HEAD SUSPENSION WITH FLEXIBLE CIRCUIT INTERCONNECT FOR REDUCED MOISTURE PERMEABILITY

Background of the Invention

Field of the Invention

The invention relates to a disk drive suspension of a head suspension assembly using a flexible circuit interconnect with reduced moisture permeability, and attendant reduced curl, wherein at least one major surface of the circuit is selectively or continuously coated with at least one layer of diamond like carbon film.

Description of the Related Art

Head suspension assemblies used in rotatable data storage devices are spring structures that hold and position a floating head just nanometers away from a rapidly spinning data storage device such as a magnetic hard disk drive or optical disk drive. The assembly comprises such components as the suspension, usually formed of a metal such as stainless steel, a spring, a load beam and a gimbal fixture, each of which must have rigid areas and flex spring areas, and a head which includes a highly sensitive transducer that is attached to an air bearing head or "slider".

The gimbal is one of the most critical regions of the suspension. The closer the suspension assembly can float on a cushion of air (or "fly") to the surface of the data storage device, the more densely information can be stored on the device. However, it is critical that the suspension assembly not touch the disk as the impact with the spinning disk can destroy not only the suspension assembly but the storage disk and the data stored thereon. Therefore there must be precise balancing of the suspension assembly and the gimbal fixture. The gimbal must be responsive in order to maintain a level height above the microsized peaks and valleys of the data storage disk. It must also resist static pitch and roll.

Conventional gimbal fixtures are formed from a single sheet of material and include a pair of outer flexible arms around a central aperture. See, e.g., U.S. Patent 4,167,765. As the head reads and writes to and from the data storage device, it receives and sends electrical pulses of information. These pulses are related to appropriate amplifying and processing circuitry. Discrete wires have typically been

used to connect the amplifying system to the head of the assembly. Their use is advantageous in that they can be manufactured separately and can adapt to a variety of configurations. However, as technology advances this "interconnect" system must be able to carry a plurality of signals, and may requires multiple conductors and other features. However, as the number of conductors increases, the interaction of the interconnect system may impose unpredictable biases and loads which might alter the positioning of the head or cause difficulty in the suspension assemblies reaction of variation in the disk surface. This would significantly affect density if information stored, and the reliability of reading this information. The interconnect system may also negatively affect the flexibility of the gimbal region by adding rigidity to this critical area. Further, fragile conductors may be damaged during production steps. Various types of improvements have been attempted to upgrade the interconnect system without reducing data storage density or increasing the potential for read/write errors.

Electrical flex circuits have also been used for interconnect systems in suspension assemblies. The flex circuits follow the surface topology of the suspension assembly and may be attached at various regions. They offer the option of increasing or decreasing the resistance along the path of the flexible circuit. They are lower profile than discrete wires, and have controlled impedances. However, their use does create at least two significant problems. Moisture absorption causes undesirable stresses and curling, and the film substrates give the flexible circuit a high stiffness value.

Various types of flexible circuits, that is circuits formed on flexible substrates, are known in the industry. Flexible circuits are circuits which are formed on flexible dielectric substrates such as polymeric materials and include one or more conductive layers as in U.S. Patent 4,231,154. The circuits may also include other layers including additional insulative layers including adhesive layers, encapsulants, stiffeners and the like. Means for interconnection of the flexible circuits to another, e.g., another flexible circuit, a printed circuit board, and the like may also vary. Circuitry may be on only one surface or on both major surfaces, see e.g., U.S. Patent No. 4,480,288.

U.S. Patent No. 4,819,094 discloses a damped magnetic head suspension assembly where a flexible circuit is adhesively bonded to a suspension to provide damping and profile reduction over discrete wires.

U.S. Patent 4,996,623 discloses a suspension assembly having an interconnect system which includes a sheet of polyimide material sandwiched between two metal layers. A plurality of conductors can be formed in the copper layer.

U.S. Patent No. 5,491,597 discloses a gimbal fixture having an electrical interconnect assembly which is sturdy and self-supporting that the very interconnect system is shaped and used as a gimbal when attached to a head suspension assembly. This gimbal-interconnect includes a set of traces preferably formed from beryllium copper, and coated with a thin dielectric coating. The traces may be laminated to the load beam by means of an adhesive, which may also be a dielectric material.

UK Patent Application GB 2295918A discloses a head suspension system for supporting a magnetic read/write head (slider) having two flexure arms with two flexible finger regions. The electrical interconnect system includes electrical conductors to the head positioned along one or both flexure arms or adjacent to, but outside of, the second flexure arm so as not to contribute to the stiffness of the second flexure arm. The conductors are composed of a laminated material which includes a conductor layer, a dielectric layer and a support layer.

However, a difficulty with flexible circuits not addressed by the previous efforts is the moisture absorption of the dielectric material used in the flexible circuit. When the dielectric material absorbs water, it expands which causes it to curl. This changes the static attitude of the suspension assembly and can result in a loss of signal. Data storage devices such as disk drives need to operate in humid environments. It would therefore be desirable for flexible circuits to having less water absorption and curl. Humidity variations between the point of disk drive assembly and the point of use can cause moisture related problems in the suspension flex circuit.

Diamond coatings and diamond like carbon films are also known. These products provide hard coatings and improved wear resistance, and are typically coated

onto rigid surfaces subject to friction and wear, such as glass for use as eyeglass lenses, windshields, and the like.

U.S. Patent No. 5,508,071 discloses a diamond coating for an annular interior surface to improve abrasion resistance. The coating is deposited on a substrate such as metal, alloys, and ceramics. Because chemical vapor deposition (CVD) of diamond layers is takes place at very high temperatures, it cannot be used for many polymeric substrates such as polyimide which will degrade at the elevated diamond-forming temperatures. Further, the polycrystalline nature of CVD diamond dictates a very hard, brittle coating with little flexibility. The term "diamond like carbon" is typically applied to noncrystalline materials, especially those in which tetrahedral diamond bonds predominate.

U.S. Patent No. 4,576,964 discloses barrier films made from flexible polymeric substrates having amorphous carbon coatings adhering thereto.

U.S. Patent 5,508,092 discloses optically transparent abrasion wear resistant coated substrates comprising a parent substrate, one or more interlayers and a top coating of diamond like carbon or other low-friction material.

The current inventors have now discovered that one or more conformal layers of diamond like carbon deposited onto a flexible circuit can provide not only protection against abrasion but reduce curl associated with increased humidity by providing an effective moisture barrier, and provide a measure of stability and material robustness that will substantially reduce processing damage of these delicate materials. Finally, a coating of diamond like carbon will provide a non-outgassing covercoat or insulator for the conductors.

The flexible circuits may be selectively coated such that the bonding area is kept free of the coating or fully coated and then ablated from bonding areas. Further, a conformal layer of diamond like carbon may be coated directly onto the nonconductor side of the substrate of the flexible circuit, or it may be coated after such steps as development, etching, and plating of the circuitry, or a layer can be coated at each of these steps.

Summary of the Invention

The present invention provides a disk drive suspension incorporating a flexible circuit having at least one layer of diamond like carbon deposited on at least one major surface thereof, and a process for making the gimbal including the flexible circuit.

Disk drive suspensions of the invention comprise:

a) at least one layer of polymer dielectric material having at least one layer of conductive material thereon, each layer having two major surfaces, at least one of said layers having at least one aperture therein,

b) at least one layer of diamond like carbon on at least one major surface of at least one layer, said coating having a thickness of between 300 Angstroms to 3000 Angstroms, and a hardness of from 8 to 9.

In one embodiment, a layer of diamond like carbon is deposited over the entire flexible circuit. In another embodiment, a layer is deposited only in selected areas, such as around vias or through holes. A layer of diamond like carbon may also be deposited on the interior walls of such vias or through holes. In yet another embodiment, layers of diamond like carbon are deposited on a plurality of layers as the circuit structure is built.

The flexible circuit may be attached to the suspension either with a continuous layer of adhesive or it may have adhesive only at pre-selected locations (spot-bonding). In the embodiment where the circuit is attached to the suspension with a continuous layer of adhesive, a layer of diamond like carbon is required only on the side of the circuit opposite the adhesive layer. Where the circuit is attached by means of spot-bonding, a layer of diamond like carbon should be coated on both sides of the circuit. This provides an additional benefit by providing a barrier against moisture between the circuit and the assembly. Reducing or substantially eliminating the moisture in this area substantially improves fly characteristics and dimensional stability.

The following terms have the defined meanings when used herein.

1. The term "gimbal assembly" means the portion of the suspension that allows the head to roll and pitch.

2. The term "suspension" means the components that carry the head and provide the spring force which acts against an air bearing force to maintain the head at a constant height above the disk.

3. The terms "diamond like carbon" and "carbon rich film" are synonymous and interchangeable in the industry, and refer to carbon films primarily consisting of carbon without long range atomic order as disclosed in *Plasma Deposited Films*, Ed. J Mort and F. Joanne, CRC Press, Boca Raton, FL, 1986.

4. The term "aperture" refers to an opening in a layer of the flexible circuit. The aperture may extend through a portion of the layer, or may extend completely through the layer. Apertures may be formed by a variety of techniques including mechanical punching, chemical milling, and laser ablation.

5. The term "through hole" refers to an aperture which extends completely through a layer of the flexible circuit exposing a metal trace on one side.

6. The term "via" refers to a metallized through hole that connects a conductive trace to another conductive trace or plane.

7. The term "blind via" refers to a metallized aperture which does not extend completely through a layer of the flexible circuit.

8. The terms "etching" and "milling" are used synonymously, and include mechanical, chemical and optical processes for removing material, including chemical etching, laser ablation, mechanical milling and the like.

All ratios, parts, and percents described herein are by weight, unless otherwise specifically stated.

Brief Description of the Figures

Figure 1 shows a perspective view of a disk drive suspension of the invention.

Figure 2 shows a side cut away view of a disk drive suspension of the invention.

Figure 3 shows a side cut away view of a disk drive suspension.

Figure 4 shows a perspective view of another embodiment of a disk drive suspension of the invention.

Figure 5 shows a cross-sectional view of conventional substrate for a disk drive suspension interconnect.

Figure 6 shows a substrate with a performance enhancing diamond like carbon coating applied to both sides of a polyimide film.

Figure 7 shows a substrate with a performance enhancing surface coating applied to both sides of a copper clad polyimide film.

Figure 8 shows that the test fixture allows the curling associated with moisture absorption to be measured.

Detailed Description of the Invention

Disk drive suspensions of the invention comprise at least one conformal coating of diamond-like carbon (DLC). Also known as "thin film carbon rich coatings", diamond-like carbon coatings contain two types of carbon-carbon bonds; trigonal graphite bonds (sp2) and tetrahedral diamond bonds (sp3), with tetrahedral bonds predominating. The films thus exhibit many of the properties of diamond, e.g., it is quite hard, chemically inert, corrosion resistant and impervious to water vapor and oxygen, and some of the properties of graphite, e.g., smoothness, and strong adhesion to polymeric materials. It also has an extremely low electrical conductivity and excellent optical transparency over a wide range of wavelengths. Useful diamond-like carbon layers for flexible circuit carriers and flexible circuits of the invention have a thickness of from 300 Angstroms, to 3000 Angstroms, preferably from 1000 Angstroms to 2000 Angstroms.

When tested against uncoated polyimide under the same conditions, a layer of diamond-like carbon having a thickness of 1000 Angstroms coated onto a 50 μm (2 mil) polyimide has been found to substantially eliminate curl; increase concentricity and registration of laser ablated apertures by as much as 95%; decrease the transmission rate of water and oxygen by as much as 92% and 93%, respectively; decrease adhesion loss between the polyimide and copper by as much as 96%; increase the flexural stiffness by as much as 43%.

In some cases, a layer or layers of diamond-like carbon will be deposited on the bare substrate dielectric material, typically a polyimide film, prior to forming of the circuit. In other cases, it will be desirable to coat an intermediate layer or layers of diamond-like carbon between the various circuit forming steps such as development, etching, and plating, or between each of these steps. A layer of diamond-like carbon

may also be coated onto any dielectric layer such as the metallic layers. The desired attributes of the resulting construction dictate the design, placement, and number of the diamond-like carbon layers. Any additional layers must also be flexible enough to bend with the flex circuits to facilitate processing, handling and assembly without causing cracking or causing damage to the circuit.

Circuits of the invention may comprise diamond-like carbon layers coated by any of the variety of methods (ion beam, plasma, etc.) which have been developed to deposit such layers including those using either solid carbon or hydrocarbon sources. The deposition method may be batchwise deposition or continuous deposition, although continuous deposition is preferred for manufacturing efficiency.

In preferred articles and processes of the invention, diamond-like carbon layers are deposited using a continuous plasma process coupled with ion acceleration. In general, the carbon rich plasma is created by applying a high frequency electric field to a carbon containing environment by powering a rotatable electrode element. Ions within the carbon rich plasma accelerate toward the electrode, where they strike a substrate in contact with the rotating electrode.

The diamond-like carbon may also be functionalized with such materials as fluorine, silicon, oxygen, sulfur, nitrogen, copper, chromium, titanium, and nickel. The initial deposition can be achieved using a blend of suitable gases before the final stages of diamond-like carbon deposition, by gradually increasing the respective gas concentration and decreasing the hydrocarbon precursor concentration. Such process is also called "doping".

The flexible circuit substrate is a flexible polymeric dielectric film which may be partially cured or substantially fully cured. Useful organic polymers include polyimides including modified polyimides such as polyester imides and poly-imide-esters, polysiloxane imides, and polyamide, polymethylmethacrylate, polyesters such as poly(ethylene terephthalate), polycarbonates, polytetrafluoroethylenes and mixtures thereof. The polyimides are preferred, with an especially preferred polyimide polymer being made from the anhydride of pyromellitic acid and 4,4 diamino-diphenyl ether available from E.I. DuPont de Nemours and Company under the tradename Kapton®. Variations include Kapton® H, Kapton® E and Kapton® V,

among others. Another useful polyimide precursor is also available from DuPont as Pyralin™. Upilex™, available from Ube Industries Ltd., and Apical™, available from Kameka Films, are also useful herein.

The conductive layer(s) are typically formed from conductive metals such as tin, gold, silver, copper and the like. The thicknesses and disposition of such layers is highly dependent on the particular type of circuit or electronic package desired.

The flexible circuit may also include intermediate layers, stiffeners, ground planes, further insulative layers, and the like, which will be discussed, *infra*, with the preferred embodiments.

The diamond like carbon (DLC) layers or coatings are deposited, on flexible circuits used in disk drives of the invention, to provide a variety of benefits to the circuit and the disk drive suspension. Thin film carbon rich coatings contain two types of carbon-carbon bonds: trigonal graphite bonds (sp2) and tetrahedral diamond bonds(sp3), with tetrahedral bonds predominating. The films thus exhibit many of the properties of diamond, e.g., it is quite hard, chemically inert, corrosion resistant and impervious to water vapor and oxygen, and some of the properties of graphite, e.g., smoothness, and strong adhesion to polymeric materials. It also has an extremely low electrical conductivity and optical transparency over a wide range.

Useful diamond like carbon layers have a thickness of from 300 Angstroms, to 3000 Angstroms, preferably from 500 Angstroms to 2000 Angstroms.

Description of the Carrier and Circuit-Making Process

The process of making flexible circuits and carriers according to the invention comprises the step of depositing at least one layer of diamond-like carbon thereon which may be used in conjunction with various known procedures such as metal sputtering, plating resist laminating, resist exposing, developing, etching, and plating. The sequence of such procedures may be varied as desired for the particular application. Multiple deposition steps may be used where more than one layer of diamond-like carbon is desirable, e.g., a layer deposited directly on the substrate for improved planarity and via creation, and a layer deposited atop a metallic layer to provide such benefits as abrasion resistance and thermal management. The procedures described herein apply equally to carriers and flexible circuits.

One additive method for making a flexible circuit or carrier has a typical sequence of steps described as follows:

First, a conformal diamond-like carbon layer is deposited onto the polymer side, e.g., polyimide side, of a film substrate. The substrate may be made by various methods such as adhesively bonding a cured polymer layer onto copper foil, coating liquid polyimide on copper foil or the like. Typically, the substrate consists of a polymeric film layer of from 25 micrometers to 125 micrometers, with the copper layer being from 1 to 5 micrometers thick. The coating may be deposited on only one side or on both sides of the polyimide.

Next, sputtering of the polyimide film, or diamond-like carbon coated film, with a seed layer of chrome and copper is performed. Photoresists, which may be aqueous or solvent based, and may be negative or positive photoresists, are then laminated onto both sides of a substrate having a polymeric film side and a copper side, using standard laminating techniques with hot rollers. The thickness of the photoresist is from 35 to 50 micrometers. The photoresist is then exposed on both sides to ultraviolet light or the like, through a mask or phototool, crosslinking the exposed portions of the resist. The unexposed portions of the photoresist are then developed with the appropriate, solvent, in the case of aqueous resists a dilute aqueous solution, e.g., a 0.5-1.5% sodium or potassium carbonate solution, is applied until desired patterns are obtained on both sides of the laminate. The photoresist is then removed, so that the copper side of the laminate can be then further plated to desired circuit thickness. One or more layers of diamond-like carbon may also be deposited atop the copper, or on the opposing surface, if desired.

The laminate is then placed into a bath of concentrated base at a temperature of from 50°C to 120°C which etches the portions of the polymeric film not covered by the crosslinked resist. This exposes certain areas of the original thin copper layer. The resist is then stripped off both sides of the laminate in a 2-5% solution of an alkaline metal hydroxide at from 20°C to 80°C, preferably from 20°C to 60°C. Subsequently, the original thin copper layer is etched where exposed with an etchant which does not harm the polymeric film, e.g., Perma-etch®, available from Electrochemicals, Inc. The final circuits have copper circuitry on one side, and

diamond-like coating on polyimide surface on the opposing side, and any diamond-like carbon layers deposited between internal layers or on individual features.

The circuits are then converted and audited; that is, the substrate is cut into smaller strips, and checked for quality.

In an alternate type of process called a substractive process, polyimide film is sputtered with a seed layer of chrome and copper. The aqueous processible photoresists are laminated onto both sides of a substrate having a polymeric film side and a thick copper side, using standard laminating techniques. The substrate used in this process consists of a polymeric film layer 12 micrometers to 125 micrometers thick with the copper layer being from 12 to 40 micrometers thick (in the additive process, the copper layer is 1-5 micrometers thick).

The photoresist is then exposed on both sides to ultraviolet light or the like, through a suitable mask, crosslinking the exposed portions of the resist. The image is then developed with a dilute aqueous solution until desired patterns are obtained on the trace side of the laminate. The thick copper layer is then etched to obtain circuitry, and portions of the polymeric layer thus exposed.

An additional layer of aqueous photoresist is then laminated over the first resist on the copper side and crosslinked by flood exposure to a radiation source in order to protect exposed polymeric film surface (on the copper side) from further etching. Areas of the polymeric film (on the film side) not covered by the crosslinked resist are then etched with the concentrated base at a temperature of from about 70°C to about 120°C, and the photoresists are then stripped from both sides with a dilute basic solution. The circuits are then converted and audited; that is, the substrate is cut into smaller strips, and checked for quality.

As with the additive process, the diamond-like carbon layer may be coated after initial laminating and sputtering steps are completed.

The previous methods coat the diamond like carbon layer over the entire substrate. In the selective coating processes, the layer is coated only in areas of the polyimide surface where protection is desired. These processes are typically completed postcircuitization. One selective process is a mechanical masking process

wherein the diamond like carbon layer is coated through an appropriate mask after the flash etching and converting step.

Other steps may also be included in these processes, such as soaking the film in hot water before or after the etching bath, rinse steps and the like. Acid baths may also be used as a post-etching neutralization, web cleaning steps may follow plating steps.

To create finished flexible circuits, further layers may be added and processed, the copper plating may be plated with gold, tin, or nickel for subsequent soldering procedures and the like according to conventional means. When using a selective coating process such as the mechanical masking process, the diamond like carbon layer may also be coated after this final plating step.

Means for interconnection of the flexible circuit to the suspension of the suspension may be selected from any conventional means, connecting the pads or other connection points including solder balls, reflow solder, thermal compression bonding, wire bonding, inner lead bonding and the like.

The embodiments discussed in the drawings are meant to be illustrative and are not intended to limit the scope of the invention which is expressed solely by the claims.

Detailed Description of the Drawings

Figure 1 shows a hard disk drive suspension in which a conventional stainless steel flexure 100 has attached thereto a flexible circuit 120, with traces 130 on the exposed surface of the flexible circuit 120, and a bonded heat 140 to the flexible circuit 120. No diamond like carbon coating is present on the exposed side of the flexible circuit 120.

Figures 2 and 3 show a side cut away view of differing embodiments of the invention. In Figure 2, the circuit has two continuous layers of diamond like carbon 260, one layer on each surface of the polyimide substrate 280. The circuit traces 270 are then formed. In Figure 3, the embodiment has a continuous coating of diamond like carbon 360 on the side of the polyimide adjacent to the stainless steel suspension. Another layer of diamond like carbon 360 has been selectively coated atop the circuit traces 350.

In Figure 4, a disk drive suspension is shown in which a stainless steel suspension 400 has a flexible circuit, 420 attached thereto, with traces 430 on the exposed surface of the flexible circuit 420, and a bonded head 440 attached to the flexible circuit 420. In this embodiment, a diamond like carbon coating 460 has been deposited on the exposed side of the flexible circuit 420.

Figure 5 shows a conventional substrate 500 for a disk drive suspension interconnect having a layer of polyimide 510 with a layer of copper 520 plated thereon. In the substrate 600 of Figure 6, both surfaces of the polyimide 610 has been modified with a diamond like carbon coating 630 that reduces moisture and oxygen permeability and the copper layer 630 is separated from the polyimide 610 by such layer 630.

Figure 7 shows a substrate 700 having a polyimide layer 710 and a copper cladding 720. Both sides of the clad film have a diamond like carbon coating 730 coated thereon.

Figure 8 shows a test fixture 800 wherein a sample 810 is conditioned in a chamber with a known humidity and temperature. This allows the curling associated with moisture absorption to be measured. The sample is placed into a clamp 820 at one end into the fixture and exposed to an environment with a higher humidity than the conditioning humidity. The curl is a measurement of the distance the sample deflects from the surface of the test fixture. When samples without any diamond like carbon coating were exposed to 100% relative humidity (RH), the curl was approximately 5 mm. When samples similar to those shown in Figures 6 and 7 were coated and subjected to 100% RH, no curl was observed.

What is Claimed is:

1. A disk drive suspension comprising:

a transducer head electrically connected to a suspension by means of a flexible circuit, said circuit comprising

a) at least one layer of polymer dielectric material (710) having two major surfaces,

b) at least one layer of conductive material (720) thereover having two major surfaces,

c) at least one layer of diamond-like carbon (730) on at least one major surface of at least one layer, said layer of diamond-like carbon having a thickness of between about 30 nm to about 300 nm, and a hardness of from about 8 to about 9.

2. A disk drive suspension according to claim 1 wherein said flexible circuit has a layer of diamond-like carbon coated onto at least a portion of at least one major surface of said layer of polymer dielectric material.

3. A disk drive suspension according to claim 2 wherein said layer of diamond-like carbon is coated over both major surfaces of said layer of said polymer dielectric material.

4. A disk drive suspension according to claim 1 wherein said flexible circuit has a layer of diamond-like carbon coated onto at least one major surface of said conductive material of said flexible circuit.

5. A disk drive suspension according to claim 1 wherein said flexible circuit has a layer of diamond-like carbon coated onto one major surface of said conductive material, and one major surface of said polymer dielectric material.

6. A disk drive suspension according to claim 1 wherein said flexible circuit has said layer of diamond-like carbon coated continuously on at least one surface.

7. A disk drive suspension according to claim 1 wherein said flexible circuit has said layer of diamond-like carbon coated selectively on at least one surface.

8. A disk drive suspension according to claim 1 wherein said layer of conductive material is adhesively attached to said layer of polymer dielectric material.