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AMORPHOUS DIAMOND-LIKE CARBON GAPS IN MAGNETORESISTIVE HEADS

BACKGROUND OF THE INVENTION

This invention relates to magnetoresistive heads, particularly to magnetoresistive heads for reading data from an adjacent magnetic media.

Magnetoresistive (MR) elements are widely used in magnetic transducing heads for reading data from a magnetic disk. MR elements are characterized in that the resistance of the element changes with variations in the magnetic field due to recorded data on the adjacent magnetic disk. Resistance changes in the MR element are sensed by passing a current through the element and measuring the voltage change across it, or by placing a voltage across the element and measuring the current change through it. In either case, the varying signal represents the data on the disk and the MR head provides an accurate transducer for reading high density digital information from the adjacent magnetic media. Typically, the MR element is located on the magnetic head between two thick soft magnetic films, such as Sendust or permalloy, which act as flux shields for the MR head. Typically, these shields are isolated from the MR element by electrically insulating material, such as aluminum oxide (Al_2O_3).

One problem associated with MR heads is that considerable heat is often generated by current passing through the MR element. Although the current is typically small (of the order of milliamperes), the size of the MR element film is likewise small, causing a substantial concentration of the heat in the MR element. While the magnetic film shields could provide a good heat sink for dissipating excess heat generated by the MR head, the presence of the electrically insulating layer between the magnetic films and the MR element thermally insulates the MR element from the magnetic material.

There is, accordingly, a need for at least one of the half-gaps adjacent the MR element be of a material that exhibits high thermal conductivity and low electrical conductivity.

SUMMARY OF THE INVENTION

In accordance with the present invention, at least one of the half-gaps of an MR head located between the MR element and a shield is fabricated of an amorphous diamond-like carbon film having good thermal conductivity and high resistivity characteristics. Preferably, the at least one half-gap formed of the diamond-like carbon film is located between the MR element and the magnetic film formed on the supporting substrate to thereby dissipate heat. Optionally, both half-gaps may be formed of the amorphous diamond-like carbon film.

The amorphous diamond-like carbon film employed in accordance with the present invention is a very hard material resistant to abrasion. Consequently, one optional and desirable feature of the present invention resides in the inclusion of the amorphous diamond-like carbon film to the air bearing surface of the head to protect the MR element from abrasion upon take off and landing of the head against the disc.

Another optional feature of the present invention is the formation of the write gap of a write transducer with an amorphous diamond-like carbon film having good thermal conductivity and high resistivity characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a section view of one form of a head in accordance with the presently preferred embodiment of the present invention;

Figure 2 is a frontal view of the air-bearing surface of the head shown in Figure 1; and

Figure 3 is a partial section view, as in Figure 1, of an MR head in accordance with a modification of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figures 1 and 2 illustrate a magnetic head in accordance with one form of the present invention. The head includes a thick film layer 10

of soft magnetic material, such as Sendust, which has been deposited on a substrate (not shown) in a customary manner. A read head 12 is formed of a first electrically insulative, non-magnetic, thermally conductive layer 14 formed of amorphous diamond-like carbon described below. MR element 16 is formed of a layer of magnetic material whose resistance varies with changes in the magnetic field from a disc (not shown) adjacent air-bearing surface 18 of the head. MR element 16 is a preferably thin film of permalloy deposited onto a surface of film 14. Conductive films 20 and 20′ are deposited over films 14 and 16, and a second electrically insulative, non-magnetic, thermally conductive layer 22, formed of amorphous diamond-like carbon is deposited over conductors 20 and 20′ and MR element 16. As shown particularly in Figure 2, conductors 20 and 20′ are positioned at opposite sides of MR element 16 to form the transducing sensor in the region of MR element 16 between the conductors.

The write head is formed in a conventional manner by a magnetic film 26 (such as permalloy), gap material 28, such as aluminum oxide (Al_2O_3) forming the write gap 30, permalloy layer 32 on layers 26 and 28 and encapsulated coil 34 in polymer layers 36.

The present invention is directed to the use of an amorphous diamond-like carbon film forming at least layer 14, and optionally layer 22, sandwiched between MR element 16 and one or both magnetic films 18 and 26. Such material is known as "diamond-like carbon" or "DLC" and is commercially available from Diamonex, Inc. and from Minnesota Mining and Manufacturing Company (3M). The amorphous diamond-like carbon is similar to diamond in physical properties, except that it is amorphous in structure, rather than polycrystaline. The material is a hydrogenated carbon typically having a hydrogen content between about 30 to 50 percent and a large fraction of sp^3 carbon-carbon bonds rather than sp^2 found in ordinary graphite. The material is typically formed from a hydrogenated carbon

feedstock, such as methane (CH_4), processed by any of a variety of processes, such as an ion beam deposition process. It is theorized that during formation of diamond-like carbon, hydrogen is removed from the feedstock material forming an amorphous network of sp^3 bonded carbon atoms, rather than an ordered array of sp^2 bonded carbon, i.e. graphite. The material resembles a hard, highly cross-linked polymer and exhibits a higher thermal conductivity than common electrical insulating material (such as Al_2O_3) and a high electrical resistivity, of the order of about 10^{10} Ω-cm. Amorphous diamond-like carbon films are similar to diamonds in that they exhibit very high hardness ranges (1,000 to 5,000 on the Vickers hardness scale), a low coefficient of friction (of the order of less than 0.1) and densities between about 1.7 and 2.2. The material is commercially referred to as "diamond-like" because of its similarity in characteristics to natural and synthetic diamond, which are polycrystaline materials rather than amorphous materials. Moreover, like natural and synthetic diamond, the diamond-like carbon exhibits a high resistivity.

The diamond-like carbon layer 14 is preferably formed by ion beam deposition onto layer 10, and the diamond-like carbon layer 22 is preferably formed by ion beam deposition onto layers 16 and 20, 20'. The relative simplicity of the ion beam process also allows the formation of low defect films, which are necessary for the formation of very thin insulating layers between the MR element and the magnetic film shields.

Diamond-like carbon layer 14 and/or 22 provides dissipation of heat in MR element 16 to thermally conductive magnetic shield layers 10 and/or 26. Layer 10 and/or 26 provides a good heat sink for the dissipation of heat. At the same time, the diamond-like carbon of layer 14 and/or 22 provides a good electrical insulator for the gap material of the MR head. Another advantage of diamond-like carbon as a gap material is its ability to be dry etched. Simple oxygen-based gas phase reactions can be used with

standard photo processes to pattern diamond-like carbon films. This avoids the need to use more complex and difficult to control patterning processes, such as wet etching and ion milling.

Figure 3 illustrates a modification of the present invention that layer 50 forms air bearing surface 18 over MR element 16. Since the diamond-like carbon forming layer 14 is extremely hard (Vickers hardness scale of 1,000 to 5,000), layer 50 provides a shield for MR element 16 against abrasion upon take off and/or landing of the head on the disc.

Another optional feature of the present invention is the use of the diamond-like carbon to form write gap 30 for the write transducer. In this regard, layer 28 is formed of the diamond-like carbon so that the write gap is thermally conductive and hard. The use of diamond-like carbon for layer 28 provides a wear-resistant gap.

Magnetoresistive elements of MR heads currently in use have thicknesses of the order of about 300 Angstroms (compared to magnetic layers of about 3 microns thick and electrically insulating Al_2O_3 gap layers between about 1000 and 4000 Angstroms thick). The use of diamond-like carbon to increase heat dissipation from the MR element permits the use of even thinner layers for the MR element without risking destruction by enhanced electromigration. Thinner MR read elements give higher signals which in turn permit reduction of the track width of the recorded magnetic bit, thereby increasing data density and contributing to even higher performance of disc drives than heretofore possible.

Although the present invention is described as having both gap layers 14 and 22 constructed of amorphous diamond-like carbon, it is understood that it may be desirable to form only one of those films 14 or 22 of such material. For example, it may be desirable to dissipate heat only to film 10 in certain cases, such as to minimize thermally induced stress where layers 16, 20 (20'), 22 and 26 meet. In either case, the high thermal

conductivity of the material of layer 14 and/or 22 dissipates heat from the MR element to the adjoining magnetic film 10 and/or 26 to help dissipate heat from the MR element.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

WHAT IS CLAIMED IS:

1. An assembly comprising a magnetoresistive element, a thermally conductive member, and a film of thermally conductive, high electrical resistivity amorphous diamond-like carbon sandwiched between the magnetoresistive element and the thermally conductive member.

2. The assembly of claim 1, wherein the amorphous diamond-like carbon has a hydrogen content between about 30 and 50%.

3. The assembly of claim 1, wherein the amorphous diamond-like carbon has a resistivity of the order of 10^{10} Ω-cm.

4. The assembly of claim 1, wherein the thermally conductive member is a magnetic film.

5. The assembly of claim 1, wherein the amorphous diamond-like carbon film is patterned using a dry etch process.

6. A sensor for reading data from a magnetic media comprising a first thermally conductive magnetic film, a magnetoresistive element, at least two conductors attached to the magnetoresistive element and a first film of thermally conductive, high electrical resistivity amorphous diamond-like carbon sandwiched between the magnetoresistive element and the magnetic film.

7. A sensor of claim 6, wherein the amorphous diamond-like carbon has a hydrogen content between about 30 and 50%.

8. A sensor of claim 6, including a write transducer for writing data onto a magnetic media, the write transducer including a thermally conductive magnetic film, and a second film of thermally conductive, high electrical resistivity amorphous diamond-like carbon sandwiched between the second magnetic film and the magnetoresistive element.

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9. A sensor of claim 8, wherein the write transducer includes a write gap formed of a third film of thermally conductive, high electrical resistivity amorphous diamond-like carbon.

10. A sensor for writing data to a magnetic media comprising first and second thermally conductive magnetic films, a third film of thermally conductive, high electrical resistivity amorphous diamond-like carbon sandwiched between the first and second films to form a gap, and a coil at least partially between the third film and one of the first and second films for inducing a magnetic flux into a region adjacent the gap.

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