 can be significantly smaller than the height of pads 378. Thus, a large menisci is formed between crown portion 372 and medium 374 which leads to relatively large stiction. For example, Figure 9B is an example of stiction versus belly clearance (i.e., crown clearance) for a 50% slider design having four pads 378. The data from Figure 9B is the three second dwell stiction for sliders having four pads with a 15 Å lubricant film having a medium molecular weight. The variations in the belly heights for the five different heads plotted are caused by variations in the crown while the pad height was roughly constant at about 1.3 to 1.4 μinches. As illustrated in Figure 9B, there is a strong correlation between stiction and belly clearance. In particular, a low belly clearance (i.e., highly crowned) slider exhibits very high stiction whereas heads with greater clearance provide significantly less stiction. Since the height of pads 378, and in particular the height of

the rear pad, is constrained by the requirement that when the head is flying over medium 374 the trailing edge of the slider which carries the transducer must be positioned very close to the disc surface, this stiction represents a critical issue in four pad designs having crowned rails.

Figure 9C is a bottom plan view of a slider 390 in accordance with another embodiment. Slider 390 includes rails 392 extending from a leading edge 394 to a trailing edge 396. Slider 390 further includes outer edge pads 398 and middle pads 400. The addition of middle pads 400 cause the effective crown between adjacent pads to be reduced by a factor of 4 in comparison to the four pad designs shown in Figure 9A. Consequently, the clearance problems shown in Figure 9B are mitigated.

In another aspect of the present invention, the problem associated with crown can be eliminated by leaving the slider uncrowned and using only four pads. The four pads lift the slider air bearing surface off of the medium when the head is at rest such that a crown is not necessary for take-off. With such a zero crown design, the separation between the air bearing surface and the medium surface is determined by the pad height and the stiction problem illustrated in Figures 9A and 9B is eliminated. In another embodiment, a slight crown is provided such that the clearance is sufficiently great to provide the desired stiction reduction. For example, using the data given in Figure 9B, if the crown is less than 0.2 μinches, the disc to air bearing surface separation will be determined primarily by the pad height.

In another aspect of the present invention, it has been recognized that various portions of a slider

are subjected to contact with the disc surface during take off. During the initial phase of take off, the middle portion (i.e., "belly") of the slider contacts the medium. As the velocity increases, the leading edge of the slider contacts the medium because the slider tips forward. Finally, after take off, formation of the air bearing causes the slider to tip in the opposite direction leading to contact with the trailing edge. Thus, different portions of the slider are in contact with the medium surface during different take off periods. In one experiment, contact start/stop testing was performed on an air bearing surface in accordance with embodiments set forth herein having DLC pads on a highly polished medium surface. It was discovered that the pads located at the leading edge of the air bearing were broken due to high adhesive forces experienced during take off by the leading edge. However, pads located in the middle portion of the slider and near the trailing edge were not broken and were not substantially worn.

Figure 10 is a bottom plan view of a slider 420 in accordance with another embodiment. Slider 420 includes leading edge 422 and trailing edge 424 having a center island 426 carried thereon. Rails 428 extend along either side of the slider 420. As illustrated in Figure 10, the rails of slider 420 are divided generally into three sections, a leading section 430, a mid section 432 and a trailing section 434. Leading section 430 carries pads 436 having a relatively large diameter (or area) to provide additional strength and reduce the likelihood of breakage. Similarly, trailing section 434 also carries large size pads 438 to provide additional strength and reduce the possibility of breakage. Mid section 432 carries smaller pads 440 which provide a

smaller cross-sectional area which may be optimized to reduce stiction and improve flyability. The increased size of pads 438 also reduces the amount of wear should prolonged contact with media occur during operation.

The pads 436,438,440 shown in Figure 10 may be fabricated using a single masking operation. However, should differing pads be desired, multiple masks may be provided. For example, the leading edge pads may be made higher such that they may sustain more wear without allowing the slider substrate to contact the medium surface which would substantially increase stiction.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. In general, the pads may be placed along any protruding portion of the air bearing surface such as the side rails, a center rail, a center island, etc. In general, the present invention includes all of the various sizes, shapes, heights, placings, configurations, densities, etc. of the pads set forth herein. Such pads may be made in accordance with any of the processes set forth herein or may be fabricated using other processes as desired. Similarly, the specific process herein are not limited to fabrication of those pads which have been specifically set forth herein. The invention may be used with any type of transducing element including inductive, magnetoresistive and optical elements. In general, in these designs the pads only contact the disc surface during CSS and do not contact the disc surface during normal flying.

WHAT IS CLAIMED IS:

1. A disc drive storage system for storing information on a surface of a rotating disc, comprising:

a transducing means for reading and writing information on the disc surface; and

slider means for carrying the transducing means proximate the disc surface.

2. A disc drive storage system, comprising:

a rotating disc having a disc surface;

a transducing head for reading and writing on the disc surface;

transducing circuitry coupled to the transducing head;

a slider having rails formed thereon and having an air bearing surface, the slider supporting the transducing head proximate the disc surface; and

a plurality of pads carried on the rails having an area which contacts the disc surface during contact start/stop (CSS) and a height selected to provide a desired maximum stiction during CSS.

3. The disc drive storage system of claim 2 including a lubricant carried on the disc surface and wherein there is a substantially linear relationship between thickness of the lubricant and stiction between the slider and the disc surface.

4. A method of fabricating a slider in a disc drive storage system, comprising:

obtaining a slider having an air bearing surface;

depositing a mask on the air bearing surface, the mask having an opening formed

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

therein which exposes a portion of the air bearing surface;

depositing a landing pad layer of material in the opening of the mask; and

removing the mask from the air bearing surface thereby forming a landing pad from the landing pad material on the air bearing surface.

5. A method of fabricating a slider in a disc drive storage system, comprising:

obtaining a slider having an air bearing surface;

illuminating portions of the air bearing surface with a laser beam of sufficient intensity and for a sufficient duration to ablate portions of the air bearing surface; and

controlling the laser beam to form at least one pad on the air bearing surface.

6. A method of fabricating a slider in a disc drive storage system, comprising:

obtaining a slider having an air bearing surface;

depositing a mask on the air bearing surface, the mask having an opening formed therein which exposes a portion of the air bearing surface;

ablating the air bearing surface through the opening in the mask to form a pad in the air bearing surface; and

removing the mask from the air bearing surface thereby exposing the air bearing surface with the pad formed thereon.

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

7. A disc drive storage system, comprising:
a rotating disc having a disc surface;
a transducing head for reading and writing on the disc surface;
transducing circuitry coupled to the transducing head;
a slider having an air bearing surface, the slider supporting the transducing head proximate the disc surface; and
a plurality of micro-pores formed in the air bearing surface causing a hydrodynamic effect on the air bearing surface during operation.

8. The disc drive storage system of claim 7 including at least one pad on the air bearing surface and extending from the air bearing surface in the direction toward the disc surface.

9. A disc drive storage system, comprising:
a rotating disc having a disc surface;
a transducing head for reading and writing on the disc surface;
transducing circuitry coupled to the transducing head; and
a slider having an air bearing surface adapted to carry the transducing head proximate the disc surface, the slider including a plurality of pads extending from the air bearing surface in a direction substantially toward the disc surface, wherein the pads are distributed over substantially the entire air bearing surface of the slider.

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

10. A disc drive storage system, comprising:
a rotating disc having a disc surface;
a transducing head for reading and writing on the disc surface;
transducing circuitry coupled to the transducing head;
a slider for positioning the transducing head proximate the disc surface, the slider having an air bearing surface generally facing the disc surface for forming an air bearing therebetween;
a leading edge pad positioned on the air bearing surface closer to the leading edge of the slider;
a trailing edge pad positioned on the air bearing surface near the trailing edge of the slider; and
wherein the leading edge and trailing edge pads have differing heights.

11. A disc drive storage system, comprising:
a rotating disc having a disc surface;
a transducing head for reading and writing on the disc surface;
transducing circuitry coupled to the transducing head;
a slider for positioning the transducing head proximate the air bearing surface, the slider having an air bearing surface generally facing the disc surface for forming an air bearing therebetween;
a leading edge pad positioned on the air bearing surface closer to the leading edge of the slider;

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

a trailing edge pad positioned on the air bearing surface near the trailing edge of the slider; and

a midsection pad positioned on the air bearing surface between the leading edge pad and the trailing edge pad.

12. A disc drive storage system, comprising:

a rotating disc having a disc surface;

a transducing head for reading and writing on the disc surface;

transducing circuitry coupled to the transducing head;

a slider having an air bearing surface for supporting the transducing head proximate the disc surface;

at least one landing pad on the air bearing surface extending in a direction away from the air bearing surface for use during CSS of the slider; and

a kick pad positioned between a trailing edge of the slider and the landing pad, the kick pad having a height which is less than the height of the landing pad and having a height and a position to limit a pitch angle of the slider.

13. A disc drive storage system, comprising:

a rotating disc having a disc surface;

a transducing head for reading and writing on the disc surface;

transducing circuitry coupled to the transducing head;

a slider for positioning the transducing head proximate the disc surface, the slider

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

including an air bearing surface having a textured portion formed thereon; and

wherein the textured portion comprises diamond-like carbon (DLC) including a plurality of particles encapsulated therein to thereby form the texturing.

14. The disc drive storage system of claim 13 wherein the textured portion comprises a landing pad.

15. A disc drive storage system, comprising:

a rotating disc having a disc surface;

a transducing head for reading and writing on the disc surface;

transducing circuitry coupled to the transducing head;

a slider for supporting the transducing head proximate the disc surface, the slider including an air bearing surface formed thereon;

a first landing pad carried on the slider having a first contact area for contacting the disc surface during CSS; and

a second landing pad carried on the air bearing surface and positioned between the first landing pad and a leading edge of the slider, the second landing pad having a second contact area for contacting the disc surface during CSS which is greater than the area of the first landing pad.

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED