

## Power Devices

# Notes for Temperature Measurement Using Thermocouples

The surface temperature of a package is measured to estimate the junction temperature of a semiconductor device. However, correct results may not be obtained if the measurement is performed incorrectly. This application note explains cautions regarding the temperature measurement. The content of this application note is generally applicable, irrespective of the types of semiconductor devices.

### Thermal measurement using thermocouples

Thermocouples are used as a means of measuring the surface temperature of semiconductor packages. However, care must be taken because the results obtained may be different from the actual conditions if the thermocouples are handled incorrectly. Although the surface temperature can also be measured using thermography, final products are enclosed in chassis and measurement targets cannot be viewed in most cases. Therefore, ROHM employs contact type measurements using thermocouples.

### Notes when using thermocouples

The first point is regarding types of thermocouples. Although there are 10 types of thermocouples, thermocouples referred to as Types K and T are suited for the surface temperature

measurement of semiconductors. Table 1 summarizes the specifications of these two types of thermocouples. Although Type T has a small tolerance, its positive electrode has a high thermal conductivity. Therefore, the thermocouple may serve as a heat sink, decreasing the measured temperature below the actual temperature. Thus, it is considered that thermocouples of Class 1 Type K are ideal for the thermal measurement.

The second point is regarding the size of thermocouples. Since a thermocouple with a large wire diameter causes heat radiation from the thermocouple itself, the temperature of the measurement target is decreased below the actual value. To mitigate this effect, the thermocouple to be used should be as thin as possible. In the relevant JEDEC Standard, AWG 36 to 40 is recommended. At ROHM, AWG 38 (0.102 mm, 0.0040 inch) is normally employed.

IEC code	Component material		Class	Temperature range	Tolerance	Color code (reference)	
	Positive electrode	Negative electrode				EN60584-3 JIS C 1610:2012	ASTM E230
K	Nickel-chromium alloy $\lambda \leq 19 \text{ W/m}\cdot\text{K}$	Nickel-aluminum alloy $\lambda \leq 30 \text{ W/m}\cdot\text{K}$	1	-40 to 375 °C 375 to 1000 °C	$\pm 1.5 \text{ }^\circ\text{C}$ $\pm 0.004 \times  t $	Green (Blue in JIS C 1610:1995)	Yellow
			2	-40 to 333 °C 333 to 1200 °C	$\pm 2.5 \text{ }^\circ\text{C}$ $\pm 0.0075 \times  t $		
			3	-164 to 40 °C -200 to -167 °C	$\pm 2.5 \text{ }^\circ\text{C}$ $\pm 0.015 \times  t $		
T	Copper $\lambda \leq 385 \text{ W/m}\cdot\text{K}$	Copper-nickel alloy $\lambda \leq 19 \text{ W/m}\cdot\text{K}$	1	-40 to 125 °C 125 to 350 °C	$\pm 0.5 \text{ }^\circ\text{C}$ $\pm 0.004 \times  t $	Brown	Blue
			2	-40 to 133 °C 133 to 350 °C	$\pm 1.0 \text{ }^\circ\text{C}$ $\pm 0.0075 \times  t $		
			3	-67 to 40 °C -200 to -67 °C	$\pm 1.0 \text{ }^\circ\text{C}$ $\pm 0.015 \times  t $		

References: IEC 60584-1:2013

$\lambda$ : Thermal conductivity

Table 1. Summary of specifications of Type K and T thermocouples

Figure 1 shows the results measured using thermocouples using different types of thermocouples with different wire diameters. The picture on the left shows an example in which Type K and AWG 38 (small wire diameter) is used, while the picture on the right shows an example in which Type T (higher thermal conductivity than that of Type K) and AWG 28 (large wire diameter) is used. Since the heat radiation through the thermocouple is larger on the right side, the measured temperature is 24% (16.7°C) lower than the left side. This effect becomes larger as the package size is decreased.

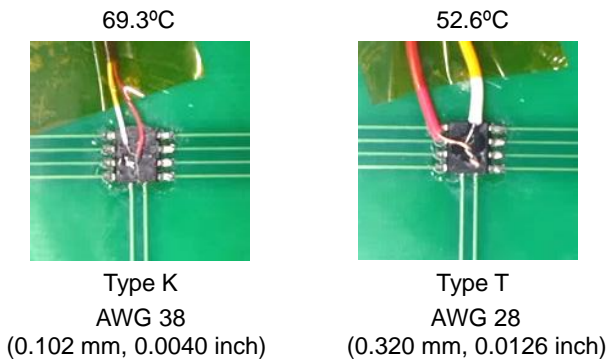


Figure 1. Example of difference in measured temperatures due to difference in types and wire diameters of thermocouples

The third point is regarding tip treatment of thermocouples. The simplest method is to twist the tip several times to make it a twisted wire as shown in Figure 2. Nevertheless, since the temperature is measured at the first contact point in this method, the remaining section is unnecessary and may cause undesirable heat radiation. However, since cutting off the remaining section compromises the contact, the temperature becomes unstable.

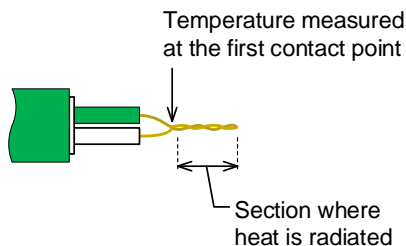


Figure 2. Thermocouple with twisted wire as tip treatment

The best method is to weld the tip as shown in Figure 3. For welding, use a commercial spot welder for thermocouples.

Alternatively, a thermocouple with a welded tip can be used.

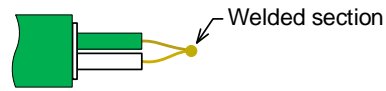


Figure 3. Thermocouple with welded tip as tip treatment

Figure 4 shows an example of the difference in measured temperatures when the tip is welded or twisted. The twisted tip provided a result 2.3% (1.6°C) lower than the welded tip. This effect also becomes larger as the package size is decreased.

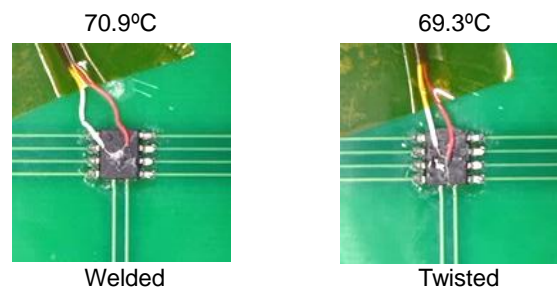


Figure 4. Example of difference in measured temperatures due to difference in tip treatment  
Type K, AWG 38 (0.102 mm, 0.0040 inch)

The fourth point is regarding the position for attaching the thermocouple. JEDEC Standard specifies that the package surface temperature should be measured at the center of the upper surface of the package. As the example of thermocouple installation in Figure 5 shows, draw diagonals from the four corners of the package and use their intersection as a guide to install the thermocouple.

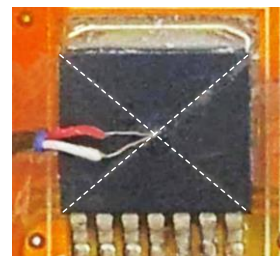
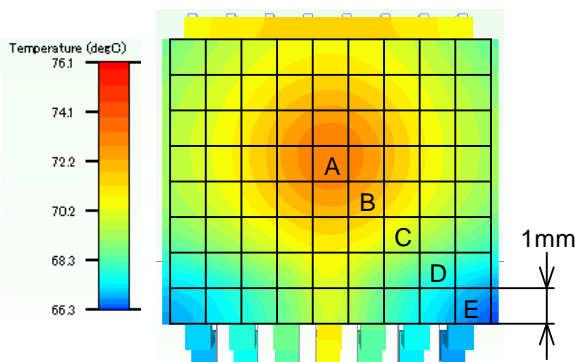


Figure 5. Example of thermocouple installation where diagonals are drawn from the four corners of a package and their intersection is used as guide

Figure 6 shows the results of simulating the temperature difference due to position displacement. A shift of approximately 1.4 mm from point A to point B causes a 1.6% (1.2°C) decrease, while a shift of approximately 2.8 mm from point A to point C causes a 3.7% (2.7°C) decrease. Be careful to keep the thermocouple at the center as much as possible.

The fifth point is regarding the method of securing thermocouples. The easiest method is to secure the thermocouple with heat resistant polyimide tape. Although this method facilitates securing and removing the thermocouple, the thermocouple can be lifted from the device due to peeling during the measurement. In addition, since the convection with the atmosphere is prevented if the tape is attached over the device, the temperature is measured in a heat radiation environment that is different from the original environment.

JEDEC Standard recommends using the minimum amount of epoxy adhesive to secure a thermocouple. ROHM also employs this method. Since the epoxy adhesive is unlikely to peel off during the measurement and requires less area to secure the thermocouple, the effect on the measurement is limited. It is necessary to secure the thermocouple so that the epoxy resin will not flow into the space between the device and the thermocouple.



A	B	C	D	E
73.3 °C	72.1 °C	70.6 °C	68.2 °C	66.6 °C

Figure 6. Example of difference in temperatures due to difference in measurement positions  
Simulated with HRP7 package

Figure 7 shows an example of the temperature difference due to the difference in securing methods. The polyimide tape provided

a result 3.7% (2.6°C) lower compared with the adhesive. This can be attributed to a poor adherence between the thermocouple and the device. At a higher temperature, the adhesive strength of the tape is decreased and the measured temperature is further decreased.

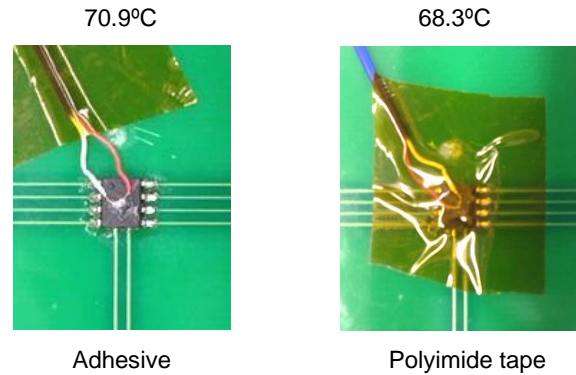


Figure 7. Example of difference in temperatures due to difference in methods of securing thermocouple  
Type K, AWG 38 (0.102 mm, 0.0040 inch)

The sixth point is regarding the method of wiring thermocouples. While the thermocouple is secured to the device and its wire is drawn to a measuring instrument, the route of the wiring can affect the measurement. As shown in Figure 8, the wire should be arranged along the main body of the package to the PCB. This can mitigate the decrease in temperature of the thermocouple junction due to the heat radiation from the wire. This is also described in JEDEC Standard as a wiring technique.

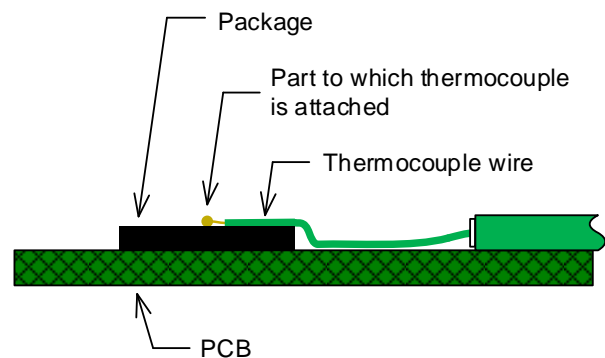


Figure 8. Wiring method of thermocouple wire: Wiring along the main body of the package to the PCB can mitigate the decrease in temperature of the thermocouple junction due to the heat radiation from the wire

The seventh point is that the measurement environment must be identical to the environment of the final product. As an example, consider a case in which an evaluation board is measured in a thermostat chamber. Figure 9 shows an example of a measurement board installed in a thermostat chamber. A circulation fan is installed in the chamber to make the temperature uniform, creating a forced air cooling environment. If the board or the device is cooled by the forced air cooling, it is necessary to install a protection, such as a wind shield, to create an environment close to natural convection.

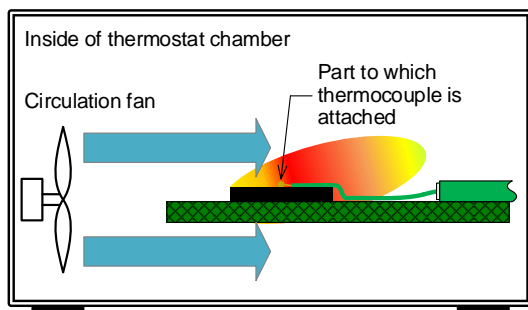


Figure 9. Effect of circulation fan in thermostat chamber on thermal measurement

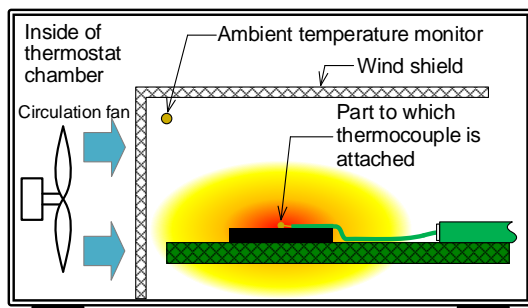


Figure 10. Example of protection against effect of circulation fan

Figure 10 shows an example of protection against the effect of the circulation fan. Install a wind shield (or a box) so that the subject of the measurement will not be exposed to the wind from the circulation fan. Place a separate thermocouple where the thermocouple is not directly exposed to the wind, and wait for the ambient temperature to be stabilized.

Moreover, if the final product is sealed within a chassis or if there is another heat source, the condition is different from the result measured with only one evaluation board. Therefore, the

evaluation must be performed in a state equivalent to that of the final product.

## Summary

The features and cautions for the temperature measurement using thermocouples are summarized as follows.

### Features

- The surface temperature of the package is measured.
- Since the measurement is of the contact type, it is prone to errors due to the way the thermocouple is attached.
- The junction temperature cannot be measured directly.

### Cautions

1. There are many types of thermocouples. Using a thermocouple inappropriate for a given application decreases the measured temperature. Class 1 Type K is recommended for semiconductor device applications.
2. A large wire diameter decreases the measured temperature due to the heat radiation from the thermocouple itself. AWG 36 to 40 is recommended.
3. Welding is ideal for tip treatment. Twisted wire decreases the measured temperature.
4. Attach the thermocouple at the center of the package surface. If the thermocouple is shifted from the center, the temperature cannot be measured correctly.
5. A minimum amount of epoxy adhesive is recommended as the securing method. Polyimide tape can be lifted from the device, decreasing the measured temperature.
6. The wire should be arranged along the main body of the package to the PCB. This can mitigate the decrease in temperature of the thermocouple junction due to the heat radiation from the wire.
7. The measurement environment must be identical to the environment of the final product.

## References

- [1] JESD51-1:1995, *Integrated Circuits Thermal Measurement Method – Electrical Test Method (Single Semiconductor Device)*
- [2] JESD51-2A:2008, *Integrated Circuits Thermal Test Method Environmental Conditions - Natural Convection (Still Air)*
- [3] IEC 60584-1:2013, *Thermocouples - Part1: EMF specifications and tolerances*
- [4] IEC 60584-3:2007, *Thermocouples-Part3: Extension and compensating cables – Tolerances and identification system*
- [5] JEITA, 2016, *Temperature measurement guideline using a thermocouple*, EDR-7338, February 2016
- [6] JIS 1602, 2015, *Thermocouples*
- [7] JIS 1610:2012, *Extension and compensating cables for thermocouples*
- [8] JIS 1610:1995, *Extension and compensating cables for thermocouples*

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