MAGNETIC-PIEZOELECTRIC COMBINE SENSOR USING PIEZOELECTRIC SINGLE CRYSTAL

Abstract: The present invention relates to a combined magnetic-piezoelectric semiconductor sensor using the piezoelectric phenomenon of a piezoelectric single crystalline thin film and the magnetization reversal and magnetostriction phenomena of a magnetic substance, and, more particularly, to a combined sensor which is capable of detecting a physical phenomenon, such as sound pressure or magnetic force, in the form of a highly sensitive electric signal, thus being able to be used as a sensor for detecting a biosignal, recognizing a magnetic pattern or detecting an external magnetic field, electromagnetic waves, physical force or voltage.
Description

MAGNETIC-PIEZOELECTRIC COMBINE SENSOR USING PIEZOELECTRIC SINGLE CRYSTAL

Technical Field

The present invention relates to a combined magnetic-piezoelectric semiconductor sensor using the piezoelectric phenomenon of a piezoelectric single crystalline thin film and the magnetization reversal and magnetostriction phenomena of a magnetic substance, and, more particularly, to a combined sensor which is capable of detecting a physical phenomenon, such as sound pressure or magnetic force, in the form of a highly sensitive electric signal, thus being able to be used as a sensor for detecting a biosignal, recognizing a magnetic pattern or detecting an external magnetic field, electromagnetic waves, physical force or voltage.

Background Art

Acoustic sensors in which a piezoelectric element is formed of a piezoelectric single crystal which is a ferroelectric substance and also has excellent piezoelectric characteristics in a bulk or film form are known. Such an acoustic sensor is a sensor which acquires an electric signal based on sound pressure using the principle that vibrations occur depending on the shape and polarization direction of single crystal substance and an external electric field direction. Meanwhile, up to the present, information recording and reading technology based on a Magnetic Tunneling Junction (MTJ), which is a recording method using an externally applied magnetic field, has been developed and has been disclosed in U.S. Patent Nos. 6,518,588, 6,097,625 and 5,640,343. Meanwhile, the importance of a technology for controlling magnetization reversal which is used as a method for controlling voltage in a recording method using a magnetic field is currently increasing. For this purpose, a technology supporting a method of recording and reading information, the magnetization direction of which has been controlled by applying current or an electric field, is disclosed in U.S. Patent No. 6,829,157, but a problem arises in that it is difficult to design a combined device due to low sensitivity.

Disclosure of Invention

Technical Problem

The present inventor devised the present invention with an eye on the fact that a physical phenomenon, such as sound pressure or magnetic force, could be detected using the acoustic sensor principle and the magnetic substance magnetization reversal and the magnetostriction phenomenon in the form of a highly sensitive electric signal. Accordingly, the present invention proposes a combined device, in which two
electrodes configured such that voltage can be applied thereto or an electric signal can be acquired thereby and composed of positive (+) and negative (-) electrodes are formed such that voltage can be easily applied to a piezoelectric layer formed of a piezoelectric single crystal exhibiting an excellent piezoelectric effect or an electric signal can be acquired, input information is acquired in such a way that stress is generated in the piezoelectric single crystal layer to which voltage has been applied and reverses the magnetization direction of a magnetic layer, formed above the piezoelectric layer, to a parallel or perpendicular direction, and the acquired information is read on the basis of a change in resistance caused by a change in the magnetization of the magnetic layer based on current using two current lines having a reading function, so that input information can be processed at a high sensitivity or an electric signal based on a change in the external magnetic field, electromagnetic waves or physical force can be acquired. On the basis of the design according to the present invention, information can be acquired using a PMN-PT-based or PZN-PT-based piezoelectric single crystal exhibiting an excellent piezoelectric effect regardless of low voltage or a weak electric field, so that a very low power design can be achieved and a combined device which can be used as a biosignal sensor or the like having a weak signal input can be designed.

Accordingly, an object of the present invention is to provide a low-power design, combined sensor which is capable of detecting a physical phenomenon, such as sound pressure or magnetic force, using the acoustic sensor principle and magnetic substance magnetization reversal and magnetostriction phenomenon in the form of a highly sensitive electric signal.

Another object of the present invention is to provide a combined device which can be used as a sensor for detecting a biosignal, recognizing a magnetic pattern or detecting an external magnetic field, electromagnetic waves, physical force or voltage, or memory which has a construction to which the above principle has been applied.

Technical Solution

In order to accomplish the above objects, the present invention provides a combined magnetic-piezoelectric semiconductor sensor using a piezoelectric single crystal film, including an Si substrate; two parallel electrodes placed on the substrate and composed of a positive (+) electrode and a negative (-) electrode which are configured such that external voltage may be applied thereto or an electric signal may be obtained thereby, and a piezoelectric single crystalline thin film layer disposed between the electrodes so as to come into contact with sides of the electrodes; a magnetic layer placed on the film layer, disposed not to come into contact with one of the electrodes, and configured to have a magnetization direction parallel or perpendicular to a surface of the film layer;
and a first current line placed on the magnetic layer, and a second current line extended perpendicular to the first current line and placed on the one of the electrodes.

Furthermore, an insulating layer may be interposed between the second current line and the one of the electrodes, and a void space for collecting and strengthening input signals may be formed in a bottom of the substrate.

According to the present invention, the piezoelectric single crystalline thin film layer may be made of any one selected from the group consisting of a PMN-PT-based material and a PZN-PT-based material. The thin film layer may be attached to the top of the substrate using epoxy.

Advantageous Effects

As described above, the present invention configured as described above enables recording and reading to be performed with no difficulty regardless of low voltage or a weak electric field using two electrode lines including positive (+) and negative (-) electrodes and a piezoelectric single crystal exhibiting an excellent piezoelectric effect, thereby enabling an ultra-low power design to be achieved and speed to be increased. Furthermore, the present invention is configured to process a variety of types of biosignals requiring low-signal and high-capacity data processing, thereby enabling the application of ubiquitous sensors to the field of health care.

Brief Description of Drawings

FIG. 1 is a schematic longitudinal side view showing a combined sensor according to an embodiment of the present invention;

FIG. 2 is a schematic longitudinal side view showing a combined sensor according to an embodiment of the present invention; and

FIG. 3 is a schematic transverse side view showing a combined sensor according to an embodiment of the present invention.

Best Mode for Carrying out the Invention

The substrate is an Si substrate, and the electrode layer is formed by evaporation using any one selected from the group consisting of Pt, Pd, Cu, Al, Ru and W. The magnetic layer may be formed of at least one layered structure which is disposed not to come into contact with one of the electrodes. Preferably, the magnetic layer is formed by sequentially placing a free ferromagnetic layer, a non-magnetic layer and a pinned ferromagnetic layer one on top of another. In the case of the multi-layered magnetic layer, the free ferromagnetic layer and the pinned ferromagnetic layer may be formed of a Co/Pd alloy, or any one selected from the group consisting of alloy A including Co, Fe, Ni and Tb, alloy B including Co, Fe, Ni and C, alloy C including Pd, Pt, Au, Cu, Al and W, and alloy D including Sm, Dy and Tb or a mixture thereof. The non-magnetic layer may be formed of Cu, Ru or an alloy thereof. The current lines are used
for a reading function, and may be formed of Cu.

One of the characteristics of the combined sensor according to the present invention is that a single crystal substance having an excellent piezoelectric characteristic is used. A PMN-PT-based (lead magnesium niobate-lead titanate-based) or PZN-PT-based (lead zinc niobate-lead titanate-based) material may be used as the single crystal substance. It is preferred that the single crystal substance satisfy the composition defined by the following Chemical Formula 1:

\[
x[P]y[M]z[N]p[T], \text{ where}
\]

\[x\] is greater than or equal to 0.55 and is less than or equal to 0.65, 
\[y\] is greater than or equal to 0.09 and is less than or equal to 0.20, 
\[z\] is greater than or equal to 0.09 and is less than or equal to 0.20, and 
\[p\] is greater than or equal to 0.01 and is less than or equal to 0.1.

Since a single crystal substance having the above composition can be manufactured by a method disclosed in Korean Patent Application No. 2003-47458 previously filed by the present inventor, the content disclosed in this Korean patent application is incorporated into the present specification and constitutes part of the present specification. Furthermore, the recording and reading principles using a voltage control magnetization reversal phenomenon according to the present invention are disclosed in the Korean patent application, and these principles are incorporated into the present invention and constitute part of the present specification.

The operation of the present invention will be described below.

In the combined sensor according to the present invention, a mechanism for recording information will be described as follows:

The first step is the step of applying voltage to electrodes. This voltage may be a voltage itself, or a physical signal, particularly a voltage through an acoustic sensor. The second step is the step in which the deformation of a piezoelectric single crystalline thin film layer is caused by an electric field generated by the voltage applied to the electrodes. Accordingly, the last step is the step in which the magnetization state of a magnetic layer placed on the piezoelectric single crystalline thin film layer is spontaneously magnetized from a parallel state to a perpendicular state. The change in this case is recorded using the electrodes.

Furthermore, a mechanism for reading the acquired information will be described as follows:
The first step is the step of applying current to any one of two perpendicularly arranged current lines. Accordingly, the second step is the step in which the current is transmitted to the magnetic layer. The last step is the step in which the transmitted current senses a change in resistance caused by a change in the spontaneous magnetization direction of the magnetic layer and then flows into the other current line, thereby enabling reading.

The present invention is intended to implement a very highly efficient, very highly integrated, non-volatile combined sensor, in which using the excellent piezoelectric effect of the piezoelectric single crystal, the layered magnetic substance structure and the combined piezoelectric/magnetic construction, the deformation of the piezoelectric single crystalline thin film layer can be caused regardless of low voltage or a weak electric field, and can be recorded and read by detecting the deformation using the magnetic layer. In particular, the present invention is characterized in that the piezoelectric single crystalline thin film layer is formed of any one of a PMN-PT-based piezoelectric single crystal or a PZN-PT-based piezoelectric single crystal.

The construction of the present invention will be described in detail below with reference to the accompanying drawings.

FIG. 1 is a longitudinal side view showing a combined sensor including piezoelectric single crystal/magnetic layers according to embodiment 1 of the present invention. FIG. 2 is a longitudinal side view showing a combined sensor including piezoelectric single crystal/magnetic layers according to embodiment 1 of the present invention, and FIG. 3 is a schematic transverse side view showing the combined sensor according to embodiment 1 of the present invention. As shown in FIGS. 1 to 3, the combined sensor, including a piezoelectric single crystal and a magnetic layer, according to the present invention includes an Si substrate 10; two parallel electrodes 21 and 22 placed on the substrate and composed of a positive (+) electrode and a negative (-) electrode which are configured such that external voltage may be applied thereto or an electric signal may be obtained thereby, and a piezoelectric single crystalline thin film layer 30 disposed between the electrodes to come into contact with the sides of the electrodes; a magnetic layer 40 placed on the film layer, disposed not to come into contact with one of the electrodes, and configured to have a magnetization direction parallel or perpendicular to the surface of the film layer; and a first current line 51 placed on the magnetic layer, and a second current line 52 extended perpendicular to the first current line and placed on one electrode 21 of the electrodes. Furthermore, an insulating layer 60 may be interposed between the second current line 52 and one electrode 21 of the electrodes, and at least one void space 11 for amplifying an input signal may be formed in the bottom of the substrate. Furthermore, the surfaces of the electrodes 21 and 22 may be extended in directions parallel to the substrate, thereby expanding contact areas.
(see embodiment 2).

Meanwhile, in the combined sensor 100, two electrode layers 21 and 22 are first formed on an Si substrate by evaporation, function as recording lines to which voltage is applied in a process of recording information, and are configured to extend parallel to the substrate in a lateral direction so as to connect respective devices. Furthermore, as shown in FIG. 2, one electrode 21 may be designed so as to increase its area which is in contact with the substrate, and the other electrode 22 may be extended and placed so as to increase its area which is in contact with a magnetic layer 40 placed on the electrode 22. Here, the electrodes are formed by evaporating any one selected from the group consisting of Pt, Pd, Cu, Au, Al, Ru and W.

Furthermore, a piezoelectric single crystalline thin film layer is formed between the positive (+) electrode and the negative (-) electrode so that it can come into contact with the sides of the two electrode layers. As described above, the film layer is made of material with a high piezoelectric constant d33, such as PMN-PT-based material or PZN-PT-based material, and the thickness of the film layer is determined within a range in which the greatest deformation is applied at a low voltage.

Meanwhile, the magnetic layer 40 may be formed of, although not limited to, a layered structure, preferably including a free ferromagnetic layer 41 disposed not to come into contact with one 21 of the electrodes, a non-magnetic layer 42, and a pinned ferromagnetic layer 43 sequentially from the bottom of the structure. Here, a magnetic thin film with high magnetic reluctance and magnetostriction constant is used as the free ferromagnetic layer 41, and the free ferromagnetic layer 41 is evaporated on the film layer. The free ferromagnetic layer is preferably formed of a Co/Pd alloy. The non-magnetic layer 42 is placed on the free ferromagnetic layer, and is preferably formed of a Cu layer or a Cu/Ru alloy. The pinned ferromagnetic layer 43 is placed on the non-magnetic layer, and a ferromagnetic substance such as NiFe is used as the pinned ferromagnetic layer 43. The pinned ferromagnetic layer is magnetized in a parallel direction. Unlike those in the present embodiment, the free ferromagnetic layer and the pinned ferromagnetic layer may be formed of, although not limited to, a Co/Pd alloy, or any one selected from the group consisting of alloy A including Co, Fe, Ni and Tb, alloy B including Co, Fe, Ni and C, alloy C including Pd, Pt, Au, Cu, Al and W, and alloy D including Sm, Dy and Tb or a mixture thereof.

One current line 51 of the two current lines 51 and 52 is evaporated on the pinned ferromagnetic layer, and a copper line is generally used as the current line 51. However, unlike that in the present embodiment, it is possible to form the current line using any one of Pt, Pd, Cu, Au, Al, Ru and W. The other one 52 of the two current lines 51 and 52 is disposed beside a side surface of the free ferromagnetic layer 41 and above the electrode layer 51, and is separated from the electrode layer 21 by the in-
ulating layer 60. On the basis of the disposition of the two current lines, current flowing from one current line passes through the magnetic layer 40 and then flows into the other current line, so that recorded information can be read. Furthermore, the individual current line can be selected from the disposition of the devices using a solid switch, such as a transistor, so that the individual devices can be read.

On the basis of the above-described piezoelectric single crystal/magnetic substance structure, the combined sensor according to the present invention can perform excellent signal control using the piezoelectric effect of the piezoelectric single crystal, thereby enabling a combined device capable of being used as a biosignal sensor to which small input signals are input to be designed. Furthermore, a physical phenomenon, such as sound pressure or magnetic force, can be acquired in the form of a highly sensitive electric signal using the acoustic sensor principle and the magnetic substance magnetization reversal and magnetostriction phenomena, so that a combined device which can be used as a sensor for recognizing a magnetic pattern or detecting an external magnetic field, electromagnetic waves, physical force or voltage or memory can be provided.

Although the preferred embodiments of the present invention have been disclosed for illustrative purposes, the scope of the present invention is not limited to these embodiments, and those skilled in the art will appreciate that various modifications, additions and substitutions are possible without departing from the scope and spirit of the invention as disclosed in the accompanying claims.
Claims

[1] A combined magnetic-piezoelectric semiconductor sensor using a piezoelectric single crystal film, comprising:
an Si substrate;
two parallel electrodes placed on the substrate and composed of a positive (+) electrode and a negative (-) electrode which are configured such that external voltage may be applied thereto or an electric signal may be obtained thereby, and a piezoelectric single crystalline thin film layer disposed between the electrodes so as to come into contact with sides of the electrodes;
a magnetic layer placed on the film layer, disposed not to come into contact with one of the electrodes, and configured to have a magnetization direction parallel or perpendicular to a surface of the film layer; and
a first current line placed on the magnetic layer, and a second current line extended perpendicular to the first current line and placed on the one of the electrodes.

[2] The combined magnetic-piezoelectric semiconductor sensor as set forth in claim 1, wherein an insulating layer is interposed between the second current line and the one of the electrodes.

[3] The combined magnetic-piezoelectric semiconductor sensor as set forth in claim 1, wherein a void space for collecting and strengthening input signals is formed in a bottom of the substrate.

[4] The combined magnetic-piezoelectric semiconductor sensor as set forth in any one of claims 1 to 3, wherein the piezoelectric single crystalline thin film layer is made of any one selected from the group consisting of a PMN-PT-based material and a PZN-PT-based material.

[5] The combined magnetic-piezoelectric semiconductor sensor as set forth in any one of claims 1 to 3, wherein the electrodes or current lines are made of any one selected from the group consisting of Pt, Pd, Cu, Au, Al, Ru and W.

[6] The combined magnetic-piezoelectric semiconductor sensor as set forth in any one of claims 1 to 3, wherein the magnetic layer is formed of at least one layered structure.

[7] The combined magnetic-piezoelectric semiconductor sensor as set forth in claim 6, wherein the magnetic layer includes a free ferromagnetic layer, a non-magnetic layer and a pinned ferromagnetic layer sequentially from a bottom of the layered structure.

[8] A combined sensor for detecting a biosignal, recognizing a magnetic pattern, or detecting an external magnetic field, an electromagnetic wave, physical force or
voltage having the construction set forth in claim 1.

[9] The combined sensor as set forth in claim 8, wherein the combined sensor is attached to a portable or stationary electronic device and is configured to detect a signal harmful or harmless to a human body.

### A. CLASSIFICATION OF SUBJECT MATTER

**HOIL 41/04(2006.01)1, GOlH 11/08(2006.01)1**

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

**IPC HOIL**

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

- Korean Utility models and applications for Utility models since 1975
- Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

- eKIPASS (KIPO internal) & keyword "piezoelectric", "magnetic", "sensor"

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>JP 2006-179891 A (KOREA ADVANCED INST OF SCIENCE &amp; TECHNOL) 6 July 2006</td>
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☐ Further documents are listed in the continuation of Box C

☐ See patent family annex

- **X**: Special categories of cited documents
- **A**: document defining the general state of the art which is not considered to be of particular relevance
- **E**: earlier application or patent but published on or after the international filing date
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- **&**: document member of the same patent family

**Date of the actual completion of the international search**

30 MARCH 2009 (30 03 2009)

**Date of mailing of the international search report**

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