Thermopiles

Shigeru Hidaka, Nikkohm Co., Ltd. 2000/09/20, 2004/09,12

1. Thin film thermopile.

A thin film thermopile is the detector of the radiation energy which the prototype was completed in 1966, and improvement was done in sensitivity and response time by Nikkohm thin film technology by the end of today. The radiation energies are as such as ultraviolet, visible and infrared light, the wavelength zone of the energy of a detection element is very wide, and detection sensitivity features flat characteristics to wavelength as compared with the pyroelectric detector of the quantum mechanics. Furthermore, the output voltage of a detector is dc, and chopping mechanism at input is not necessary, and is very easy to use as compared with the pyroelectric element. Furthermore, taking advantage of the feature of a thin film, the response time of a thermopile, LP-111S is very high-speed. Major application includes output power control of CO2 laser, and total actual production amounts to hundreds of thousands of pieces. Also, applications include a non-contacting radiation thermometer, the detection element of laser power of an infrared domain, a RMS-DC conversion module, etc., and are used also as a national standard about radiation energy.

2. Structure and a principle of operation.

A thin film thermopile operates based on the principle of thermocouple, theoretically as heat electromotive force from the contacts of two kinds of metal, and thermocouple will be used for precision temperature measurement.

Metal	−100C	+100C
Copper	−0.37mV	+0.76mV
Cu−Ni 50/50 alloy	+2.98mV	−3.51mV
Bismuth	+7.54mV	−7.34mV
Antimony	−	+4.89mV

A table shows the electromotive force over Platinum. + shows current flow direction from 0 degree C contact to the way of Platium, and - shows the opposite direction

Table 1. Thermoelectricity of metals

The combination of a material of large heat electromotive force, therefore thin film thermopile uses the combination of a bismuth and an antimony. The typical structure is as being shown in Fig. 1. The model figure of the built-in pattern is as shown in Fig. 2.

Radiation energy passes through the hole of metal rings is absorbed into metal black. Absorbed energy is changed into heat, and heats the hot junction of a thermopile pattern. On the other hand, since the cold junction is in contact with the metal ring with large heat capacity, it is maintained at fixed ambient temperature. By the difference of temperature of hot junction to cold junction, electromotive force is generated in thermocouple of bismuth and antimony. The dc voltage which appeared in the terminal appears on output terminal as proportional voltage to the number of couples connected in series.

If ambient temperature changes, although the temperature of a metal ring will change gently and a cold junction temperature will change, the difference of temperature for the temperature rise by radiation energy carrying out incidence to a hot junction does not change with ambient temperature, and output voltage does not change with ambient temperature, theoretically.

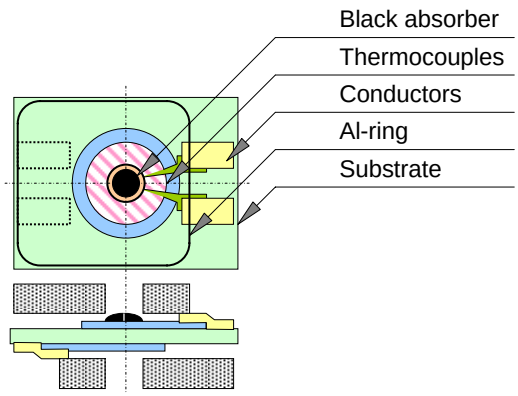


Fig. 1. The typical structure of a thermopile

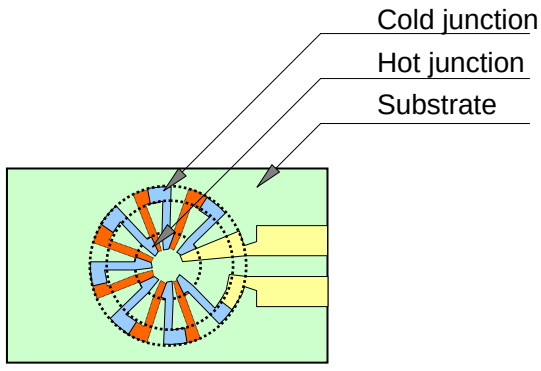
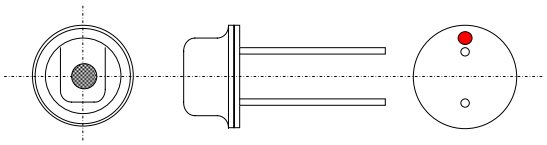


Fig. 2. Thermocouple pattern.

If ring temperature changes quickly, since the difference of temperature of a hot junction and a cold junction may lose temperature balance transitionally and terminal voltage may sway greatly. Holding the case temperature, i.e., holding temperature of cold junction of a thin film thermopile, constant temperature is necessary if possible, or to cover in the case where heat capacity is big.

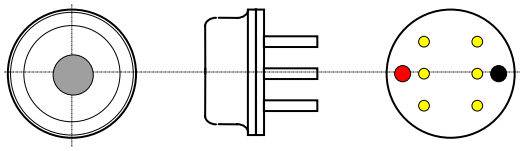
3. Products and specifications of thermopiles.

LP-111S features a high-speed response and LP-231S permits large input power of aperture diameter, and LP-31B measures precision incident power. LP-31B has a calibration resistor in it. Absorbed incidence power is compared with temperature rise by heating resistor, then absolute power is given absolutely. Each appearances are shown in Fig. 3, Fig. 4, and Fig. 5.



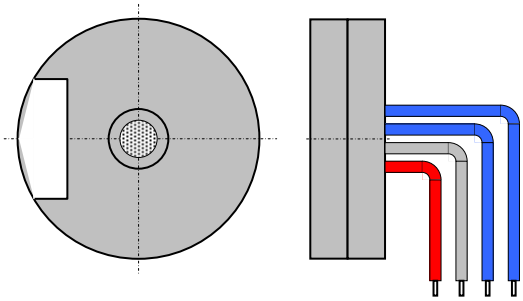
The red mark on a terminal shows a side of + voltage in hot incidence.

Fig. 3. Appearance of LP-111S



The red mark on a terminal shows a side of + voltage in hot incidence.

Fig. 4. Appearance of LP-231S



Red lead is +, black lead is − terminal and the blue leads are for calibration resistance.

Fig. 5. Appearance of LP−31B.

Table 2 shows the specifications. The wavelength range has flat detection sensitivity in the zone of this wavelength. The maximum input power permits measuring the radiation energy to this input power, continuously. Absolute maximum input power permits the excessive input within for only 3 seconds, but thermopile will be damaged at the value with a possibility of deteriorating, if incidence is carried out continuously. Sensitivity is the output voltage, mV of the detection terminal to the input radiation power per mW.

A linearity error shows the linearity of output voltage when changing incidence power from zero to the maximum input. 63% time constant is a constant at the time of the rise time of the output voltage when adding step-like power. A diameter of the metal black is effective diameter of absorption area which absorbs radiation energy. The number of contacts is number of internal thin film thermocouples. Internal resistance is the internal resistance of an element seen from the output terminal. The resistance of calibration resistor is for having mounted only in LP-31B, supplying electric power from the outside of an element from blue colored terminals, comparing electric power with incidence energy, and measuring for the power of incidence energy, absolutely. Since a substrate material is very delicate in order to improve the characteristic of the response time and to increase detection sensitivity of the thin film thermopile, the storage temperature range and the operation temperature range have been specified in narrow.

	LP-111S	LP-231S	LP-31B
Wave Length	0.4-20.0μm		
Max Input	10 mW		
Abs Max Input	20mW	50mW	200mW
Sensitivity	10mV/mW	4.5mV/mW	0.45mV/mW
Linearity Error	+/-2%	+/-2%	+/-2%
63% Response	45msec.	250msec.	4000msec.
Dia. of apertures	1.0 mm	4.5 mm	5.0 mm
Thermocouples	22	30	36
Internal resistance	2k+/-1K	4k+/-2K	6.5k+/-3.5k
Cal. Resistance	none	none	250-550ohm
Storage Temp.	0-40 degree C		
Operating Temp.	0-40 degree C		

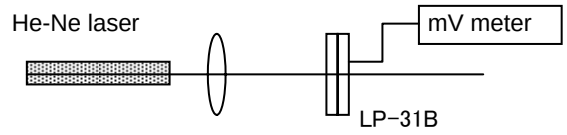
Table 2. Specifications

4. The characteristic of thin film thermopile.

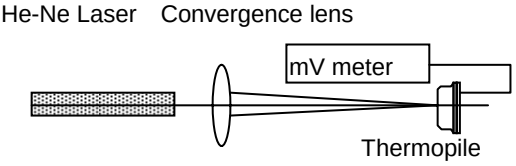
4-1. Measurement of sensitivity.

Although there are various sensitivity measurement methods of a thin film thermopile, a system as shown in Fig. 6 is common, and is used also for final inspection of Nikkohm. As shown in Fig. 6, a LP-31B calibrates the intensity of He-Ne laser power. Where, output voltage is V, sensitivity of LP-31B is R, then obtained power P explains as P=V/R. Distance between He-Ne laser and target of the thermopile is adjusted so that laser light may

be irradiated to the target (aperture), which diameter is 1mm in case of LP-111S. The output voltage of LP-111S (DUT) is E., sensitivity of DUT is obtained by R=E/P. Usually, He-Ne laser power may be about 1.4-1.7mW.



Step 1. The output of HeNe laser is calibrated by standard power detector LP-31B.



Step 2. A standard detector is removed. The distance of a lens and a measured thermopile are adjusted so that a laser beam may be irradiated by the target diameter of a measured thermopile.

Fig. 6. Sensitivity measurement for thermopile

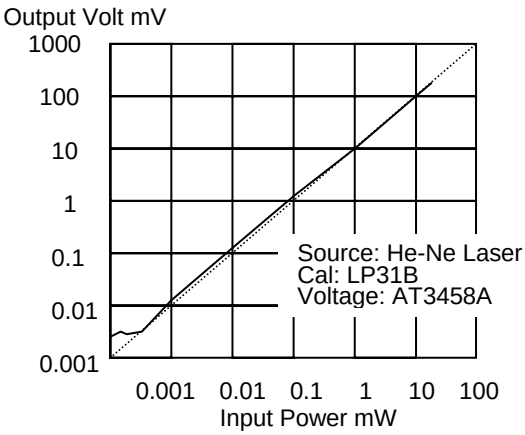


Fig. 7. Input power vs. output voltage, LP-111S

4-2. Input-and-output characteristic.

The relation of the incidence power of LP111S vs. output voltage is shown in Fig. 7 as a typical value. Incidence radiation power 0.0002mW or less cannot detect easily because of the generating noise of a thin film thermopile.

Although the relation between incidence power and thermopile output voltage is linear as shown in Fig. 7, the relation with temperature has the shape of not a straight line but a curve.

Detecting radiation energy from black furnace by the thermopile measures characteristics shown in Fig. 8. LP-111S are set to the distance of 120mm of fronts of 60mm diameter aperture standard black furnace, and changing from normal temperature to 250 degrees C of black furnace temperature obtains Fig. 8 by measuring output voltage.

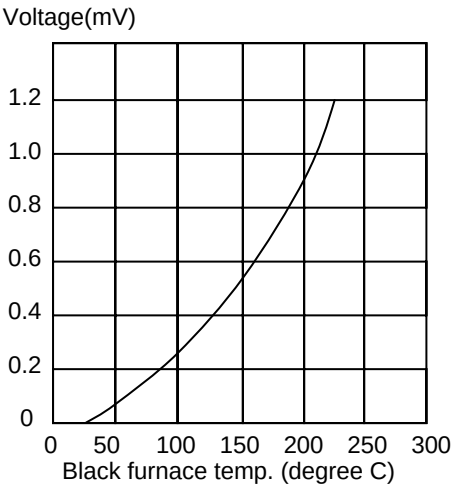


Fig. 8. Furnace temp. vs. output voltage, LP-111S

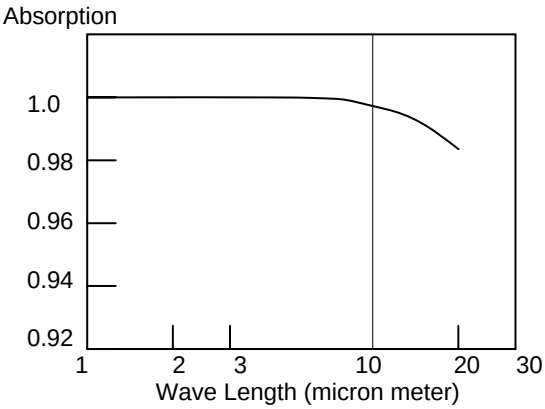


Fig. 9. Absorption of target black (JASCO).

4-3. Reflectance of a target and metal black.

It is a collection of very fine spherical particles, incidence energy repeats reflection on the spherical surface, it takes into consideration and the target which absorbs radiation energy is made so that re-discharge of energy may not be carried out. It is shown in Fig. 9, using the measurement result of the absorptivity of a target as a representation value.

4-4. The sensitivity distribution within a target area. In LP-31B or LP-231S, the metal layer is prepared in the under layer of a hot junction target, and it is improved that the thin beam of radiation energy can measure power correctly in which position of a target even if. Of course, since heat capacity increases so much, sensitivity falls. The result which measured the sensitivity distribution within the field of LP-31B with the laser beam of 0.2mm of diameters of spot is shown in Fig. 10.

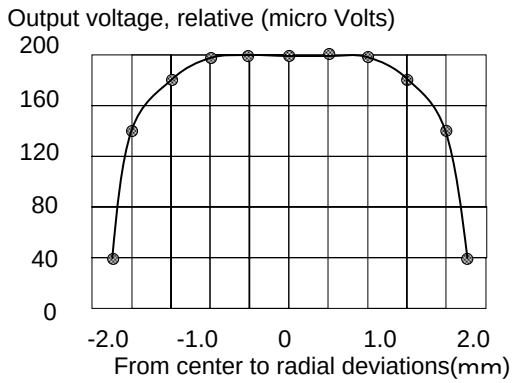


Fig10. Sensitivity distribution in target area of LP-31B

4-5. Rresponse Time and time constant.

When the beam of fixed power is irradiated to the target of a thin film thermopile, the temperature of a target begins to rise, a heat flows toward a cold junction from a hot junction simultaneously, and after a certain time passes, the temperature of a hot junction will become fixed stably. Therefore, if transitional input power is applied to a thin film thermopile by the mechanical chopper, output voltage will rise exponentially and will output DC voltage stabilized at the end. In the case of a use which performs output control of laser power, the response time of a thin film thermopile is an important performance. LP-111S are designed as accelerated response speed, at shipping inspection, all the LP-111S are carry out final inspection of response speed. Change of the output voltage when mechanical chopping input energy applied is shown in Fig. 11.

5. Optical characteristic.

5-1. Directivity of sensitivity.

Since the target of a thermopile has the shape of a circular plate, the directive characteristic becomes a round shape mostly according to a cosign rule. A survey result is shown in Fig. 12. Moreover, a lens can be prepared in front of aperture and sensitivity directivity can be made sharp. If the easy method of making sharp directivity sharp prepares a cylinder-like pipe in the front of aperture and gloss is made to the inside of the cylinder, it can give sharp directivity.

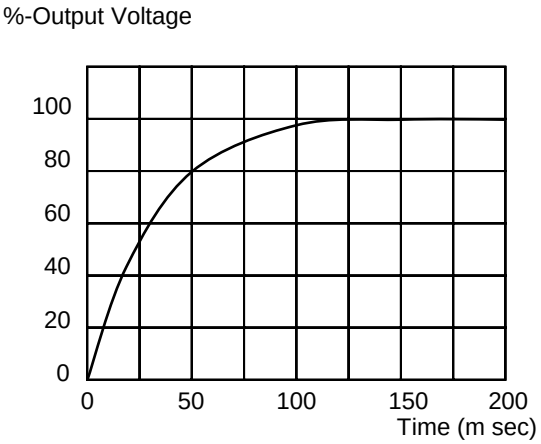


Fig. 11. Response time of LP-111S

Fig. 13 is the result of measuring the directivity characteristic of putting a sleeve with 4.0mm of inner diameters and with a length of 20mm which carried out gloss plating of the inside on the front of LP-111S. In the normal room temperature without an air flow, measuring thermopile output voltage shows these directivity characteristics placed the heat source of the shape of a pillar with a diameter of about 3mm and with a temperature of about 300 degrees C ahead thermopile, changed the distance and the direction of a heat source.

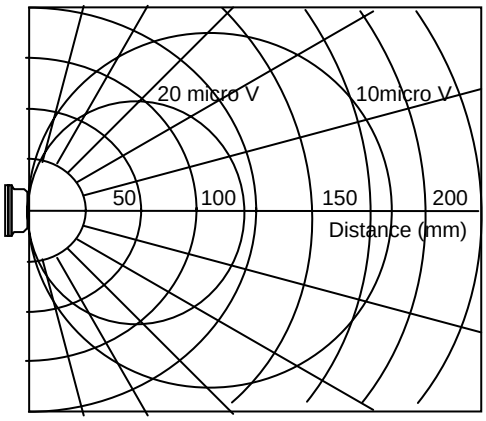


Fig. 12. Directivity of sensitivity, LP-111S without filter and lens.

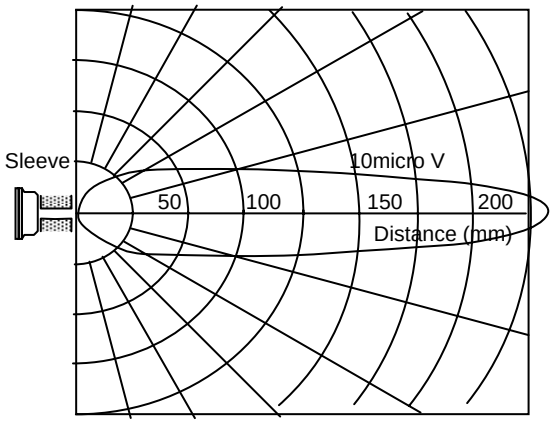


Fig. 13. Directivity of sensitivity, LP-111S with sleeve lens of 4mm dia. 20mm length.

Furthermore, in order to acquire the sharp directivity characteristic, a gloss plated reflector (parabola) shown as Fig. 14, optical lens of polyethylene resin or a CaF single crystal lens can be used. Human body temperature is detectable in normal temperature with 10m distance using the reflector of nickel gloss plating with a diameter of 80mm by LP-111S.

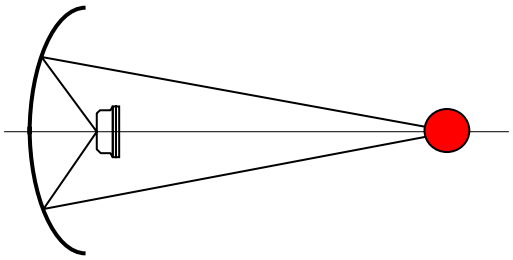


Fig. 14. Directivity improved by using reflector.

5-2. Optical filter.

In order to detect specific wavelength, a silicone single crystal, a CaF single crystal, and a polyethylene film can be used as an optical filter. If a filter is inserted, sensitivity will fall several 10%. Insertion of a silicone single crystal filter reduces output voltage to about 70% in a passage wavelength zone compared with the state of no filter. The amount of attenuation changes with the thickness of a film with a polyethylene film. The thickness of the filter of a polyethylene film and the measured value of output voltage are shown in Fig. 15.

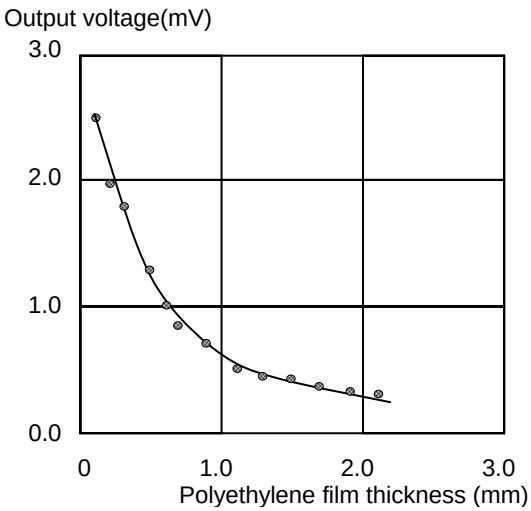


Fig. 15. Output voltage decreasing by polyethylene film thick.

6. Sensor amplifier.

A thermopile is an element of generating dc voltage, and since the output voltage is about 1mV in case it is actually used, the high sensitivity dc amplifier is needed. Usually, internal resistance of thermopile is as low as several K ohms, the input impedance of an amplifier is designed as several Mega ohms. The amplifier circuit for an experiment is shown in Fig. 16.

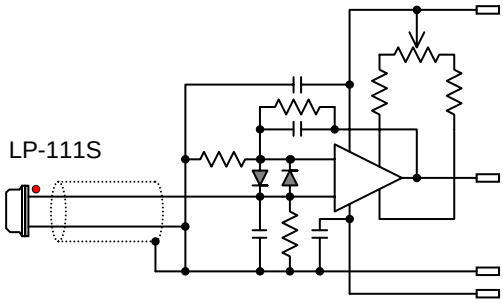


Fig. 16. Typical dc amplifier with 60dB - 80dB gain.

7. Applications.

7-1. A non-contacting thermometer.

Since a thermopile detects the difference of a cold junction temperature and a hot junction, in case it applies to a non-contacting thermometer, it needs to build-in the structure of measuring the temperature of a cold junction. Moreover, the cold junction temperature does not change rapidly by the operator, it is necessary to prepare a unit of homoiothermy.

Since the relation of temperature measured and a thermopile output voltage is not straight lines as shown in figure 8., a linearizing is necessary. Furthermore, since the radiation energy of a measured thing changes with the reflectance the surface of the object remarkably, it needs to install the structure of the rate compensation of reflectance.

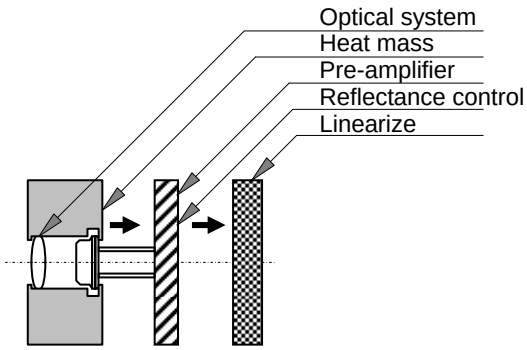


Fig. 17. Block diagram of non-contact thermometer

7-2. The power detection of CO2 laser.

The oscillation wavelength of CO2 laser is 10.7 micrometers, and is an infrared domain. Since there is no suitable detector of semiconductor detector in this wavelength area, a thermostat pile is often used. Generally the power of a laser beam is not uniform to a beam section. An integration sharer is used in order to prevent a measurement error. The integration ball is the shape of a hollow globular form. The surface of inside of the globular form is finished as rough side and plating with gold. And reflectance may be set to about 1.0, if incidence of the laser beam is put from one place of an integration ball, a beam repeats random reflection inside, and even if the receiving power per unit area of the surface of a wall takes which portion, distribution will become uniform. Loss of the beam in an integration ball occurs, and in order to avoid that the temperature of an integration ball rises, an integration ball is cooled with water.

When a opening is prepared in integration balls and aperture of thermopile LP-111S is turned in an integration ball, LP-111S will be given only the aperture diameter and power equivalent to 1.0mm diameter. The power which a thermopile takes a lecture on becomes the ratio of the area S of the inside in an integration ball, and the aperture area of a thermopile, and is detected.

The appearance of NLP-400 series used for an integration ball is shown in Fig. 18. LP-111S of high-speed response type detector are mounted as a detection element, and it has come to be able to perform exchange from the front in this detection unit.

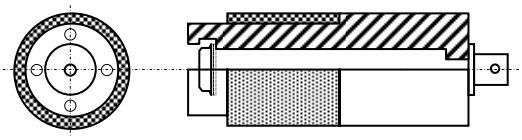


Fig. 18. NLP-400 for integration sphere.

8. Information.

I welcome a criticism and question about this technical note. Please contact to a following telephone or a following E-mail. Thank you.

Customer Service of Nikkohm Co., Ltd.
Tel: +81-176-53-2105, FAX: +81-176-53-2106
Email: info@nikkohm.co.jp

■

20090601