Technical note

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Thermopile detectors

Contents

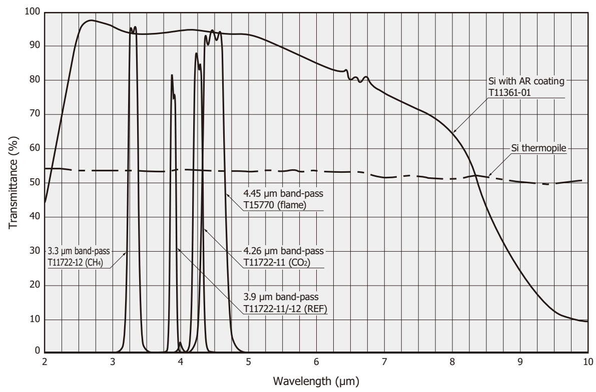
1. Overview

Infrared detectors are broadly classified into two types: thermal and quantum. Thermopile detectors are thermal detectors that utilize the Seebeck effect in which a thermal electromotive force generates in proportion to the incident infrared light energy. Quantum type detectors have high sensitivity and high-speed response, thus are used in spectrometers, analytical instruments, etc. that require high accuracy. Thermal detectors, on the other hand, are not wavelength dependent on sensitivity, do not require cooling, have a long life, and are low cost [Table 1-1]. The thermopiles of a thermal type detector are used for gas analysis, flame detection, and radiation thermometers [Table 1-2] by selecting the sensitivity wavelength with the window material [Figure 1-1].

[Table 1-1] Comparison of thermal detectors and quantum type detectors

Parameter	Thermal detectors	Quantum type detectors
Sensitivity	☆☆	☆☆☆
Response	☆☆	☆☆☆
Wavelength dependence of sensitivity	No	Yes
Cooling	Not required	Required depending on the application
Cost advantage	☆☆☆	☆

[Figure 1-1] Spectral transmittance characteristics of window materials



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[Table 1-2] Hamamatsu thermopile detectors

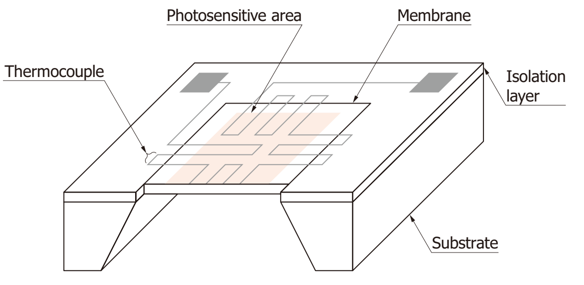
Type no.	Number of elements	Package	Window material	Spectral response	Thermistor	Applications
T11361-01	1	TO-18	Si with AR coating	3 to 5 µm	○	Gas analysis
T15770			Band-pass filter	4.45 µm	-	Flame detection
T11722-11	2	TO-5	Band-pass filter	3.9 µm, 4.26 µm	○	Gas analysis: CO_2
T11722-12				3.9 µm, 3.3 µm	○	Gas analysis: CH_4

2. Structure

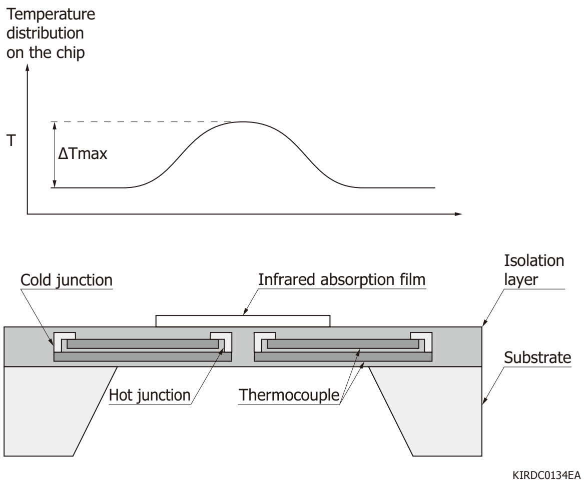
In order to obtain a large output voltage, Hamamatsu thermopile detectors have many thermocouples that are serially connected on a silicon substrate. The hot junction side (photosensitive area) is designed to be a thermally isolated structure, so heat generation caused by light absorption is kept to the membrane (thin film), increasing the temperature difference between the hot junction and cold junction. An infrared absorption film is attached to the membrane to increase its light absorption efficiency. To make the thermally isolated structure, MEMS technology is used to process the membrane to make it float in a hollow space. Our thermopile detectors use materials that have a large Seebeck coefficient (thermal electromotive force) and are easily formed by the semiconductor process.

When infrared light enters a thermopile detector having the above mentioned structure, the hot junction on the membrane heats up and produces a temperature difference (ΔT) between the hot and cold junctions accompanied by generation of a thermal electromotive force (ΔV).

[Figure 2-1] Cross-sectional structure



[Figure 2-2] Membrane temperature distribution (uniform incident light) and cross section



When uniform light is incident on the photosensitive area, the temperature rises highest in the center of the membrane. A structure that arranges the hot junctions as close as possible to the center of the membrane and the cold junctions around the membrane is effective for increasing the output voltage. The arrangement of hot and cold junctions is different for each thermocouple, so the temperature difference between hot junctions and cold junctions is different, and the output voltage is also different. When n number of thermocouples are connected in series, the output voltage of the thermopile detector is expressed as the sum of outputs from these thermocouples [equation (2-1)].

$$\Delta V = \Delta V_1 + \Delta V_2 + \cdots \Delta V_n$$
$$= n \times \Delta V_{ave} \quad \cdots\cdots\cdots\cdots \quad (2\text{-}1)$$

ΔV : thermopile detector output voltage
ΔVn : thermocouple output voltage
ΔVave: average output voltage of each thermocouple

3. Characteristics

3 - 1 Sensitivity

The sensitivity of the thermopile detector is defined by the output voltage relative to uniform incident light [equation (3-1)].

$$S = \Delta V/(D \times A) \quad \cdots\cdots\cdots \ (3\text{-}1)$$

S : sensitivity [V/W]
ΔV: output voltage [V]
D : light density of incident light [W/cm²]
A : photosensitive area [cm²]

The sensitivity, when a light spot with a small beam diameter relative to the photosensitive area is incident, is different from the sensitivity defined by uniform incident light. The sensitivity also changes depending on the incident position of the light spot.

3 - 2 Noise

Thermal noise called Johnson noise in the element resistance is predominant in thermopile detector noise. Noise (V_N) is expressed by equation (3-2).

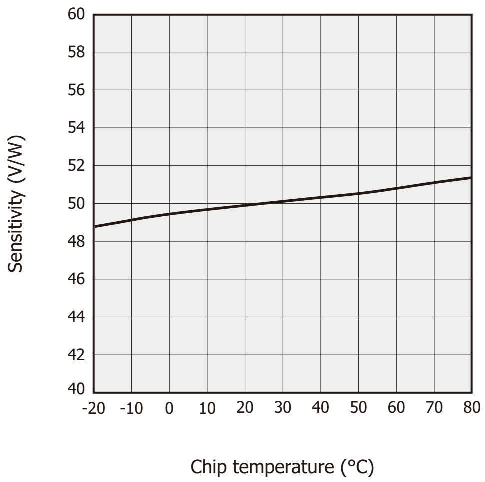
$$V_N = \sqrt{4k\ T\ Rd\ \Delta f} \quad [\text{V rms}] \ \cdots\cdots\cdots \ (3\text{-}2)$$

k : Boltzmann's constant
T : absolute temperature
Rd: element resistance
Δf : bandwidth

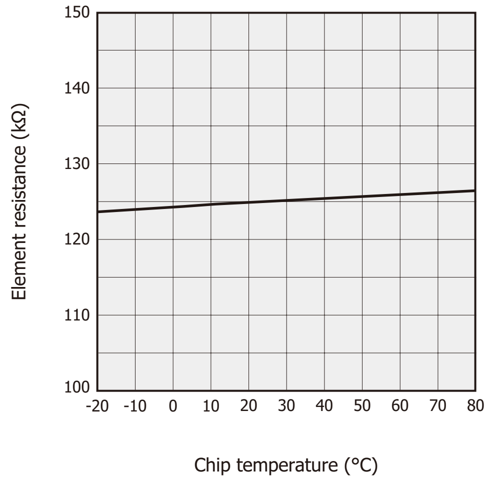
3 - 3 Temperature characteristics

Thermopile sensitivity and element resistance have temperature characteristics.

[Figure 3-1] Temperature characteristics of sensitivity (single element type T11361-01, typical example)



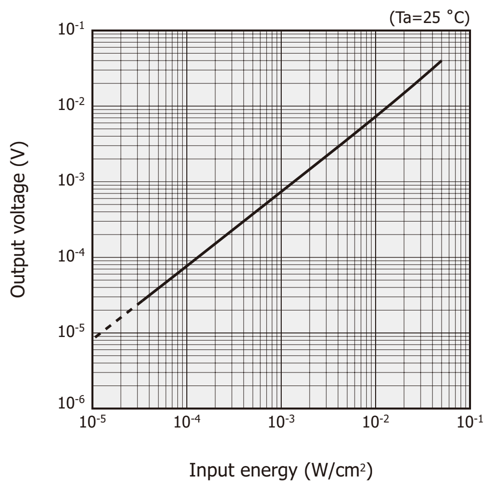
[Figure 3-2] Temperature characteristics of element resistance (T11361-01, typical example)



3 - 4 Linearity

Figure 3-3 shows an example of the relation between the input energy and output voltage. Thermopile detector output voltage is proportional to the input energy.

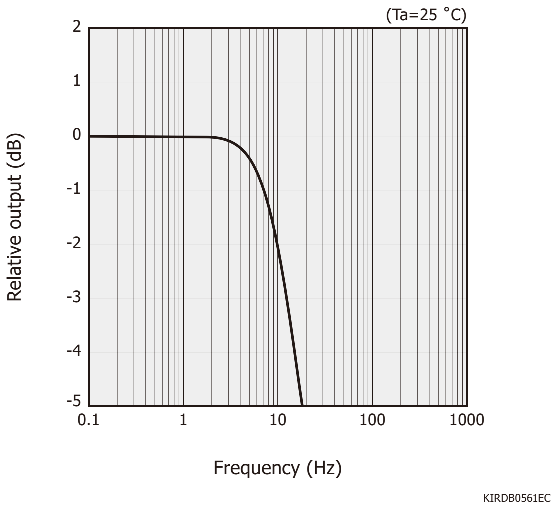
[Figure 3-3] Output voltage vs. input energy (T11361-01, typical example)



3 - 5 Frequency characteristics

Figure 3-4 shows the frequency characteristics of thermopile detectors each having a different photosensitive area. Frequency response tends to decrease as the photosensitive area becomes larger.

[Figure 3-4] Frequency characteristics (T11361-01, typical example)



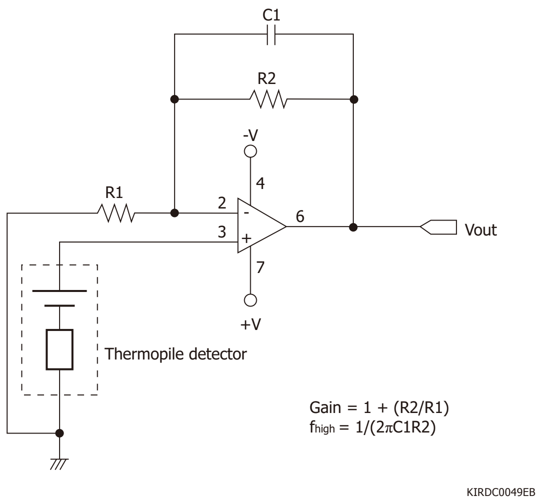
4. How to use

4 - 1 Basic circuit

Here is shown the basic circuit for amplifying the thermopile detector signal.

Dual-polarity power supply type

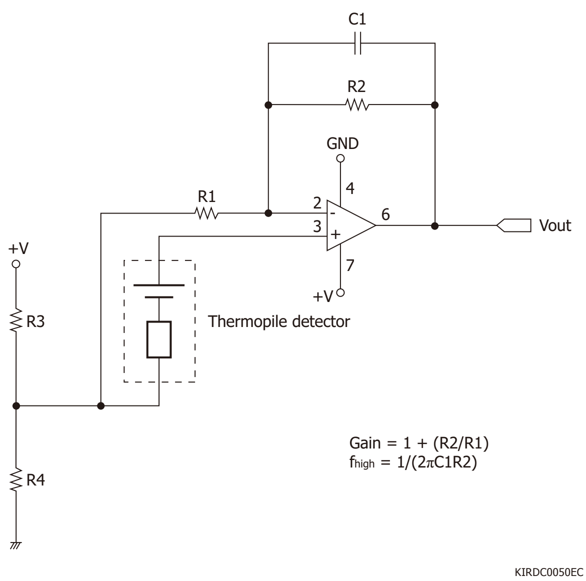
[Figure 4-1] Amplifier circuit (dual-polarity power supply type)



Single power supply type

When using an op amp that operates from a single power supply, an error occurs near ground potential which is caused by the op amp's offset voltage and nonlinearity. To cope with this, the thermopile detector is operated with one terminal biased. In the circuit shown in Figure 4-2, the op amp supply voltage is biased with dividing resistors R3 and R4.

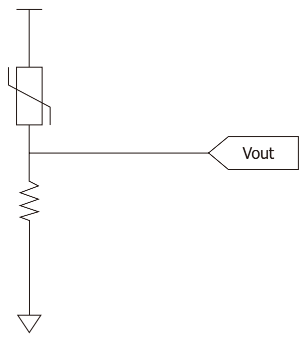
[Figure 4-2] Amplifier circuit (single power supply type)



4 - 2 Circuit using thermistor

Sensitivity of the thermopile detector is dependent on temperature. In order to measure with high accuracy using a non-contact thermometer, gas sensor, etc., it is necessary to do temperature compensation of the thermopile sensitivity using the thermistor output. Connect the thermistor to the linearization circuit [Figure 4-3]. The typical method is to input the thermopile detector and thermistor signals to the microcontroller to correct the thermopile sensitivity.

[Figure 4-3] Thermistor linearization circuit



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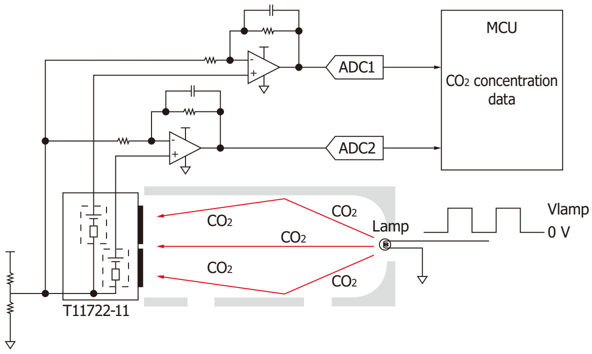
5. Applications

5 - 1 CO_2 sensors

Thermopile detectors are used for non-dispersive infrared (NDIR) detection type CO_2 sensors. Figure 5-1 shows a structure example of a CO_2 sensor.

[Figure 5-1] Structure example of CO_2 sensor



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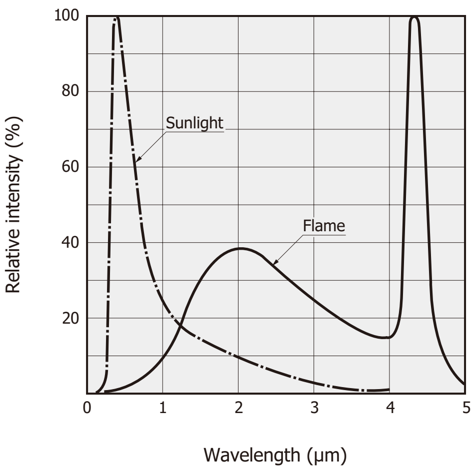
CO_2 has a very strong absorption band at wavelengths around 4.26 µm. Use a light source in the mid infrared region that contains this spectral band (e.g., tungsten lamp). In the structure example shown in Figure 5-1, the light from the light source is attenuated according to the distance traveled by the light and the CO_2 concentration, then CO_2 concentration is calculated from that attenuated output. The distance between the thermopile detector and the light source must be set appropriately according to the CO_2 concentration. When measuring low concentrations of CO_2, it is necessary to extend the distance between the thermopile detector and the light source and use a high luminance light source.
The thermopile detector T11722-11 is a dual type, developed for high accuracy measurement of carbon dioxide (CO_2) concentration. It is structured from two-element high sensitivity thermopile chips and two types of band-pass filters, in order to simultaneously detect two wavelengths [4.26 µm: for CO_2, 3.9 µm: for reference light (absorption is small in the various gases in the atmosphere)]. The CO_2 concentration can be obtained with high accuracy by calculating the ratio of outputs from the two elements, which is done to eliminate the effect of instability of light emission from the light source.

5 - 2 Flame detection

Radiant wavelengths from flames are widely distributed over the ultraviolet to infrared region, and there is a peak at a wavelength of 4.45 μm (CO_2 resonant radiation). A thermopile detector with a 4.45 μm band-pass filter is used for flame detection.

[Figure 5-2] Radiant spectrum from flame



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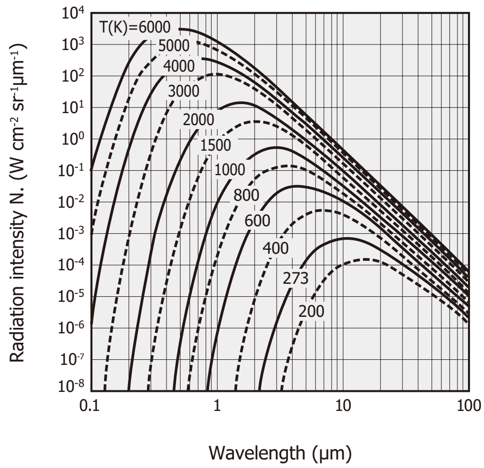
5 - 3 Radiation thermometers

The radiation thermometer measures the amount of infrared light energy emitted by an object, and uses this to calculate its temperature. The radiant energy of an object near room temperature has peaks from mid infrared to far infrared. The thermopile detector has sensitivity over a wide spectral range, so it is suitable for radiation thermometers near room temperature.

[Figure 5-3] Black body radiation law (Planck's law)



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Cat. No. KIRD9005E04 May 2024 DN