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Optical sensor

Abstract

An optical sensor includes a support film, a thermoelectric conversion material portion, a heat sink, a light absorption film, a first electrode, and a second electrode. The thermoelectric conversion material portion includes a plurality of first material layers and a plurality of second material layers. The support film includes a first layer arranged on the heat sink side in a thickness direction and configured with a phononic structure having a large number of holes, and an insulating second layer arranged on the first layer and in contact with the thermoelectric conversion material portion.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
(1) The present application claims priority based on Japanese Patent Application No. 2022-017812 filed Feb. 8, 2022, the entire contents of which are incorporated herein by reference.
BACKGROUND OF THE INVENTION
1. Field of the Invention
(2) The present invention relates to an optical sensor.
2. Description of the Related Art
(3) A thermoelectric conversion element having thermoelectric conversion materials composed of compound semiconductors is know (see, e.g., Patent Literature 1 and Patent Literature 2). An infrared sensor using a phononic structure is also known (see, e.g., Non-Patent Literature 1).
CITATION LIST
Patent Literature
(4) Patent Literature 1: international Publication WO 2021/039074 Patent Literature 2: Japanese Patent Application Laid-Open No. 2017-223644
Non-Patent Literature
(5) Non-Patent Literature 1: Tambo, Naoki, et al., "Sensitivity improved thermal infrared sensor cell applying the heat insulating phononic crystals", Image Sensing Technologies: Materials, Devices, Systems, and Applications VIE. Vol. 11723, International Society for Optics and Photonics, 2021
SUMMARY OF THE INVENTION
(6) An optical sensor according to the present disclosure includes: a support film; a thermoelectric conversion material portion arranged on one main surface of the support film and operative to convert thermal energy into electrical energy; a heat sink arranged on another main surface of the support a light absorption film operative to convert light energy of received light into thermal energy; a first electrode electrically connected to the thermoelectric conversion material portion; and a second electrode arranged separate from the first electrode and electrically connected to the thermoelectric conversion material portion. The thermoelectric conversion material portion includes a plurality of strip-shaped first material layers formed of SiGe having a first conductivity type and operative to convert thermal energy into electrical energy, and a plurality of strip-shaped second material layers formed of SiGe having a second conductivity type different from the first conductivity type and operative to convert thermal energy into electrical energy. Each first material layer includes a first region including a first end located on one side in a longitudinal direction, and a second region including a second end located on another side in the longitudinal direction. Each second material layer includes a third region including a third end located on one side in a longitudinal direction, and a fourth region including a fourth end located on another side in the longitudinal direction. The first electrode is electrically connected to the first region of one of the plurality of first material layers. The second electrode is electrically connected to the third region of one of the plurality of second material layers. The plurality of first material layers and the plurality of second material layers are alternately arranged in series in such a manner that, except for the first region of the first material layer connected to the first electrode and the third region of the second material layer connected to the second electrode, the first region and the third region are electrically connected to each other and the second region and the fourth region are electrically connected to each other. The light absorption film is arranged to form a temperature difference in the longitudinal direction in each of the first and second material layers. The support film includes a first layer arranged on the heat sink side in a thickness direction and configured with a phononic

structure having a large number of holes, and an insulating second layer arranged on the first layer and in contact with the thermoelectric conversion material portion.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIGS. **1** and **2** are schematic plan views of the appearance of an optical sensor in Embodiment 1;

(2) FIG. **3** is a schematic cross-sectional view taken along the line III-III in FIGS. **1** and **2**;

(3) FIG. **4** is a schematic cross-sectional view of a portion of the optical sensor in Embodiment 1;

(4) FIG. **5** is a schematic cross-sectional diagram showing in enlarged view a portion of the optical sensor shown in FIG. **4**;

(5) FIG. **6** is a schematic diagram showing in enlarged view a portion of a first layer configured with a phononic structure;

(6) FIG. **7** is a flowchart illustrating typical steps of an optical sensor producing method in Embodiment 1;

(7) FIG. **8** is a schematic diagram illustrating a setting for forming the first layer;

(8) FIG. **9** is a schematic diagram illustrating a setting for forming a second layer;

(9) FIG. **10** is a graph illustrating a difference in sensitivity between the optical sensor in Embodiment 1 and an optical sensor having a support film composed only of the second layer;

(10) FIG. **11** is a graph illustrating a relationship between the thickness of layers and thermal conductance;

(11) FIG. **12** is a graph illustrating a relationship of yield and optical sensor sensitivity with the thickness of the second layer;

(12) FIG. **13** is a schematic plan view of the appearance of an optical sensor in Embodiment 2;

(13) FIG. **14** is an enlarged schematic plan view of a partial region XIV of the optical sensor shown in FIG. **13**; and

(14) FIG. **15** is a schematic cross-sectional view taken along the line XV-XV in FIG. **14**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Problems to be Solved by Present Disclosure

(15) An optical sensor is required to be good in sensitivity. Therefore, one of the objects of the present disclosure is to provide an optical sensor with which the sensitivity can be improved.

Advantageous Effects of Present Disclosure

(16) According to the optical sensor described above, the sensitivity can be improved.

DESCRIPTION OF EMBODIMENTS OF PRESENT DISCLOSURE

(17) Firstly, embodiments of the present disclosure will be listed and described. An optical sensor according to the present disclosure includes: a support film; a thermoelectric conversion material portion arranged on one main surface of the support film and operative to convert thermal energy into electrical energy; a heat sink arranged on another main surface of the support film; a light absorption film operative to convert light energy of received light into thermal energy; a first electrode electrically connected to the thermoelectric conversion material portion; and a second electrode arranged separate from the first electrode and electrically connected to the thermoelectric conversion material portion. The thermoelectric conversion material portion includes a plurality of strip-shaped first material layers formed of SiGe having a first conductivity type and operative to convert thermal energy into electrical energy, and a plurality of strip-shaped second material layers formed of SiGe having a second conductivity type different from the first conductivity type and operative to convert thermal energy into electrical energy. Each first material layer includes a first region including a first end located on one side in a longitudinal direction, and a second region including a second end located on another side in the longitudinal direction. Each second material

layer includes a third region including a third end located on one side in a longitudinal direction, and a fourth region including a fourth end located on another side in the longitudinal direction. The first electrode is electrically connected to the first region of one of the plurality of first material layers. The second electrode is electrically connected to the third region of one of the plurality of second material layers. The plurality of first material layers and the plurality of second material layers are alternately arranged in series in such a manner that, except for the first region of the first material layer connected to the first electrode and the third region of the second material layer connected to the second electrode, the first region and the third region are electrically connected to each other and the second region and the fourth region are electrically connected to each other. The light absorption film is arranged to form a temperature difference in the longitudinal direction in each of the first and second material layers. The support film includes a first layer arranged on the heat sink side in a thickness direction and configured with a phononic structure having a large number of holes, and an insulating second layer arranged on the first layer and in contact with the thermoelectric conversion material portion.

(18) A thermopile type optical sensor, such as an infrared sensor, using thermoelectric conversion materials that convert temperature differences (thermal energy) into electrical energy may include a light absorption film operative to convert light energy into thermal energy, and a thermoelectric conversion material portion (thermopile) operative to convert thermal energy into electrical energy. In the thermoelectric conversion material portion, a thermocouple may be used, for example, which is formed by connecting a thermoelectric conversion material portion of a first conductivity type, n type, and a thermoelectric conversion material portion of a second conductivity type, p type, different from the first conductivity type. A plurality of strip-shaped n-type thermoelectric conversion material portions and a plurality of strip-shaped p-type thermoelectric conversion material portions are alternately connected in series to increase the output. The sensitivity in an optical sensor is expressed by the expression shown in Math. 1 below.

(19) $D^* = \frac{\eta \times n \times \alpha}{\mathrm{Gth}}$ [Math . 1]

(20) In the above expression, D* represents sensitivity, η represents emissivity, n represents the number of thermocouples, α represents Seebeck coefficient, and Gth represents thermal conductance. As understood from the expression, reduced thermal conductance leads to improved sensitivity in the optical sensor.

(21) Here, the present inventors considered achieving reduction in thermal conductance of the optical sensor in order to improve the sensitivity of the optical sensor. They found that, among the components included in the optical sensor, the support film supporting the thermoelectric conversion material portion had large thermal conductivity, making it difficult to improve the sensitivity. Therefore, the present inventors focused on the point that the thermal conductivity of the support film should be reduced. They also found that according to the structure of Non-Patent Literature 1, the thermoelectric conversion material would enter into the holes, and it would be difficult to properly form the thermoelectric conversion material portion. The present inventors thus studied diligently and finally arrived at the structure of the present disclosure.

(22) In the optical sensor according to the present disclosure, the support film includes the first layer arranged on the heat sink side in the thickness direction, and the insulating second layer arranged on the first layer and in contact with the thermoelectric conversion material portion. According to such a configuration, since the support film includes the insulating second layer, the support film can reliably support the thermoelectric conversion material portion arranged on the second layer. The first layer is configured with the phononic structure having a large number of holes. That the first layer included in the support film includes the phononic structure can reduce the thermal conductivity as the support film. As a result, the sensitivity can be improved with such an optical sensor. As used herein, the phononic structure refers to a structure that has a periodic structure on the nanometer order and artificially inhibits the propagation of phonons.

(23) In the optical sensor described above, the second layer may be formed of a material containing Si. Such a material can easily secure insulating properties.
(24) In the optical sensor described above, the second layer may be formed of SiO.sub.2 or SiN. Such materials are suitable for the insulating second layer included in the support film of the optical sensor.
(25) In the optical sensor described above, the second layer may have a thickness of more than 0 nm and not more than 200 nm, With this, the sensitivity can be improved while increasing the yield during the production of the optical sensor. It is therefore possible to achieve both improved sensitivity and good productivity of the optical sensor.
(26) In the optical sensor described above, the thickness of the second layer may be not less than 10 nm and not more than 50 nm. This makes it possible to more reliably achieve both improved sensitivity and good productivity of the optical sensor.
(27) In the optical sensor described above, either one or both of the first material layers and the second material layers may be formed of SiGe that has at least one of an amorphous structure and a nanocrystalline structure with a grain size of not less than 3 nm and not more than 200 nm. With this, the thermoelectric conversion efficiency can be improved, and thus, the sensitivity can be improved.
(28) In the optical sensor described above, either one or both of the first material layers and the second material layers may be formed of polycrystalline SiGe. Such SiGe as a polycrystal is also suitably used in the optical sensor of the present disclosure. It should be noted that the polycrystal in the optical sensor of the present disclosure leas the crystallinity of 99% or more.
(29) In the optical sensor described above, the phononic structure may be configured with an insulating film containing Si. The pitch spacing between the holes may be not less than 20 inn and not more than 200 nm. This can more reliably reduce the thermal conductivity in the phononic structure. Accordingly, the sensitivity of the optical sensor can be improved more reliably.
(30) In the optical sensor described above, the holes may have a diameter of not less than 10 nm and not more than 100 nm. This can more reliably reduce the thermal conductivity in the phononic structure. Accordingly, the sensitivity of the optical sensor can be improved more reliably.
(31) In the optical sensor described above, the thermoelectric conversion material portion may include a plurality of third material layers formed of metal. Each third material layers may be arranged to contact the first and third regions or to contact the second and fourth regions. In this case, the third material layers with good conductivity can improve the electrical conductivity between the first and second material layers. Accordingly, such a configuration can also improve the sensitivity of the optical sensor.

DETAILS OF EMBODIMENTS OF PRESENT DISCLOSURE

(32) Embodiments of the optical sensor of the present disclosure will be described below with reference to the drawings. In the drawings referenced below, the same or corresponding portions are denoted by the same reference numerals and the description thereof will not be repeated.

Embodiment 1

(33) An optical sensor according to Embodiment 1 of the present disclosure will now be described. FIGS. **1** and **2** are schematic plan views of the appearance of the optical sensor in Embodiment 1. For ease of understanding, an infrared absorption film and an insulating film, which will be described later, are not illustrated in FIG. **1**. In FIG. **1**, the dashed line indicates an outer edge **23***a* of the infrared absorption film when disposed. FIG. **3** is a schematic cross-sectional view taken along the line III-III in FIGS. **1** and **2**. FIG. **4** is a schematic cross-sectional view of a portion of the optical sensor in Embodiment 1. FIG. **4** is a schematic cross-sectional diagram showing in enlarged view a portion including first, second, third, and fourth regions, which will be described later. FIG. **5** is a schematic cross-sectional diagram showing in enlarged view a portion of the optical sensor shown in FIG. **4**.
(34) Referring to FIGS. **1** to **5**, an optical sensor **11***a* is, for example, an infrared sensor. The optical

sensor **11***a* includes a support film **13**, a thermoelectric conversion material portion **12**, a heat sink **14**, an infrared absorption film **23** as a light absorption film, a first electrode **24**, and a second electrode **25**. The optical sensor **11***a* detects a potential difference occurring between the first electrode **24** and the second electrode **25** to thereby detect infrared rays irradiated to the optical sensor **11***a*. When the optical sensor **11***a* as a whole is of a plate shape, the thickness direction thereof is indicated by the Z direction.
(35) The support film **13** is of a thin film shape. In the present embodiment, the support film **13** has a rectangular shape as viewed in the thickness direction (Z direction) The support film **13** supports the thermoelectric conversion material portion **12**, the infrared absorption film **23**, the first electrode **24**, and the second electrode **25**. The support film **13** includes one main surface **13***h* located on one side in the thickness direction, and another main surface **13***a* located on the other side in the thickness direction. Other configurations of the support film **13** will be described in detail later.
(36) The heat sink **14** includes one surface **14***a* and another surface **14***b* arranged apart from each other in the thickness direction of the optical sensor **11***a*. The heat sink **14** is arranged on the other main surface **13***a* of the support film **13**. More specifically, the heat sink **14** is arranged such that the one surface **14***a* of the heat sink **14** contacts the other main surface **13***a* of the support film **13**. The other surface **14***b* of the heat sink **14** is exposed. In the present embodiment, the heat sink **14** has an annular shape. An outer edge **14***c* of the entire heat sink **14** and an outer edge **13***c* of the support film **13** extend continuously in the Z direction. In the cross section illustrated in FIG. **3**, the heat sink **14** is expressed as two trapezoidal shapes arranged apart from each other in the X direction. The heat sink **14** is sufficiently thick compared to the support film **13**, For example, the thickness of the heat sink **14** is at least ten times the thickness of the support film **13**. In the present embodiment, the heat sink **14** is a so-called substrate. The heat sink **14** is formed of, for example, silicon (Si).
(37) The optical sensor **11***a* has a recess **16** formed to be concave in the thickness direction. In a region corresponding to the recess **16** as viewed from the other surface **14***h* side, the support film **13**, more specifically the other main surface **13***a* of the support film **13**, is exposed. In FIG. **1**, the long dashed short dashed line indicates an inner edge **16***a* of the heat sink **14**, which is a boundary between the heat sink **14** and the support film **13**, as viewed in the thickness direction (Z direction) of the optical sensor **11***a*. As shown in FIG. **1**, in the present embodiment, the inner edge **16***a* of the heat sink **14** has a square shape as viewed in the thickness direction of the support film **13**. The heat sink **14** is arranged to surround the recess **16**. An inner peripheral surface **14***d* of the heat sink **14** surrounding the recess **16** is of a so-called tapered shape, which is wider on an opening side located on the surface **14***b* side. The recess **16** is formed, for example, by subjecting a plate-shaped substrate to anisotropic wet etching. The recess **16** thus formed can suppress the escape of heat from the infrared absorption film **23** to the heat sink **14**. This can further increase a temperature difference in the longitudinal direction of first material layers **21** and second material layers **22**, which will be described later.
(38) The first electrode **24** and the second electrode **25** are arranged on the one main surface **13***b* of the support film **13**, outside a region **15** which will be described later. The second electrode **25** is arranged separate from the first electrode **24**. The first electrode **24** and the second electrode **25** are each, for example, a pad electrode. For the material of each of the first electrode **24** and the second electrode **25**, gold (Au), titanium (Ti), platinum (Pt), or the like, for example, is adopted.
(39) The thermoelectric conversion material portion **12** is arranged on the one main surface **13***b* of the support film **13**. The thermoelectric conversion material portion **12** includes a plurality of first material layers **21**, including first material layers **21***a*, **21***b*, **21***c*, and **21***d*, and a plurality of second material layers **22**, including second material layers **22***a*, **22***b*, **22***c*, and **22***d*. The first material layers **21** and the second material layers **22** included in the thermoelectric conversion material portion **12** are each formed of Site. That is, the first material layers **21** and the second material

layers **22** are each formed of a compound semiconductor containing Si and Ge as constituent elements. The first material layers **21** are formed of a thermoelectric conversion material of n type as a first conductivity type. The second material layers **22** are formed of a thermoelectric conversion material of p type as a second conductivity type different from the first conductivity type.

(40) A first material layer **21** has a strip shape. The first material layer **21** includes a first region **28***a*, which includes a first end **28***c* located on one side in the longitudinal direction, and a second region **28***b*, which includes a second end **28***d* located on the other side in the longitudinal direction. The direction in which a line connecting the first region **28***a* and the second region **28***b* extends is the longitudinal direction of the strip-shaped first material layer **21**.

(41) The first material layers **21** are arranged on the one main surface **13***b* of the support film **13**. The first material layers **21** are arranged to fit within the region **15** indicated by the long dashed double-short dashed rectangular shape in FIG. **1**. The plurality of first material layers **21** are arranged spaced apart from each other. Except for the first material layers **21***a*, **21***b*, **21***c*, and **21***d*, the first material layers **21** are each arranged such that the longitudinal direction coincides with the X or Y direction. Except for the first material layers **21***a*, **211**, **21***c*, and **21***d*, the first material layers **21** are each arranged to extend from one side toward the opposite side of the square region **15** (such that the longitudinal direction coincides with that direction). As viewed in the thickness direction of the support film **13**, the first material layers **21** are each arranged such that the first region **28***a* is located on the side close to the inner edge **16***a* of the heat sink **14** and the second region **28***b* is located on the side close to the outer edge **23***a* of the infrared absorption film **23**.

(42) The thermoelectric conversion material portion **12** includes an insulating film **26**. For the material of the insulating film **26**, SiO.sub.2, for example, is selected. The insulating film **26** is arranged on the first material layers **21** in the portion where the first material layers **21** are disposed, and arranged on the one main surface **13***b* of the support film **13** in the portion where the first material layers **21** are not disposed. The insulating film **26** is arranged so as not to cover the first region **28***a* and the second region **28***b* of the first material layers **21**.

(43) A second material layer **22**, similar to the first material layer **21**, has a strip shape. The second material layer **22** includes a third region **29***a*, Which includes a third end **29***c* located on one side in the longitudinal direction, and a fourth region **29***b*, which includes a fourth end **29***d* located on the other side in the longitudinal direction. The direction in which a line connecting the third region **29***a* and the fourth region **29***b* extends is the longitudinal direction of the strip-shaped second material layer **22**.

(44) The second material layers **22**, similar to the first material layers **21**, are arranged to fit within the region **15** indicated by the long dashed double-short dashed rectangular shape in FIG. **1**. The plurality of second material layers **22** are each arranged such that the longitudinal direction is inclined with respect to the X or Y direction. The second material layers **22** are each arranged on a portion of the one main surface **13***b* of the support film **13**, on a portion of the insulating film **26**, and on a portion of the first material layer **21**. As viewed in the thickness direction of the support film **13**, the second material layers **22** are each arranged such that the third region **29***a* is located on the side close to the inner edge **16***a* of the heat sink **14** and the fourth region **29***b* is located on the side close to the outer edge **23***a* of the infrared absorption film **23**.

(45) The plurality of first material layers **21** and the plurality of second material layers **22** are alternately connected, except for the first region **28***a* connected to the first electrode **24** and the third region **29***a* connected to the second electrode **25**. More specifically, a first material layer **21** has its first region **28***a* connected to the third region **29***a* of a second material layer **22** that is adjacent to the first material layer **21** on one side. The first material layer **21** has its second region **28***b* connected to the fourth region **29***b* of a second material layer **22** that is adjacent to the first material layer **21** on the other side. The first material layers **21** and the second material layers **22** have the second regions **28***h* and the fourth regions **29***b* connected to each other and the first

regions **28***a* and the third regions **29***a* connected to each other, except for the first region **28***a* connected to the first electrode **24** and the third region **29***a* connected to the second electrode **25**. That is, with a first material layer **21** and a second material layer **22** making a pair, the adjacent first and second material layers **21** and **22** are electrically connected in series alternately at the regions including their ends. In the present embodiment, the third region **29***a* is disposed on the first region **28***a*, and the fourth region **29***b* is disposed on the second region **28***b*. With respect to the direction of the temperature gradient generated when light is irradiated onto the optical sensor more specifically onto the infrared absorption film **23**, the voltage generated in the first region **28***a* including the first end **28***c* located on one side of the first material layer **21** and the voltage generated in the third region **29***a* including the third end **29***c* located on one side of the second material layer **22** have their polarities opposite to each other.
(46) Of the alternately connected first material layers **21** and second material layers **22**, the first material layer **21** arranged at the most end has its first region **28***a* connected to the first electrode **24**. Of the alternately connected first material layers **21** and second material layers **22**, the second material layer **22** located at the most end has its third region **29***a* connected to the second electrode **25**.
(47) The infrared absorption film **23** converts infrared rays into heat. For the material of the infrared absorption film **23**, carbon (C), for example, is selected.
(48) As viewed in the thickness direction of the support film **13**, the infrared absorption film **23** is arranged in a region surrounded by the inner edge **16***a* of the heat sink **14**. In the present embodiment, as viewed in the thickness direction of the support film **13**, the outer edge **23***a* of the infrared absorption film **23** has a square shape. The infrared absorption film **23** is arranged such that the center of the square shape formed by the outer edge **23***a* of the infrared absorption film **23** coincides with the center of the square shape formed by the inner edge **16***a* of the heat sink **14**.
(49) The infrared absorption film **23** is arranged so as to form a temperature difference in the longitudinal direction of each first material layer **21**, more specifically between the first region **28***a* and the second region **28***b*. Further, the infrared absorption film **23** is arranged so as to form a temperature difference in the longitudinal direction of each second material layer **22**, more specifically between the third region **29***a* and the fourth region **29***b*. In the present embodiment, the infrared absorption film **23** is arranged to expose the first regions **28***a* of the first material layers **21** and the third regions **29***a* of the second material layers **22** and to cover the second regions **28***b* of the first material layers **21** and the fourth regions **29***h* of the second material layers **22**. That is, each connecting portion where the second region **28***b* and the fourth region **29***b* are connected overlaps the infrared absorption film **23** as viewed in the thickness direction of the support film **13**. The first regions **28***a* of the first material layers **21** and the third regions **29***a* of the second material layers **22** are not covered with the infrared absorption film **23**. The first material layers **21** and the second material layers **22** are each thermally connected to the infrared absorption film **23** so as to form a temperature difference in the longitudinal direction of each of the first and second material layers **21** and **22**, The infrared absorption film **23** is arranged such that the heat of the infrared absorption film **23** is actively propagated to the second regions **28***b* of the first material layers **21** and the fourth regions **29***b* of the second material layers **22**.
(50) The first material layers **21** convert temperature differences (thermal energy) between the first and second regions **28***a* and **28***b* into electrical energy. The second material layers **22** convert temperature differences (thermal energy) between the third and fourth regions **29***a* and **29***h* into electrical energy. A temperature difference is formed in the longitudinal direction in each of the first material layers **21** and the second material layers **22**. The thermoelectric conversion material portion **12**, with the first material layers **21** and the second material layers **22** configured as described above, converts the temperature differences (thermal energy) into electrical energy. The optical sensor **11***a* can detect infrared rays by efficiently using the temperature differences formed by the infrared absorption film **23** and the heat sink **14**.

(51) A specific configuration of the support film **13** will now be described. The support film **13** includes a first layer **17** arranged in contact with the heat sink **14** and an insulating second layer **18** arranged on the first layer **17**. The first layer **17** includes one main surface **17***b* located on one side in the thickness direction, and another main surface **17***a* located on the other side in the thickness direction. The other main surface **17***a* in the thickness direction of the first layer **17** is the other main surface **13***a* in the thickness direction of the support film **13**. The second layer **18** includes one main surface **18***b* located on one side in the thickness direction, and another main surface **18***a* located on the other side in the thickness direction. The one main surface **18***b* in the thickness direction of the second layer **18** is the one main surface **13***b* in the thickness direction of the support film **13**. The one main surface **17***h* of the first layer **17** is in contact with the other main surface **18***a* of the second layer **18**.
(52) The first layer **17** has a thickness T.sub.1 of not less than 100 nm and not more than 2000 nm. In the present embodiment, the thickness T.sub.1 of the first layer **17** is 700 nm. The second layer **18** has a thickness T.sub.2 of more than 0 nm and not more than 200 nm. In the present embodiment, the thickness T.sub.2 of the second layer **18** is 10 nm.
(53) Here, the first layer **17** is configured with a phononic structure having a large number of holes **31**. The large number of holes **31** means that the holes **31** have an areal density of 25 to 2500 holes/μm.sup.2. FIG. **6** is a schematic diagram showing in enlarged view a portion of the first layer **17** configured with the phononic structure. FIG. **6** illustrates the first layer **17** as viewed in the Z direction. Referring also to FIG. **6**, the first layer **17** is configured with the phononic structure having a large number of holes **31**. Although the holes **31** are illustrated to have an outer shape of perfect circle in the schematic diagram in FIG. **6** for ease of understanding, the outer shape of the holes **31** is not limited to a strictly perfect circle; it may be elliptical or polygonal. The first layer **17** has a lame number of holes **31** formed spaced apart from each other in a sheet-shaped base portion **32**. The material for the first layer **17** is SiO.sub.2 or SiN. The first layer **17** can be formed, for example, by forming a resist pattern and vapor-depositing a vapor deposition material. This will be described later.
(54) The holes **31** have a pitch spacing D.sub.1, as indicated by a length D.sub.1 in FIG. **6**, of not less than 20 nm and not more than 200 nm. In the present embodiment, the pitch spacing D.sub.1 of the holes **31** is 40 nm. The pitch spacing D.sub.1 of the holes **31** is a spacing between the centers **33***a* and **33***b* of the neighboring holes **31**. Further, the holes **31** have a diameter D.sub.2, as indicated in FIG. **6**, of not less than 10 nm and not more than 100 nm. In the present embodiment, the diameter D.sub.2 of the holes **31** is 15 nm.
(55) A method of producing the optical sensor **11***a* in Embodiment 1 will now be described in brief. FIG. **7** is a, flowchart illustrating typical steps of the method of producing the optical sensor **11***a* in Embodiment 1. Referring to FIG. **7**, in the method of producing the optical sensor **11***a* in Embodiment 1, a substrate preparing step is performed as a step S**10**. In this step S**10**, firstly, a flat plate-shaped substrate is prepared, which is made of Si and becomes a base of the heat sink **14**.
(56) Next, a first layer forming step is performed as a step S**20**. In this step S**20**, a phononic structure is drawn on the substrate with ion beams (EB) to form a resist pattern. Thereafter, a first layer **17** is formed, which is an insulating layer containing Si such as SiO.sub.2, SiN, or the like.
(57) FIG. **8** is a schematic diagram illustrating a setting for forming the first layer **17**. Referring to FIG. **8**, a substrate **54** includes a first surface **54***a* located on one side in the thickness direction, and a second surface **54***h* located on the other side in the thickness direction. The support film **13** is to be formed on the second surface **54***b* of the substrate **54**. In a chamber **51**, with the second surface **54***b* of the substrate **54** facing a vapor deposition material ejecting portion **52**, a vapor deposition material **53** is ejected from the vapor deposition material ejecting portion **52** while the substrate **54** is being rotated along the arrows **55***a*, whereby SiO.sub.2 or SiN as the vapor deposition material **53** is vapor-deposited on the second surface **54***h*. At this time, the vapor deposition is carried out with the vapor deposition material ejecting portion **52** and the substrate **54** being in parallel.

Thereafter, lift-off is carried out to form the first layer **17** included in the support film **13**, It should be noted that the vapor deposition material ejecting portion **52** and the substrate **54** do not have to be in parallel; the substrate **54** may be slightly inclined with respect to the vapor deposition material ejecting portion **52**.
(58) Next, a second layer forming step is performed as a step S**30**. In this step S**30**, the vapor deposition material **53** ejected from the vapor deposition material ejecting portion **52** is vapor-deposited while the substrate **54** inclined at a large angle is being rotated. FIG. **9** is a schematic diagram illustrating a setting for forming the second layer **18**. Referring to FIG. **9**, in the chamber **51**, in the state where the second surface **54***b* of the substrate **54** faces the vapor deposition material ejecting portion **52**, the vapor deposition material **53**, such as SiO.sub.2 or SiN, ejected from the vapor deposition material ejecting portion **52** is vapor-deposited while the substrate **54** is being rotated along the arrows **55***b*. At this time, the angle θ between the vapor deposition material ejecting portion **52** and the second surface **54***b* of the substrate **54** is set at a large angle, specifically at least 45 degrees, for example. By thus vapor-depositing the vapor deposition material **53** on the first layer **17** in the state where the substrate **54** is inclined at a large angle, the second layer **18** can be formed efficiently on the first layer **17** with a large number of holes **31** formed therein. In this manner, the second layer **18** is formed on the first layer **17**. Accordingly, the support film **13** is formed.
(59) Thereafter, a thermoelectric conversion material portion forming step is performed as a step S**40**. In this step S**40**, the thermoelectric conversion material portion **12** is formed on the second layer **18**. Specifically, for example, the first material layers **21**, the layer of insulating film **26**, and the second material layers **22** are formed in this order. For formation of each layer, resist coating, photolithography, vapor deposition, and lift-off, for example, are used. Thereafter, a finishing step is performed as a step S**50**. This step S**50** includes a step of forming the infrared absorption film **23**, a step of forming the first electrode **24** and the second electrode **25**, and a step of forming the recess **16** by anisotropic etching. In this manner, the optical sensor **11***a* of the above configuration is obtained.
(60) According to the optical sensor **11***a* of such a configuration, the support film **13** includes the insulating second layer **18**, allowing the thermoelectric conversion material portion **12** arranged on the second layer **18** to be reliably supported. Further, the first layer **17** is configured with the phononic structure having a large number of holes. By the first layer **17** included in the support film **13** thus including the phononic structure, the thermal conductivity as the support film **13** can be reduced. Such an optical sensor **11***a* can therefore be improved in sensitivity.
(61) In the present embodiment, the second layer **18** is formed of a material containing Si. Such a material can easily secure insulating properties.
(62) In the present embodiment, the second layer **18** is formed of SiO.sub.2 or SiN. Such materials are suitable for the insulating second layer **18** included in the support film **13** of the optical sensor **11***a*.
(63) In the present embodiment, the second layer **18** has a thickness of more than 0 nm and not more than 200 nm. This can improve the sensitivity while securing a high yield during the production of the optical sensor **11***a*. It is therefore possible to achieve both improved sensitivity and good productivity of the optical sensor **11***a*.
(64) The sensitivity of the optical sensor **11***a* in Embodiment 1 described above will now be described. FIG. **10** is a graph illustrating a difference in sensitivity between the optical sensor **11***a* in Embodiment 1 and an optical sensor in which the support film **13** is formed only of the second layer **18**. The vertical axis represents sensitivity (V/W) of the optical sensors. The sensitivity of the optical sensor **11***a* in Embodiment 1 is indicated as S.sub.2, and the sensitivity of the optical sensor with the support film **13** formed only of the second layer **18** is indicated as St. Referring to FIG. **10**, under certain measurement conditions, the sensitivity of the optical sensor including no first layer, i.e. no phononic structure, is 1000 V/W as indicated by S.sub.1. In comparison, under the same

measurement conditions, the sensitivity of the optical sensor **11***a* in Embodiment 1 is 4680 V/W as indicated by S.sub.2. That is, it can be understood that the sensitivity of the optical sensor **11***a* in Embodiment 1 is improved by about 4.7 times compared to the sensitivity of the optical sensor having no first layer.

(65) It should be noted that the sensitivity of an optical sensor is measured according to how much voltage is detected with respect to infrared rays (W/m.sup.2) irradiated from a thermal light source (filament). For the thermal light source, SA10510-8M3 (manufactured by Cal Sensors Inc.) was used, and the measurement was conducted with the voltage of 2.2 V and the current of 1.1 A, at a distance of 7 cm.

(66) FIG. **11** is a graph illustrating a relationship between the thickness of layers and thermal conductance. The horizontal axis represents the thickness of each layer (nm), and the vertical axis represents thermal conductance (W/K). In FIG. **11**, an x indicates the thickness of the second layer, a rhombus indicates the thickness of the first layer, and a circle indicates the total sum. Referring to FIG. **11**, in the first layer having the phononic structure, the thermal conductance is constant at 1.0×10.sup.5 W/K, irrespective of the layer thicknesses. In contrast, it can be understood that in the second layer, the thermal conductance increases with increasing thickness and the thermal conductance exceeds that of the first layer when the thickness of the second layer becomes 150 nm or more.

(67) While the thickness T.sub.2 of the second layer **18** is set to be more than 0 nm and not more than 200 nm in the above embodiment, not limited thereto, the thickness T.sub.2 of the second layer **18** may be not less than 10 nm and not more than 50 nm. This makes it possible to more reliably achieve both improved sensitivity and good productivity of the optical sensor.

(68) FIG. **12** is a graph illustrating a relationship of the yield and the sensitivity of the optical sensor with respect to the thickness of the second layer. The horizontal axis represents the thickness (nm) of the second layer, the vertical axis on the left represents the yield (%), and the vertical axis on the right represents the sensitivity (V/W) of the optical sensor. The higher yield means the better productivity. In FIG. **12**, a circle indicates the yield, and a rhombus indicates the sensitivity of the optical sensor. Referring to FIG. **12**, although the sensitivity is better with the thinner second layer, the yield deteriorates correspondingly. By setting the thickness of the second layer to be not less than 10 nm and not more than 50 nm, the sensitivity of the optical sensor can be made 3500 V/W or more, while securing the yield of 70% or more. That is, setting the thickness of the second layer to be not less than 10 nm and not more than 50 nm can more reliably achieve both the improved sensitivity and good productivity of the optical sensor.

Embodiment 2

(69) Another embodiment, Embodiment 2, will now be described. FIG. **13** is a schematic plan view of the appearance of an optical sensor in Embodiment 2. FIG. **14** is an enlarged schematic plan view of a partial region XIV of the optical sensor shown in FIG. **13**. FIG. **15** is a schematic cross-sectional view taken along the line XV-XV in FIG. **14**. For ease of understanding, the infrared absorption film and the insulating film are not illustrated in FIGS. **13**, **14**, and **15**. FIG. **13** corresponds to FIG. **1**.

(70) Referring to FIGS. **13**, **14**, and **15**, the optical sensor **11***b* in Embodiment 2 includes first material layers **21** and second material layers **22** that are arranged on a same plane, specifically on the support film **13**, different from the case of the optical sensor **11***a* in Embodiment 1 in which the first and second material layers are arranged partially overlapped in the thickness direction. The strip-shaped first material layers **21** and the strip-shaped second material layers **22** are each arranged on the support film **13** such that its longitudinal direction coincides with the X or Y direction. The first material layers **21** and the second material layers **22** are alternately arranged spaced apart from each other.

(71) The thermoelectric conversion material portion **12** includes a plurality of third material layers **36***a*, **36***b*, **36***c*, **36***d*, **37***a*, **37***b*, **37***c*, and **37***d* formed of metal. Examples of the metal constituting the

third material layers **36***a*, **36***b*, **36***c*, **36***d*, **37***a*, **37***b*, **37***c*, and **37***d* include nickel (Ni), tungsten (W), molybdenum (Mo), titanium (Ti), gold (Au), palladium (Pd), germanium (Ge), hafnium (Hf), and aluminum (Al). The third material layers **36***a*, **36***h*, **36***c*, and **36***d* are each arranged on the outer edge sides of the first material layer **21** and the second material layer **22**, to extend across, and in contact with, the neighboring first and third regions **28***a* and **29***a*, More specifically, in the present embodiment, the third material layers **36***a*, **36***b*, **36***c*, and **36***d* are each arranged to cover a first region **28***a*, a third region **29***a*, a portion of the side face of the first region **28***a*, and a portion of the side face of the third region **29***a*. The third material layers **37***a*, **37***b*, **37***c*, and **37***d* are each arranged on the inner edge sides of the first material layer **21** and the second material layer **22**, to extend across, and in contact with, the neighboring second and fourth regions **28***b* and **29***b*.

(72) The support film **13** includes a first layer **17** arranged on the heat sink **14** side in the thickness direction and configured with a phononic structure having a large number of holes, and an insulating second layer **18** arranged on the first layer **17** and in contact with the thermoelectric conversion material portion **12**.

(73) According to the present embodiment, the third material layers **36***a*, **36***b*, **36***c*, **36***d*, **37***a*, **37***b*, **37***c*, and **37***d* with good conductivity can improve the electrical conductivity between the first and second material layers **21** and **22**. Therefore, the sensitivity of the optical sensor **11***b* can also be improved with such a configuration. It should be noted that the optical sensor **11***b* in Embodiment 2 is formed by firstly forming the first material layers **21** and the second material layers **22**, and then removing, by dry etching, the oxide films formed on the first and second material layers **21** and **22**.

OTHER EMBODIMENTS

(74) While the support film **13** is configured with the first layer **17** and the second layer **18** in the above-described embodiments, not limited thereto, two second layers **18** may be configured to sandwich a first layer **17** therebetween, for example.

(75) Alternatively, the support film **13** may be configured to further include a third layer different from the first and second layers **17** and **18**. Still alternatively, a plurality of first layers **17** may be stacked one on another.

(76) Further, while the first layer **17** and the second layer **18** are formed over the entire surface of the support film **13** in the thickness direction in the above-described embodiments, not limited thereto, the first layer **17** and the second layer **18** may be formed for a portion of the support film **13** as viewed in the thickness direction.

(77) It should be noted that in the above-described embodiments, either one or both of the first material layers and the second material layers may be formed of SiGe that has at least one of an amorphous structure and a nanocrystalline structure with a grain size of not less than 3 nm and not more than 200 nm. This can improve the thermoelectric conversion efficiency. Therefore, the sensitivity can be improved.

(78) For the measurement of the grain size of the crystals, transmission electron microscope (TEM) images were observed. For the device, JEM-2100F (manufactured by JOEL Ltd.) was used, at an acceleration voltage of 200 kV. The electronic probe diameter of 0.2 nm was used, and for the EDX mapping conditions, the pixel count was 256 pixels×256 pixels, the dwell time was 0.5 ms/pixel, and the number of integrations was 15.

(79) Further, for SiGe as the constituent material of the first and second material layers **21** and **22**, SiGe of the amorphous structure, for example, may be heat-treated at a temperature of, e.g., about 500° C. to create a nanocrystalline structure in a portion thereof. SiGe may have a nanocrystalline structure or an amorphous structure. SiGe may be polycrystalline. Such SiGe as a polycrystal is also suitably used for the optical sensor of the present disclosure. The polycrystal in the optical sensor of the present disclosure has the crystallinity of 99% or more. The crystallinity was measured as follows. The device used was HORIBA LabRAM HR-PL. For the measurement conditions, the laser wavelength was 532 nm and the laser power was 2.5 mW. For the analysis condition, a peak around 400 cm.sup.−1 was analyzed. For the analysis, the Gaussian function and

the pseudo-Voigt function were fitted. The Gaussian function G(x) is expressed by the expression shown in Math. 2 below

(80) $G(x) = A_g \exp(-\frac{4\ln 2}{W_g^2}(x - x_g)^2)$ [Math. 2]

(81) The pseudo-Voigt function F(x) is expressed by the expression shown in Math. 3 below.

(82) $F(x) = A_F \frac{m}{\pi}[\frac{W_f}{(x - x_f)^2 + W_f^2}] + A_F \frac{1-m}{\sqrt{2\pi}W_f}\exp[-\frac{(x - x_f)^2}{2W_f^2}]$ [Math. 3]

(83) In the Gaussian function G(x) with variables A.sub.g, W.sub.g, and x.sub.g, the initial value of x.sub.0 was set to 400 cm.sup.−1. In the pseudo-Voigt function F(x) with variables A.sub.f, W.sub.f, x.sub.f, and m, the initial value of x.sub.0 was set to 380 cm.sup.−1, and g was set to 0.5. Each parameter was optimized with the least squares method, and the pseudo-Voigt function and the Gaussian function were integrated to obtain an area. The crystallinity was calculated, assuming that the area derived using the Gaussian function corresponds to that of the amorphous phase and the area derived using the pseudo-Voigt function corresponds to that of the crystalline phase, by using the following equation:
Crystallinity=Area derived using pseudo-Voigt function/(Area derived using pseudo-Voigt function+Area derived using Gaussian function)

(84) It should be understood that the embodiments disclosed herein are illustrative and non-restrictive in every respect. The scope of the present invention is defined by the terms of the claims, rather than the description above, and is intended to include any modifications within the scope and meaning equivalent to the terms of the claims.

Claims

1. An optical sensor comprising: a support film; a thermoelectric conversion material portion arranged on one main surface of the support film and operative to convert thermal energy into electrical energy; a heat sink arranged on another main surface of the support film; a light absorption film operative to convert light energy of received light into thermal energy; a first electrode electrically connected to the thermoelectric conversion material portion; and a second electrode arranged separate from the first electrode and electrically connected to the thermoelectric conversion material portion; the thermoelectric conversion material portion including a plurality of strip-shaped first material layers formed of SiGe having a first conductivity type and operative to convert thermal energy into electrical energy, and a plurality of strip-shaped second material layers formed of SiGe having a second conductivity type different from the first conductivity type and operative to convert thermal energy into electrical energy, each of the first material layers including a first region including a first end located on one side in a longitudinal direction, and a second region including a second end located on another side in the longitudinal direction; each of the second material layers including a third region including a third end located on one side in a longitudinal direction, and a fourth region including a fourth end located on another side in the longitudinal direction, the first electrode being electrically connected to the first region of one of the plurality of first material layers, the second electrode being electrically connected to the third region of one of the plurality of second material layers, the plurality of first material layers and the plurality of second material layers being alternately arranged in series in such a manner that, except for the first region of the first material layer connected to the first electrode and the third region of the second material layer connected to the second electrode, the first region and the third region are electrically connected to each other and the second region and the fourth region are electrically connected to each other, the light absorption film being arranged to form a temperature difference in the longitudinal direction in each of the first and second material layers, the support film including a first layer arranged on the heat sink side in a thickness direction and configured with a phononic structure having a large number of holes, and an insulating second layer arranged on the

first layer and in contact with the thermoelectric conversion material portion.
2. The optical sensor according to claim 1, wherein the second layer is formed of a material containing Si.
3. The optical sensor according to claim 2, wherein the second layer is formed of SiO_2 or SiN.
4. The optical sensor according to claim 1, wherein the second layer has a thickness of more than 0 nm and not more than 200 nm.
5. The optical sensor according to claim 4, wherein the thickness of the second layer is not less than 10 nm and not more than 50 nm.
6. The optical sensor according to claim 1, wherein either one or both of the first material layers and the second material layers are formed of SiGe having at least one of an amorphous structure and a nanocrystalline structure having a grain size of not less than 3 nm and not more than 200 nm.
7. The optical sensor according to claim 1, wherein either one or both of the first material layers and the second material layers are formed of polycrystalline SiGe.
8. The optical sensor according to claim 1, wherein the phononic structure is configured with an insulating film containing Si, and the holes have a pitch spacing of not less than 20 nm and not more than 200 nm.
9. The optical sensor according to claim 1, wherein the holes have a diameter of not less than 10 nm and not more than 100 nm.
10. The optical sensor according to claim 1, wherein the thermoelectric conversion material portion includes a plurality of third material layers formed of metal, and the third material layers are each arranged to contact the first and third regions or to contact the second and fourth regions.
11. The optical sensor according to claim 2, wherein either one or both of the first material layers and the second material layers are formed of SiGe having at least one of an amorphous structure and a nanocrystalline structure having a grain size of not less than 3 nm and not more than 200 nm.
12. The optical sensor according to claim 3, wherein either one or both of the first material layers and the second material layers are formed of SiGe having at least one of an amorphous structure and a nanocrystalline structure having a grain size of not less than 3 nm and not more than 200 nm.
13. The optical sensor according to claim 4, wherein either one or both of the first material layers and the second material layers are formed of SiGe having at least one of an amorphous structure and a nanocrystalline structure having a grain size of not less than 3 nm and not more than 200 nm.
14. The optical sensor according to claim 5, wherein either one or both of the first material layers and the second material layers are formed of SiGe having at least one of an amorphous structure and a nanocrystalline structure having a grain size of not less than 3 nm and not more than 200 nm.
15. The optical sensor according to claim 2, wherein either one or both of the first material layers and the second material layers are formed of polycrystalline SiGe.
16. The optical sensor according to claim 3, wherein either one or both of the first material layers and the second material layers are formed of polycrystalline SiGe.
17. The optical sensor according to claim 4, wherein either one or both of the first material layers and the second material layers are formed of polycrystalline SiGe.
18. The optical sensor according to claim 1, wherein the second layer is formed of SiO_2 or SiN, the second layer has a thickness of not less than 10 nm and not more than 50 nm, either one or both of the first material layers and the second material layers are formed of SiGe having at least one of an amorphous structure and a nanocrystalline structure having a grain size of not less than 3 nm and not more than 200 nm, the phononic structure is configured with an insulating film containing Si, the holes have a pitch spacing of not less than 20 nm and not more than 200 nm, the holes have a diameter of not less than 10 nm and not more than 100 nm, the thermoelectric conversion material portion includes a plurality of third material layers formed of metal, and the third material layers are each arranged to contact the first and third regions or to contact the second and fourth regions.