

Description

Field of the invention

This invention relates to magnetic recording playback heads, particularly to such heads wherein non-inductive means are utilized for sensing localized magnetic field patterns of a magnetic recording medium.

Description of the prior art

With an apparently never-ending quest to increase the storage density on magnetic recording media have come increased demands not only on the magnetic recording media per se, but also on the transducers used for both recording and playing back the recorded information. As the recorded bit size has progressively decreased, the recording and playback head gaps in typical ring shaped heads have also decreased until it is now virtually impossible to reduce them further using discrete spacer layers. There has consequently been developed a new class of recording and playback heads utilizing thin films, in which high permeability materials are formed as thin film pole pieces, metallic thin films are formed to provide inductive windings around the thin film pole pieces, and insulative thin films are formed to provide both a gap between the pole pieces and to insulate the respective windings where appropriate.

Such thin film heads were perhaps first disclosed in U.S. Patent US-A-3,344,237 assigned to Minnesota Mining and Manufacturing Company, the assignee of the present invention. Since the initial development, many types of thin film heads have been developed in various attempts to improve the reliability and signal-to-noise ratio while reducing manufacturing costs, complexity, and the like. Relevant to the present invention are non-inductive thin film playback heads, such as those utilizing magneto-resistive films. U.S. Patent US-A-3,987,485 (Sugaya et al) is exemplary of prior art disclosing such heads. The device there disclosed includes a semiconductive substrate on which may be deposited, along with the magnetoresistive film, or films for multitrack heads, integrated circuits such as switching circuits and amplifiers which are connected to the magnetic heads. In a somewhat similar fashion, U.S. Patent US-A-3,908,194 (Romankiw) depicts a thin film magnetoresistive read head integrated with a thin film inductive write head.

In addition to such magnetoresistive thin film heads, it is also known to utilize heads including thin films having magnetostrictive properties. Thus, for example, Brunsch et al, IBM Tech. Disclosure Bulletin, Vol. 21, No. 2, July 1978, pp. 667-668, depicts a thin film head, with both read and write capabilities, in which magnetostrictive films having permanent anisotropy surround a single turn inductive winding, forming a working gap therebetween, and are in turn mechanically coupled to a piezoelectric substrate. In the head there depicted, read or write signals appear to be coupled from or to the conductor and hence

inductively from or to the gap, while DC or AC voltages are applied to the piezoelectric substrate, causing stress in the magnetostrictive films, which, in turn, rotates the anisotropy to allow the signals to be more readily coupled through the gap. Such a head is thus actually an inductive type device in which magnetostriction is utilized in a secondary manner.

US-A-3 800 193 discloses a magnetic sensing head in which the magnetic flux sensitive device is formed as a film on a semiconductor substrate but there is no suggestion in this reference of the use of a strain sensitive element as required by the present invention. IBM Technical Disclosure Bulletin, Vol. 17, No. 11, April 1975, pages 3478-3480 disclose a magnetoresistive head but there is no disclosure of a magnetoresistive material.

A device in which mechanically coupled magnetostrictive and piezoelectric films are used to directly sense localized fields is depicted in U.S. Patent US-A-3,909,809 (Kinsner et al). The device there set forth is adapted for sensing magnetic bubble domains such as may be present in magnetic bubble memories in which the bubble memory and sensing device are both stationary, i.e. one does not move relative to the other, as is otherwise the case in a magnetic recording medium and associated record or playback head. Further, the device disclosed therein does not incorporate amplifiers or other electronic circuits as an integral part thereof.

IBM Technical Disclosure Bulletin, Vol. 16, No. 8, January 1974, pages 2491-2492 discloses a piezoresistive stratum mechanically coupled to a magnetostrictive material for enabling a strain produced in the magnetostrictive material to produce a corresponding change in the electrical resistivity of the piezoresistive stratum. This reference makes no use of magnetostrictive and piezoresistive properties to detect a field of, for example, a magnetic tape and neither does this reference suggest an integrated solid state amplifier. This reference forms the pre-characterising basis of the present claim 1.

Disclosure of invention

In contrast to thin film magnetoresistive playback heads and magnetic field sensors such as discussed above, in accordance with this invention there is provided a magnetic sensor, comprising a magnetostrictive stratum, a first piezoresistive stratum coupled to the magnetostrictive stratum enabling strain magnetically induced in the magnetostrictive stratum to produce in said piezoresistive stratum a corresponding change in the electrical resistivity thereof, and characterized by a solid state amplifier formed as a single integrated structure together with said first piezoresistive stratum, said amplifier including a piezoresistively responsive region of the said first piezoresistive stratum mechanically coupled to said magnetostrictive stratum for sensing said change in resistivity and for supplying an electrical output signal in

response thereto which is representative of the intensity of magnetic fields impressed upon said magnetostrictive stratum.

Localized magnetic field patterns such as may be present in a record track in a magnetic recording medium positioned adjacent the magnetostrictive stratum may thereby be sensed independently of speed, or changes in the speed, of the head relative to the medium.

Desirably, a piezoresistive substrate having a magnetostrictive thin film thereon is fabricated together with a carrier member adapted to be mounted with the plane of the thin film substantially normal to the surface of a magnetic recording medium, thereby enabling localized magnetic patterns in the medium and oriented normal to the surface thereof to be impressed upon the length of the magnetostrictive thin film, thus producing a lengthwise strain which is coupled to the piezoresistive substrate.

If desired, the mechanically coupled magnetostrictive and piezoresistive strata may be positioned proximate to high permeability thin film pole pieces configured to optimize detection of either vertically or longitudinally oriented magnetic media such that magnetic fields coupled to the pole-pieces induce in the magnetostrictive stratum a mechanical strain which is coupled to the piezoresistive stratum as described hereinabove.

Also, in order to minimize interference from undesired stimuli, a further embodiment of the present invention includes an additional stratum of a non-strain sensitive material which has substantially the same area as that of the magnetostrictive stratum and which extends over a different portion of the piezoresistive stratum. In such embodiments, a change in the resistance in the piezoresistive stratum proximate the non-strain sensitive stratum is compared with the change in resistance in another section of the piezoresistive stratum proximate the magnetostrictive stratum so that undesired non-magnetic stimuli, both time varying and steady state, applied to both portions of the piezoresistive stratum may be suppressed while allowing stimuli present only in one portion, such as that magnetically induced in the magnetostrictive stratum, to be readily detected.

When the sensor of the present invention is adapted for use as a magnetic recording playback head, it satisfies an existing need for a device for reading high density magnetic information stored in advanced memory systems.

Brief description of the drawing

Figure 1 is a sectional view of a preferred embodiment of a device according to the present invention wherein a magnetostrictive stratum is applied directly to the gate of an N-channel MOSFET transistor having a piezoresistive region proximate the gate;

Figure 2A is a plane view of a further embodiment of the present invention utilizing asymmetric pole pieces to provide a playback head suitable for reproduction of vertical recording;

Figure 2B is a cross-sectional view taken along the lines 2B showing the relationships among the various layers making up the integrated device;

Figure 3 is a perspective view of a further embodiment of the present invention wherein a plurality of magnetostrictive-piezoresistive sensing elements are used in combination to provide a multi-channel playback head;

Figure 4 is a combined cross-sectional view and electrical schematic of a further embodiment of the present invention incorporating a single substrate having dual MOSFET amplifiers thereon, each of which has a piezoresistively responsive channel, and in which a magnetostrictive stratum is proximate one of the gates while a non-magnetostrictive stratum is proximate the other gate so as to provide common mode noise rejection; and

Figure 5 is a perspective view of the present invention utilizing both magnetostrictive and non-magnetostrictive films, thereby providing common mode noise rejection such as shown in Figure 4, wherein the device is assembled in a conventional integrated circuit chip carrier to facilitate further mounting.

Detailed description

As set forth herein, the device of the present invention may be constructed in a variety of configurations including embodiments wherein the magnetostrictive and piezoresistive strata are applied on separate substrates from that of an associated amplifier, as well as embodiments wherein the elements are directly coupled together. Figure 1 sets forth a preferred embodiment of the latter wherein a magnetostrictive film is deposited over a piezoresistively responsive region associated with the gate area of a MOSFET transistor.

In order to better understand the operation of such an embodiment, a short description of the operation of a conventional MOSFET device will be useful. When a potential of suitable magnitude and polarity is applied to a gate electrode a conductive channel is formed between the source and drain regions. Application of a potential between those regions results in a current flow in the channel connecting those regions, the magnitude of which is determined by the polarity and magnitude of the applied potential.

Accordingly, as shown in Figure 1, the device 10 includes a substrate 12 of P-type silicon in which two zones have been heavily doped to provide N-type regions 14 and 16, respectively. On top of the substrate and adjoining the N-type regions 14 and 16 are formed insulating SiO_2 regions 18, 20, and 22, respectively, and on top of the regions 18 and 22 are deposited metallic contact regions 24 and 26 respectively. In lieu of a conventional metallic electrode on top of the oxide region 20, a metallic magnetostrictive film 28 is then deposited, thus completing a modified MOSFET transistor. As the Si substrate, particularly in channel area 31, is appropriately strain sensitive, i.e. having appreciable piezoresistive characteristics, strain induced

in the magnetostrictive film 28 from external magnetic fields and coupled through the underlying oxide layer 20 to the strain sensitive region 30, causes a change in the resistance in this region, so as to alter the current flow between the source and drain electrodes 24 and 26. Appropriate bias potentials such as provided by sources 30 and 32 may be applied to the device via conductors 34, 36, and 38 secured to the contacts 24, 26, and 28, respectively, and an output signal developed across resistor 40.

A device such as that set forth in Figure 1 was constructed in the following manner. A P-channel enhancement mode MOSFET transistor was fabricated from an N-type silicon substrate utilizing conventional MOSFET technology, wherein the gate electrode was prepared having dimensions of approximately 25 by 1,000 micrometers. A magnetostrictive thin film approximately 500 nanometers thick was ion beam sputtered onto the gate electrode from a 98%+ pure nickel foil target. Alternatively, other magnetostrictive thin films may also be deposited, such as an alloy of approximately $\text{Fe}_{70}\text{Si}_{30}$.

Equivalent devices to that shown in Figure 1 may be made using either N-channel or P-channel silicon substrates, operating in either an enhancement or depletion mode. Also, analogous devices may be constructed using bipolar transistors.

In addition to the embodiment discussed hereinabove with respect to Figure 1, an alternative device may utilize a totally passive substrate, such as formed of a planar sheet of glass or the like, onto which is then adhered a conventional MOSFET transistor having the respective doped regions, insulating layers, and metallic contacts, as described hereinabove with respect to the MOSFET of the device 10 and set forth in Figure 1. Onto an adjacent portion of the passive substrate is similarly adhered a second portion of the device consisting of a substrate and a magnetically activated piezoresistor, formed by first depositing a piezoresistive film. Suitable electrical contacts are applied to two sides of the film. Overlying the region of the film between the contacts is deposited an insulating thin film, such as SiO_2 , and overlying this layer is deposited a thin film of a magnetostrictive material, such as Ni. Appropriate electrical contacts are then provided to couple the piezoresistor and bias potentials to the MOSFET transistor.

In another embodiment of the present invention, a device functionally equivalent to that described in conjunction with Figure 1 hereinabove may be constructed by adding suitable high permeability pole pieces to enable remote sensing of localized magnetic fields such as may be present in magnetic recording media. One such device is set forth in plane view in Figure 2A, and associatedly, in cross-section view in Figure 2B. As there set forth, the device 90 includes a silicon substrate 92 having a region 94 having appreciable piezoresistive characteristics. At opposite ends of the region 94 are deposited electrodes 96 and 98. Overlying the piezoresistive

region 94 is a thin film insulator 100 and overlying the insulating thin film 100 is a thin film of a magnetostrictive material 102. Finally, overlying the thus deposited films are two high permeability thin film pole pieces 104 and 106, respectively. The magnetostrictive film 102 and adjacent piezoresistive region 94 are thus formed within the gap of the pole pieces 104 and 106. When a perpendicularly recorded bit within a magnetic recording layer 110 and an associated high-permeability underlayer 112 such as would be provided with vertically oriented magnetic recording medium 114, passes under the high permeability leg 104, the flux therefrom is concentrated and channelled up to the gap between the pole pieces 104 and 106. A substantial proportion of the flux will then bridge through the magnetostrictive film 102 across the gap, and the flux loop will close back onto the bit through the large area pole piece 106 and the high permeability underlayer 112. The pole piece 106 is desirably made sufficiently extensive in area to result in a flux density sufficiently low to avoid magnetically affecting recorded data passing adjacent that pole piece. The flux thus induced in the magnetostrictive film 102 will produce an associated electrical output from the piezoresistive region.

In the embodiment set forth in Figure 2A, a conventional bipolar transistor 116 is separately fabricated and bonded to the silicon substrate 92 as there shown. The electrodes 96 and 98 may then be coupled between a source of potential 120 and the base 122 of the transistor 116. Also the collector and emitter 124 and 126, respectively, can be coupled via leads 128 and 130 to an appropriate bias circuit.

As shown in more detail in the cross-sectional view of Figure 2B, such a device includes the substrate 92 having a piezoresistive region 94. On top of the region 94 are the metal electrodes 96 and 98, the insulating film 100 and the magnetostrictive film 102, respectively. The high permeability thin film pole pieces 104 and 106 are similarly shown deposited over the magnetostrictive film, leaving the gap region therebetween.

An alternative construction may provide the capability to read both longitudinally and perpendicularly recorded data. Such a device utilizes symmetric, thin film pole pieces deposited over a magnetostrictive-piezoresistive transducer substantially the same as that shown in Fig. 2A. One pole piece would thus terminate with an underlying pole tip substantially covered by a second pole tip, the two pole tips being separated by an insulative thin film, thus forming the working gap of the resultant head. The construction of such thin film heads is well known to those skilled in thin film recording and playback head technology.

In another embodiment, the present invention may also be utilized with external pole pieces to provide both a read and write capability. Such a device may include a silicon substrate on which are deposited successive thin films so as to form a single turn inductive winding around the approp-

te pole pieces together with a magnetostrictive-piezoresistive transducer assembly as described above.

Figure 3 sets forth in perspective view a further preferred embodiment of the present invention wherein a plurality of magnetostrictive-piezoresistive sensing elements are provided, thus enabling simultaneous playback of parallel tracks. Alternatively, such a device may also be used to maintain the head positioned over a single track via a dynamic servoing system. As there set forth, such a head 182 may include a silicon substrate 184 into which is diffused a plurality of piezoresistively responsive regions 186, 188 and 190, into the ends of which are formed highly conductive regions 192 and 194, 196 and 198, and 200 and 202, respectively. As desired, several discrete insulating films and overlying magnetostrictive films 204 and 206, 208 and 210, and 212 and 214, respectively, may then be deposited onto the piezoresistive regions. Separate contacts may then be provided to the highly conductive regions via leads 216 and 218, 220 and 222, and 224 and 226 respectively, thus coupling each discrete sensor to an appropriate amplifier (not shown). In the device there set forth, it will be recognized that strain, separately induced in any one of the magnetostrictive elements 206, 210, and 214, respectively, will induce a localized strain in the piezoresistive region proximate the particular strained magnetostrictive element, thereby modulating an electrical signal applied to the respective leads. While, in the embodiment there shown, a single substrate having a plurality of discrete piezoresistive regions have been utilized, separate piezoresistive strata matching the magnetostrictive strata may likewise be used.

Due to the close proximity of three piezoresistive elements, a certain amount of "crosstalk" may occur between them, particularly, if the magnetostrictive elements produce strain over regions larger than that physically covered by each discrete piezoresistive region. Consequently, in such an application, a certain amount of mechanical isolation between the respective piezoresistive regions may be desirable.

In certain magnetic sensing situations, a small magnetic signal must be detected in the presence of noise that is both time varying and/or steady state. A further difficulty sometimes encountered is that various piezoresistive materials are not only pressure-sensitive, but are sensitive to undesired stimuli such as temperature as well. In addition, non-magnetically induced strains can also couple unwanted signals via the piezoresistive film. Figure 4 sets forth a preferred embodiment of the present invention wherein additional components are provided for suppressing unwanted effects of stimuli other than the main magnetic signals of interest. In such an embodiment, a pair of sensing elements as nearly geometrically identical as possible are provided, with only one of the sensing elements receiving the

stimuli of interest, but with both the sensing elements equally receiving all background stimuli. Accordingly, the device set forth in Figure 4 incorporates a common mode noise rejection feature. As there shown, the device 232 includes a common substrate 234 within which are fabricated two separate MOSFET transistors each shown generally extending over two separate regions 236 and 238, respectively, of the substrate. Each of the MOSFET transistors are conventional in nature so far as having the requisite doped regions, metal oxide layers and source, gate, and drain electrodes, but further modified to have piezoresistively responsive channels. Further, as shown in Figure 4, the common mode noise rejection capability is provided by depositing over the respective gate regions 240 and 242 a magnetostrictive film 244 and a similarly configured non-magnetostrictive film 246, such as may be provided by a thin film of aluminum, or the like. Contacts (not shown) to each of the respective films 244 and 246 may be provided to allow applications of appropriate bias potentials. Appropriate sources of potential and biasing resistors, 248 and 250, and 252 and 254, respectively, will also be provided for energization of the two separate MOSFET sections. The output from the two respective MOSFET sections will then typically be coupled to a differential amplifier 256 to provide an appropriate differential output signal.

In an alternative embodiment, common mode noise rejection may be obtained even though both the films 244 and 246 are magnetostrictive in nature. In such an embodiment, only one of the films would be exposed to the desired magnetic field, with appropriate shielding provided if desired to minimize cross-talk. Hence, the difference between the outputs of the two would represent a magnetically induced signal with common mode noise rejected.

In another alternative construction, common mode noise rejection may similarly be achieved using a single MOSFET device. Thus, for example, such a device can be fabricated using a single silicon substrate, upon a first portion of which is fabricated a conventional MOSFET transistor. Within the same substrate but within another region, a single piezoresistive zone is then formed, having separated, highly conductive regions of equal resistance. Overlying one half of the piezoresistive zone would then be provided an insulating layer, and on top of that layer would be provided a magnetostrictive layer. Analogously, overlying the other half of the piezoresistive zone would be another insulating layer and on top of that layer would be a non-magnetostrictive layer. The two piezoresistors thus formed, in combination with a source of potential, constitute a biasing network for the MOSFET. Application of an external magnetic field thus modulates the resistance of the zone underlying the magnetostrictive layer, and results in a change in the bias potential applied to the MOSFET.

A desirable arrangement for mounting the

devices of the present invention is set forth in the perspective view of Figure 5. As there set forth, one such device 304 includes a conventional ceramic chip carrier 306 which is arranged to have an internal recess and to be open at one end 308. Such chip carriers typically have a plurality of bonding pads positioned about their periphery for enabling electrical connections to be made to the various portions of a semiconductor substrate positioned therein. Thus, as set forth in Figure 5, a silicon substrate 310 is mounted within the carrier 306 using an appropriate thermally conductive adhesive, with one end of the substrate terminating substantially coincident with the open end of the carrier 308. In order to provide a common mode noise rejection configuration like that set forth in Figure 4, a magnetostrictive film 314 and a non-magnetostrictive film 316 are deposited over an insulating film 318 covering separate piezoresistive zones 320 and 322. The magnetostrictive film is a thin film of an iron-silicon alloy having the approximate composition $\text{Fe}_{70}\text{Si}_{30}$ with a thickness in the range of 200–800 nanometers. The non-magnetostrictive film 316 may be a sputtered film of aluminum having a thickness of approximately 300 to 500 nanometers, and of similar physical dimensions. As shown schematically by leads 324 and 326, respectively, the differently fabricated piezoresistors may be coupled to the electrodes of integrated transistors 328 and 330, bonded to another portion of the substrate 310 via a suitable thermally conductive adhesive, or fabricated as an integral portion thereof. In a typical case, the periphery of the chip carrier 306 will include bonding pads (not shown) so that connections to appropriate biasing potentials and input and/or output signals may be made to the transistors.

A chip carrier such as described in the foregoing, having the respective films terminating proximate the open end of the carrier, may be utilized to detect perpendicularly encoded localized magnetic field patterns within a magnetic recording medium. Such a medium may include a layer of a vertically oriented magnetic recording material over a high permeability substrate, which thereby provides an efficient flux return path. As such a medium is moved past the carrier, localized bits will come proximate the magnetostrictive and metallic films, and differential strain will be induced within the magnetostrictive film 314 to provide an appropriate signal from the transistors.

As described herein, the amplifier which desirably forms an integrated part of the device of the present invention may be a MOSFET, JFET or bipolar type transistor and thus provides the first stage of amplification as well as impedance matching, to the magnetostrictive-piezoresistive portion of the device. In any event, the transistors desirably used in the present devices can be fabricated by standard IC processes. In such possible configurations, the device of the present invention can be fabricated with MOSFET amplifiers employing either N-type or P-type channels,

operating in either the enhancement or depletion mode.

Finally, with respect to the magnetostrictive stratum, such a layer is desirably deposited in intimate mechanical contact with the piezoresistive stratum. A number of materials may be used as magnetostrictive elements. Among these are various compositions of FeSi, FeB, Ni, FeSiTb, FeNi, etc. Optimum thicknesses and application techniques will depend upon the particular material selected. There are a variety of techniques available to provide for coupling between the magnetostrictive and piezoresistive strata. The magnetostrictive material may be sputtered, evaporated, plated, or even adhered with, for example, a thin epoxy layer over the piezoresistive material. Of course, the mechanical and electrical characteristics of the device will depend on the particular deposition or application method employed.

It is the magnetostrictive film that actually couples to a magnetic field. Consequently, its properties are perhaps the most critical to device performance. The basic material characteristics required are relatively low coercivity, so that the film magnetization can be easily switched, and a relatively high magnetostriction coefficient. The particular properties of the magnetostrictive layer can be tailored somewhat to match the properties of the piezoresistive stratum and amplifier being used. However, in general it is desirable to have the highest possible induced strain per unit applied field, consistent with achieving magnetic saturation in digital applications at an acceptably low field intensity. The physical dimensions of the film determine the spatial field resolution and bandwidth of the sensor. Thin film, photolithographically patterned elements can achieve maximum bandwidth and resolution.

While various specific constructions and circuit configurations have been set forth in conjunction with the figures discussed herein, it will be readily apparent to those skilled in the art that many variations and alternatives are feasible. Thus as examples, the various circuit connections, grounds, etc., may be inverted, off set by suitable D.C. potentials, or equivalent amplifiers and the like provided. Likewise, the various constructional configurations may be inverted, additional films included, alternative pole piece geometries substituted, etc. Also wide variations in the thickness and other dimensions of the respective films utilized in the device can be employed depending upon the specifications desired.

Claims

1. A magnetic sensor comprising a magnetostrictive stratum (28, 244), a first piezoresistive stratum (12, 236) coupled to the magnetostrictive stratum enabling strain magnetically induced in the magnetostrictive stratum to produce in said piezoresistive stratum a corresponding change in the electrical resistivity thereof, and

devices of the present invention is set forth in the perspective view of Figure 5. As there set forth, one such device 304 includes a conventional ceramic chip carrier 306 which is arranged to have an internal recess and to be open at one end 308. Such chip carriers typically have a plurality of bonding pads positioned about their periphery for enabling electrical connections to be made to the various portions of a semiconductor substrate positioned therein. Thus, as set forth in Figure 5, a silicon substrate 310 is mounted within the carrier 306 using an appropriate thermally conductive adhesive, with one end of the substrate terminating substantially coincident with the open end of the carrier 308. In order to provide a common mode noise rejection configuration like that set forth in Figure 4, a magnetostrictive film 314 and a non-magnetostrictive film 316 are deposited over an insulating film 318 covering separate piezoresistive zones 320 and 322. The magnetostrictive film is a thin film of an iron-silicon alloy having the approximate composition $\text{Fe}_{70}\text{Si}_{30}$ with a thickness in the range of 200–800 nanometers. The non-magnetostrictive film 316 may be a sputtered film of aluminum having a thickness of approximately 300 to 500 nanometers, and of similar physical dimensions. As shown schematically by leads 324 and 326, respectively, the differently fabricated piezoresistors may be coupled to the electrodes of integrated transistors 328 and 330, bonded to another portion of the substrate 310 via a suitable thermally conductive adhesive, or fabricated as an integral portion thereof. In a typical case, the periphery of the chip carrier 306 will include bonding pads (not shown) so that connections to appropriate biasing potentials and input and/or output signals may be made to the transistors.

A chip carrier such as described in the foregoing, having the respective films terminating proximate the open end of the carrier, may be utilized to detect perpendicularly encoded localized magnetic field patterns within a magnetic recording medium. Such a medium may include a layer of a vertically oriented magnetic recording material over a high permeability substrate, which thereby provides an efficient flux return path. As such a medium is moved past the carrier, localized bits will come proximate the magnetostrictive and metallic films, and differential strain will be induced within the magnetostrictive film 314 to provide an appropriate signal from the transistors.

As described herein, the amplifier which desirably forms an integrated part of the device of the present invention may be a MOSFET, JFET or bipolar type transistor and thus provides the first stage of amplification as well as impedance matching, to the magnetostrictive-piezoresistive portion of the device. In any event, the transistors desirably used in the present devices can be fabricated by standard IC processes. In such possible configurations, the device of the present invention can be fabricated with MOSFET amplifiers employing either N-type or P-type channels,

operating in either the enhancement or depletion mode.

Finally, with respect to the magnetostrictive stratum, such a layer is desirably deposited in intimate mechanical contact with the piezoresistive stratum. A number of materials may be used as magnetostrictive elements. Among these are various compositions of FeSi, FeB, Ni, FeSiTb, FeNi, etc. Optimum thicknesses and application techniques will depend upon the particular material selected. There are a variety of techniques available to provide for coupling between the magnetostrictive and piezoresistive strata. The magnetostrictive material may be sputtered, evaporated, plated, or even adhered with, for example, a thin epoxy layer over the piezoresistive material. Of course, the mechanical and electrical characteristics of the device will depend on the particular deposition or application method employed.

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While various specific constructions and circuit configurations have been set forth in conjunction with the figures discussed herein, it will be readily apparent to those skilled in the art that many variations and alternatives are feasible. Thus as examples, the various circuit connections, grounds, etc., may be inverted, off set by suitable D.C. potentials, or equivalent amplifiers and the like provided. Likewise, the various constructional configurations may be inverted, additional films included, alternative pole piece geometries substituted, etc. Also wide variations in the thickness and other dimensions of the respective films utilized in the device can be employed depending upon the specifications desired.

Claims

1. A magnetic sensor comprising a magnetostrictive stratum (28, 244), a first piezoresistive stratum (12, 236) coupled to the magnetostrictive stratum enabling strain magnetically induced in the magnetostrictive stratum to produce in said piezoresistive stratum a corresponding change in the electrical resistivity thereof, and



characterized by

a solid state amplifier formed as a single integrated structure together with said first piezoresistive stratum, said amplifier including a piezoresistively responsive region of the said first piezoresistive stratum mechanically coupled to said magnetostrictive stratum for sensing said change in resistivity and for supplying an electrical output signal in response thereto which is representative of the intensity of magnetic fields impressed upon said magnetostrictive stratum.

2. A sensor according to claim 1, characterized by said first piezoresistive stratum being within a substrate and wherein said magnetostrictive stratum (28) overlies said substrate.

3. A magnetic sensor according to claim 1, characterized by said solid state amplifier comprising a MOSFET type amplifier in which the said piezoresistively responsive region is a channel region (31) to which said magnetostrictive stratum (28) is mechanically coupled.

4. A magnetic sensor according to claim 1, further characterized by another stratum (246) having substantially the same area as said magnetostrictive stratum (244) and coupled to a second piezoresistive stratum (238) enabling stimuli applied in the region of said another stratum and coupled to said second piezoresistive stratum to produce therein a corresponding change in electrical resistivity, and

the amplifier comprising means (252, 254 and 256) for sensing changes in the electrical resistivity in said second piezoresistive stratum (238) and for supplying a second output signal in response thereto which is representative of stimuli applied in the region of said another stratum,

whereby stimuli applied to both piezoresistive strata may be suppressed in said amplifier operating in a differential mode, while allowing stimuli coupled to only one of said piezoresistive strata to be readily detected.

5. A sensor according to claim 4, characterized by said another stratum (246) comprising a material having substantially no magnetostrictive characteristics, thereby enabling undesired non-magnetic stimuli, both time-varying and steady state, applied to both said first and second piezoresistive strata to be suppressed while magnetic stimuli present only in the first piezoresistive stratum (236) are readily detected.

6. A sensor according to claim 1 adapted for use as a playback head for magnetic recording media, characterized by said magnetostrictive stratum (28) comprising a thin film of a magnetostrictive material applied to a semiconductor substrate having the piezoresistive stratum (12, 236) therein and further comprising means (104) for coupling magnetic flux derived from a magnetic recording medium to said magnetostrictive stratum.

7. A sensor according to claim 6, characterized by said sensor further comprising carrier means (306) for supporting the said substrate having appreciable piezoresistive characteristics and the thin film of a magnetostrictive material thereon, said carrier means being open at one end and

having said substrate and said magnetostrictive thin film terminating substantially coplanar with said open end, and wherein said carrier means and elements supported therein are adapted to be mounted with the plane of said thin film substantially normal to the surface of the magnetic recording medium, thereby enabling localized magnetic patterns in said medium and oriented normal to the surface thereof to be impressed on the length of the magnetostrictive thin film extending away from said recording medium surface to thereby impart a lengthwise strain which is coupled to said piezoresistive substrate.

8. A sensor according to claim 7, characterized by said flux coupling means (104) including at least one pole piece comprising a first thin film of a high permeability material supported by said carrier means and terminating substantially coplanar with said open end such that the plane of said pole piece may be mounted substantially normal to the plane of the magnetic recording medium, thereby enabling magnetic fields associated with localized magnetic patterns in said medium to be coupled to said pole piece, and wherein said magnetostrictive thin film is positioned within said carrier means and is magnetically coupled to said pole piece to thereby impress said coupled magnetic fields onto said magnetostrictive thin film.

9. A sensor according to claim 8, characterized by said pole piece (104) terminating within said carrier means to define one boundary of a back gap, and wherein a second thin film (106) of a high permeability material of appreciably larger area is supported by said carrier means, one portion of which terminates within said carrier means to define another boundary of said back gap and a second portion having an extended width terminates substantially coplanar with said open end to distribute said coupled magnetic fields back to said medium, and wherein said magnetostrictive thin film is positioned within said carrier means and substantially across said back gap defined by said pole pieces to thereby impress said coupled magnetic fields onto said magnetostrictive thin film.

10. A sensor according to claim 6, characterized by said semiconductor substrate comprising a single crystal having either n or p type characteristics and including at least one piezoresistive responsive region in the said piezoresistive stratum, the region being of opposite conductivity type, and over which said thin film of magnetostrictive material is applied, such that an electrical potential applied to said region results in a current flow localized within the region covered by said magnetostrictive thin film.

11. A sensor according to claim 10, characterized by said semiconductor substrate including at least two electrically isolated piezoresistive responsive regions in the said piezoresistive stratum, the regions being of said opposite conductivity type, said magnetostrictive thin film overlying one of said regions, and by said amplifier comprising means for differentially detecting



electrical resistance changes in the two regions of said piezoresistive stratum, whereby undesired stimuli, both time-varying and steady state, applied to both regions of said piezoresistive stratum may be suppressed, while allowing stimuli present in only one portion thereof to be readily detected.

Patentansprüche

1. Magnetischer Sensor, umfassend eine Magnetostriktionsschicht (28, 244) und eine erste Piezowiderstandsschicht (12, 236), die mit der Magnetostriktionsschicht derart gekuppelt ist, daß in der Magnetostriktionsschicht magnetisch induzierte Verformungen in der Piezowiderstandsschicht eine entsprechende Veränderung des spezifischen elektrischen Widerstandes derselben bewirken, gekennzeichnet durch:

einen Festkörpervverstärker, der zusammen mit der ersten Piezowiderstandsschicht eine einzige integrierte Struktur bildet und der einen Piezowiderstandseigenschaften besitzenden Bereich der ersten Piezowiderstandsschicht aufweist, der zum Erfassen der Veränderung des spezifischen Widerstandes mit der Magnetostriktionsschicht gekuppelt ist und dazu dient, auf Grund dieser Veränderung ein elektrisches Ausgangssignal abzugeben, das die Stärke von der Magnetostriktionsschicht aufgeprägten Magnetfeldern darstellt.

2. Sensor nach Anspruch 1, dadurch gekennzeichnet, daß die erste Piezowiderstandsschicht in einem Substrat angeordnet ist und die Magnetostriktionsschicht (28) über dem Substrat liegt.

3. Magnetischer Sensor nach Anspruch 1, dadurch gekennzeichnet, daß der Festkörpervverstärker einen MOSFET-Verstärker umfaßt, in dem Piezowiderstandseigenschaften besitzende Bereich ein Kanalbereich (31) ist, mit dem die Magnetostriktionsschicht (28) mechanisch gekuppelt ist.

4. Magnetischer Sensor nach Anspruch 1, gekennzeichnet durch eine mit der Magnetostriktionsschicht (246) im wesentlichen flächengleiche, weitere Schicht (244), die derart mit einer zweiten Piezowiderstandsschicht (238) gekuppelt ist, daß auf den Bereich der genannten weiteren Schicht einwirkende Reize auf die zweite Piezowiderstandsschicht übertragen werden und in dieser eine entsprechende Veränderung des spezifischen elektrischen Widerstandes bewirken, und daß der Verstärker Mittel (252, 254 und 256) aufweist, die dazu dienen, Veränderungen des spezifischen elektrischen Widerstandes der zweiten Piezowiderstandsschicht (238) zu erfassen und auf Grund derselben ein zweites Ausgangssignal abzugeben, das auf den Bereich der genannten anderen Schicht einwirkenden Reizen entspricht.

5. Sensor nach Anspruch 4, dadurch gekennzeichnet, daß die genannte andere Schicht (246) wenigstens teilweise aus einem Material besteht, das im wesentlichen keine Magnetostriktionseigenschaften hat, so daß auf die erste und die

zweite Piezowiderstandsschicht einwirkende, zeitlich veränderliche und stationäre Reize unterdrückt werden können, während nur auf die ersten Piezowiderstandsschicht (236) einwirkende magnetische Reize ohne weiteres erfaßt werden.

6. Sensor nach Anspruch 1, der für die Verwendung als Wiedergabekopf für magnetische Aufzeichnungsmedien geeignet ist, dadurch gekennzeichnet, daß die Magnetostriktionsschicht (28) eine dünne Schicht aus einem magnetostriktiven Material umfaßt, das auf ein Halbleitersubstrat aufgetragen ist, das die erste Piezowiderstandsschicht (12, 236) enthält, und daß Mittel (104) vorgesehen sind, die dazu dienen, einen von einem magnetischen Aufzeichnungsmedium abgeleiteten magnetischen Kraftfluß auf die Magnetostriktionsschicht zu übertragen.

7. Sensor nach Anspruch 6, dadurch gekennzeichnet, daß der Sensor ferner eine Trägeranordnung (306) aufweist, die zum Abstützen des genannten Substrats, das beträchtliche Piezowiderstandseigenschaften hat, sowie der darauf vorhandenen dünnen Schicht aus Magnetostruktionsmaterial dient, daß die Trägeranordnung am einen Ende offen ist, daß das Substrat und die dünne Magnetostriktionsschicht im wesentlichen in einer Ebene mit dem offenen Ende enden, und daß die Trägeranordnung und die darin abgestützten Elemente derart montierbar sind, daß die Ebene der dünnen Schicht zu der Oberfläche des magnetischen Aufzeichnungsmediums im wesentlichen normal ist, so daß in dem genannten Medium vorhandene, normal zu dessen Oberfläche orientierte magnetische Muster der dünnen Magnetostriktionsschicht über deren sich von der Oberfläche des Aufzeichnungsmediums weg erstreckende Länge aufprägbare sind, um ihr eine Längsverformung zu erteilen, die auf das Piezowiderstandssubstrat übertragen wird.

8. Sensor nach Anspruch 7, dadurch gekennzeichnet, daß die Kraftflußübertragungsmittel (104) mindestens einen Polschuh aufweisen, der eine erste aus einem Material hoher Permeabilität bestehende dünne Schicht besitzt, die auf der Trägeranordnung abgestützt ist und im wesentlichen in einer Ebene mit dem genannten offenen Ende endet, so daß die Ebene des Polschuhs im wesentlichen normal zu der Ebene des magnetischen Aufzeichnungsmediums montierbar ist und Magnetfelder, die lokalen magnetischen Mustern in dem genannten Medium zugeordnet sind, an den Polschuh angekoppelt werden können, und daß die dünne Magnetostriktionsschicht in der Trägeranordnung angeordnet und mit dem Polschuh magnetisch gekoppelt ist, so daß sie die angekoppelten Magnetfelder der dünnen Magnetostriktionsschicht aufprägt.

9. Sensor nach Anspruch 8, dadurch gekennzeichnet, daß der Polschuh (104) in der Trägeranordnung derart endet, daß er eine Begrenzung eines Scherungsspaltens bildet, daß die Trägeranordnung eine beträchtlich flächengrößere, zweite dünne Schicht (106) aus einem Material hoher Permeabilität trägt, von der ein Teil in der Trägeranordnung endet und eine weitere Begren-



zung des hinteren Spalts bildet, während ein verbreiteter zweiter Teil derselben im wesentlichen in einer Ebene mit dem offenen Ende endet, um die angekoppelten Magnetfelder auf das genannte Medium zurückzukoppeln, und daß die dünne Magnetostruktionschicht in der Trägeranordnung angeordnet ist und sich im wesentlichen quer über den von den Polschuhen begrenzten Scherungsspalt erstreckt, so daß die übertragenen Magnetfelder der dünnen Magnetostruktionschicht aufgeprägt werden.

10. Sensor nach Anspruch 6, dadurch gekennzeichnet, daß das Halbleitersubstrat einen Einkristall von Typ n oder p umfaßt, daß die Piezowiderstandsschicht mindestens einen Bereich mit Piezowiderstandseigenschaften besitzt, der vom entgegengesetzten Leitfähigkeitstyp ist und über den die dünne Schicht aus Magnetostruktionsmaterial aufgetragen ist, so daß ein an den genannten Bereich angelegtes elektrisches Potential einen Stromfluß bewirkt, der auf den von der dünnen Magnetostruktionschicht bedeckten Bereich lokalisiert ist.

11. Sensor nach Anspruch 10, dadurch gekennzeichnet, daß das Halbleitersubstrat in der Piezowiderstandsschicht mindestens zwei elektrisch isolierte Piezowiderstandsbereiche enthält, die von dem genannten, entgegengesetzten Leitfähigkeitstyp sind, daß die dünne Magnetostruktionschicht über einem der genannten Bereiche liegt, und daß der Verstärker Mittel zum differentiellen Erfassen von Veränderungen des elektrischen Widerstandes in den beiden Bereichen der Piezowiderstandsschicht aufweist, so daß auf beide Bereiche der Piezowiderstandsschicht einwirkende, zeitlich veränderliche und stationäre, unerwünschte Reize unterdrückbar sind, während nur in einem Teil derselben vorhandene Reize ohne weiteres erfassbar sind.

Revendications

1. Capteur magnétique comprenant:
une couche magnétostrictive (28, 244),
une première couche piézorésistive (12, 236)
couplée à la couche magnétostrictive pour permettre à une déformation magnétique induite dans la couche magnétostrictive de produire dans ladite couche piézorésistive un changement correspondant de sa résistivité électrique, et caractérisé par

un amplificateur statique formé comme une structure intégrée unique en combinaison avec ladite première couche piézorésistive, ledit amplificateur comprenant une région piézorésistive mécaniquement couplée à ladite couche magnétostrictive pour détecter ledit changement de résistivité et pour fournir un signal de sortie électrique, en réponse à cette détection, qui est représentatif de l'intensité des champs magnétiques s'exerçant sur ladite couche magnétostrictive.

2. Capteur suivant la revendication 1, caractérisé en ce que ladite première couche piézorésis-

tive est formée dans un substrat et en ce que ladite couche magnétostrictive (28) est superposée audit substrat.

3. Capteur magnétique suivant la revendication 1, caractérisé en ce que ledit amplificateur statique comprend un amplificateur de type MOSFET dans lequel ladite région piézorésistive sensible est une région de canal (31) à laquelle ladite couche magnétostrictive (28) est mécaniquement couplée.

4. Capteur magnétique suivant la revendication 1, caractérisé en outre par une autre couche (246) ayant sensiblement la même surface que ladite couche magnétostrictive (244) et couplée à une deuxième couche piézorésistive (238) de façon à permettre aux excitations appliquées dans la région de ladite autre couche et couplées à ladite deuxième couche piézorésistive d'engendrer dans celle-ci un changement correspondant de résistivité électrique, et

l'amplificateur comprenant des moyens (252, 254 et 256) pour détecter les changements de la résistivité électrique dans ladite deuxième couche piézorésistive (238) et pour fournir un deuxième signal de sortie, en réponse à cette détection, qui est représentatif des excitations appliquées dans la région de ladite autre couche,

de sorte que les excitations appliquées aux deux couches piézorésistives peuvent être éliminées dans ledit amplificateur fonctionnant en mode différentiel, tout en permettant la détection facile des excitations couplées à une seule desdites couches piézorésistives.

5. Capteur suivant la revendication 4, caractérisé en ce que ladite autre couche (246) comprend une matière n'ayant sensiblement pas de caractéristiques magnétostrictives, ce qui permet d'éliminer les excitations non magnétiques indésirables, aussi bien variables dans le temps que stationnaires appliquées à la fois auxdites première et deuxième couches piézoélectriques, tandis que les excitations magnétiques présentes seulement dans la première couche piézorésistive (236) sont facilement détectées.

6. Capteur suivant la revendication 1, prévu pour l'utilisation comme tête de reproduction pour des supports d'enregistrement magnétique, caractérisé en ce que ladite couche magnétostrictive (28) comprend un film mince d'une matière magnétostrictive appliquée à un substrat semi-conducteur dans lequel est prévue la première couche piézorésistive (12, 236) et comprenant en outre des moyens (104) pour le couplage du flux magnétique provenant d'un support d'enregistrement magnétique à ladite couche magnétostrictive.

7. Capteur suivant la revendication 6, caractérisé en ce que ledit capteur comprend en outre un élément porteur ou boîtier (306) pour supporter ledit substrat ayant des caractéristiques piézorésistives appréciables et le film mince d'une matière magnétostrictive sur ce substrat, ledit élément porteur étant ouvert à une extrémité et ledit substrat et ledit film mince magnétostrictif se terminant sensiblement dans le même plan que



ladite extrémité ouverte, et dans lequel ledit élément porteur et les éléments supportés dans celui-ci sont prévus pour être montés de sorte que le plan dudit film mince est sensiblement perpendiculaire à la surface du support d'enregistrement magnétique, ce qui permet à des configurations magnétiques localisées dans ledit support et orientées perpendiculairement à la surface de s'exercer sur la longueur du film mince magnétostrictif s'étendant à partir de ladite surface du support d'enregistrement, afin d'engendrer une déformation longitudinale qui est transmise audit substrat piézorésistif.

8. Capteur suivant la revendication 7, caractérisé en ce que lesdits moyens de couplage de flux (104) comprennent au moins une pièce polaire comportant un premier film mince d'une matière de haute perméabilité supporté par ledit élément porteur et se terminant sensiblement dans le plan de ladite extrémité ouverte, de sorte que le plan de ladite pièce polaire peut être monté sensiblement perpendiculairement au plan du support d'enregistrement magnétique, permettant ainsi aux champs magnétiques associés à des configurations magnétiques localisées dans ledit support d'être couplés à ladite pièce polaire, et en ce que ledit film mince magnétostrictif est placé à l'intérieur dudit élément porteur et est couplé magnétiquement à ladite pièce polaire de sorte que lesdits champs magnétiques couplés s'exercent sur ledit film mince magnétostrictif.

9. Capteur suivant la revendication 8, caractérisé en ce que ladite pièce polaire (104) se termine dans ledit élément porteur de manière à définir une limite d'un entrefer arrière, en ce qu'un deuxième film mince (106) en matière de haute perméabilité de surface sensiblement plus grande est supporté par ledit élément porteur, une partie de ce film se terminant dans ledit élément porteur, de manière à définir une ature limite dudit entrefer arrière, et une deuxième partie de plus

grande largeur se terminant sensiblement dans le même plan que ladite extrémité ouverte de manière à répartir lesdits champs magnétiques couplés en retour audit support, et en ce que ledit film mince magnétostrictif est placé à l'intérieur dudit élément porteur et sensiblement en travers dudit entrefer arrière défini par lesdites pièces polaires de sorte que lesdits champs magnétiques couplés s'exercent sur ledit film mince magnétostrictif.

10. Capteur suivant la revendication 6, caractérisé en ce que ledit substrat semiconducteur comprend un cristal unique ayant des caractéristiques de type n ou p et comprend au moins une région piézorésistivement sensible dans ladite couche piézorésistive, la région étant de type de conductivité opposé, et sur laquelle ledit film mince de matière magnétostrictive est appliqué, de sorte qu'un potentiel électrique appliqué à ladite région engendre une circulation de courant localisée dans la région couverte par ledit film mince magnétostrictif.

11. Capteur suivant la revendication 10, caractérisé en ce que ledit substrat semiconducteur comprend au moins deux régions piézorésistivement sensibles et électriquement isolées dans ladite couche piézorésistive, les régions étant dudit type de conductivité opposé, ledit film mince magnétostrictif étant superposé à l'une desdites régions, et en ce que ledit amplificateur comprend des moyens pour détecter différentiellement des changements de résistance électrique dans les deux régions de ladite couche piézorésistive, de sorte que des excitations indésirables, aussi bien variables dans le temps que stationnaires, appliquées aux deux régions de ladite couche piézorésistive, peuvent être éliminées, tout en permettant la détection facile des excitations présentes dans une seule région de cette couche.

