The Fresnel-IRDET Motion Sensor

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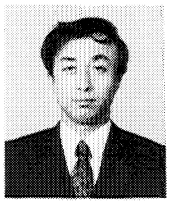

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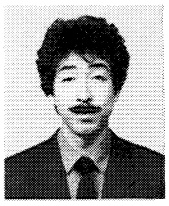

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Abstract

Horiba has begun the manufacture of the model IM-02 infrared module, which has a pyroelectric infrared detector for sensing human movement; this model is distributed commercially under the name Fresnel-IRDET. The model IM-02 design reduces the number of components to the absolute minimum and concentrates these into a single unit that holds the light-gathering lens, the circuit boards, the case, and the detector. This compact unit can then be used as a motion sensor with just the addition of a few auxiliary components. The pyroelectric infrared detector has recently come to be used in a wide range of applications. However, it is necessary to be familiar with the relevant optical systems and electronic circuitry using this type of detector in an infrared sensor system designed for the detection of the motion. In this paper, we introduce the model IM-02 infrared module; and in order to understand the principles of its operation, we also look at the design and principles of the pyroelectric infrared detector.

1. Introduction

If we were to mention the topic of sensing human movement, devices such as intruder alarms, safety devices for machine tools, for example, in factories or manufacturing divisions, and the sensors used in automatic doors would probably come to mind. However, recently, the sensing of human movement or the number of people, is being applied in an attempt to create a more comfortable environment such as in lighting control, visitor sensors, or the detailed control of the airflow of indoor air conditioners or air cleaners. As a result, the sensing of human movement is becoming closer to our daily lifestyles.

One method of sensing human movement is to detect the changes in infrared radiated energy, that occurs due to human movement, within a specified area. This method is simple and highly accurate, and is the mainstream method in use. If we look at the wavelength distribution of the infrared energy radiated from a body near room temperature, such as human body temperature, we can see that infrared energy peaks at around 10μm, and that sensitivity must be provided at that wavelength band in order to detect "human movement."

Horiba has been continuing research and development into pyroelectric-type infrared detectors for many years now as the major component of nondispersive infrared analyzers, a key Horiba product. Pyroelectric-type infrared detectors have flat spectral sensitivity over a wide wavelength region, and good features such as applicability at room temperature without the need for cooling elements. Incorporating an infrared interference filter designed to allow only specific wavelength regions to pass through allows the pyroelectric-type infrared detector to be housed in many products such as systems for measuring the concentration of hydrocarbons (HC) in automotive exhaust gas or nitrogen oxide (NO_x) in the atmosphere, or systems for measuring the concentration of carbon dioxide (CO_2) used for controlling air conditioning in buildings. This also helps to downsize these systems and improve their reliability. Horiba has also been developing a detector, that incorporates an infrared interference filter that efficiently allows light of wavelength about 10μm to pass through, designed for use in a wider range of applications such as intruder alarms and radiation thermometers.

When using pyroelectric infrared detectors in human-movement sensors or other various analyzers, we must, of course, know about the detector itself, and to some extent know about the light gathering system and electronic circuitry. In order to further understanding when introducing this detector, we have distributed commercially the IM-02 "Fresnel-IRDET" infrared module for sensing human movement that concentrates the absolute minimum functions such as the Fresnel lens and circuit boards in a single unit.

2. Pyroelectric-type Infrared Detector

Infrared detectors are classified into two types: quantum type detectors that use semiconductor materials such as PbSe or HgCdTe, and thermal type detectors such as thermistors or thermopiles. While quantum type detectors have high sensitivity and fast response, they are lacking in that they unavoidably dependent on wavelength sensitivity and their elements must be cooled. On the other hand, thermal type detectors excel in that they are extremely easy to use, they are not dependent on wavelength sensitivity, and they can be used at room temperature. However, their sensitivity and response are insufficient. Of these thermal type detectors, pyroelectric-type infrared detectors have both excellent response and sensitivity, and so are being used in a wider range of applications.

2.1 Principles of Operation

When infrared radiation is absorbed by the pyroelectric element, a minute change in temperature occurs near the surface of the element. This temperature change causes a change in spontaneous polarization to occur inside the element, which results in a load to be excessively induced at the surface of the element. This phenomenon (pyroelectric effect) is used to detect infrared radiation. The induced load is received at a load resistor of about $10^{11}\Omega$, where it is converted to a voltage signal.

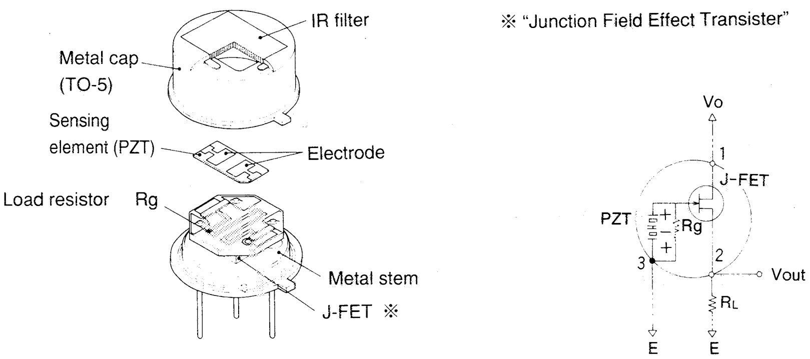
2.2 Sensing Element

The elements of the sensing element must, of course, be highly sensitive; the elements must exhibit little disparity in characteristics, have excellent environment resistance, and be low-priced. As lead zirconate titanate (PZT) ceramic exhibits a high Curie point of about 320°C and a high dielectric constant (e = about 400), PZT ceramic has excellent stability with respect to the ambient temperature.

2.3 Configuration of the Detector

Fig.1 (A) shows the configuration of the detector, while **Fig.1 (B)** shows the internal circuitry.

As the electrode is made up of a pair of complementary-connected elements, pyroelectric currents occur in mutually inverse directions with respect to signals simultaneously entering both elements caused by sudden changes in ambient temperature, vibration, or shock, and these pyroelectric currents are canceled out. This mechanism increases the stability and reliability with respect to external disturbances.



(A) Configuration of the detector (B) Internal circuitry

Fig.1 Pyroelectric infrared detector

2.4 Spectral Sensitivity Characteristics

The sensing element exhibits flat spectral sensitivity characteristics regardless of the wavelength of incident light. In order to reduce the effect of solar light, the sensing element is used in combination with an IR filter (Infrared Multilayer interference filter). This IR filter is used in order to cut out light of wavelengths 6µm or less and allow detection of light of wavelength 6 to 14µm. **Fig.2** shows the spectral transmission of the infrared interference filter.

2.5 Frequency Response Characteristics

Frequency response characteristics are determined by thermal time constant τ_t, which is determined by the material characteristics and shape of the element, and electric time constant τ_e. When using the pyroelectric infrared detector for sensing human movement, each of the element parameters were designed with the importance placed on the low-frequency response characteristics (up to 10Hz). **Fig.3** shows the frequency characteristics. **Fig.4** shows an example of a response wave form of the IM-02 caused by actual human movement. As the detector is configured using dual elements, this results in a complex response wave form. You can also tell from **Fig.4** that the response wave form and sensitivity change as the speed of motion.

3. Fresnel-IRDET IM-02

In order to use a pyroelectric-type infrared detector for sensing human movement, the detector must be designed to have a optical system made up of a lens, reflecting mirror, etc., and electronic circuitry. These components must also be incorporated into the detector. The Fresnel-IRDET IM-02 contains these compo-

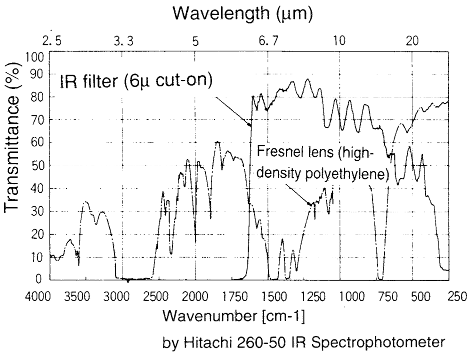


Fig.2 The spectral transmission of the IR filter and Fresnel Lens

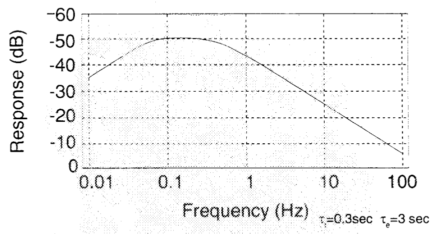


Fig.3 Example of frequency response of the pyroelectric infrared detector

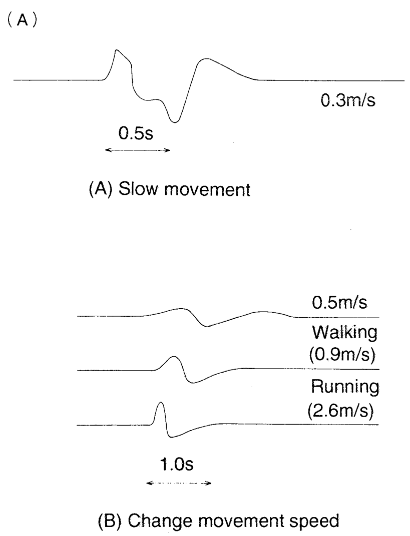


Fig.4 Response wave form of the detector when a person has crossed the detection area

nents in a compact plastic case as a single module.

The IM-02 has the following features:

- Functions required for sensing human movement are compactly concentrated in a single module.
- Open collector output
- Built-in timer circuit allows the output hold time to be adjusted up to 200s.
- Built-in circuit for suppressing unwanted output immediately after turning the power supply on.
- The case sides are provided with ribs for attaching to a panel.
- Resistant to ambient noise

Fig.5 shows the external view of the IM-02. **Table 1** shows the specifications of the model IM-02.

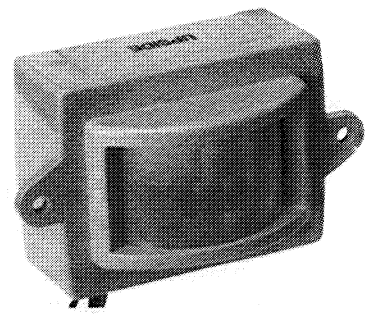


Fig.5 External View of the Model IM-02

		IR Sensor Module	Pyroelectric Detector		
Model Number		Fresnel-IRDET IM-02	IP-220/-222	IP-240/-242	IP-260
Sensing Element		PZT	PZT	PZT	PZT
Spectral Response Range		8 to 13μm	6 to 25μm (transmittance is more than 70% from 7 to 14μm)	6 to 25μm (transmittance is more than 70% from 7 to 14μm)	6 to 25 μm (transmittance is more than 70% from 7 to 14μm)
Responsivity (500, 0.5)		Maximum sensing area:5m	2,200V/W	2,200V/W	2,200V/W
Detectability (D*) (500, 0.5, 0.3)		————	0.9 x 10^8 cmHz1/2/W	0.9 x 10^8 cmHz1/2/W	0.9 x 10^8 cmHz1/2/W
Offset Voltage		Operating current: 10mA or less	0.7V or less (VD=5V, RS=10KΩ)	0.7V or less (VD=5V, RS=10KΩ)	Less than 0.7V (VD=5V, RS=10KΩ)
Operating Voltage		4.5 to 7V	3 to 10V	3 to 10V	3 to 10V
Recommended Operating Temperature		0 to 50°C	-20 to 60°C	-20 to 60°C	-20 to 60°C
Rise Time		————	300ms	300ms	300ms
Element Size		2 x 1mm, two elements	2 x 1mm, two elements	2 x 1mm, two elements	Trapezoid shape (1.8mm2), two elements
F.O.V.	Horizontal	80°	40°, two directions	45°, two directions	47°, two directions
	Vertical	32°	40°, two directions	45°, two directions	47°, two directions
Remarks		Can be stored in compact case 57 (W) x 35 (D) x 42 (H). On-time of output is specified up to 200 seconds.	High-mount type (H=5.1mm) IP-220 (standard type) IP-222 (special type arranged to avoid the effects of visible light)	Low-mount type (H=3.5, 1mm) IP-240 (standard type) IP-242 (special type arranged to avoid the effects of visible light)	Designed to get wide F.O.V. and a wide dead angle

Table 1 Specifications of the Model IM-02

3.1 Principles of Measurement

We are not very familiar with infrared radiation as we cannot see it. However, all bodies in the natural world radiate infrared light in proportion to the temperature of the body. **Fig.6** shows the spectral radiation of a black body.

The surface temperature of a human being varies according to clothing worn and ambient temperature. However, generally speaking, the surface temperature is within the range 20 to 35°C, and radiation peaks near wavelength 10μm. **Fig.7** shows an example of surface temperature distribution at various parts of the human body.

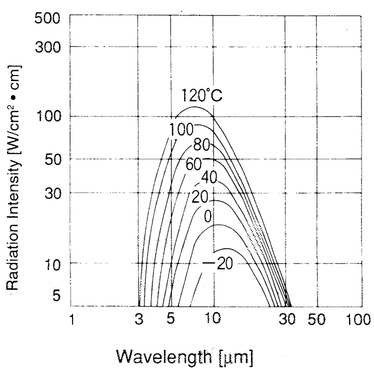
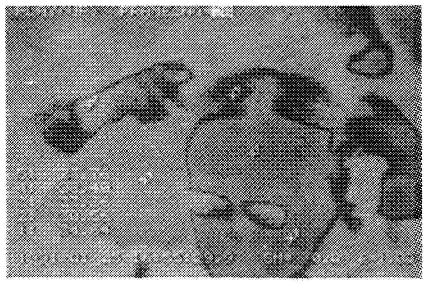


Fig.6 Spectral radiation of a black body

The model used to obtain this data was a heat source of 20 to 35°C of width within about 20 to 50cm moving at a speed of 0.1 to 10m/s. The method used to detect human presence was as follows. A detector in combination with a reflecting mirror and Fresnel lenses were used to capture changes in detected light that occur when the heat source in this model moved within a specified area.

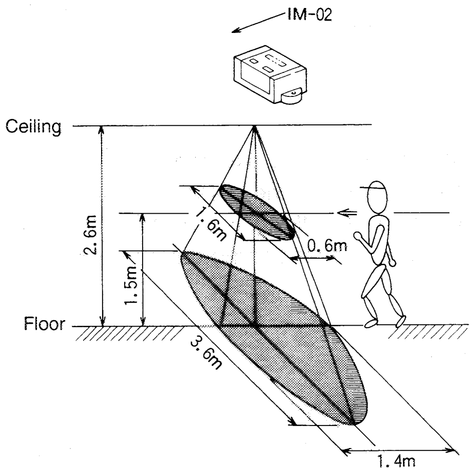


	Human Part	Surface Temperature (°C)
1	Forehead	34.6
2	Arm	30.6
3	Cheek	33.4
4	Hair	28.4
5	Background	23.8

Fig.7 Sample measurement of the surface temperature of a human being

3.2 Optical System

A light gathering element such as a lens is required to effectively gather the minute amounts of infrared radiation radiated from the human body on the light detecting surface of the detector. So that the IM-02 can effectively detect over a wide angle, 13 Fresnel lens are used in combination with multiple lens chips to configure 13 independent surfaces, and 26 detection areas are arranged in a radial pattern. The Fresnel lenses are made of high-density polyethylene which exhibits comparatively good transmittance in this wavelength region. **Fig.8** shows the design specifications of the Fresnel lens.



(1) Number of lens elements: 13
(2) Focal length: 20mm
(3) Lens material:
High-density polyethylene sheet
(4) Lens thickness: 0.7mm
(5) Outline: 44mm x 24.8mm

Fig.8 Design specifications of the Fresnel lens

3.3 Electronic Circuitry

Fig.9 shows the electronic circuitry.

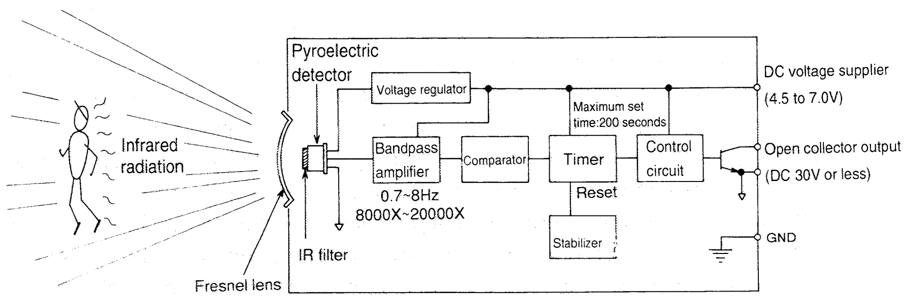


Fig.9 Circuitry configuration of the IM-02

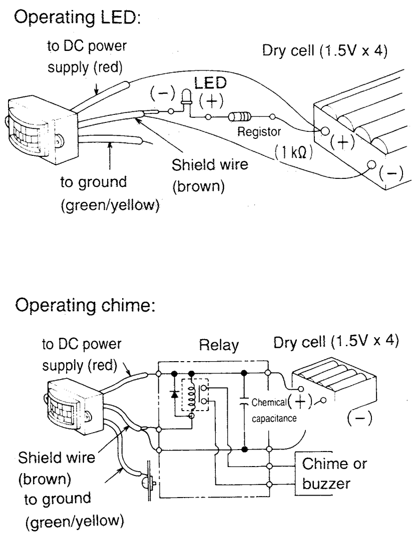


Fig.10 Circuit configuration examples for operating LED and chime

Fig.11 Use of the Model IM-02 in a lighting-control system
(Example here shows the unit mounted in the ceiling)

(1) Amplifier circuit

A high amplification factor is required as the change in light detected by the detector, that is caused by human movement, is small at several μW. The amplification factor of the IM-02 is set to within the range 8,000 to 20,000 times. Though the speed of human movement is within the range about 0.1 to 10m/s, this speed varies according to the purpose of movement. When converted to frequency, this range of human movement (0.1 to 10m/s) translates to a frequency range of about 0.3 to 5Hz. The response characteristics of the sensor are calculated by overlapping the response frequency characteristics of the detector and the amplification bandwidth. As the frequency response of the detector used in the IM-02 is 0.05 to 0.8Hz, the bandwidth required for the amplification circuit is about 0.7 to 8Hz.

(2) Timer circuit

When using the IM-02 for automatic lighting, output must be held for a fixed length of time. For this reason, a timer circuit that allows the output hold time to be adjusted up to 200 seconds is built into the IM-02.

(3) Warm-up circuit

As the resistance of the light sensing element is extremely high at 1011 to 1012W), about 10 to 20 seconds are required for the detector components to stabilize after the power supply is turned on. The IM-02 is provided with a circuit for suppressing output for about 30 seconds after turning the power supply in order to suppress unwanted output.

(4) Noise occurring to the power supply

Detector output is a very small signal. For this reason, detector output is easily influenced by noise in the power supply, which may cause unnecessary output or malfunction. A constant voltage IC built into the IM-02 eliminates the influence of power supply noise.

4. Application Example of IM-02

Fig.10 shows an example of a circuit in which the IM-02 is used for lighting an LED or sounding a chime. Adding on an extra small component such as a resistor or relay in this way allows the IM-02 to be used as a human-movement sensor.

Automatic lighting is one of the most familiar application examples of the IM-02. **Fig.11** shows the automatic lighting system installed at Horiba's research facilities (nicknamed the "Fun House") built at Kuchiki-mura, Shiga Prefecture in Japan. Adding a power control circuit provides a function for turning on the decorative lighting facilities (eight Halogen lamps totaling 480W) in the center of the hall or the lighting in washrooms when a person enters. A large scale version of this same system is also being used for the automatic lighting of the underground stack rooms in the new Library of Congress building. In this system, sensors are installed in each of the passageways, and only manned bookshelf areas are automatically lit for a fixed length of time when a library attendant goes to take out books requested for reading. The IM-02 comes in handy when installed at relatively infrequently accessed locations like this, as people are free from the trouble of frequently turning switches on and off.

The IM-02 is also being incorporated as a sensor in air conditioners and air cleaners for enabling finer control matched to the number of people and amount of activity and for providing comfortable spaces.

5. New Uses of Infra-red Detectors

As the IM-02 is used in more and more applications, the demands made on the detector become more diversified. These often directly lead to more extensive demands being placed on the detector such as improved reliability or additional functions. Below are a few of the latest examples of new uses of the IM-02.

(1) Reduced effect of visible light

Up till now, the IM-02 was limited to indoor use. However, recently, there has been a demand for semi-outdoor use in visitor announcing systems or garage automatic lighting, for example. When solar light or strong light such as that from the headlights of an automobile directly enters the detector, re-radiation caused by partial absorption at the detector window or at adhesive molded sections sometimes results in unwanted output. Horiba has increased the reflectance by coating those parts with a metal layer of gold or chrome, resulting in the reduced effect of visible light. **Fig.12** shows an example of this.

(2) Dead angle-free detector

With dual-element type conventional detectors, a non-sensitive direction, namely a "dead angle," existed according to the direction in which a person crossed the detection area. **Fig.13 (A)** shows an example of this. When using the IM-02 attached on the ceiling as a spot area sensor, the detector is required to have sensitivity whichever direction the field of vision is crossed from. For this reason, Horiba developed a detector (IP-260) having elements shaped as shown in **Fig.13 (B)**. From the figure, you can tell that sensitivity can be obtained even at the angles (90° and 270°) where sensitivity could not conventionally be obtained. A detector having the elements shaped as shown in **Fig.13 (C)** is effective in further improving the directional dependency of sensitivity. This detector is particularly useful as uniform sensitivity can be intrinsically obtained whichever direction it is crossed from.

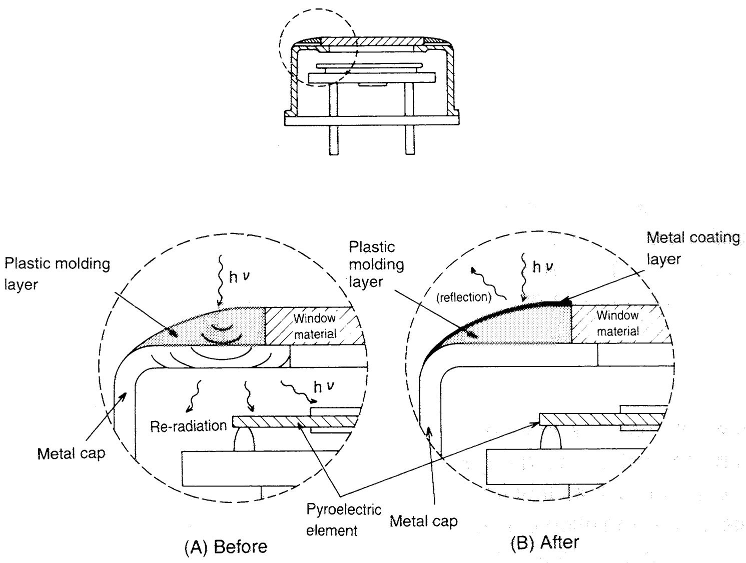


Fig.12 Reducing the Effects of Strong Visual Light

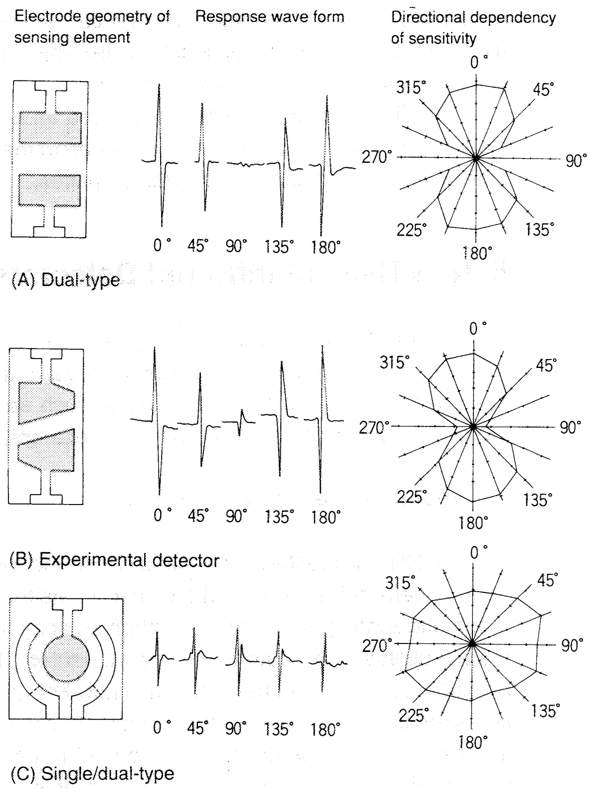


Fig.13 Directional Dependency of Sensitivity and Element Pattern

6. Future Themes

The research and development into pyroelectric-type infrared detectors is being pursued along two courses. The first course is to improve the basic characteristics of the detector in order to further extend its field of application. Reducing the thickness of element films will be a useful means of increasing sensitivity, reducing noise, and speeding up response. The second course is to make detectors easier to use through lower pricing or combination with other components. Horiba is devoting most of its efforts in this area.

On the other hand, applied products using pyroelectric-type infrared detectors are being developed in order to achieve a more comfortable environment and easier-to-use machines for human beings. Research into not only detectors but also compatibility with peripheral technologies such as in optical systems and amplifiers will become more and more important in order to more effectively use these devices and systems.

7. Conclusion

This concludes the introduction of the pyroelectric-type infrared detector and the Fresnel-IRDET IM-02 infrared module using this detector.

Pyroelectric-type infrared detectors are highly sensitive, and can be used at room temperature. They are also suited to mass-production, and can be sold at a low price. For these reasons, we feel that demand for these detectors will increase more and more in the future. We also hope that infrared modules such as the Fresnel-IRDET will be fully used in a variety of fields in the future, and that they will help in further popularizing and extending the use of infrared sensor systems.

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