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## MAGNETIC HEAD AIR BEARING DESIGN WITH ISLAND BLOCKER FOR SMEAR MITIGATION


### Abstract

A slider for a data storage device may include a trailing pad comprising a recording head, an outer surface, and an inner surface, wherein the outer surface is at the media-adjacent level and the inner surface is at the first recessed level. The slider may further include particle-blocking structure comprising a hole in the inner surface of the trailing pad, wherein a bottom surface of the hole is at the second recessed level, and an island blocker situated within the hole, wherein a media-facing surface of the island blocker is at the media-adjacent level, wherein the recording head is situated between the island blocker and a trailing edge of the slider. Also disclosed are data storage devices comprising sliders having particle-blocking structures comprising a hole and an island blocker. Also disclosed are methods of manufacturing sliders having particle-blocking structures comprising a hole and an island blocker.



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## Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to, and hereby incorporates by reference in its entirety for all purposes, China patent application No. 202410178991.6, which is entitled “MAGNETIC HEAD AIR BEARING DESIGN WITH ISLAND BLOCKER FOR SMEAR MITIGATION” and was filed on Feb. 8, 2024.

BACKGROUND

[0002] Data storage systems are used to store large amounts of information. A data storage system typically includes a read/write transducer for retrieving and storing information. Some data storage systems use rotating storage devices, such as rotating optical devices (e.g., CD and DVD drives) or hard disk drives containing rotating magnetic disks (also referred to as platters or media). In some such data storage systems, a suspended slider supports a head that includes the read/write transducer. The slider provides mechanical support for the head and the electrical connections between the head and the rest of the data storage system.

[0003] When the data storage system is in operation, the slider floats a small distance above the recording medium (e.g., a hard disk in a hard disk drive), which rotates at high speeds. Components of the data storage system move the slider and, therefore, the head to a desired radial position over the surface of the rotating medium, and the head reads or writes information. The slider rides on a cushion or bearing of air or gas created above the surface of the medium as the disk rotates at its operating speed. The slider has an air-bearing surface (ABS) that faces the medium. The ABS is designed to generate an air-bearing force that counteracts a preload bias that pushes the slider toward the medium. The ABS causes the slider to fly above and out of contact with the medium.

[0004] Many older data storage devices operate in a standard air (e.g., nitrogen, oxygen, and water vapor mixture) atmosphere. Spinning recording media in hard disk drives at high revolutions per minute against the friction of an air atmosphere is largely inefficient and requires a certain amount of power. To address this inefficiency, a data storage device can be filled at least partially with a lower-density gas, such as helium or hydrogen, and sealed to control and maintain the internal environment of the data storage device. Sealing mitigates or prevents leakage of internal gases from within the data storage device. The use of helium, which has a density that is approximately one-seventh that of air, reduces friction and vibration in the data storage device, thereby creating less drag and turbulence. Consequently, by running the data storage device in a less-dense atmosphere, such as an atmosphere of helium or a mixture of helium and oxygen, friction on the recording media is reduced, thereby causing the recording media to require less power in order to spin at a similar rate as the recording media in data storage devices that operate in standard air conditions. The use of helium generally also reduces the operating temperature of the data storage device, as well as the amount of noise it generates.

[0005] Higher storage bit densities in magnetic media used in disk drives have reduced the size (volume) of data cells to the point where the cell dimensions are limited by the grain size of the magnetic material. Although grain size can be reduced further, the data stored within the cells may not be thermally stable. That is, random thermal fluctuations at ambient temperatures may be sufficient to erase data. This state is described as the superparamagnetic limit, which determines the maximum theoretical storage density for a given magnetic media. This limit may be raised by increasing the coercivity of the magnetic media or by lowering the temperature. Lowering the temperature may not always be practical when designing hard disk drives for commercial and consumer use. Raising the coercivity, on the other hand, may result in a need for write heads that incorporate higher magnetic moment materials, or techniques such as perpendicular recording (or both).

[0006] Another solution uses heat to lower the effective coercivity of a localized region on the magnetic media surface and writes data within this heated region. The data state becomes “fixed” upon cooling the media to ambient temperatures. This technique is broadly referred to as “thermally assisted (magnetic) recording” (TAR or TAMR), “energy assisted magnetic recording” (EAMR), or “heat-assisted magnetic recording” (HAMR). The term “HAMR” is used herein to refer to all of TAR, TAMR, EAMR, and HAMR.

[0007] In HAMR, a magnetic recording material with high magneto-crystalline anisotropy (Ku) is heated locally during writing to lower the coercivity enough for writing to occur, but the coercivity/anisotropy is high enough that the recorded bits are thermally stable at the ambient temperature of the disk drive (i.e., the normal operating or “room” temperature of approximately 15-30 degrees Celsius). In some proposed HAMR systems, the magnetic recording material is heated to near or above its Curie temperature. The recorded data may then be read back at ambient temperature by a conventional magnetoresistive read head. HAMR disk drives have been proposed for both conventional continuous media, wherein the magnetic recording material is a continuous layer on the disk, and for bit-patterned media (BPM), in which the magnetic recording material is patterned into discrete data islands or “bits.”

[0008] One type of HAMR data storage device uses a laser source and an optical waveguide coupled to an optical near-field transducer (NFT) for heating the recording material on the media. A “near-field” transducer refers to “near-field optics,” wherein light is passed through a first element with subwavelength features and the light is coupled to a second element, such as a substrate (e.g., of a magnetic recording medium), located a subwavelength distance from the first element. The NFT is typically located at the air-bearing surface (ABS) of an air-bearing slider that also supports the read/write head and rides or “flies” above the media surface. An NFT may have a generally triangular output end, such that an evanescent wave generated at a surface of the waveguide couples to surface plasmons excited on the surface of the NFT, and a strong optical near-field is generated at the apex of the triangular output end.

[0009] One potential issue with HAMR devices is that excessive heating of the NFT can cause performance degradation and eventually failure of the data storage device. One possible cause of failure due to excessive heating may be due to adsorption of carbonaceous material on the slider overcoat near the NFT tip. Relative to data storage devices that use older recording technologies such as perpendicular magnetic recording, HAMR devices tend to have a thicker carbon overcoat on the media. Hydrocarbon molecules from the recording media overcoat and lubricant can become mobile at elevated temperatures and adsorb on the ABS of the slider. Over time, these molecules can form a “smear” on the ABS that absorbs power from the laser source and causes the NFT, which normally operates at very high temperatures, to become even hotter than usual. The heat transfer can result in diffusion of the NFT metal until the NFT tip rounds and recording degrades, eventually possibly leading to failure of the data storage device.

[0010] In addition to potentially affecting the NFT, smear can affect the fly height of the slider in a manner that is not consistent over time. The carbonaceous material can build up as the data storage device operates, and then become detached (e.g., when thick enough that it touches the media and drops off). Accordingly, the changing characteristics of smear (e.g., its presence, thickness, etc.) can cause variations in the slider fly height. These variations can adversely affect the performance of the data storage device, such as its writing performance.

[0011] Smear is common in data storage devices that use HAMR. It is also common in sealed data storage devices that have fewer oxygen molecules.

[0012] Therefore, there is a need for improvements to mitigate the effects of smear in these and other types of data storage devices.

SUMMARY

[0013] This summary represents non-limiting embodiments of the disclosure.

[0014] Disclosed herein are sliders that include particle-blocking structures, methods of manufacturing such sliders, and data storage devices including such sliders. The particle-blocking structures include a hole in a trailing pad of the slider, and an island blocker situated within the hole. In some embodiments, the island blocker includes a lower portion and an upper portion, with a ledge between the lower and upper portions. In some embodiments, a media-facing surface of the island blocker is at the level of the ABS that is closest to the media when the slider is installed in a data storage device. In some embodiments, the hole has a large depth (e.g., between about 800 nm and about 5000 nm relative to the media-facing surface of the NFT) to facilitate the capture of particles. In some embodiments, the island blocker has a form factor (e.g., size and/or shape) such that, regardless of the slider skew angle, the island blocker is situated to block and/or redirect particles heading toward the recording head.

[0015] In some aspects, the techniques described herein relate to a slider for a data storage device, the slider having an ABS that includes at least three levels, the at least three levels including a media-adjacent level, a first recessed level, and a second recessed level, wherein, in an orientation in which the ABS is oriented upward, the media-adjacent level is above the first recessed level, and the first recessed level is above the second recessed level. In some embodiments, the slider includes a trailing pad including a recording head, an outer surface, and an inner surface, wherein the outer surface is at the media-adjacent level and the inner surface is at the first recessed level. In some embodiments, the slider further includes a hole in the inner surface of the trailing pad, wherein a bottom surface of the hole is at the second recessed level, and an island blocker situated within the hole, wherein a media-facing surface of the island blocker is at the media-adjacent level. In some embodiments, the recording head is situated between the island blocker and a trailing edge of the slider.

[0016] In some aspects, the techniques described herein relate to a slider, a maximum width of the hole in a cross-track direction is at least 75 percent of a maximum width of the inner surface of the trailing pad in the cross-track direction.

[0017] In some aspects, at least one of a size or a shape of the island blocker is configured to block and/or redirect particles moving in an airflow direction toward the recording head at all slider skew angles between a maximum inner-diameter skew angle and a maximum outer-diameter skew angle.

[0018] In some aspects, the first recessed level is recessed from the media-adjacent level by between about 50 nm and about 300 nm. In some aspects, the second recessed level is recessed from the media-adjacent level by between about 500 nm and about 2500 nm.

[0019] In some aspects, the recording head includes a HAMR writer.

[0020] In some aspects, the techniques described herein relate to a method of manufacturing a slider that has a particle-blocking structure, the method including: in a first manufacturing step in which at least one other surface at the second recessed level is created, creating the hole; and in a second manufacturing step in which at least one other surface at the media-adjacent level is created, creating the island blocker.

[0021] In some aspects, the island blocker includes a lower portion and an upper portion.

[0022] In some aspects, the island blocker includes a ledge at the first recessed level.

[0023] In some aspects, the techniques described herein relate to a method of manufacturing a slider that has a particle-blocking structure including a ledge at the first recessed level, the method including: in a first manufacturing step in which at least one other surface at the second recessed level is created, creating the hole; in a second manufacturing step in which at least one other surface at the first recessed level is created, creating the ledge; and in a third manufacturing step in which at least one other surface at the media-adjacent level is created, creating the media-facing

surface of the island blocker.
[0024] In some aspects, the techniques described herein relate to a slider for a HAMR data storage device, the slider including a HAMR head including an NFT and a particle-blocking structure configured to mitigate a formation of smear on a media-facing surface of the NFT. In some embodiments, the particle-blocking structure includes an island blocker within a hole in a trailing pad of the slider, the hole extending perpendicular to an ABS of the slider. In some embodiments, the island blocker has a form factor such that the island blocker blocks oncoming particles with angles of arrival within a specified range of a centerline of the slider.
[0025] In some aspects, the specified range includes a first angular range on a first side of the centerline and a second angular range on a second side of the centerline.
[0026] In some aspects, a depth of the hole is between about 800 nm and about 5000 nm relative to the media-facing surface of the NFT.
[0027] In some aspects, the techniques described herein relate to a method of manufacturing a slider that has a particle-blocking structure, the method including: in a first manufacturing step, creating the hole; and in a second manufacturing step performed after the first manufacturing step, creating the island blocker.
[0028] In some aspects, the island blocker includes a lower portion and an upper portion.
[0029] In some aspects, the island blocker includes a ledge, wherein the ledge is recessed from a media-facing surface of the island blocker.
[0030] In some aspects, a recess distance between the media-facing surface of the island blocker and the ledge is between about 50 nm and about 300 nm.
[0031] In some aspects, the techniques described herein relate to a method of manufacturing a slider that has a particle-blocking structure that includes a ledge, the method including: in a first manufacturing step, creating the hole; in a second manufacturing step performed after the first manufacturing step, creating the ledge; and in a third manufacturing step performed after the second manufacturing step, creating the media-facing surface of the island blocker.
[0032] In some aspects, the techniques described herein relate to a data storage device that includes a recording media and a slider that includes a particle-blocking structure.

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## Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0033] Objects, features, and advantages of the disclosure will be readily apparent from the following description of certain embodiments taken in conjunction with the accompanying drawings in which:
[0034] FIG. **1**A is a plan view illustrating an example of a data storage device that may include one or more of the embodiments disclosed herein.
[0035] FIG. **1**B is a perspective view of a conventional slider.
[0036] FIG. **1**C is a schematic cross-sectional view illustrating an example of a HAMR head according to the prior art.
[0037] FIG. **1**D is an ABS view of a trailing edge pad.
[0038] FIG. **1**E is a cross-section view of the trailing edge pad of FIG. **1**D at the location indicated in FIG. **1**D.
[0039] FIG. **1**F is a diagram illustrating skew angles of the slider at different positions with respect to the recording medium.
[0040] FIGS. **2**A, **2**B, **2**C, **2**D, and **2**E illustrate an example of the particle-blocking structure in accordance with some embodiments.
[0041] FIGS. **3**A, **3**B, and **3**C illustrate an example of an island blocker in accordance with some embodiments.

[0042] FIGS. **4**A and **4**B illustrate how the particle-blocking structure is configured to mitigate or prevent particles from reaching the recording head when the slider is at, respectively, the maximum inner-diameter skew angle and the maximum outer-diameter skew angle.
[0043] FIG. **5**A is a flow diagram illustrating a method of manufacturing a slider that includes a particle-blocking structure in accordance with some embodiments.
[0044] FIG. **5**B is flow diagram of another method of manufacturing a slider that includes a particle-blocking structure in accordance with some embodiments.
[0045] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially utilized in other embodiments without specific recitation. Moreover, the description of an element in the context of one drawing is applicable to other drawings illustrating that element.

DETAILED DESCRIPTION

[0046] Disclosed herein are slider ABS designs to improve performance in the presence of smear. The disclosed designs promote blocking and/or trapping of particles (e.g., carbonaceous material) that might otherwise cause smear. By blocking and/or trapping these particles, the new ABS designs reduce variations in slider fly height due to smear build-up and drop-off, thereby promoting a more consistent slider fly height. In addition, the new designs provide higher damping of transient disturbances (e.g., to the slider fly height due to smear drop-off).
[0047] FIG. **1**A is a plan view illustrating an example of a data storage device **500**, illustrated as a hard disk drive, that may include one or more of the embodiments disclosed herein. The data storage device **500** may operate under standard air conditions, or it may be a sealed device (e.g., filled with helium, a helium mixture, or another gas or mixture of gases). FIG. **1**A illustrates an example of the functional arrangement of components of the data storage device **500**, including a slider **525** that includes a recording head **540**. The recording head **540** (which may also be referred to as a transducer or a read/write transducer) includes a write element and a read element for, respectively, writing information to and reading information from a recording medium **520** of the data storage device **500**. The recording head **540** may be, for example, a HAMR head, as described further below.
[0048] The data storage device **500** includes at least one head gimbal assembly (HGA) **510**, which includes the slider **525**, a suspension and actuator arm **530** attached to the slider **525**, and a load beam **535** attached to the suspension and actuator arm **530**. The data storage device **500** also includes at least one recording medium **520**, which may be, for example, a magnetic recording medium, rotatably mounted on a spindle **524**, and a drive motor (not shown) attached to the spindle **524** for rotating the recording medium **520**. The recording medium **520**, which may include a plurality of disks, may be affixed to the spindle **524** with a disk clamp **528**.
[0049] The data storage device **500** further includes an arm **532** attached to the HGA **510**, a carriage **534**, a voice-coil motor (VCM) that includes an armature **536** including a voice coil **541** attached to the carriage **534**, and a stator **544** including a voice-coil magnet. The armature **536** of the VCM is attached to the carriage **534** and is configured to move the arm **532** and the HGA **510** to access portions of the recording medium **520**. The carriage **534** is mounted on a pivot-shaft **548** with an interposed pivot-bearing assembly **562**. In the case of an HDD having multiple disks (also sometimes referred to as “platters”), the carriage **534** may be called an “E-block,” or comb, because the carriage **534** is arranged to carry a ganged array of arms (multiple instances of the arm **532**) that gives it the appearance of a comb.
[0050] An assembly comprising a head gimbal assembly (e.g., HGA **510**), including a suspension flexure to which the slider **525** is coupled, an actuator arm (e.g., the arm **532**) to which the suspension is coupled, and an actuator (e.g., the VCM) to which the actuator arm is coupled, may be collectively referred to as a head stack assembly (HSA). The HSA also includes a suspension tail. Generally, the HSA is the assembly configured to move the slider **525** to enable the recording

head **540** to access portions of the recording medium **520** (e.g., magnetic-recording disks) for read and write operations.

[0051] In the example data storage device **500** shown in FIG. **1**A, electrical signals (for example, current to the voice coil **541** of the VCM, write signals to and read signals from the recording head **540**, etc.) are provided by a flexible interconnect cable **556** (which may be referred to as a "flex cable"). Interconnection between the flex cable **556** and the recording head **540** may be provided by an arm-electronics (AE) module **560**, which may have an on-board pre-amplifier for the read signal, as well as other read-channel and write-channel electronic components. The AE module **560** may be attached to the carriage **534** as shown. The flex cable **556** is coupled to an electrical-connector block **564**, which provides electrical communication through electrical feed-throughs provided by a data storage device housing **568**. The data storage device housing **568**, in conjunction with a cover (not shown), provides a protective enclosure for the information storage components of the data storage device **500**. The enclosure may be sealed and filled with helium, a helium mixture, or another gas or gas mixture.

[0052] Other electronic components, including a disk controller and servo electronics such as a digital-signal processor (DSP), can be included in the data storage device **500** to provide electrical signals to the drive motor, the voice coil **541** of the VCM, and the recording head **540** of the HGA **510**. The electrical signal provided to the drive motor enables the drive motor to spin, thereby providing a torque to the spindle **524**, which is in turn transmitted to the recording medium **520** that is affixed to the spindle **524** by the disk clamp **528**; as a result, the recording medium **520** spins in a direction **572**. Because it is spinning, the recording medium **520** creates a cushion of air (or gas) that acts as an air bearing or gas bearing on which the air-bearing surface (ABS) of the slider **525** rides so that the slider **525** flies above the surface of the recording medium **520** without making contact with a thin magnetic-recording layer of the recording medium **520** in which information is recorded. (It is to be appreciated that the term "air-bearing surface" is used herein regardless of whether the data storage device operates in standard air conditions or other conditions (e.g., in helium or a helium mixture).)

[0053] The electrical signal provided to the voice coil **541** of the VCM enables the recording head **540** of the HGA **510** to access a track **576** on which information is recorded. Thus, the armature **536** of the VCM swings through an arc **580**, which allows the HGA **510** attached to the armature **536** by the arm **532** to access various tracks on the recording medium **520**. Information is stored on the recording medium **520** in a plurality of sectored tracks arranged in sectors on the recording medium **520**, for example, sector **584**. Correspondingly, each track is composed of a plurality of sectored track portions, for example, the sectored track portion **588**. Each sectored track portion **588** includes recorded data and a header containing a servo-burst-signal pattern, for example, an ABCD-servo-burst-signal pattern, information that identifies the track **576**, and error correction code information. In accessing the track **576**, the read element of the recording head **540** of the HGA **510** reads the servo-burst-signal pattern, which provides a position-error-signal (PES) to the servo electronics, which controls the electrical signal provided to the voice coil **541** of the VCM, enabling the recording head **540** to follow the track **576**. Upon finding the track **576** and identifying a particular sectored track portion **588**, the recording head **540** either reads data from the track **576** or writes data to the track **576**, depending on instructions received by the disk controller from an external agent, for example, a microprocessor of a computer system to which the data storage device **500** is connected.

[0054] For reading the information stored on the recording medium **520**, the recording head **540** may include only one read sensor, or it may include multiple read sensors. The read sensor(s) in the recording head **540** may include, for example, one or more giant magnetoresistance (GMR) sensors, tunneling magnetoresistance (TMR) sensors, or another type of magnetoresistive sensor. When the slider **525** passes over a track **576** on the recording medium **520**, the recording head **540** detects changes in resistance due to magnetic field variations recorded on the recording medium

**520**, which represent the recorded bits.

[0055] FIG. **1**B is a perspective view of a conventional slider **525**. To facilitate the explanations herein, FIG. **1**B includes a set of axes for a rectangular coordinate system. The x direction denotes a cross-track direction, and the y direction denotes an along-the-track or down-track direction. The z direction is perpendicular to both the x and y directions. Using the illustrated axes, the slider **525** has a leading-edge surface **120** in an x-z plane, a trailing-edge surface **125** in another x-z plane, an outer-diameter edge **135** in a y-z plane extending between the leading-edge surface **120** and the trailing-edge surface **125**, and an inner-diameter edge **130** extending in another y-z plane that also extends between the leading-edge surface **120** and the trailing-edge surface **125**.

[0056] The slider **525** also has an ABS **150**, which includes, among other things, two mid-slider cavities, namely, an outer-diameter side cavity **110**A and an inner-diameter side cavity **110**B. The outer-diameter side cavity **110**A and inner-diameter side cavity **110**B increase the stability of the slider **525** by encouraging air (or gas) flow in to the outer-diameter side cavity **110**A and inner-diameter side cavity **110**B, particularly at large skew angles, discussed further below. The outer-diameter side cavity **110**A and inner-diameter side cavity **110**B can have mouths (openings) at the outer-diameter edge **135** and the inner-diameter edge **130** of, for example, around 3 microns.

[0057] The slider **525** also has a leading edge pad **170** and a trailing edge pad **140**. The trailing edge pad **140** has an outer region **142** and an inner region **144**. As described further below, the recording head **540** resides on/in the outer region **142** of the trailing edge pad **140**, near the trailing-edge surface **125**.

[0058] FIG. **1**C is a schematic cross-sectional view illustrating an example of a HAMR head according to the prior art. The HAMR head shown in FIG. **1**C is capable of functioning as the recording head **540** in some embodiments. In FIG. **1**C, the recording medium **520**, which moves in the direction **20**, is depicted as a conventional magnetic disk with the recording layer **31** being a continuous non-patterned magnetic recording layer of magnetizable material with magnetized regions, referred to herein as bits **34**. The bits **34** are physically adjacent to one another, and the boundaries between adjacent bits are referred to as magnetic transitions **37**. The bits **34** are recorded in individual data sectors. The recording layer **31** is typically formed of a high-anisotropy (Ku) substantially chemically-ordered FePt alloy (or CoPt alloy) with perpendicular magnetic anisotropy. The recording medium **520** includes an overcoat **36**, typically formed of amorphous diamond-like carbon (DLC), and a liquid lubricant layer **38**, typically a bonded perfluropolyether (PFPE).

[0059] The slider **525** is supported by a suspension **35**. The slider **525** has a surface **122** that faces the recording medium **520**. An overcoat **124** is deposited onto the surface **122**. The overcoat **124** is typically a DLC overcoat with a thickness in the range of about 10 to 30 Å. An optional adhesion film or undercoat (not shown), such as a 1 to 5 Å silicon nitride (SiNx) film, may be deposited on the surface **122** before deposition of the overcoat **124**.

[0060] In the illustrated example, the slider **525** supports a write head **50**, a magnetoresistive (MR) read head **60**, and magnetically permeable read head shields S**1** and S**2**. A recording magnetic field is generated by the write head **50** made up of a coil **56**, a main magnetic pole **53** for transmitting flux generated by the coil **56**, a write pole **55** with a write pole end **52**, and a return pole **54**. A magnetic field generated by the coil **56** is transmitted through the main magnetic pole **53** to the write pole end **52** located near an NFT **74**. The write head **50** is typically capable of operating at different clock rates so as to be able to write data at different frequencies. The NFT **74**, also known as a plasmonic antenna, typically uses a low-loss metal (e.g., Au, Ag, Al or Cu) shaped in such a way to concentrate surface charge motion at a tip located at the ABS **150** when light from the optical waveguide **73** is incident. Oscillating tip charge creates an intense near-field pattern, heating the recording layer **31**. The metal structure of the NFT **74** can create resonant charge motion (surface plasmons) to further increase intensity and heating of the recording layer **31**. To record to the recording medium **520**, the recording layer **31** of recording medium **520** is heated by the optical near-field generated by the NFT **74** and, at the same time, a region or bit **34** is magnetized and thus written onto the recording layer **31** by applying a recording magnetic field generated by the write pole end **52**.

[0061] A semiconductor laser **90** is mounted to the top surface of slider **525**. An optical waveguide **73** for guiding light from the semiconductor laser **90** to the NFT **74** is formed inside the slider **525**. The semiconductor laser **90** is typically capable of operating at different power levels. Materials that ensure a refractive index of the optical waveguide **73** core material to be greater than a refractive index of the cladding material may be used for the optical waveguide **73**. For example, Al.sub.2O.sub.3 may be used as the cladding material and TiO.sub.2, Ta.sub.2O.sub.5 and SiO.sub.XN.sub.y as the core material. Alternatively, SiO.sub.2 may be used as the cladding material and Ta.sub.2O.sub.5, TiO.sub.2, SiO.sub.XN.sub.y, or Ge-doped SiO.sub.2 as the core material. The optical waveguide **73** that delivers light to NFT **74** is preferably a single-mode waveguide.

[0062] FIG. **1**D is an ABS view of a trailing edge pad **140**. The trailing edge pad **140** has an outer region **142** and an inner region **144**. A location of a recording head **540** is also depicted in FIG. **1**D, but it is to be appreciated that the rectangle representing the recording head **540** in the drawing is not to scale. In the illustrated example in FIG. **1**D, the outer region **142** of the trailing edge pad **140** has a surface **141** that is part of the media-adjacent surface of the ABS **150**, and the inner region **144** of the trailing edge pad **140** has a surface **145** that is recessed from the surface **141**. The media-adjacent surface of the ABS **150** is the surface, or plurality of surfaces, of the ABS **150** that are closest to the recording medium **520** when the slider **525** is installed in a data storage device **500**, ignoring that the slider **525** may fly at a pitch angle relative to horizontal. FIG. **1**D also shows a cavity **180**, which has a surface **181**. In the z direction, the surface **181** is recessed from the surface **145**. Thus, with the trailing edge pad **140** as shown in FIG. **1**D, the slider **525** has at least three surfaces at at least three levels. As explained above, the surface **141** is part of the media-adjacent surface of the ABS **150**. The media-adjacent surface of the ABS **150** can be said to be at a media-adjacent level of the ABS **150**. The surface **145** is part of a first recessed surface of the ABS **150**, which can be said to be at a first recessed level, where the recess is in the z direction from the media-adjacent surface. The surface **181** is part of a second recessed surface of the ABS **150**, which can be said to be a second recessed level, where the recess is in the z direction from both the media-adjacent surface and the first recessed surface. It is to be appreciated that the ABS **150** can have more than two recessed levels.

[0063] FIG. **1**E is a cross-section view of the trailing edge pad **140** at the location indicated in FIG. **1**D. The surface **181** is at the lowest level of the ABS **150** in the illustrated example. In the z direction, the surface **181** is recessed from the surface **141** of the trailing edge pad **140** by a distance **233**. The surface **145** of the trailing edge pad **140** is recessed from the surface **141** by a distance **231** in the z direction. The distance **233** may be significantly larger than the distance **231**. For example, the distance **233** may be on the order of a micron or more (e.g., 500 nm to 2500 nm), whereas the distance **231** may be much smaller (e.g., 50-300 nm).

[0064] FIG. **1**F is a diagram of a slider **525** over a recording medium **520** of a data storage device **500** to illustrate skew angles of the slider **525** at different positions with respect to the recording medium **520**. The suspension and actuator arm **530** supports the slider **525** above the surface of the recording medium **520** at locations including an inner diameter (ID) position PID, an outer diameter (OD) position POD, and positions between PID and POD, including the mid-disk (MD) position PMD. As the recording medium **520** spins, it produces airflow in a direction tangential to the recording medium **520** in the direction the recording medium **520** spins, as shown by the arrow A. The angle of misalignment of the direction of the airflow and the centerline **21** of the slider **525** is known as the skew angle.

[0065] When the slider **525** is at the mid-disk position PMD, the centerline **21** of the slider **525** is approximately aligned with the direction of the airflow produced by the recording medium **520**. In this case, the skew angle is approximately 0 (zero). When the slider **525** is at other positions over the recording medium **520**, however, the centerline **21** of the slider **525** is not aligned with the direction of the airflow produced by the recording medium **520**. As shown in FIG. **1**F, when the slider **525** is at the ID position PID, the skew angle is a, which is the maximum skew angle in the ID direction. When the slider **525** is at the OD position POD, the skew angle is β, which is the maximum skew angle in the OD direction.

[0066] The skew angle affects the aerodynamic characteristics of the slider ABS and particle robustness of the slider **525** at different positions over the recording medium **520**. Generally, the greater the skew angle, the lower the lift produced for a given airflow velocity. Moreover, when the slider **525** skew angle is nonzero, unwanted particles can enter the outer-diameter side cavity **110**A and/or the inner-diameter side cavity **110**B along with desired airflow. Greater skew angles typically result in a higher likelihood of particles entering the outer-diameter side cavity **110**A and the inner-diameter side cavity **110**B. This problem can be particularly acute when the slider **525** is at the ID position PID and when the slider **525** is at the OD position POD. Even when the skew angle is zero, particles, lube pick-up, contaminants, and/or other debris, referred to generally herein as smear, can build up on the ABS **150**, which can lead to undesirable fly height variability and/or damage the recording media and head sensors (e.g., the NFT **74**), thereby causing data stored on the media to be erased.

[0067] As explained above, smear build-up, and changes to smear build-up, can have an adverse impact on the performance of a data storage device **500**. Smear may be largely unavoidable, however. Accordingly, one objective of the approaches disclosed herein is to mitigate or prevent smear build-up in particular locations of the ABS **150** (e.g., avoid build-up where it is more likely to cause fly height changes, where it is more likely to heat the NFT **74**, etc.).

[0068] Disclosed herein are slider ABS designs that provide improved robustness to smear and/or particles without sacrificing flight characteristics (e.g., slider stability). The disclosed embodiments promote particle collection and/or smear build-up in locations where the presence of and/or changes to smear do not have an appreciable effect on performance (e.g., of the NFT **74**, to the fly height, etc.).

[0069] In particular, disclosed herein are slider ABS designs that prevent at least some particles from reaching the recording head **540**, thereby preventing or mitigating the formation of smear at the recording head **540** (e.g., on the NFT **74** at the ABS **150**). In some embodiments, as described further below, the slider **525** includes a deep hole in the trailing edge pad **140** and an island blocker situated inside of the hole. The hole is provided to trap particles (e.g., suction particles into the hole's interior) so they do not reach the recording head **540** (or the NFT **74**) or build up on the surfaces of the trailing edge pad **140**. The island blocker is configured to block particles before they reach the recording head **540** for all expected skew angles (e.g., between and including the maximum ID and maximum OD skew angles). The island blocker may be configured to direct particles to locations where they will have a negligible effect on the flight characteristics (e.g., fly height) of the slider **525**. For example, the island blocker can redirect particles into the hole in the trailing edge pad **140**. The hole and island blocker, which can be referred to as a particle-blocking structure, may be created using conventional fabrication processes (e.g., photolithography).

[0070] FIGS. **2**A, **2**B, **2**C, **2**D, and **2**E illustrate an example of a particle-blocking structure in accordance with some embodiments. In particular, FIG. **2**A is a perspective view of an example of a slider **525** that includes a particle-blocking structure **200** in accordance with some embodiments. FIG. **2**B is a closer perspective view of the trailing edge pad **140** of the slider **525**, showing the particle-blocking structure **200** in more detail. FIG. **2**C is an ABS view of the trailing edge pad **140** showing the particle-blocking structure **200** of FIGS. **2**A and **2**B. FIG. **2**D is a closer ABS view of the particle-blocking structure **200** of FIGS. **2**A, **2**B, and **2**C. FIG. **2**E is a cross-section view of the particle-blocking structure **200** and a portion of the rest of the trailing edge pad **140** at the location indicated in FIG. **2**D.

[0071] As illustrated by FIGS. **2**A-**2**E, the particle-blocking structure **200** is situated in the trailing edge pad **140** of the slider **525**. A location of a recording head **540** is also depicted in FIGS. **2**B and **2**C, but it is to be appreciated that the rectangle representing the recording head **540** in the drawings is not to scale. The particle-blocking structure **200** is a separate feature from the recording head **540**, and the particle-blocking structure **200** is situated some distance from the recording head **540**. For example, the recording head **540** is not inside of the hole **205** or the island blocker **210**, nor does the recording head **540** touch the island blocker **210**. In the example illustrated in FIGS. **2**A-**2**E, the particle-blocking structure **200** is situated in the inner region **144** of the trailing edge pad **140**, whereas the recording head **540** is situated in the outer region **142** of the trailing edge pad **140**. As explained further below, in the airflow direction, at all expected skew angles, the particle-blocking structure **200** is in front of the recording head **540**.

[0072] The particle-blocking structure **200** includes a hole **205** and an island blocker **210** situated within the hole **205**. The hole **205** has a bottom surface **206** and, in the illustrated example, vertical walls that extend up from the bottom surface **206** when the slider **525** is in an orientation in which the ABS **150** is oriented upward (i.e., facing up). The hole **205** is open only at the ABS **150**. In other words, when the slider **525** is oriented with the ABS **150** facing upward, the hole **205** has an opening only at its top. There is no path into or out of the hole **205** from any side direction.

[0073] The hole **205** can have any suitable size and shape. The examples illustrated herein are not intended to be limiting. In the cross-track direction, the hole **205** has a maximum width **207**. In some embodiments, the maximum width **207** is at least 75 percent of the maximum width **147** of the inner region **144**. In FIGS. **2**A-**2**E, the hole **205** is illustrated as being at the deepest level of the ABS **150** (e.g., at the same level as the surface **181**), but it is to be appreciated that the hole **205** can be less deep than illustrated. As explained further below, it may be advantages for the hole **205** to be deeper rather than shallower to provide good particle-capture properties and/or to improve robustness to vibrations due to, for example, smear drop-off.

[0074] The island blocker **210** does not touch any surface of the hole **205** except the bottom surface **206**. In other words, the island blocker **210** is situated inside of the hole **205**, and part of it may extend in the z direction beyond the hole **205**, but the island blocker **210** does not contact any of the interior surfaces of the hole **205** except the bottom surface **206** (hence the name "island blocker").

[0075] The island blocker **210** can have any suitable size and shape. In some embodiments, the island blocker **210** has a form factor (e.g., at least one of size or shape) selected such that, regardless of the skew angle, the island blocker **210** blocks and/or redirects (e.g., into the hole **205**) particles that are moving toward the recording head **540** in the airflow direction. In other words, the size and/or shape and/or form factor of the island blocker **210** is such that the island blocker **210** is situated in front of the NFT **74** in the airflow direction at all skew angles between (and including) the maximum inner-diameter skew angle and the maximum outer-diameter skew angle. As a result, the island blocker **210** is designed and situated to prevent oncoming particles traveling substantially in the airflow direction from reaching the recording head **540** and the NFT **74**.

[0076] It may be desirable or convenient to design the island blocker **210** such that it will block oncoming particles having angles of arrival within a specified range. This specified range may account for the expected skew angles of the slider **525** as the data storage device **500** operates. It may be convenient to specify the angles of arrival of particles to be blocked relative to the centerline **21** of the slider **525** (e.g., angles of arrival within a specified number of degrees or radians to either side of the centerline **21**). For example, the island blocker **210** can have a form factor such that the island blocker **210** blocks oncoming particles with angles of arrival within a specified range of the centerline **21**. As a specific example, the island blocker **210** can have a form factor (e.g., physical design, size, shape) such that it blocks oncoming particles with angles of arrival within a first angular range on a first side of the centerline **21** and within a second angular range on a second side of the centerline **21**. The extents of the first and second angular ranges could be, for example, the maximum inner-diameter and outer-diameter skew angles.

[0077] In the example illustrated in FIGS. **2**A-**2**E, the island blocker **210** has a lower portion **212** and an upper portion **214**, which are labeled in FIGS. **2**D and **2**E. The upper portion **214** extends from the top of the lower portion **212** by a distance **231**, which, in the illustrated example, is also the distance by which the surface **145** of the trailing edge pad **140** (the inner region **144**) is recessed from the surface **141** of the trailing edge pad **140** (the outer region **142**). The upper portion **214** of the island blocker **210** has a media-facing surface **211**. The media-facing surface **211** is at the same level of the ABS **150** as the surface **141** of the outer region **142**.

[0078] In the illustrated example, the upper portion **214** of the island blocker **210** extends out of the lower portion **212**. The top surface of the lower portion **212** of the island blocker **210** forms a ledge **213** that, in the ABS view, surrounds the upper portion **214** (see FIGS. **2**C and **2**D). In the example, the ledge **213** is recessed from the surface **141** of the outer region **142** of the trailing edge pad **140** by the distance **231**, which is also the recess distance of the surface **145** of the inner region **144** relative to the surface **141** of the outer region **142**. Stated another way, the ledge **213** is at the same level of the ABS **150** as the surface **145** of the inner region **144** of the trailing edge pad **140**. The distance **231** can be any suitable value (e.g., between about 50 nm and about 300 nm).

[0079] It is not a requirement for the island blocker **210** to include a lower portion **212** and an upper portion **214**. It may be convenient for the island blocker **210** to have such a configuration, however. For example, as will be appreciated by those having ordinary skill in the art, certain photolithography steps can cause the formation of non-vertical sidewalls in the photoresist patterns, an effect known as “fencing.” If the manufacturing step used to create the hole **205** causes fencing to be present on the lower portion **212**, it may be desirable to create an upper portion **214** of the island blocker **210** using a process that does not cause fencing to reduce the likelihood that the media-facing surface **211** of the island blocker **210** has sharp edges that could damage the recording medium **520**.

[0080] FIGS. **3**A, **3**B, and **3**C illustrate an example of an island blocker **210** that does not include a lower portion **212** and an upper portion **214**. In particular, FIG. **3**A is an ABS view of the trailing edge pad **140** showing the particle-blocking structure **200**, FIG. **3**B is a closer ABS view of the particle-blocking structure **200** of FIG. **3**A, and FIG. **3**C is a cross-section view of the particle-blocking structure **200** and a portion of the rest of the trailing edge pad **140** at the location indicated in FIG. **3**B. As illustrated, in the example shown in FIGS. **3**A, **3**B, and **3**C, the island blocker **210** has no ledge **213**. An island blocker **210** such as shown in FIGS. **3**A, **3**B, and **3**C may be suitable if the manufacturing process used to create surfaces at the level of the media-facing surface **211** does not introduce fencing, or if any surface irregularities or defects in the island blocker **210** left by the manufacturing process do not result in intolerable performance degradations (e.g., too much fly height variability due to particles sticking to side surfaces of the island blocker **210**, damage to the recording medium **520**, etc.).

[0081] As explained above in the discussion of FIG. **1**F, in a data storage device **500** that uses spinning media (e.g., hard disk drives, such as HAMR drives), the slider skew angle changes depending on the position of the slider **525** over the recording medium **520**. In some embodiments, the particle-blocking structure **200**, and in particular the size and/or shape of the island blocker **210**, are selected so that the island blocker **210** blocks and/or redirects oncoming particles that, absent the presence of the particle-blocking structure **200**, would likely arrive at the recording head **540** (e.g., absent changing course). FIG. **4**A is a diagram to illustrate how the particle-blocking structure **200** is configured to mitigate or prevent particles from reaching the recording head **540** when the slider **525** is at the maximum inner-diameter skew angle **215**A (where, as explained above, the skew angle is the angle between the centerline **21** of the slider **525** and the air flow direction). Assuming the particles fly in the direction of the arrow **220** shown in FIG. **4**A, which is the air flow direction (see, e.g., the direction **572** of FIG. **1**A and/or the arrow labeled A in FIG. **1**F), the island blocker **210** is wide enough in the x direction (the cross-track direction) to block oncoming particles, even at the maximum inner-diameter skew angle **215**A.

[0082] Similarly, FIG. **4**B is a diagram to illustrate how the particle-blocking structure **200** is configured to mitigate or prevent particles from reaching the recording head **540** when the slider **525** is at the maximum outer-diameter skew angle **215**B. Assuming again that the particles fly in the direction of the arrow **220**, which is the air flow direction, the island blocker **210** is wide enough in the x direction (the cross-track direction) to block oncoming particles, even at the maximum outer-diameter skew angle **215**B.

[0083] Another interpretation of FIGS. **4**A and **4**B is that the island blocker **210** has a form factor such that it blocks oncoming particles with angles of arrival within a specified range of a centerline of the slider. In the illustrated example, the specified range includes a first angular range extending from the centerline **21** to the maximum inner-diameter skew angle **215**A on a first side of the centerline **21** and a second angular range extending from the centerline **21** to the maximum outer-diameter skew angle **215**B on a second side of the centerline **21**.

[0084] Although FIGS. **2**A through **4**B illustrate the island blocker **210** as having particular shapes (e.g., in the ABS views), in general, the island blocker **210** can have any suitable size and/or shape that allow it to block particles that might otherwise reach the recording head **540** while not having an adverse effect on the fly height of the slider **525**. To mitigate the impact of the island blocker **210** on the fly height, it is desirable for the island blocker **210** to be small. To provide good particle blocking and/or deflection, it is desirable for the island blocker **210** to have a wide enough extent in the cross-track direction (the x direction, using the axes shown in the drawings) so that it effectively blocks and/or redirects particles at both the maximum inner-diameter skew angle **215**A and the maximum outer-diameter skew angle **215**B. As explained above, manufacturing processes, and expected imperfections in the island blocker **210**, can also be taken into account to design a suitable island blocker **210** (e.g., an island blocker **210** that includes a lower portion **212** and an upper portion **214** and has a ledge **213**).

[0085] The particle-blocking structure **200** disclosed herein offers a number of potential advantages. For example, creating the particle-blocking structure **200** does not require additional manufacturing steps. Instead, it can be created using and during the same manufacturing steps used to create the rest of the slider **525**. For example, assuming the slider **525** is manufactured using photolithography, the particle-blocking structure **200** can be created simply by modifying the masks used. The hole **205** can be created during the same step as other areas/features with the same depth (which can be any suitable depth, e.g., between about 800 nm and about 5000 nm from the media-facing surface **211**) are created. The island blocker **210** example shown in FIGS. **3**A through **4**B can be created during the same manufacturing step in which the outer region **142** is created. The lower portion **212** of the island blocker **210** example shown in FIGS. **2**A through **2**E (e.g., the ledge **213**) can be created during the same manufacturing step as the inner region **144**, and the upper portion **214** (e.g., the media-facing surface **211**) can be created during the same manufacturing step in which the outer region **142** is created. Thus, the particle-blocking structure **200** is a cost-effective approach to smear mitigation and management.

[0086] FIG. **5**A is a flow diagram illustrating a method **300** of manufacturing a slider **525** that includes a particle-blocking structure **200** in accordance with some embodiments. The method **300** could be used, for example, to manufacture a slider **525** with a particle-blocking structure **200** as shown in FIGS. **3**A through **4**B. The method **300** begins at block **302**. At block **304**, the hole **205** of the particle-blocking structure **200** is created in the same manufacturing step in which at least one other surface at the second recessed level of the ABS **150** is created. The manufacturing step can use any suitable process (e.g., milling, etc.). At block **306**, the island blocker **210** is created in the same manufacturing step in which at least one other surface at the media-adjacent surface of the ABS **150** is created. The manufacturing step can use any suitable process (e.g., etching, etc.). At block **308**, the method **300** ends.

[0087] FIG. **5**B is flow diagram of another method **350** of manufacturing a slider **525** that includes

a particle-blocking structure **200** in accordance with some embodiments. The method **350** could be used, for example, to manufacture a slider **525** with a particle-blocking structure **200** as shown in FIGS. **2**A through **2**E. The method **350** begins at block **352**. At block **354**, the hole **205** of the particle-blocking structure **200** is created in the same manufacturing step in which at least one other surface at the second recessed level of the ABS **150** is created. The manufacturing step can use any suitable process (e.g., milling, etc.). At block **356**, the ledge **213** of the island blocker **210** is created in the same manufacturing step in which at least one other surface at the first recessed surface (e.g., the surface **145** of the inner region **144** of the trailing edge pad **140**) of the ABS **150** is created. The manufacturing step can use any suitable process (e.g., etching, etc.). At block **358**, the media-facing surface **211** of the island blocker **210** is created in the same manufacturing step in which at least one other surface of the media-adjacent surface of the ABS **150** is created. The manufacturing step can use any suitable process (e.g., etching, etc.). At block **360**, the method **300** ends.
[0088] Another potential advantage of the particle-blocking structure **200** is that it provides robustness to smear without sacrificing other slider **525** performance objectives. For example, the particle-blocking structure **200** has little effect on the overall flying characteristics of the slider **525** because it is small (e.g., the media-facing surface **211** of the island blocker **210** is small in comparison to the rest of the features of the media-adjacent surface of the slider **525**). Therefore, the particle-blocking structure **200** can be added to the ABS **150** and can mitigate the effects of particles and smear without significantly affecting the flying characteristics of the slider **525**.
[0089] Another potential advantage of the particle-blocking structure **200** is that it offers two types of protection against smear. The hole **205** is provided to trap particles, and the island blocker **210** is provided to block particles that are not trapped by the hole **205**. This dual approach provides good smear mitigation.
[0090] Another potential advantage of the particle-blocking structure **200** is that the hole **205** traps particles that could otherwise build up elsewhere on the slider **525** (e.g., on the surface **145** of the inner region **144** of the trailing edge pad **140**) and thereby cause the fly height to change (e.g., increase due to smear build-up and decrease due to smear drop-off). Thus, use of the particle-blocking structure **200** can reduce fly height variability and other effects that smear can have on the slider **525** flight characteristics.
[0091] A related potential advantage of the particle-blocking structure **200** is that the discontinuities it creates in the ABS **150** provide higher damping of vibrations. For example, smear drop-off can cause the trailing edge of the slider **525** to vibrate. In addition to reducing smear build-up (and drop-off) events (e.g., by trapping particles in the hole **205**), the particle-blocking structure **200** provides better damping when such events do occur. As a result, the effects of transient fly height changes are reduced. Viscous shearing is lower because the trailing edge of a slider **525** with the particle-blocking structure **200** vibrates less, and for a shorter period of time, than a slider **525** without the particle-blocking structure **200**.
[0092] In the foregoing description and in the accompanying drawings, specific terminology has been set forth to provide a thorough understanding of the disclosed embodiments. In some instances, the terminology or drawings may imply specific details that are not required to practice the invention.
[0093] To avoid obscuring the present disclosure unnecessarily, well-known components are shown in block diagram form and/or are not discussed in detail or, in some cases, at all.
[0094] Unless otherwise specifically defined herein, all terms are to be given their broadest possible interpretation, including meanings implied from the specification and drawings and meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc. As set forth explicitly herein, some terms may not comport with their ordinary or customary meanings.
[0095] As used in the specification and the appended claims, the singular forms “a,” “an” and “the” do not exclude plural referents unless otherwise specified. The word “or” is to be interpreted as inclusive unless otherwise specified. Thus, the phrase “A or B” is to be interpreted as meaning all

of the following: “both A and B,” “A but not B,” and “B but not A.” Any use of “and/or” herein does not mean that the word “or” alone connotes exclusivity.
[0096] As used in the specification and the appended claims, phrases of the form “at least one of A, B, and C,” “at least one of A, B, or C,” “one or more of A, B, or C,” and “one or more of A, B, and C” are interchangeable, and each encompasses all of the following meanings: “A only,” “B only,” “C only,” “A and B but not C,” “A and C but not B,” “B and C but not A,” and “all of A, B, and C.”
[0097] To the extent that the terms “include(s),” “having,” “has,” “with,” and variants thereof are used in the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term “comprising,” i.e., meaning “including but not limited to.”
[0098] The terms “exemplary” and “embodiment” are used to express examples, not preferences or requirements.
[0099] The term “coupled” is used herein to express a direct connection/attachment as well as a connection/attachment through one or more intervening elements or structures.
[0100] The terms “over,” “under,” “between,” and “on” are used herein refer to a relative position of one feature with respect to other features. For example, one feature disposed “over” or “under” another feature may be directly in contact with the other feature or may have intervening material. Moreover, one feature disposed “between” two features may be directly in contact with the two features or may have one or more intervening features or materials. In contrast, a first feature “on” a second feature is in contact with that second feature.
[0101] The term “substantially” is used to describe a structure, configuration, dimension, etc. that is largely or nearly as stated, but, due to manufacturing tolerances and the like, may in practice result in a situation in which the structure, configuration, dimension, etc. is not always or necessarily precisely as stated. For example, describing two lengths as “substantially equal” means that the two lengths are the same for all practical purposes, but they may not (and need not) be precisely equal at sufficiently small scales. As another example, a structure that is “substantially vertical” would be considered to be vertical for all practical purposes, even if it is not precisely at 90 degrees relative to horizontal.
[0102] The drawings are not necessarily to scale, and the dimensions, shapes, and sizes of the features may differ substantially from how they are depicted in the drawings.
[0103] Although specific embodiments have been disclosed, it will be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the disclosure. For example, features or aspects of any of the embodiments may be applied, at least where practicable, in combination with any other of the embodiments or in place of counterpart features or aspects thereof. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

## Claims

**1**. A slider for a data storage device, the slider having an air-bearing surface (ABS) that includes at least three levels, the at least three levels including a media-adjacent level, a first recessed level, and a second recessed level, wherein, in an orientation in which the ABS is oriented upward, the media-adjacent level is above the first recessed level, and the first recessed level is above the second recessed level, the slider comprising: a trailing pad comprising a recording head, an outer surface, and an inner surface, wherein the outer surface is at the media-adjacent level and the inner surface is at the first recessed level; a hole in the inner surface of the trailing pad, wherein a bottom surface of the hole is at the second recessed level; and an island blocker situated within the hole, wherein a media-facing surface of the island blocker is at the media-adjacent level, wherein the recording head is situated between the island blocker and a trailing edge of the slider.
**2**. The slider recited in claim 1, wherein a maximum width of the hole in a cross-track direction is at least 75 percent of a maximum width of the inner surface of the trailing pad in the cross-track

direction.

**3**. The slider recited in claim 1, wherein at least one of a size or a shape of the island blocker is configured to block and/or redirect particles moving in an airflow direction toward the recording head at all slider skew angles between a maximum inner-diameter skew angle and a maximum outer-diameter skew angle.

**4**. The slider recited in claim 1, wherein the first recessed level is recessed from the media-adjacent level by between about 50 nm and about 300 nm.

**5**. The slider recited in claim 4, wherein the second recessed level is recessed from the media-adjacent level by between about 500 nm and about 2500 nm.

**6**. The slider recited in claim 1, wherein the recording head comprises a heat-assisted magnetic recording (HAMR) writer.

**7**. A method of manufacturing the slider recited in claim 1, the method comprising: in a first manufacturing step in which at least one other surface at the second recessed level is created, creating the hole; and in a second manufacturing step in which at least one other surface at the media-adjacent level is created, creating the island blocker.

**8**. The slider recited in claim 1, wherein the island blocker comprises a lower portion and an upper portion.

**9**. The slider recited in claim 1, wherein the island blocker comprises a ledge at the first recessed level.

**10**. A method of manufacturing the slider recited in claim 9, the method comprising: in a first manufacturing step in which at least one other surface at the second recessed level is created, creating the hole; in a second manufacturing step in which at least one other surface at the first recessed level is created, creating the ledge; and in a third manufacturing step in which at least one other surface at the media-adjacent level is created, creating the media-facing surface of the island blocker.

**11**. A data storage device, comprising: a recording media; and the slider recited in claim 1.

**12**. A slider for a heat-assisted magnetic recording (HAMR) data storage device, the slider comprising: a HAMR head comprising a near-field transducer (NFT) situated on an outer region of a trailing pad of the slider; and a particle-blocking structure configured to mitigate a formation of smear on a media-facing surface of the NFT, the particle-blocking structure comprising an island blocker within a hole in an inner surface of the trailing pad of the slider, the hole extending perpendicular to an air-bearing surface (ABS) of the slider, wherein: the island blocker has a form factor such that the island blocker blocks oncoming particles with angles of arrival within a specified range of a centerline of the slider.

**13**. The slider recited in claim 12, wherein the specified range includes a first angular range on a first side of the centerline and a second angular range on a second side of the centerline.

**14**. The slider recited in claim 12, wherein a depth of the hole is between about 800 nm and about 5000 nm relative to the media-facing surface of the NFT.

**15**. A method of manufacturing the slider recited in claim 12, the method comprising: in a first manufacturing step, creating the hole; and in a second manufacturing step performed after the first manufacturing step, creating the island blocker.

**16**. The slider recited in claim 12, wherein the island blocker comprises a lower portion and an upper portion.

**17**. The slider recited in claim 12, wherein the island blocker comprises a ledge, wherein the ledge is recessed from a media-facing surface of the island blocker.

**18**. The slider recited in claim 17, wherein a recess distance between the media-facing surface of the island blocker and the ledge is between about 50 nm and about 300 nm.

**19**. A method of manufacturing the slider recited in claim 17, the method comprising: in a first manufacturing step, creating the hole; in a second manufacturing step performed after the first manufacturing step, creating the ledge; and in a third manufacturing step performed after the

second manufacturing step, creating the media-facing surface of the island blocker.
**20**. A data storage device, comprising: a recording media; and the slider recited in claim 12.