Product Introduction

Infrared Thermometer for Semiconductor Production Equipment IT-470F-H

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We developed the infrared thermometer "IT-470F-H" specialized for temperature measurement in the dry etching equipment. Infrared sensor is the most core technology of the infrared thermometer. The infrared sensor installed into "IT-470F-H" is developed utilizing our original MEMS technology. The infrared sensor has higher responsivity and shorter response time than our previous sensor. With the infrared sensor, the repeatability improves to 0.1°C which is one-third of our previous infrared thermometer (IT-470A). Furthermore, the stability to transient change of ambient temperature improves very well.

Introduction

It has been more than ten years since we developed an infrared thermometer for semiconductor production process for the first time in 2002. The reasons that the infrared thermometers are utilized for semiconductor production process are as follows;

1) Measuring objects are in dynamic situation (e.g. rotating and moving). The thermopile cannot be utilized for the semiconductor production equipment because the thermopile needs to contact the measuring objects.
2) The temperature measurement is one of the most important factors in the chemical dry etching process.
3) The accurate temperature control of wafers is needed for yield improvement since wafers are high added value. Recently, the high repeatability of an infrared thermometer and the connectivity with the other control devices are required for the infrared thermometer by the diversification of semiconductor production equipment.

In order to accommodate these requests, we developed the infrared thermometer "IT-470F-H" which has the infrared sensor developed utilizing MEMS technology, and added the current output in addition to the optical digital output.

Principle of an Infrared Thermometer

The infrared thermometer detects infrared rays radiated from the surface of the object, and converted to temperature. The principle of an infrared thermometer is explained in this chapter.

Fundamentally, heat can be transferred from one place to another by three methods: conduction, convection, and radiation. (Figure 1)

Conduction is the transfer of thermal energy within a body due to a temperature gradient. Convection is the transfer of heat from one place to another by the movement of fluids. For example, warm air rises and cold air descends. Radiation is electromagnetic radiation (e.g. visible light, infrared ray) generated by the thermal motion of charged particles in object. The infrared thermometer detects this radiation.

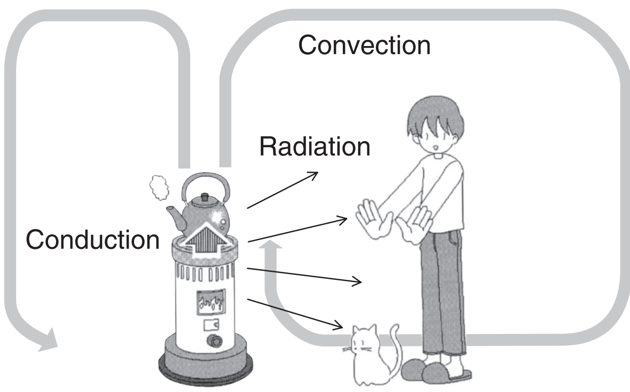

Figure 1 Heat transfer

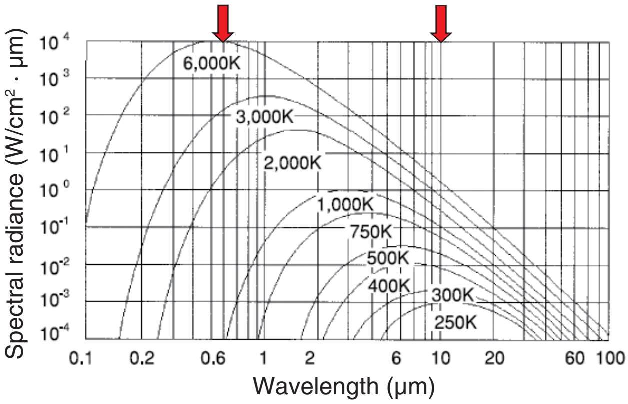

Figure 2 Relation between temperature and energy of object[1]

Figure 2 shows the relation between the wavelength and the infrared energy (spectral radiance) in various temperatures. This relation is based on Planck's law. As the temperature is raised, the total energy increases and the peak wavelength of spectral radiance shifts to shorter wavelength. The kinds of electromagnetic waves depend on the wavelength (e.g. ultra-violet: 0.1~0.4 μm, visible: 0.4~0.7 μm, infrared ray: 0.7~100 μm). Temperature measuring of the object that is under 850 K needs the infrared sensor, because the object emits the infrared rays only. Our infrared thermometers use a thermal infrared sensor, called thermopile. Figure 3 shows the thermopile and the composition of infrared thermometer. Thermocouple is composed of two different metals. The temperature difference (ΔT) between hot junction and cold junction generates the thermal electromotive power based on the temperature difference. The thermopile is composed of many thermocouples connected in series. The hot junctions are gathered in central, as shown in Figure 3. Therefore, if one hundred thermocouples are connected in series, the thermal electromotive power increases one hundred times of a thermocouple. Infrared rays from a measuring object are concentrated in the hot junction of thermopile by infrared condensing lens. The temperature of hot junction is raised by the infrared rays of measuring object.

The thermopile measures this relative temperature difference between a measuring object and the thermometer (i.e. the cold junction). Therefore, we need to measure the temperature of the thermometer in order to calculate the absolute temperature of measuring object. The temperature (T) of cold junction is measured by installing a thermistor to the infrared sensor. From the thermal electromotive power of the thermopile and signal of the thermistor, the absolute temperature of an object is worked out.

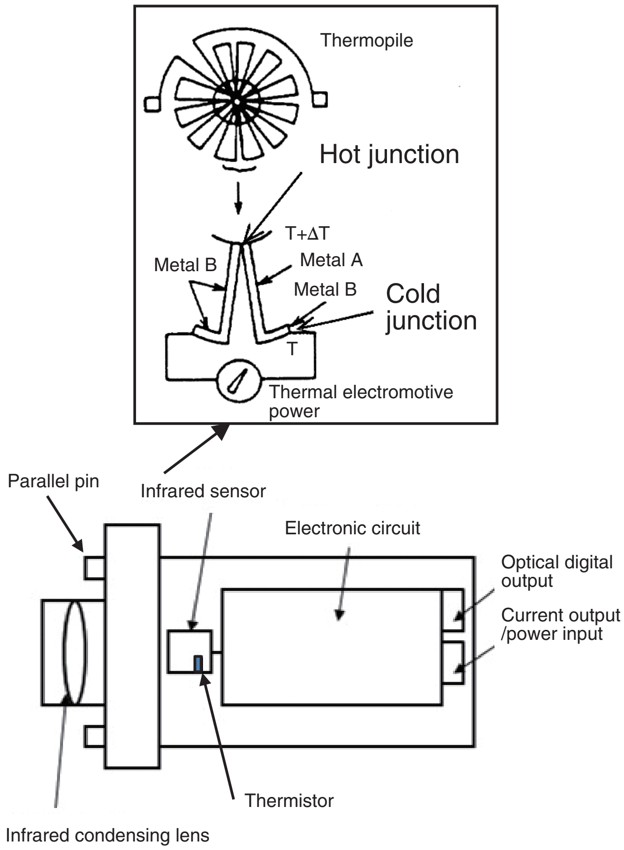

Figure 3 Thermopile and composition of Infrared Thermometer

The infrared thermometer is calibrated by cavity type blackbody furnace. Blackbody furnace radiates the energy of set temperature based of Planck's law.

Next, the advantages and disadvantages of the infrared thermometer are described below.

Advantages:

a) Non-contact temperature measurement
  - Temperature measurement of object distantly-positioned
  - No contamination
  - Temperature measurement of food and human body without pollution and infection
  - Temperature measurement of dynamic object (e.g. rolling tire)

b) High-speed temperature measurement due to short response time

c) Temperature measurement of low heat capacity object

d) Temperature measurement of object with rugged surface

Disadvantages:

a) Measurement of materials which has glossy surface is not easy because radiation energy and wavelength depend on surface conditions and refractive indices of objects.

b) Securing of high temperature accuracy is difficult comparison to contact-type thermometer.

c) Measurement of the temperature of the inside of object is impossible.

d) It is expensive than thermocouple.

e) The measurement position cannot be estimated by eyes because the measurement probe of infrared thermometers (i.e. infrared rays) is invisible.

As a result, infrared thermometer can be applied in various fields.

Feature and Specification of “IT-470F-H”

Figure 4 shows the picture of “IT-470F-H”. The infrared sensor incorporates electrical circuits by utilizing our MEMS technique. This infrared sensor has 1.7 times higher in responsivity, 2.7 times shorter in response time than our previous sensor. Furthermore, the repeatability and the stability to transient change of ambient temperature are improved from our previous infrared thermometer (IT-470A) because the temperature of the cold junction can be measured more accurately by integrating thermistor in the infrared sensor. The housing is made of aluminum alloy which has high heat conductivity. Therefore, “IT-470F-H” isn’t affected by the transient change of ambient temperature in the temperature fluctuation.

Some of semiconductor production equipments generate high-frequency electromagnetic waves at the plasma generating process. In order to achieve the demand of the electromagnetic compatibility, we improved the grounding structure of housing and revised the shield material and the electric circuit. Table 1 shows the specification of the infrared thermometer “IT-470F-H”. Our conventional infrared thermometers had optical digital output only. The digital-analog converter was needed in order to output the measurement data. Current output function is added to “IT-470F-H” newly. Therefore, the user can use two kind outputs flexibly.

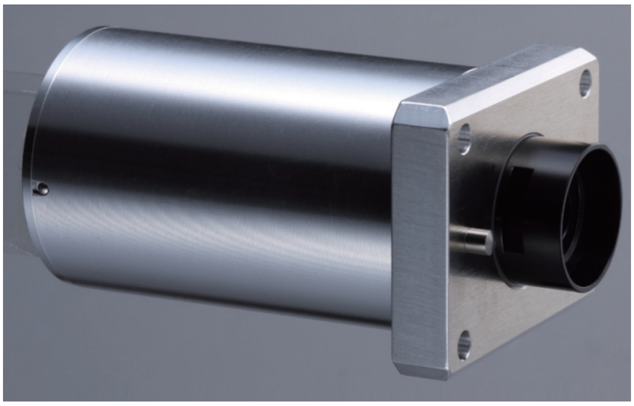

Figure 4 Picture of “IT-470F-H”

Table 1 Specifications of IT-470F-H

	Specifications
Measurement temp. range	-50 ~ 200°C
Spectral response	8 ~ 14 μm
Range of emissivity ε	0.001 ~ 1.000
Accuracy (Optical digital output, Emissivity (ε) = 1.000)	±4.0°C (Target -50°C)
	±0.8°C (Target -20°C)
	±0.6°C (Target 0°C)
	±0.5°C (Target 23°C)
	±0.4°C (Target 100°C ~)
Repeatability (Optical digital output, Emissivity (ε) = 1.000)	0.7°C (Target -50°C)
	0.5°C (Target 23°C)
	0.5°C (Target 200°C)
Target size (Measurement field / distance)	ø8/150 mm
Output	Optical digital output, Current output 4 mA to 20 mA
Power supply	DC 24 V
Power consumption	30 mA or less
Dimensions	55(W) × 44(L) × 96(H) mm
Mass	Approx. 300 g

Performance

Accuracy

Figure 5 shows the evaluation result of measurement accuracy of temperature. The horizontal axis shows the temperature of blackbody furnace which is temperature standard and the vertical one shows the error which is subtracted temperature of the blackbody furnace from the measurement value. The result shows the high accuracy in temperature from -50°C to 200°C and “IT-470F-H” can be used for the accurate control of various temperatures with wide range.

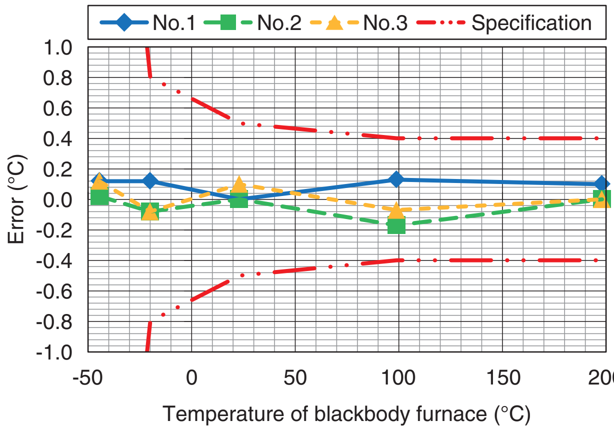

Figure 5 Accuracy of measurement

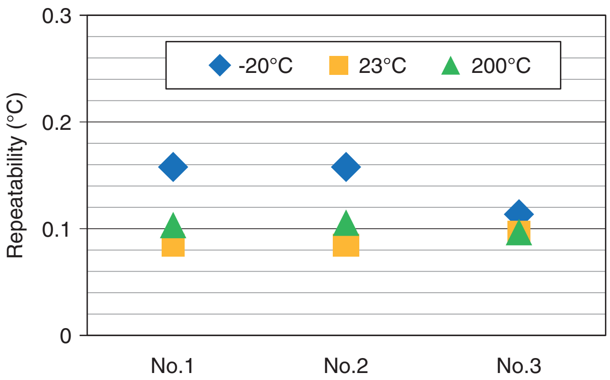

Figure 6 Repeatability

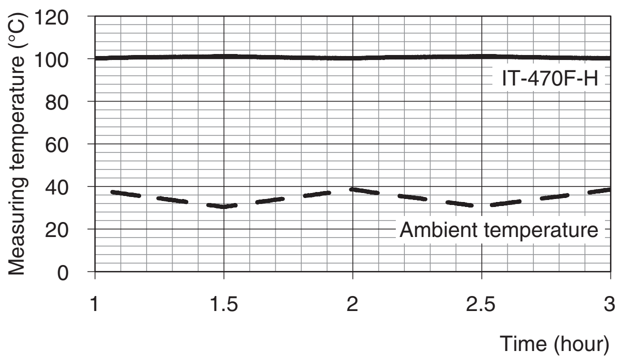

Figure 8 Transient characteristic of ambient temperature

Repeatability

Figure 6 shows the evaluation result of repeatability. We set up "IT-470F-H" in front of the blackbody furnace and measured the temperature of the blackbody furnace of 200°C ten times at five-second intervals. The repeatability is defined as twice the standard deviation of ten times temperature measurement. The repeatability improves to 0.1°C which is one-third of our previous infrared thermometer (IT-470A).

Responsiveness

Figure 7 shows the evaluation result of responsiveness. We measured temperature of two blackbody furnace of 0°C and 100°C alternately. Enlarged view of one part of Figure 7 is shown at the right side of Figure 7. "IT-470F-H" responds to changes of measuring temperature quickly. This result shows the high responsiveness of the infrared thermometer.

The stability to transient change of ambient temperature

Figure 8 shows the stability to transient change of ambient temperature. We measured temperature of object of 100°C under environment fluctuating between 30°C and 38°C in slope of 8°C/30 min. This environment was assumed to the dry etching process. This result shows "IT-470F-H" isn't affected by the transient change of ambient temperature in the temperature fluctuation.

Target size

Figure 9 shows the target size of "IT-470F-H". The target size is φ8 mm at 150 mm from the infrared condensing lens. The target size is defined as the diameter of the size amounted to 90% of total energies and the remaining energies are distributed to the outside of target size as shown on the right side of Figure 9. The twice of target size is necessary so as to ensure about 100% of total energies.

Conclusion

We have developed infrared thermometer "IT-470F-H" improved in accuracy and repeatability. This thermometer became the critical measurement equipment in order to control the temperature in the dry etching process. Semiconductor industry has been progressing to the high-quality and high-mix low-volume production, and the requests of infrared thermometer would increase rapidly. We develop the epochal thermometers for these requests and contribute to the development of the semiconductor industry.

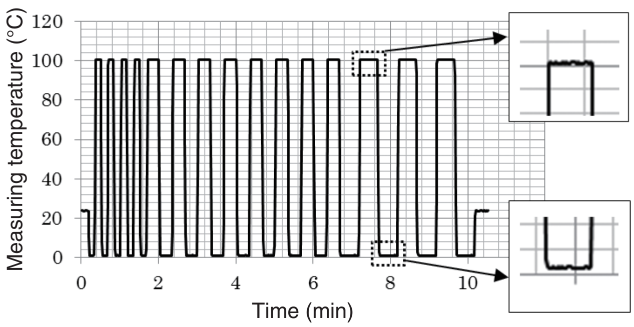

Figure 7 Responsiveness

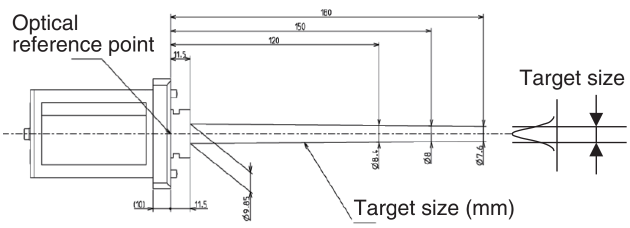

Figure 9 Target size

References

[1] T. NOMURA *et al.*, Radiation Thermometer IT-540 Series, *Readout*, **17**, 65 (1998).

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