

PYROELECTRIC INFRARED SENSOR DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a pyroelectric infrared sensor device. More particularly, the present invention relates to a pyroelectric infrared sensor device comprising a substrate of a pyroelectric material having one principal plane and a remaining principal plane, the one principal plane receiving rays of infrared light, a comb-shaped electrode on the one principal plane of said substrate, and the substrate being polarized by the comb-shaped electrode.

For example, the above pyroelectric infrared sensor device is used for human body detection in several applications including alarm systems, intelligent air conditioners, autoadjustable illumination apparatus, and auto power-on audio systems.

2. Description of the Related Art

One conventionally known pyroelectric infrared sensor device is designated by the numeral 1 in Fig.11. This infrared sensor device 1 includes electrodes 2a, 3a which are formed on the top and bottom surfaces of a rectangular-shaped pyroelectric body 1a with polarization being vertically effected between the electrodes 2a, 3a along the thickness as indicated by arrows shown. The electrodes 2a, 3a are disposed in the direction at right angles to the polarization direction.

In this conventional pyroelectric infrared sensor device 1, when rays of infrared light 9 are radiated from an object to be detected and are then incident on the light-receiving surface of the sensor device 1, slight temperature changes will occur in the pyroelectric body 1a. As a result, a packet of electrical charge carriers that has

been accumulated on the surface of pyroelectric body 1a in the equilibrium state——say, surface charge——might attempt to move causing a voltage to arise accordingly.

This voltage is for use in detecting the to-be-detected object by electrically amplifying at impedance converter circuitry employing field effect transistors (FETs), by way of example, and then converting an amplified signal into a corresponding electrical signal.

Another conventional pyroelectric infrared sensor device is shown in Figs. 12A to 12C, wherein this device is also designated by numeral 1. Fig. 12A is a plan view of the sensor device 1, Fig. 12B shows its side view, and Fig. 12C is the bottom view thereof.

As shown in Fig. 12A, the conventional pyroelectric infrared sensor 1 includes a substrate 2 made of a pyroelectric material. The pyroelectric substrate 2 has a top surface on which a pair of light-receiving electrodes 3a, 3b are disposed along with an interconnection electrode 4 connecting between them. As best shown in Fig. 12C, pyroelectric substrate 2 has its bottom surface on which a pair of spaced-apart electrodes 5a, 5b are formed overlapping the light-receiving electrode pair 3a, 3b on the top substrate surface. The pyroelectric infrared sensor 1 is designed such that polarization has been effected along the thickness direction of pyroelectric substrate 2.

One typical pyroelectric infrared sensor module 101 employing the pyroelectric infrared sensor device of Fig. 12 is shown in Fig. 13. This conventional pyroelectric infrared sensor module 101 includes a holder plate 102 as manufactured by two-color formation techniques or electrode-on-ceramics formation techniques. The holder plate 102 has a surface with complicated configuration, on which a resistor chip 103 and an FET chip 104 as well as a pyroelectric infrared sensor device 105 are

mounted. The holder plate 102 with resistor 103, FET 104 and sensor 105 mounted thereon is then attached to a support base 106. This base 106 is assembled for packaging with a cap 107 having on its top surface a light entrance window. The assembled sensor module 101 thus contains therein the electronics components 103 to 105 in an environmentally sealed manner.

Another conventional pyroelectric infrared sensor module 201 is shown in Figs. 14A to 14C. This pyroelectric infrared sensor module makes use of the pyroelectric infrared sensor device of Fig. 12. Note here that Fig. 14A shows a plan view of the sensor module, Fig. 14B is its side view, and Fig. 14C is a bottom view of a holder plate 202 used in the module.

As shown in Figs. 14A to 14B, the conventional pyroelectric infrared sensor module 201 comes with a pyroelectric infrared sensor device 205 which is attached on the upper surface of the holder plate 202. This holder plate has a lower surface on which a high-temperature resistance element 203 is mounted by conductive adhesion.

The resistance element 203 is of the high temperature bake type using carbon, thermet, or the like. An FET chip 204 is also mounted on the lower surface of holder 202 as shown in Fig. 14C. This holder plate 202 is attached to a support base 206 so that holder plate 202 is stably positioned over base 206 as best shown in Fig. 14B. A cap with a light entrance window (not shown) is assembled thereto for packaging.

The conventional sensor modules 101, 201 employing the pyroelectric infrared sensor device 1 are under strict requirement that its pyroelectric device per se must be minimized in thickness while at the same time maximizing thermal insulation characteristics in order to improve the relative detection rate indicative of the characteristics of pyroelectric device. To maximize thermal insulation characteristics, it has been required that the light entrance section to which incoming rays of infrared

light are introduced be formed into a hollow shape as shown in Figs. 13A to 13C and 14A to 14C. To this end, it has been a must for the prior art sensor modules 101, 201 to reduce or minimize the thermal capacity and thermal time constant thereof for achievement of enhanced relative detection ratio.

In other words, with the conventional pyroelectric infrared sensor modules 101, 201, since polarization is principally carried out along the thickness direction of sensor substrate, an attempt has been made to minimize the thermal capacity by forcing the device per se to decrease in thickness. This would result in a decrease in mechanical or physical strength while simultaneously reducing durability against thermal shocks applied thereto.

As far as performance concerned, the pyroelectric body can directly receive external vibrations, mechanical shocks, and thermal shocks due to strong infrared light illumination, causing the pyroelectric infrared sensor device per se to receive mechanical vibrations, which in turn results in occurrence of noises. This might reduce the signal-to-noise (S/N) ratio degrading or lowering the performance. In short, since the thickness of pyroelectric infrared sensor device is reduced rendering resultant structure mechanically weakened, the mechanical and thermal reliability is undesirably degraded thus making much difficult the handling of pyroelectric infrared sensor devices.

In addition, the reduction in thickness of pyroelectric devices can increase the risk of occurrence of malfunctions due to the piezoelectric effect of the pyroelectric body per se. This might lead to a reduction in reliability. Therefore, it is difficult for the prior art pyroelectric infrared sensor modules 101, 201 to attain excellent performance with the S/N ratio enhanced.

With regard to the fabrication/manufacture, the mechanical or physical

weakness of the pyroelectric body per se renders difficult both rigid support of the pyroelectric device and retainment of its positioning accuracy during fabrication. More practically, it becomes difficult to accurately mount and support by adhesion the pyroelectric sensor device on an associated substrate at an intended location thereof.

This would also affect performance.

A further problem encountered with the conventional techniques is that specific thermal insulation (thermal resistivity) schemes are required for rendering the light-receiving section hollow in shape thus making it unable to easily form the pyroelectric light-receiving section. Moreover, because in most cases the thickness of the pyroelectric body per se is designed to fall within the range of 70 to 100 micrometers, for example, the resulting yield of production is lowered rendering extremely difficult the manufacture of such pyroelectric infrared sensor device itself.

A still further problem faced with the conventional techniques is an increase in manufacturing cost due to an increase in number of parts or components required. More specifically, in the sensor modules 101, 201 of Figs. 13A to 14C, necessary parts or components are increased in number due to the necessity of making use of the holder plate 102 or 202 with the high-temperature resistance element 203 formed thereon, for attachment of the resistor chip 103 thereto.

One conventional approach to avoidance of such problems is to employ a pyroelectric infrared sensor device 5 shown in Fig. 15. This sensor device 5 has electrode arrangement forcing the polarization of pyroelectric body to concentratedly take place only at or near the infrared light incidence thereof. This structure comes in view of the fact that the contribution of surface layers of the light-receiving surface occupies most part of an output of pyroelectric infrared sensor devices.

More specifically, the conventional pyroelectric infrared sensor device 5 of

Fig. 15 includes a pyroelectric body or substrate 6 of a rectangular shape, for example.

Substrate 6 has a surface on which two electrodes 7, 8 are formed in such a manner that these oppose each other with a predetermined distance D being defined therebetween. Polarization treatment has been effected in advance between the two electrodes 7, 8 by application of a dielectric current (DC) voltage thereto. In this case, polarization tends to mostly occur at nearby portions of the substrate surface acting as the radiation receiving plane, causing the direction of polarization to be parallel with the infrared-light (9) incidence surface. In other words, the polarization direction is set identical to the "x" axis direction in Fig. 15. With such an arrangement, this conventional sensor device 5 is advantageous over those of Figs. 11 to 12 in that the former enables polarization of pyroelectric body 6 to occur concentratedly only at or near the light-receiving surface of the pyroelectric substrate 6, which in turn leads to an improvement in relative detection rate.

Unfortunately, the above advantage of the conventional pyroelectric infrared sensor device 5 shown in Fig. 15 does not come without accompanying serious problems which follow. While it is no longer necessary to make thinner the pyroelectric substrate per se, the area of its light-receiving section as well as the electric capacitance (electrostatic capacitance) thereof remain less rendering it unexpected to obtain a sufficient pyroelectric current while providing certain limitation to improvement in sensitivity and in relative detection rate. Another problem in the conventional techniques is that the electric capacitance (electrostatic capacitance) remains smaller so that high-frequency noise components of white noises are increased undesirably.

On the other hand, pyroelectric infrared sensor devices employing comb-

shaped electrodes placed on pyroelectric substrates have been proposed. This kind of pyroelectric infrared sensors are disclosed in Japanese laid-open publication No. 7-198478.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a pyroelectric infrared sensor device having comb-shaped electrodes capable of avoiding the problems faced with the conventional techniques.

The invention provides a pyroelectric infrared sensor device of the above mentioned kind, which is characterized in that an electrode is formed on the remaining principal plane of said substrate, and said electrode has a portion opposing said comb-shaped electrode.

In the above mentioned pyroelectric infrared sensor device, said comb-shaped electrode may have three or more of electrode pairs.

In the above mentioned pyroelectric infrared sensor device, a plurality of said comb-shaped electrodes may be electrically connected on said one principal surface of said substrate.

In the above mentioned pyroelectric infrared sensor device, said comb-shaped electrode may be variable in electrode pitch. The electrode pitch may be successively increased in interval in a specified direction.

In the above mentioned pyroelectric infrared sensor device, said comb-shaped electrode has an interelectrode distance greater than 100 micrometers.

In this type of pyroelectric infrared sensor device, since the substrate is polarized by the comb-shaped electrodes, thermal or heat energy of incoming infrared

light is to be captured only at the one principal surface of the substrate serving as the infrared light receiving plane. Accordingly, intended pyroelectric current may be obtainable only due to heat exchange at or near such one principal surface of the substrate.

In addition, since the opposite electrode as disposed on the remaining principal plane of the substrate has certain portion opposing or overlapping the comb-shaped electrodes, it becomes possible to improve dipole concentration toward between the comb-shaped electrodes, which may in turn increase the polarization rate of the substrate. This has been found out by simulation results using the finite element method. It is also possible by increasing the polarization rate of the substrate to increase the electrical capacitance (electrostatic capacitance) of the device structure as the pyroelectric infrared sensor.

Furthermore, use of the comb-shaped electrodes may increase the area of opposing electrode portions whereby the current path increases so that electric resistance decreases accordingly.

In accordance with one aspect of the invention, a plurality of comb-shaped electrode pairs are connected in series or in parallel on the top surface of the substrate. These comb-shaped electrode pairs are connected in serial or parallel manner constituting a plurality of light-receiving elements on the infrared light receiving surface. Any desired pyroelectric current is obtainable only due to heat exchange at or near the one principal plane of the substrate acting as the infrared light receiving surface. It is thus possible to suppress or eliminate crosstalk of sensitivity between adjacent ones of the light-receiving elements concerned.

In accordance with another aspect of the invention, at least one comb-shaped electrode pair has parallel open-ended finger portions variable in interval or

pitch therebetween. Use of such variable finger pitch in the comb-shaped electrodes may render likewise different the energy amount of infrared light incident every time when it crosses successive fingers of each electrode. Due to this, the time period spanning from incidence of infrared light to issuance of a corresponding output electrical signal—namely, the time constant—may increase or decrease accordingly.

In accordance with a further aspect of the invention, the interelectrode distance of each comb-shaped electrode is specifically selected so as to exceed 100 micrometers. With this numerical setting, the sensitivity may be further enhanced.

One significant advantage of the invention is that it is possible to provide a pyroelectric infrared sensor device capable of further improving the sensitivity and relative detection rate while simultaneously enabling mass production at low costs. More specifically, it is possible by employing the electrode having certain portion opposing the comb-shaped electrodes to increase the polarization rate thus enabling the electrical capacitance (electrostatic capacitance) to further increase. It is thus possible to provide increased pyroelectric current while enhancing the S/N ratio, thereby improving the sensitivity and relative detection rate.

Another advantage of the invention is that capability of rendering the pyroelectric infrared sensor characteristics independent of the direction of the substrate thickness makes it unnecessary to have to reduce the thickness of a pyroelectric substrate per se. Therefore, the mechanical and thermal strength may be enhanced enabling elimination of degradation of electrical characteristics otherwise occurring due to them.

Still another advantage of the invention is that the comb-shaped electrodes are formed on the one principal plane of the substrate making it possible to fabricate

electrical circuitry directly on the infrared light receiving surface with such circuitry being integral with the substrate. Furthermore, the presently available lithography techniques as widely employed in the IC manufacturing field may also be employed as the formation method of such comb-shaped electrodes, enabling microfabrication of any intended infrared light receiving section with reduced complexity. Moreover, avoiding the necessity of employing extra-thin pyroelectric substrate as in the conventional techniques makes it unnecessary to make use of any additional support substrate for rigid support of the pyroelectric substrate while at the same time reducing complexity in support structure and in thermal insulation scheme therefor.

Again, a reduction in complexity of manufacturing methodology with less number of required parts or components makes it possible to provide a pyroelectric infrared sensor device excellent in electrical reliability and in manufacturability with manufacturing cost reduced.

A further advantage of the invention is as follows. A plurality of light receiving elements are constituted which are connected in series or in parallel on the infrared light receiving surface while simultaneously enabling creation of pyroelectric current only due to heat exchange at or near the one principal plane of the substrate which acts as the infrared light receiving surface; as a consequence, any sensitivity crosstalk occurrable between the light receiving elements can be suppressed. Therefore, it is possible, by appropriate optical treatments such as optical chopping for example, to provide one-dimensional images or two-dimensional images with less crosstalk. This may in turn improve the detection accuracy of a target object being detected.

A still further advantage is that since the time constant may be rendered longer by use of variable finger pitch comb-shaped electrodes, where an object under

detection is a human body for example, slow or moderate movements thereof may be successfully detected with enhanced accuracy.

These and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a diagram showing a perspective view of a pyroelectric infrared light sensitive device in accordance with one preferred embodiment of the present invention.

Fig.2A is a diagrammatic representation, using a simulation by the finite element method, of the distribution of an electric field as created in a substrate of the infrared sensor device shown in Fig.1 with no opposite electrode on its bottom ; and Fig. 2B is a diagrammatic representation of the distribution of an electric field in a substrate with an opposite electrode employed on its bottom.

Fig.3 is an explosive view of a pyroelectric infrared sensor module including therein a pyroelectric infrared sensor device in accordance with another embodiment of the invention.

Fig.4 shows electrical equivalent circuitry of the pyroelectric infrared sensor module shown in Fig.3.

Figs.5A and 5B are graphs each showing the relationship of the sensitivity of the infrared sensors of Figs.3 and 4 versus the finger pair number N of comb-shaped electrodes, wherein Fig.5A shows variations of the sensitivity with the interelectrode distance a and interelectrode pitch b changed and with the intersection width W kept constant in value whereas Fig. 5B shows the same with W changed and

with a, b unchanged.

Fig.6 is an explosive view of a pyroelectric infrared sensor module in accordance with a further embodiment of the invention.

Figs.7 and 8 are partly enlarged plan views of pyroelectric infrared sensor devices also embodying the invention.

Fig.9 is a graph demonstrating how the time constant changes with time by showing the relation of an output voltage of the sensors of Fig. 8 versus elapsed time upon irradiation of incoming infrared light from a moving object under detection.

Figs.10A to 10C illustrate perspective views of several pyroelectric infrared sensor devices also embodying the invention.

Fig.11 shows a perspective view of one conventional pyroelectric infrared sensor device.

Figs.12A to 12C show another conventional pyroelectric infrared sensor device, wherein Fig.12A is its plan view, Fig.12B is its side view, and Fig.12C is a bottom view thereof.

Fig.13 is an explosive view of one conventional pyroelectric infrared sensor module making use of the sensor device shown in Fig.12.

Figs. 14A to 14C show another conventional pyroelectric infrared sensor module employing the sensor device shown in Figs.12A to 12C, wherein Fig. 14A is its plan view, Fig.14B is its side view, and Fig.14C is a bottom view of a holder plate used therein.

Fig.15 shows a perspective view of a further conventional pyroelectric infrared sensor device.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig.1, a pyroelectric infrared sensor device in accordance with one preferred embodiment is generally designated by numeral 10. This sensor device 10 includes a substrate 12 of a rectangular shape with the thickness t . The substrate 12 may be made of a chosen pyroelectric material. Preferably, this material is less in pyroelectricity along the thickness of substrate 12 than along its surface in order to provide a greater output voltage at the surface of substrate 12. This may be met by use of tetragonal-system lead titanate pyroelectric ceramics for substrate 12.

A pair of comb-shaped electrode patterns 14 are disposed on the top surface of the substrate 12 in such a manner that each has a specifically selected number of substantially equally spaced, parallel conductive open-ended "finger" portions. More specifically, one comb-shaped electrode 14 is patterned to have five equal-spaced, open-ended fingers 14a which are consecutively shorted to each other at one end and remain unconnected at the other end. Likewise, the other comb-shaped electrode 14 has five open-ended fingers 14b. These electrode fingers 14a, 14b are spatially interdigitated in relation to each other with a certain gap defined therebetween as shown in Fig.1. The comb-shaped electrodes 14 are such that the finger pair number N is set at five (5) while the interelectrode distance is represented by a , the interelectrode pitch is b , and the electrode interdigitation width is W . The interelectrode distance a , as used herein, may refer to the distance or gap between the fingers 14a and 14b of the comb-shaped electrodes 14. The interelectrode pitch b used herein refers to the center-to-center distance of each pair of one finger 14a and its neighboring finger 14b as interdigitated in relation to each other. The electrode interdigitation width W refers to the length of overlapping portions of such interdigitated fingers 14a, 14b on substrate 12 as may be readily seen from Fig.1.

The pyroelectric substrate 12 has an opposite or bottom surface on which a conductive layer 16 is entirely formed as a further electrode. This bottom-surface electrode 16 is insulatively overlapping the comb-shaped electrode pair 14 along the thickness of pyroelectric substrate 12 so that it includes portions opposing the comb-shaped electrodes 14 on the top substrate surface with substrate 12 being sandwiched therebetween. Electrode 16 may act as an opposite electrode.

In this embodiment the pyroelectric substrate 12 is made of $(\text{Pb}_x\text{Ca}_{1-x})\{(\text{Ni}_{1/3}\text{Nb}_{2/3})_{1-y}\text{Ti}_y\}\text{O}_3$ -based pyroelectric ceramics. Substrate 12 may measure 0.30 to 0.50 millimeters (mm) in thickness t . Preferably, the comb-shaped electrodes 14 and opposite electrode 16 are made of metals of good conductivity, such as gold (Au), silver (Ag) or aluminum (Al). Alternatively, these electrodes may be made of an alloy of nickel (Ni), chromium (Cr) and the like. Note here that in order to increase the sensitivity when reduction to practice, a heat absorption film or heat sink layer (not shown herein) may be additionally provided on the exposed surfaces of electrodes 14, 16 when appropriate.

In the pyroelectric infrared sensor device 10 shown in Fig.1, the top surface with the comb-shaped electrode pair 14 formed thereon serves as the radiation sensitive plane for receipt of incoming rays of infrared light as radiated from an object being detected. In this infrared sensor device 10, upon application of a DC voltage between the interdigitated electrode fingers 14a and 14b, the comb-shaped electrode pair 14 allows its underlying pyroelectric substrate material to be polarized in a selected direction identical to the Y axis direction in Fig. 1. The polarization may be done in such a way that a DC voltage of from 2.0 to 4.0 kilovolts per millimeter (kV/mm) is applied between fingers 14a, 14b of comb-shaped electrode pair 14 for sixty (60) minutes at temperatures of from 100 to 150°C.

See Figs. 2A and 2B. These figures demonstrate the results of experimental simulation as to dipole concentration for analyzing how the internal electric field is created inside the pyroelectric substrate 12 of Fig.1. More specifically, Fig.2A is a diagrammatic representation, using a simulation by the finite element method, of the distribution of an electric field created in substrate 12 in the case where the opposite electrode 16 insulatively overlapping comb-shaped electrodes 14 is not provided; and, Fig.2B is a diagrammatic representation, using such simulation by the finite element method, of the distribution of an electric field created in substrate 12 with the bottom-surface electrode 16 opposing comb-shaped electrodes 14 disposed thereon.

As may be readily seen by those skilled in the art from viewing Figs. 2A to 2B, the simulation results reveals the fact that it is possible, by forming the bottom-surface electrode 16 having portions opposing the comb-shaped electrodes 14 on the top surface of substrate 12, to improve the dipole concentration toward between the spatially interdigitated fingers 14a, 14b of comb-shaped electrode pair 14 at a nearby location of the top substrate surface. To this end, with the pyroelectric infrared sensor device 10 of Fig. 1, the opposite electrode 16 is formed on the entire bottom surface of the substrate 12 in order to enhance the dipole concentration with respect to the fingers 14a, 14b of comb-shaped electrodes 14 while improving the polarization rate.

Turning now to Fig.3, a pyroelectric infrared sensor module structure in accordance with another embodiment of the invention is generally designated by numeral 30. This sensor module 30 includes a pyroelectric infrared sensor device 20 as mounted on a support base plate 32 called the stem. The sensor device 20 is similar to that shown in Fig.1 with a series combination of two comb-shaped electrode

pairs 24, 26 pattern on a pyroelectric substrate 22 of rectangular planar shape. The sensor device 20 with such serially coupled comb-shaped electrode pairs 24, 26 may be called the "dual comb-shaped electrode sensor" in some cases.

More specifically, as shown in Fig.3, the pyroelectric infrared sensor device 20 includes on the top surface of the pyroelectric substrate 22 two pairs of comb-shaped electrodes 24, 26, each of which electrodes has five parallel open-ended fingers as spatially mated or interdigitated in relation to those of its associated comb-shaped electrode on substrate 22. These comb-shaped electrode pairs 24, 26 are centrally disposed on substrate 22 and are electrically coupled in series to each other.

The substrate 22 is polarized by the pair of comb-shaped electrode pairs 24, 26. The substrate 22 has an opposite or bottom surface not visible in Fig.3, on which an electrode 28 is entirely formed so that it has portions opposing comb-shaped electrode pairs 24, 26. Substrate 22 is mounted on the stem 32 with a thin dielectric film sheet member (not shown) being laid therebetween.

As shown in Fig.3, a field effect transistor (FET) 34 is mounted on the top surface of the pyroelectric substrate 22 such that FET 34 is disposed near one elongate peripheral side edge of substrate 22 with certain distance being defined between it and comb-shaped electrode pairs 24, 26 as shown. The stem 32 on which substrate 22 is insulatively mounted has a predetermined number—three, here—of upstanding linear conductive pins 36a, 36b, 36c acting as terminals for electrical connection with external circuitry on a printed circuit board (PCB) as operatively associated with the sensor module 30.

On the substrate 22 of the pyroelectric infrared sensor device 20, the FET 34 has a gate node electrically inter-connected through a lead pattern 38 to a first set of parallel fingers 26b of the comb-shaped electrode 26 in one pair. A second set of

fingers 26a of this comb-shaped electrode 26 are connected via an intermediate lead 40 to first fingers 24b of one comb-shaped electrode 24 in the other pair. The second fingers 24a of the remaining comb-shaped electrode 24 are connected via a lead 42 to a connection pad 44 called the "side electrode." This electrode 44 is on the opposite side wall of substrate 22 opposing the FET mount side edge thereof. Side electrode 44 elongates along the thickness of substrate 22 as shown in Fig.3. The drain node of FET 34 is connected via a conductive bonding wire 46 to one terminal pin 36a. The source of FET 34 is connected via a wire 48 to another terminal pin 36b. The remaining terminal pin 36c is used as the Earth terminal, which is in electrical contact with the side electrode 44 of substrate 22 through a conductive adhesive (not shown).

Still referring to Fig.3, the stem 32 with substrate 22 thereon is assembled with a can casing 50 providing an environmentally sealed interior space in which the pyroelectric sensor device 20 is packed. The can casing 50 may be of a hat-like shape as shown. Can casing 50 has a circular top surface or "ceiling" in which a rectangular opening 50a is centrally defined as a radiation entrance window. An optical filter 52 is rigidly attached on the inner surface of the cap ceiling to cover opening 50a thereby allowing incoming rays of infrared light to enter through optical filter 52 to hit the underlying pyroelectric sensor device 20 sealed inside of an enclosure as constituted by the can casing 50 and stem 32 after assembly. Optical filter 52 may be a 5 micrometers cut-on long-path filter, by way of example.

The pyroelectric infrared sensor assembly or package 30 of Fig. 3 has electrical equivalent circuitry shown in Fig. 4. When rays of infrared light are introduced which may be radiated from an object being detected, such as a moving target human body, thermal or heat energy is given to the radiation sensitive surface——i.e. the top surface of substrate 22 with the series combination of comb-

shaped electrode pairs 24, 26 formed thereon—of the built-in pyroelectric sensor device 20 packed. When this is done, sensor device 20 produces a corresponding amount of pyroelectric current. This pyroelectric current produced is obtainable as a voltage by passing to through a synthesis resistance of an FET gate coupled resistor R_g and an inherent resistance of the pyroelectric infrared sensor device 20. The resulting voltage is then input to the gate (G) of FET 34. At this time, a bias voltage is applied to the drain (D) of FET 34 whereas the source (S) of FET 34 is coupled to ground. The pyroelectric current as derived at infrared sensor device 20 is impedance-converted by the sensor device 20, resistor R_g and FET 34, and is then generated at output terminal pin 36b as a detection voltage signal.

See graphs shown in Figs.5A and 5B, which experimentally demonstrate that the pyroelectric infrared sensor module 30 of Fig.3 was with increased sensitivity.

More specifically, the experiments have been done using several dimension parameters of sensor module 30, including the finger pair number N of the comb-shaped electrode pairs, the ratio k of the finger gap a to the finger pitch b as given by $k=a/b$, and the finger interdigitation width W , each of which was varied in value in a way as follows. The graph of Fig. 5A shows the relation of resultant sensitivity versus finger pair number N when the finger gap-to-pitch ratio k was changed in value from 0.5 through 0.6 to 0.7 with the interdigitation width W kept constantly at 1.0mm. The graph of Fig. 5B indicates variations of the sensitivity when the interdigitation width W was changed between 0.6 mm and 1.0 mm with the value of k fixed at 0.5 mm. As can be readily seen from these experimental results, it has been found that the pyroelectric infrared sensor module 30 of Fig.3 could exhibit good sensitivity especially when N is greater than or equal to three (3) and simultaneously a goes beyond 100 micrometers in value.

One significant advantage of this pyroelectric infrared sensor module 30 is that since the comb-shaped electrode pairs 24, 26 for permitting polarization in the pyroelectric substrate 22 are formed on the surface of substrate 22 serving as the infrared light receiving plane, it becomes possible to catch the thermal energy of infrared light only at or near the top surface of substrate 22. For this reason, sensor module 30 may function as a pyroelectric infrared sensor that does no longer depend upon the thickness direction of its pyroelectric body unlike the prior art as discussed in the introductory part of the description.

Another advantage of this embodiment sensor module 30 lies in capability of attaining, due to presence of the opposite electrode 28 having portions opposing the comb-shaped electrode pairs 24 and 26, dipole concentration toward between the fingers 24a and 24b of the comb-shaped electrode pair 24 as well as between the electrode fingers 26a and 26b of comb-shaped electrode pair 26. This in turn makes it possible to increase the polarization rate of comb-shaped electrode pairs 24, 26. Moreover, it is also possible to increase the electrical capacitance (electrostatic capacitance) between the comb-shaped electrode pairs 24, 26 and opposite electrode 28. Accordingly, sufficient pyroelectric current is obtainable while at the same time rendering the S/N ratio excellent. As a consequence, with the pyroelectric infrared sensor module 30 of this embodiment, further improved sensitivity is expectable.

Still another advantage of the embodiment 30 is that since the opposite electrode 28 having portions insulatively overlapping the comb-shaped electrode pairs 24, 26 is on the bottom surface of the substrate 22, the electric resistance of the pyroelectric infrared sensor device 20 can be further decreased as a whole. Therefore, it becomes possible to eliminate use of an external resistor to be provided between the gate (G) of FET 34 and the ground (GND). Note here that the resistor

R_g in the electrical equivalent circuit diagram of Fig.4 is a mere symbolic representation of the inherent resistance of pyroelectric infrared sensor device 20, and is not any discrete element to be separately coupled thereto.

Yet another advantage of module 30 is that the pyroelectric infrared sensor device 20 used therein does not operationally depend upon the thickness direction of the pyroelectric substrate 22; therefore, it is no longer necessary for substrate 22 to be much reduced in thickness. Accordingly, the mechanical and thermal strength may be enhanced thereby eliminating, or at least greatly suppressing, any possible degradation of the electrical characteristics otherwise occurring due to a decrease in substrate thickness.

One advantage of infrared sensor device 20 lies in that the comb-shaped electrode pairs 24, 26 are on the surface of the pyroelectric substrate 22 acting as the infrared light receiving plane, thereby making it possible to integrally form electrical circuitry with substrate 22 on the infrared light receiving surface thereof. Also, since any currently available lithography techniques as widely employed in the IC fabrication field are directly applicable without any modifications as the formation methodology of comb-shaped electrode pairs 24, 26, it is possible to readily fabricate the infrared light receiving section with reduced complexity. Yet further, any pyroelectric substrate support plate is no longer required while simultaneously rendering it unnecessary to perform a variety of kinds of complicated support methods for support of such pyroelectric substrate as well as any extra thermal insulation schemes.

As a consequence, with the pyroelectric infrared sensor device 20, reducing complexity of manufacture and parts in number may make it possible to enhance the electrical reliability and manufacturability with production costs reduced.

A pyroelectric infrared sensor module in accordance with a further

embodiment of the invention is shown in Fig. 6. This module is generally designated by numeral 60 as shown. While the previous sensor module 30 of Fig.3 is of the hermetic seal-type, module 60 shown in Fig.5 is of the surface-mount component type in structure. In Fig.6, like parts or components are indicated by like reference characters for purposes of explanation only.

Principally, the pyroelectric infrared sensor module 60 of Fig.6 is similar to that shown in Fig.3 with the can casing 50 being modified in shape and also with the terminal pins 36a to 36c being deleted moreover with the FET 34 being modified in electrical interconnection scheme relating to the source, drain and gate thereof. As illustrated, can casing 50 resembles in outer appearance a thin rectangular box, rather than the hat shown in Fig.3. The drain, source and gate of FET 34 are respectively connected to external electrode pads which are distributed at specified locations on the pyroelectric substrate 22 as will be described in detail below.

Still referring to Fig. 6, the rectangular pyroelectric substrate 20 has three electrode pads 45, 47, 49. Pads 47, 49 are for electrical interconnection with the FET 34 mounted on substrate 20, and are formed along one of longitudinal opposite side edges of substrate 22 with certain distance defined therebetween. These pads 47, 49 are electrically connected by lead wires 46, 48 to the drain and source of FET 34.

Pad 47 serves as an input terminal whereas pad 49 acts as an output terminal. The remaining pad 45 is formed at the other longitudinal substrate side edge so that it faces pad 49 across the width of substrate 22. Pad 45 also extends on a corresponding portion of the side wall of substrate 22 as shown. Pad 45 acts as the ground terminal. This pad is electrically coupled to the gate of FET 34 through a series combination of two comb-shaped electrode pairs 24, 26. Specifically, ground pad 45 is connected via an on-surface lead pattern 42 to first fingers 24a of one

comb-shaped electrode pair 24, which has second fingers 24b connected by an intermediate on-surface lead 40 to the first fingers 26a of the other comb-shaped electrode pair 26. The second fingers 26b thereof are electrically coupled via an on-surface lead pattern 38 to the gate of FET 34.

Turning now to Fig.7, main part of a pyroelectric infrared sensor device 70 in accordance with a still further embodiment of the invention is shown. The infrared sensor device 70 is similar to that 20 shown in Fig. 3 with the comb-shaped electrode pairs 24, 26 being replaced by an array of rows of comb-shaped electrode pairs 74. More specifically, a plurality of series combination of comb-shaped electrode pairs 74 are provided in a serial or parallel fashion on the light-receiving surface of a pyroelectric substrate 72. Each comb-shaped electrode pair 74 in each row consists of two conductive comb-shaped electrode patterns 74a, 74b each having a selected number—three or greater—of parallel open-ended fingers. Comb-shaped electrode 74a has four fingers including its outermost ones whereas electrode 74b has three fingers each of which is positioned between a pair of successive fingers of its associated comb-shaped electrode 74a. The substrate 72 has a similar bottom-surface electrode (not visible in Fig. 7) which has portions opposing the array of serial/parallel comb-shaped electrode pairs 74.

With such an arrangement, since an increased number of serially coupled comb-shaped electrode pairs 74 are grouped in parallel rows on the infrared light receiving surface of substrate 72 while allowing each pair to function as radiation sensitive element, any intended pyroelectric current responsive to irradiation of incoming rays of infrared light is obtainable only due to thermal conversion at or near this substrate surface. This may advantageously serve to minimize or at least greatly reduce occurrence of crosstalk between adjacent ones of the comb-shaped electrode

pairs 74. Accordingly, it becomes possible to maximize or at least greatly enhance detection accuracy while simultaneously enabling successful acquisition of one-dimensional or two-dimensional images with less or no crosstalk by performing optical chipping procedures.

The array of multiple comb-shaped electrode pair rows 74 shown in Fig. 7 is modifiable such that all of the first fingers 74a of them are connected together while causing the second fingers 74b thereof to be subdivided into rows and columns of blocks each of which includes commonly coupled second fingers. This arrangement makes it possible to more accurately detect movement of an object under detection.

A pyroelectric infrared sensor device 80 also embodying the invention is shown in Fig. 8. As shown, infrared sensor device 80 is similar to that 10 of Fig. 1 with the electrode fingers 14a, 14b being replaced with fingers 84a, 84b which are variable in distance or interval between adjacent fingers—say, finger pitch $\underline{b}$. More specifically, sensor device 80 includes a pyroelectric substrate 82 having a pair of comb-shaped electrodes 84. Each electrode includes a preselected number—three or more—of parallel open-ended fingers 84a or 84b consecutively coupled together at one end. Electrode fingers 84a and 84b are spatially interdigitated with each other as shown in Fig. 8. These fingers are different or "variable" in pitch $\underline{b}$ in such a way that pitch values $b_1, b_2, b_3, b_4, \dots$ are sequentially incremented along the length of substrate 82 as defined by the direction X in Fig. 8. Such sequential increase in pitch value $\underline{b}$ causes the gap defined between one finger 84b and its associated pair of fingers 84a to gradually increase in the direction X. Substrate 82 has a similar bottom-surface electrode (not visible in Fig. 8) having portions opposing comb-shaped electrodes 84.

With the electrode finger pitch $\underline{b}$ varied, an output voltage of the infrared

sensor device 80 may vary with time as shown in Fig.9, which demonstrates variations of the time constant——this factor may correspond to a maximal deviation or difference between a time change of incident rays of infrared light and actual issuance of an electrical output signal responding thereto——upon irradiation of infrared light onto the top surface of substrate 82 with comb-shaped electrode pair 84 formed thereon. More specifically, suppose that infrared light radiated from a target object, such as a human body, is incident on the substrate surface of sensor device 80. Imagine that the object is moving. Consider that as the object moves, a spot or beam of incident infrared light hitting sensor substrate 82 moves along the direction X. In this situation resultant energy of infrared light becomes different in amount every time when it passes through a respective pair of interdigitated fingers 84a, 84b of comb-shaped electrodes 84. In other words, as can be readily seen by those skilled in the art by comparatively viewing Figs.8 and 9, as a beam spot of incident infrared light on substrate 82 moves along the length of substrate 82 in the direction X, the resulting thermal energy produced therein becomes different in intensity every time when the spot crosses a respective one of electrode fingers 84a of variable pitch, thereby causing a corresponding sensor output voltage to vary in waveform. Such output voltage variation may force the time constant——namely, the time taken from incidence of infrared light to issuance of an electrical output signal in response thereto——to increase accordingly as well demonstrated by the graph of Fig. 9. It is thus possible for sensor 80 to offer increased sensitivity in low-frequency bands in particular. This may in turn enable attainment of maximized detectability with respect to slow or moderate movement of an object being detected, in cases of detection of people who are walking slowly, by way of example.

Some other embodiments or modifications also embodying the principles

of the invention are shown in Figs.10A to 10C. These infrared sensor devices are featured in employment of three-dimensional (3D) structures as will be set forth in detail below.

A pyroelectric infrared sensor device 90A shown in Fig. 10A includes a cubic support base structure 92a having its top and bottom square planes as well as four side walls on which pyroelectric sensor substrates 94a are centrally mounted by adhesion except for the bottom. Cubic base 92a may be made of insulative materials.

Each sensor substrate 94 is similar in structure and function to that shown in Fig. 1, by way of example. With such 3D sensor structure, multidirectional detection is attainable by use of a single device. For instance, the exact movement direction of an object being detected is accurately detectable while reducing complexity.

A pyroelectric infrared sensor device 90B shown in Fig. 10B includes a triangular pyramid support base structure 92b with three slant side walls on which sensor substrates 94b are centrally placed respectively. With such an arrangement, similar advantages are attainable.

A pyroelectric infrared sensor device 90C shown in Fig. 10C includes a columnar support base structure 92c with a circumferential side surface on which spaced-part sensor substrates 94c are mounted along the axis thereof. With such an arrangement, similar advantages are also attainable.

In each of the devices 90A to 90C, the 3D support bases 92a to 92c may alternatively be made of a chosen pyroelectric material on which required comb-shaped electrode pairs are directly formed. Obviously, these bases may also be of any one of other shapes in appearance, such as rectangular solids, pyramids, circular cones, and the like.

Although the invention has been disclosed and illustrated with reference to

particular embodiments, the principles involved are susceptible for use in numerous other embodiments, modification and alterations which will be apparent to persons skilled in the art to which the invention pertains. The invention is, therefore, to be limited only as indicated by the scope of the appended claims.



What is claimed is:

1. A pyroelectric infrared sensor device (10), comprising
a substrate (12) of a pyroelectric material having one principal plane and a remaining
principal plane, the one principal plane receiving rays of infrared light,
a comb-shaped electrode (14) on the one principal plane of said substrate, and
the substrate (12) being polarized by the comb-shaped electrode (12),
characterized in that
an electrode (16) is formed on the remaining principal plane of said substrate (12), and
said electrode (16) has a portion opposing said comb-shaped electrode (14).
2. The pyroelectric infrared sensor device (10) according to claim 1,
characterized in that
said comb-shaped electrode (14) has three or more of electrode pairs (14a,14b).
3. The pyroelectric infrared sensor device (70) according to claim 1 or 2,
characterized in that a plurality of said comb-shaped electrodes (74) are electrically
connected on said one principal surface of said substrate (72).
4. The pyroelectric infrared sensor device (80) according to one of claims 1
to 3, characterized in that
said comb-shaped electrode (84) is variable in electrode pitch (b1,b2,b3,b4).
5. The pyroelectric infrared sensor device (80) according to claim 4,
characterized in that





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said electrode pitch (b1,b2,b3,b4) are successively increased in interval in a specified direction.

6. The pyroelectric infrared sensor device (10) according to one of claims 1 to 5, characterized in that said comb-shaped electrode (14) has an interelectrode distance (a) greater than 100 micrometers.

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