Power Devices

Notes for Temperature Measurement Using Forward Voltage of PN Junction

The forward voltage of a pn junction can be 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.

Method to estimate the junction temperature by measuring the sensing diode while the device is operated

By utilizing a change of around -2 mV/°C in the temperature characteristics of the forward voltage of pn junctions, you can measure the temperature characteristics of a pn junction existing inside the device in advance to estimate the junction temperature. For the pn junction to be measured, a diode element that can be accessed through a pin of the device is used and designated as the sensing diode.

As shown in Figure 1, if the power step, which is a heat source, is a MOSFET and the sensing diode is the body diode of the MOSFET, the temperature can be precisely obtained because the distance between the heat source and the sensing diode is small.

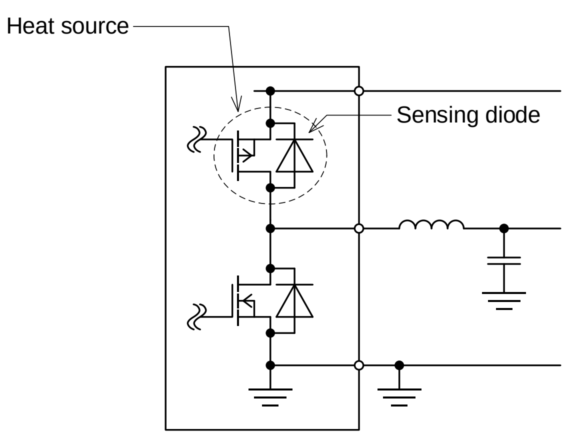

Figure 1. The temperature can be precisely obtained if the heat source is close to the sensing diode. However, it is impractical to accurately measure a minute change in the sensing diode voltage in a device operating circuit

However, as in the example shown in Figure 1, when you attempt to measure the forward voltage of the sensing diode while a circuit, such as a switching circuit, is operated, it is necessary to quickly switch between the device operating circuit and the forward voltage measurement circuit using a relay or other means. Since device operating circuits are noisy, it is impractical to stably measure a minute change in the forward voltage at high speed.

The next conceivable method is to use the pin protection diode (mainly electrostatic breakdown protection) attached to a pin that will not affect the operation of the heat source. Figure 2 shows an example of the measurement circuit. In this case, the forward voltage of the sensing diode can be simultaneously measured while the heat source is operated. In this example, the heat source and the sensing diode have their respective ground pins. However, if there is only one ground pin, it is necessary to confirm that the forward voltage is correctly measured because the ground pin voltage is modulated by the current variation of the heat source.

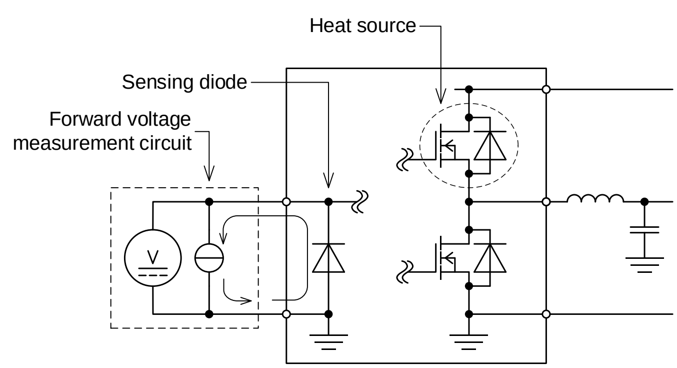

Figure 2. Example of the forward voltage measurement using a pin that will not affect the operation of the heat source

Since a semiconductor chip is small in size and measures just a few millimeters square, you may have an impression that the temperatures of the heat source and the sensing diode are nearly the same irrespective of their positional relation. However, the distance between them can actually cause a large temperature difference.

An example is shown in Figure 3. In this example, the center of the heat source is apart from the sensing diode by approximately 2 mm. The temperature is reduced by approximately 20°C, demonstrating that the temperature cannot be measured correctly. Therefore, it is necessary to measure the temperature using the pin specified by the device manufacturer, who understands the chip layout.

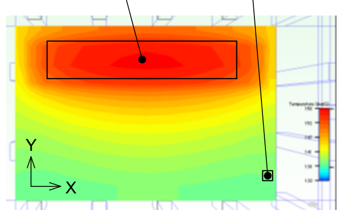

Figure 3. Chip layout and temperature
When the distance between the heat source and the temperature measurement point is large, the temperature cannot be measured correctly

Estimation of the junction temperature using Ψ_{JT}

There is a method to estimate the junction temperature using the thermal characteristics parameter Ψ_{JT}. Ψ_{JT} is the thermal characteristics parameter from the junction of the device to the center of the upper surface of the package. Since the junction temperature can be calculated with Equation (1), if Ψ_{JT} measured for the actual operation board or a board with similar specifications and the temperature at the center of the upper surface of the package measured for the actual operation board are obtained, the junction temperature can be estimated precisely.

$$T_J = T_T + \Psi_{JT} \times P \quad [°C] \tag{1}$$

T_T: Temperature at the center of the upper surface of the package [°C]

Ψ_{JT}: Thermal characteristics parameter from the junction to the center of the upper surface of the package [°C/W]

P: Power consumption of the device [W]

As shown in Figure 4, the body diode of the heat source is mainly used in the Ψ_{JT} measurement. This diode is used for the sensing as well as the heat source during the Ψ_{JT} measurement. The measurement is enabled by using a dedicated measurement instrument to quickly switch between the heating and the sensing of the body diode.

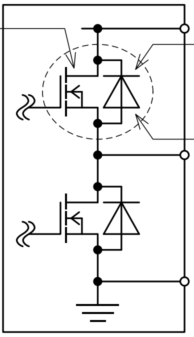

Figure 4. Sensing diode and heat source during the Ψ_{JT} measurement

For the above described method to measure the sensing diode while the device is operated, there are few devices in which the sensing diode exists at an appropriate position. Therefore, ROHM recommends the estimation of the junction temperature using Ψ_{JT}.

Summary

The features and cautions for the temperature measurement using the forward voltage of a pn junction are summarized as follows.

Features

• The junction temperature can be measured directly.

Cautions

• Since the temperature cannot be correctly measured if the distance between the heat source and the measurement point is large, it is necessary to perform the measurement using the pin specified by the device manufacturer, who understands the chip layout.

References

[1] JESD51-1:1995, *Integrated Circuits Thermal Measurement Method – Electrical Test Method (Single Semiconductor Device)*

Appendix A

Method to estimate the junction temperature using the forward voltage of a pn junction inside the chip

By utilizing a change of around -2 mV/°C in the temperature characteristics of the forward voltage of pn junctions, you can measure the temperature characteristics of a pn junction existing inside the device in advance to estimate the junction temperature. For the pn junction to be measured, a diode element that can be accessed through a pin of the device is used and designated as the sensing diode.

The measurement circuit is shown in Figure A-1. Current is applied to the sensing diode and the forward voltage is measured. The heat source device is placed in a thermostat chamber. The ambient temperature is varied from 25°C to the maximum junction temperature of the device (e.g., 150°C), and the forward voltage is measured at each temperature. After the ambient temperature is changed, it takes time for the heat to be conducted from the ambient environment to the chip (junction). Therefore, you should wait until the forward voltage is stabilized. This measurement presupposes that the ambient temperature is the same as the junction temperature.

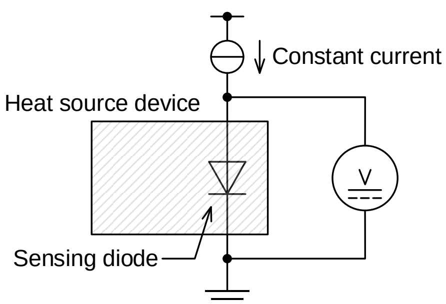

Figure A-1. Circuit for measuring the forward voltage of a diode element in a heat source device

An example of the measurement results is shown in Figure A-2. Although the characteristics somewhat depend on the dimensions and material of the element, the temperature characteristics are represented by a graph of linear function with the slope of around -2 mV/°C. This slope is referred to as the *K* factor, and can be expressed with Equation (A-1).

$$K = \left|\frac{T_{Hi} - T_{Lo}}{V_{Hi} - V_{Lo}}\right| \times 1000 \quad [°C/mV] \qquad (A-1)$$

where, T_{Hi}: $High\ temperature\ (higher\ than\ T_{Lo}\ by\ 50°C\ or\ greater)\ [°C]$

T_{Lo}: $Low\ temperature\ (25\ or\ 27)\ [°C]$

V_{Hi}: $Voltage\ at\ high\ temperature\ [mV]$

V_{Lo}: $Voltage\ at\ low\ temperature\ [mV]$

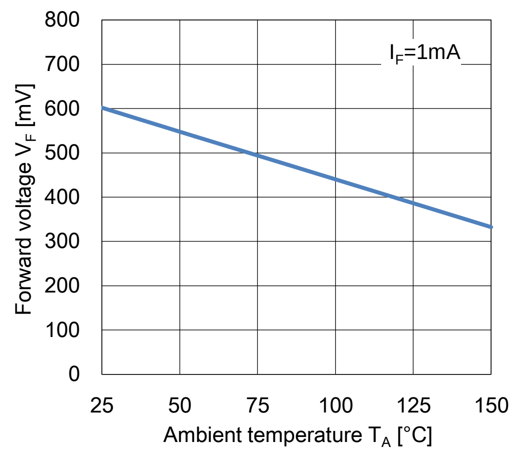

Figure A-2. Example of the temperature characteristics of the forward voltage of a diode element existing inside the device

After obtaining the *K* factor, the forward voltage of the sensing diode is measured while the device is actually operated. From the forward voltage, the junction temperature can be calculated with Equation (A-2).

$$T_J = |V_F - V_{Lo}| \times K + T_{Lo} \qquad (A-2)$$

where, V_F: $Forward\ voltage\ [mV]$

V_{Lo}: $Voltage\ at\ low\ temperature\ when\ the\ K\ factor\ is\ measured\ [mV]$

K: $Kfactor\ [°C/mV]$

T_{Lo}: $Low\ temperature\ when\ the\ K\ factor\ is\ measured\ [°C]$

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