

Selected Article

Radiation Thermometer IT-460 with the Fastest Thermopile

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One of the tools to measure the surface temperature of an object without contact is the radiation thermometer that measures the dose of infrared rays emitted from the surface of the object. HORIBA's radiation thermometer, available in various types to meet a wide range of applications, were demanded to improve their response time in applications to measurement of moving objects or observation of rapid temperature changes. The response time of the radiation thermometer is dependent on the response time of the infrared sensor installed inside the thermometer. We developed, as an infrared sensor, the thermopile with a unique heat sensing element using the MEMS (Micro-Electro-Mechanical Systems) technology, which mainly uses a silicon semiconductor processing technique to produce a microstructure. Further, we optimized the sensor structure, optical system and signal processing system and successfully realized the fastest response time as a radiation thermometer that can measure temperatures below the room temperature.

Introduction

Every object having a temperature higher than the absolute zero point emits infrared rays that match the temperature it has. Measuring the infrared rays can tell the surface temperature of the object. Radiation thermometers are used in the food industry that hates contact measurement from the aspect of good hygiene or in temperature measurement of the moving parts of machines that cannot be measured by contact thermometers^[1].



Figure 1 High-speed response radiation thermometer IT-460

But the general response time of conventional radiation thermometers is about a few hundreds ms. This is far behind the level of a few tens ms required for production lines of, for example, beverage manufacturers, where samples move at a vary fast speed. The response time of

the radiation thermometer depends on the response time of the thermopile, which is an infrared sensor installed inside. We started from developing an infrared sensor and developed a thermopile that has the fastest response time. This article describes the sensor technology and the performance and features of the high-speed response radiation thermometer IT-460 with that sensor (Figure 1).

Product Outline

The greatest feature of IT-460 is its response time, while other features include the warning output function, peak hold and bottom hold functions by gate input, and moving average function. Thus the product is designed for a wide range of applications. Figure 2 shows the basic configuration of IT-460.

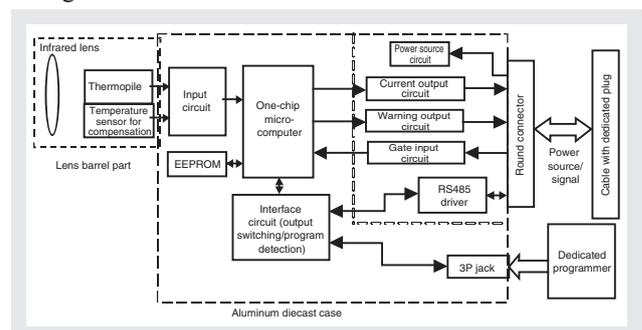


Figure 2 Basic configuration of IT-460

IT-460 has serial communication ports for interfacing with external devices. It can also change settings of output scale, moving average time, and warning level, set the level of emissivity^{*1}, and read outputs. Use of the dedicated program further facilitates those operations.

*1: Ratio of energy emitted from the surface of an object having a certain temperature to energy emitted from a black body (an imaginative matter that totally absorbs emitted energy) having the same temperature. It is 1 for a black body and 0 for a totally reflecting body.

High-speed Response Thermopile

Principle of Thermopile

A thermal infrared sensor, called thermopile, is generally used for a radiation thermometer. The thermopile is composed of thermocouples series-connected in a group of a few to dozens with their hot junctions facing inward, as shown in Figure 3. Since the thermal capacity of the thin-film elements where hot junctions are located is small and the thermal conductance of silicon substrates (heat sink) where cold junctions are located is large. From this, a temperature difference occurs between the hot and cold junctions as incident infrared rays enter. The thermopile is a sensor that detects the temperature difference caused by the entry of infrared ray as thermoelectromotive force^{*2}.

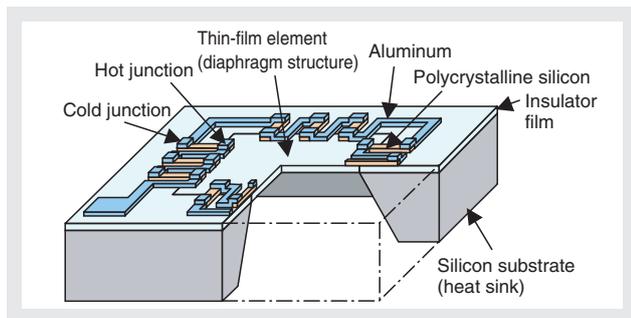


Figure 3 Thermopile structure

The type of thermopile, as shown in Figure 3, among many thermopiles, has thermocouples of aluminum and polycrystalline silicon, which are generally used as wiring materials in silicon semiconductor processes, and therefore has various features including excellent mass-productivity, high performance and multi-functionality. Utilizing those advantages, we developed a 64-pixel thermopile array that can carry out address selection and part of signal processing with the IC installed in the chip and put it into practical use for the first time in the world in the form of a commercial product two-dimensional radiation thermometer i-square^[2].

The spot-type radiation thermometer with thermopiles having a conventional organic thick-film heat detecting element was characterized by its slow response time. So we focused on the response time of the radiation thermometer as the next target of thermopile development and launched the effort to enhance the response time.

*2: Potential difference occurring from the temperature difference between contacts of different metals

Relationship between Sensitivity and Response Time

The sensitivity and response time of the thermal infrared sensor are determined by the thermal capacity C of the heat sensing element and the heat conductance G with the substrate, which is the heat sink. Thermal time constant τ is expressed as Equation (1). Increasing the response speed requires reduction in heat capacity and increase in heat conductance, but there is a trade-off relationship between the response time and the sensitivity: increasing heat conductance results in reduction in sensitivity.

$$\tau = C/G \quad \dots \dots \dots (1)$$

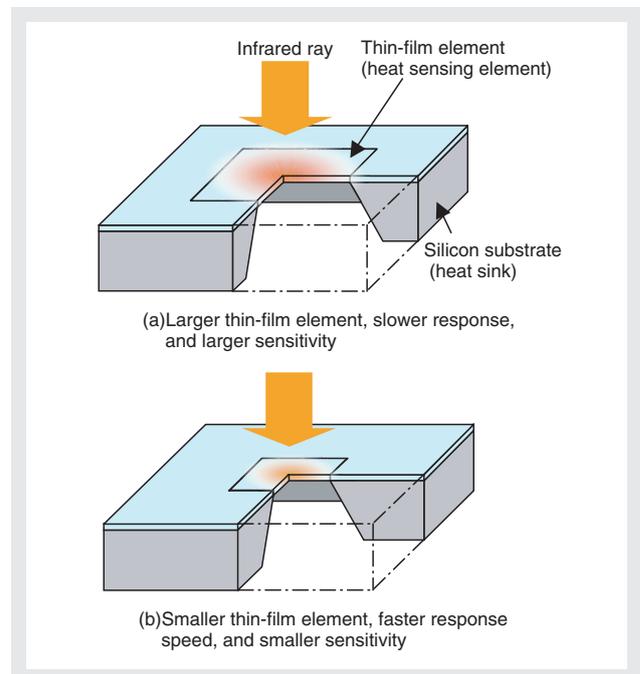


Figure 4 Relationship between the thermopile sensitivity and the response time

To explain this relationship using a thermopile of the diaphragm structure, decreasing the size of the thin-film element of the heat sensing element results in an increase in heat conductance with the substrate and an increase in the response speed, but that reduces the attained

temperature of the heat sensing element, eventually decreasing the level of sensitivity (Figure 4).

Characteristics of High-speed Response Thermopile

The time available for measuring each sample in a production line where samples move at a high speed as in beverage manufacturers is only 30 to 40 ms. The response time below 10 ms (95% response) is required for the radiation thermometer. To achieve this goal, it is necessary to improve the response time of each thermopile to below 2 ms (63% response). But as earlier mentioned, the relationship of trade-off exists between the response time and the sensitivity. We could improve the response time to 2 ms, but then the sensitivity would fail to reach the practical level.

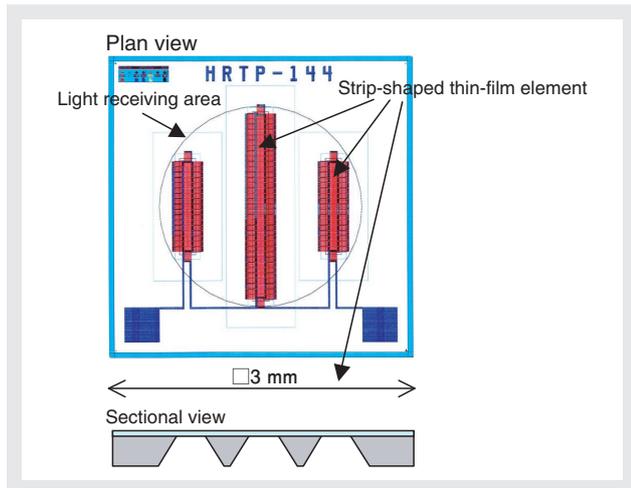


Figure 5 Conceptual diagram of high-speed response thermopile

So we devised a structure, as in Figure 5, to achieve a balance between the sensitivity and the response time. What characterized this structure is its elongated strip-shaped thin-film element, which is the heat sensing element. The heat conductance between the thin-film element and the silicon substrate, which is the heat sink, is determined by the size in the transverse direction. Thus, it is possible to improve the response speed. On the other hand, laying out thermocouples in number additionally installed in the longitudinal direction can compensate for the loss of sensitivity that would occur by the decrease in the attained temperature of the heat sensing element^[3]. The initial design for the size of the thin-film element was made by conducting thermal analytical simulation, and the size was optimized by checking it with a prototype sensor. The sensor of our development is composed of

three rows of strip-shaped thin-film elements in order to give the light receiving element the pseudo-round shape, which is highly versatile. The total number of thermocouples was 144. To prevent sensitivity deterioration by entry of infrared rays to the cold junctions, the reflective membrane was formed on the surfaces other than the heat sensing element. This structural arrangement allowed us to complete the high-speed response thermopile that satisfies both the response time of 2 ms (63% response) and the practical level of sensitivity.

Characteristics of Optical System

Structurally, the high-speed response thermopile cannot avoid having a relatively larger area for light receiving. We conducted optical simulation and experiment for verification in order to ensure efficient light collection that prevents fluctuations of readings and satisfies the viewing field characteristics. And we established an optical system that combines a lens and a mirror as shown in Figure 6^[4]. Since the light receiving mirror^[5] needs to be located as close to the sensor receiving surface as possible, the special design that provides a short distance between the window and the thermopile chip even in the sensor package was made^[6]. We thus realized an optical system that optimizes the high-speed response thermopiles and finally achieved the capability of high-precision measurement, or a measurement precision of $\pm 2^\circ\text{C}$ (0 to 200°C) and a measurement repeatability of less than 1°C .

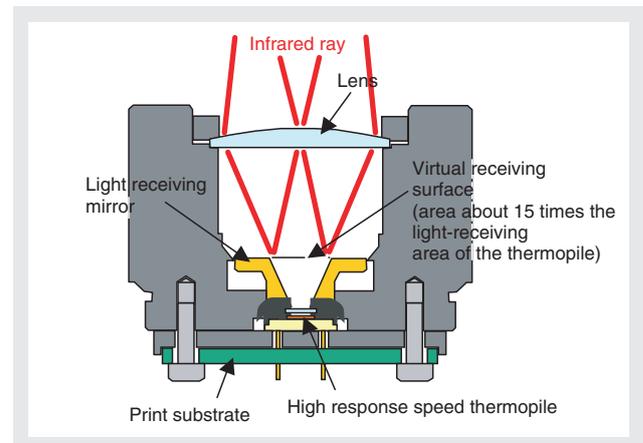


Figure 6 Optical system of IT-460

Specifications and Performance of the Product

The response characteristics of high-speed response radiation thermometer IT-460, which combines high-speed response thermopiles with the optical system and signal processing system optimized to match those thermopiles, are shown in Figure 7, and the measurement system in Figure 8. Figure 7 shows a response of about 8 ms relative to the product target specification of less than 10 ms (95% response), which means the goal was successfully attained. Note that output signals show step-wise changes because the sampling rate of IT-460 is set to 1 ms.

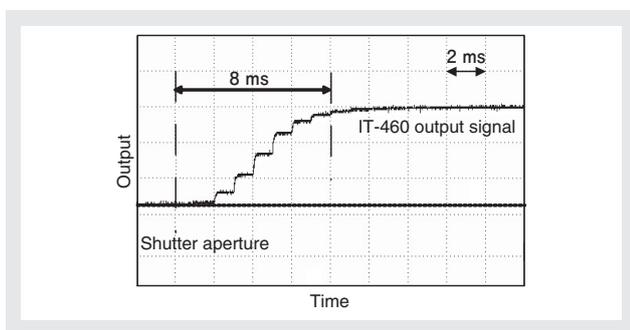


Figure 7 Response characteristics of IT-460

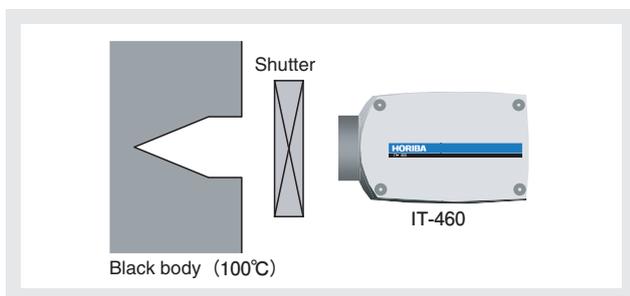


Figure 8 Measurement system of response characteristics

Table 1 Specifications of IT-460

Response time	Not more than 10 ms (95% response)
Measurement temperature range	-30 to 300 °C
Emissivity setting	0.12 to 1.20
Measurable wavelength	8 to 16 μm
Measurement precision	Within ± 2 °C (0 to 200 °C)
Repeatability	Within 1 °C
Measurement viewing field	φ15/50 mm
Signal processing function	A few holds and warning output
Analog output	4 to 20 mA current output (12 bit)
Serial communication	Setting and readout by RS485
Warning output	Open drain output
Power source	DC12 to 24 V
Power consumption	Not more than 200 mA
Operating temperature/humidity range	0 to 55 °C (35 to 85%RH)
External dimension	135×75×54 mm
Weight	About 700 g

Lastly, the specifications of IT-460 are shown in Table 1. The product has a sturdy structure made of aluminum diecast to meet the future plan of further development of stationary radiation thermometers. In addition, the drip-proof structure is also employed to make it applicable to quite a wide range of installation environments.

Conclusion

This article outlines the new-conceptual high-speed response thermopile and radiation thermometer IT-460 with the thermopiles. IT-460 is expected to play excellent roles in temperature management of rapidly moving samples, such as in production lines of beverage manufacturers, and in various fields where monitoring of rapid temperature changes is necessary.

Reference

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