

SPIN VALVE SENSOR WITH A METAL AND METAL OXIDE CAP LAYER STRUCTURE

The present invention relates to a spin valve sensor with a metal and metal oxide cap layer structure and, more particularly, to a cap layer structure which includes a gold or copper layer for specular reflection of conduction electrons and an aluminum oxide or tantalum oxide layer for protecting the gold or copper layer from degradation.

The heart of a computer is a magnetic disk drive which includes, within a housing, a rotating magnetic disk, a slider that has read and write heads, a suspension arm above the rotating disk and an actuator arm that swings the suspension arm to place the read and write heads over selected circular tracks on the rotating disk. The suspension arm biases the slider into contact with the surface of the disk when the disk is not rotating but, when the disk rotates, air is swirled by the rotating disk adjacent an air bearing surface (ABS) of the slider causing the slider to ride on an air bearing a slight distance from the surface of the rotating disk. When the slider rides on the air bearing the write and read heads are employed for writing magnetic impressions to and reading magnetic signal fields from the rotating disk. The read and write heads are connected to processing circuitry that operates according to a computer program to control the position of the magnetic head assembly so as to implement the writing and reading functions.

An exemplary high performance read head employs a spin valve sensor for sensing the magnetic signal fields from the rotating magnetic disk. The sensor includes a nonmagnetic electrically conductive first spacer layer sandwiched between a ferromagnetic pinned layer structure and a ferromagnetic free layer structure. An antiferromagnetic pinning layer interfaces the pinned layer structure for pinning a magnetic moment of the pinned layer structure 90° to an air bearing surface (ABS) wherein the ABS is an exposed surface of the sensor that faces the magnetic disk. First and second leads are connected to the spin valve sensor for conducting a sense current therethrough. A magnetic moment of the free layer structure is free to rotate upwardly and downwardly with respect to the ABS from a quiescent or bias point position in response to positive and negative magnetic field signals from a rotating magnetic disk. The quiescent position, which is parallel to the ABS, is the position of the magnetic

moment of the free layer structure with the sense current conducted through the sensor in the absence of signal fields.

The thickness of the spacer layer is chosen so that shunting of the sense current and a magnetic coupling between the free and pinned layer structures are minimized. This thickness is typically less than the mean free path of electrons conducted through the sensor. With this arrangement, a portion of the conduction electrons are scattered at the interfaces of the spacer layer with the pinned and free layer structures. When the magnetic moments of the pinned and free layer structures are parallel with respect to one another scattering is minimal and when their magnetic moments are antiparallel scattering is maximized. Changes in scattering changes the resistance of the spin valve sensor as a function of $\cos \theta$, where θ is the angle between the magnetic moments of the pinned and free layer structures. The sensitivity of the sensor is quantified as magnetoresistive coefficient dr/R where dr is the change in the resistance of the sensor as the magnetic moment of the free layer structure rotates from a position parallel with respect to the magnetic moment of the pinned layer structure to an antiparallel position with respect thereto and R is the resistance of the sensor when the magnetic moments are parallel.

In addition to the spin valve sensor the read head includes nonconductive nonmagnetic first and second read gap layers and ferromagnetic first and second shield layers. The spin valve sensor is located between the first and second read gap layers and the first and second read gap layers are located between the first and second shield layers. In the construction of the read head the first shield layer is formed first followed by formation of the first read gap layer, the spin valve sensor, the second read gap layer and the second shield layer. Spin valve sensors are classified as a top or a bottom spin valve sensor depending upon whether the pinning layer is located near the bottom of the sensor close to the first read gap layer or near the top of the sensor close to the second read gap layer. Spin valve sensors are further classified as simple pinned or antiparallel pinned depending upon whether the pinned layer structure is one or more ferromagnetic layers with a unidirectional magnetic moment or a pair of ferromagnetic layers that are separated by a coupling layer with magnetic moments of the ferromagnetic

layers being antiparallel. Spin valve sensors are still further classified as single or dual wherein a single spin valve sensor employs only one pinned layer and a dual spin valve sensor employs two pinned layers with the free layer structure located therebetween.

As stated hereinabove, the spin valve sensor has a spin scattering region which is located between the aforementioned interfaces of the spacer layer with each of the pinned and free layer structures. Unfortunately, a portion of the conduction electrons escape from the spin scattering region which reduces the aforementioned magnetoresistive coefficient dr/R . A scheme for preventing escape of these conduction electrons from the spin-dependent region is to provide a specular reflector layer in a cap structure at the top of the spin valve sensor. The specular reflector layer reflects the conduction electrons back into the spin-dependent region so as to improve the magnetoresistive coefficient dr/R of the sensor. The specular reflector layer, which is a first cap layer of the cap structure, is located between and interfaces each of a free layer structure and a second cap layer. The second cap layer is employed for protecting the specular reflector layer from subsequent processing steps. Typically, the second cap layer has been tantalum (Ta). Unfortunately, tantalum degrades the gold of the specular reflector layer which degrades its performance as a specular reflector.

The present invention provides a magnetic read head as claimed in claim 1, and a method of making a magnetic read head as claimed in claim 8, which has a spin valve sensor with a cap layer structure which includes a first cap layer which is composed of a metal, such as gold or copper, for specular reflection and a second cap layer which is composed of a metal oxide, such as aluminum oxide or tantalum oxide. The present invention also provides a magnetic head assembly having the read head as just described, and also having a write head. The present invention also provides a magnetic disk drive having the read head described above. The inventor has found that aluminum oxide or tantalum oxide is highly compatible with gold or copper and does not cause degradation thereof. In a preferred embodiment the free layer structure includes a first layer of cobalt iron and a second layer of nickel iron with the cobalt iron interfacing a copper spacer layer and the nickel iron layer interfacing the gold or copper layer. The gold or copper layer prevents an interfacing

between the nickel iron layer and the aluminum oxide or tantalum oxide layer, as well as causing specular reflection of conduction electrons.

An object of the present invention is to provide a first cap layer which causes specular reflection of conduction electrons and a second cap layer which does not degrade the first cap layer while protecting the first cap layer from subsequent processing steps.

Other objects and attendant advantages of the invention will be appreciated upon reading the following description taken together with the accompanying drawing.

Fig. 1 is an enlarged isometric illustration of the spin valve sensor according to a preferred embodiment of the present invention.

Fig. 1 is an enlarged ABS (air bearing surface) illustration of the present spin valve sensor 74 of the preferred embodiment of the present invention which is located between the first and second read gap layers 76 and 78. The spin valve sensor includes a spacer layer (S) 200 which is located between an antiparallel (AP) pinned layer structure 202 and a free layer structure 204. The pinned layer structure 202 includes an antiparallel coupling (APC) layer 206 which is located between first and second antiparallel (AP) pinned layers (AP1) and (AP2) 208 and 210. The first AP pinned layer 208 interfaces and is exchange coupled to an antiferromagnetic (AFM) pinning layer 212 which pins a magnetic moment 214 of the first AP pinned layer perpendicular to the ABS in a direction out of the sensor or into the sensor, as shown in Fig. 10. By a strong antiparallel coupling between the first and second AP pinned layers 208 and 210 the second AP pinned layer has a magnetic moment 216 which is antiparallel to the magnetic moment 214. A seed layer (SL) 218 is provided as a base for the pinning layer 212 for promoting a desirable texture of the layers deposited thereon.

The free layer structure 204 includes first and second free layers (F1) and (F2) 220 and 222. The free layer structure 204 has a magnetic moment 224 which is parallel to the ABS and to the major planes of the layers in a direction from right to left or from left to right, as shown in Fig. 10. When a signal field from the rotating magnetic disk rotates

the magnetic moment 224 of the free layer structure into the sensor, the magnetic moments 224 and 216 become more antiparallel which increases the resistance of the sensor to the sense current I_s , and when the signal field from the rotating magnetic disk rotates the magnetic moment 224 out of the sensor, the magnetic moments 224 and 216 become more parallel which decreases the resistance of the sensor to the sense current. These resistance changes are processed as playback signals by processing circuitry (not shown).

A cap layer structure 226 is located on the free layer structure 204 for reflecting conduction electrons back into the mean free path of conduction electrons and for protecting the sensor from subsequent processing steps. The cap layer structure 226 includes a specular reflector (SR) layer 228 which interfaces the second free layer 222 and a cap layer 230 which is located between the specular reflector layer 228 and the second read gap layer 78. In a preferred embodiment, the specular reflector layer 228 is gold (Au). In the past, this specular reflector layer 228 has been capped by tantalum (Ta) which degrades the performance of the gold specular reflector layer. In the preferred embodiment the cap layer 230 is preferably composed of alumina (Al_2O_3) which is compatible with gold and does not cause degradation. If the alumina cap layer 230 interfaced the nickel iron (NiFe) second free layer 222 it would cause oxidation of the second free layer. Accordingly, the gold specular reflector layer 228 isolates the alumina cap layer 230 from the nickel iron second free layer 222, as well as causing specular reflection of conduction electrons. The preferred embodiment also includes copper for the metal first cap layer and tantalum oxide for the second cap layer.

Exemplary thicknesses and materials for the layers are 30Å of tantalum for the seed layer 218, 150Å of platinum manganese for the pinning layer 212, 15Å of cobalt iron for the first AP pinned layer 208, 8Å of ruthenium for the antiparallel coupling layer 206, 20Å of cobalt iron for the second AP pinned layer 210, 23Å of copper for the spacer layer 200, 15Å of cobalt iron for the first free layer 220, 30Å of nickel iron for the second free layer 222, 10Å of gold for the specular reflector layer 228 and 30Å of aluminum oxide for the cap layer 230.

While the AP pinned layer structure 202 is preferred, it should be understood that a simple pinned layer structure, whether it is one or more ferromagnetic layers, may be employed. Further, it should be understood that while a single spin valve sensor is shown in Fig. 1, the cap layer structure may also be used in a dual spin valve sensor. Still further, the free layer structure 204 in Fig. 1 comprising a first free of cobalt iron and a second free layer of nickel iron is preferred for optimizing the magnetoresistive coefficient dr/R . However, it should be understood that other compositions may be employed for the free layer structure. The cobalt iron layers may be simply cobalt based, however, the preferred composition is cobalt iron ($\text{Co}_{90}\text{Fe}_{10}$). The preferred nickel iron is $\text{Ni}_{83}\text{Fe}_{17}$. Other pinning layers 222 may be employed, such as nickel manganese or iridium manganese. However, the preferred material for the pinning layer is platinum manganese ($\text{Pt}_{50}\text{Mn}_{50}$). It should be understood that the thicknesses of the materials are exemplary, however, the specular reflector layer 228 is preferably 10Å or less so as to minimize sense current shunting.

CLAIMS

1. A magnetic read head which has an air bearing surface (ABS), comprising:
 - a spin valve sensor (74) including:
 - a ferromagnetic pinned layer structure (202) that has a magnetic moment;
 - a pinning layer (212) exchange coupled to the pinned layer structure (202) for pinning the magnetic moment of the pinned layer structure (202);
 - a ferromagnetic free layer structure (204);
 - a nonmagnetic electrically conductive spacer layer (200) located between the free layer structure (204) and the pinned layer structure (202);
 - a cap layer structure (226);
 - the free layer structure (204) being located between the spacer layer (200) and the cap layer structure (226);
 - the cap layer structure (226) comprising first (228) and second (230) cap layers wherein the first cap layer (228) is located between and interfaces each of the free layer structure (204) and the second cap layer (230);
 - the first cap layer (228) being composed of a metal for specular reflection; and the second cap layer (230) being composed of a metal oxide.
2. A magnetic read head as claimed in claim 1 including:
 - nonmagnetic electrically nonconductive first and second read gap layers;
 - the spin valve sensor being located between the first and second read gap layers;
 - ferromagnetic first and second shield layers; and
 - the first and second read gap layers being located between the first and second shield layers.
3. A magnetic read head as claimed in any preceding claim wherein the first cap layer is composed of gold or copper and the second cap layer is composed of aluminum oxide or tantalum oxide.

4. A magnetic read head as claimed in any preceding claim including:

the free layer structure including first and second free layers wherein the second free layer is located between and interfaces each of the first free layer and the first cap layer; and

the first free layer being composed of cobalt iron (CoFe) and the second free layer being composed of nickel iron (NiFe).

5. A magnetic read head as claimed in any preceding claim wherein the pinned layer structure is an antiparallel (AP) pinned layer structure that includes:

ferromagnetic first and second antiparallel (AP) pinned layers with the first AP pinned layer interfacing the pinning layer and the second AP pinned layer interfacing the spacer layer; and

an antiparallel (AP) coupling layer located between and interfacing the first and second AP pinned layers.

6. A magnetic head assembly having a read head as claimed in any preceding claim and also having a write head.

7. A magnetic disk drive including a magnetic head as claimed in any preceding claim, the disk drive further comprising:

a housing;

a magnetic disk rotatably supported in the housing;

a support mounted in the housing for supporting the magnetic head assembly with an air bearing surface facing the magnetic disk so that the magnetic head assembly is in a transducing relationship with the magnetic disk;

a spindle motor for rotating the magnetic disk;

an actuator positioning means connected to the support for moving the magnetic head assembly to multiple positions with respect to said magnetic disk; and

a processor connected to the magnetic head assembly, to the spindle motor and to the actuator for exchanging signals with the magnetic head assembly, for controlling movement of the magnetic disk and for controlling the position of the magnetic head assembly.

8. A method of making a magnetic read head which has an air bearing surface (ABS), comprising the steps of:

a making a spin valve sensor (74) comprising the steps of:

forming a ferromagnetic pinned layer structure (202) that has a magnetic moment;

forming a pinning layer (212) exchange coupled to the pinned layer structure for pinning the magnetic moment of the pinned layer structure;

forming a ferromagnetic free layer structure (204);

forming a nonmagnetic electrically conductive spacer layer (200) between the free layer structure and the pinned layer structure;

forming a cap layer structure (226) with the free layer structure located between the spacer layer and the cap layer structure;

forming the cap layer structure with first and second cap layers wherein the first cap layer (228) is located between and interfaces each of the free layer structure and the second cap layer (230);

forming the first cap layer of a metal for specular reflection; and

forming the second cap layer of a metal oxide.

9. A method as claimed in claim 8 further including steps of:

forming nonmagnetic electrically nonconductive first and second read gap layers;

forming the spin valve sensor between the first and second read gap layers;

forming ferromagnetic first and second shield layers; and

forming the first and second read gap layers between the first and second shield layers.

10. A method as claimed in claim in any preceding method wherein the first cap layer is formed of gold or copper and the second cap layer is composed of aluminum oxide or tantalum oxide.