Technical report

Heat flow and thermal resistance of the power resistor

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1. Introduction

Thermal resistance is shown by coefficient of thermal conductivity. Coefficient of thermal conductivity is one of physical constants of materials. Coefficient of thermal conductivityκ is defined as heat quantity flowing though the 1m^2 of the board for one second, when 1℃ of temperature difference exists between each surface of the board. Unit is shown by W·m^{-1}·K^{-1} and W/m·K (Watt per meter Kelvin). Coefficient of thermal conductivity for respective materials is as follows: Silver: 428, Copper: 403, Aluminum: 236, Lead: 36, Iron (Nickel Chrome steel): 33, Constantan: 22, Nichrome: 13, Alumina substrate: 21, Soda glass: 0.6, FR4 printed board: 0.38, Polyethylene: 0.3. Coefficient of thermal conductivity is measured by a heat flowmeter (by EKO INSTRUMENTS CO., LTD, Kyoto Electronics Manufacturing Co., Ltd., etc. in Japan). Heat flow is obtained by precisely measuring the temperature at A and B points.

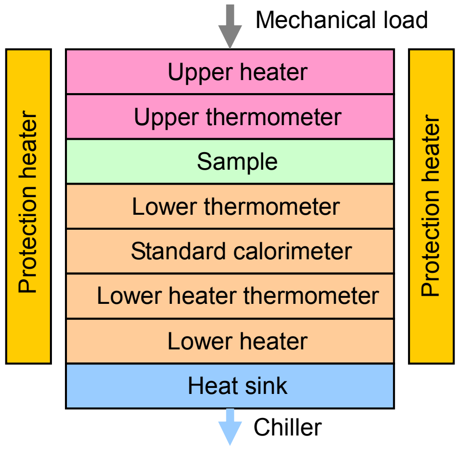

Figure 1. Measuring method of coefficient of thermal conductivity of materials Temperature difference between two points is obtained by precisely measuring the temperature at A and B points.

Heat is conducted by means of conduction, convection, emission, and condensation. To make it easier, if heat is conducted only by conduction:

Degree of thermal conductivity = Coefficient of thermal conductivity x Sectional area of heat transmission / Length (W/K) (1)

Amount of heat transport (W) is:

Amount of heat transport = Degree of thermal conductivity x Temperature difference (2)

Higher the coefficient of thermal conductivity is, larger the sectional area of heat transmission is, shorter the length is, and the larger temperature difference is, greater the degree of thermal conductivity is. Amount of heat transport (W) is equivalent to heat flow.

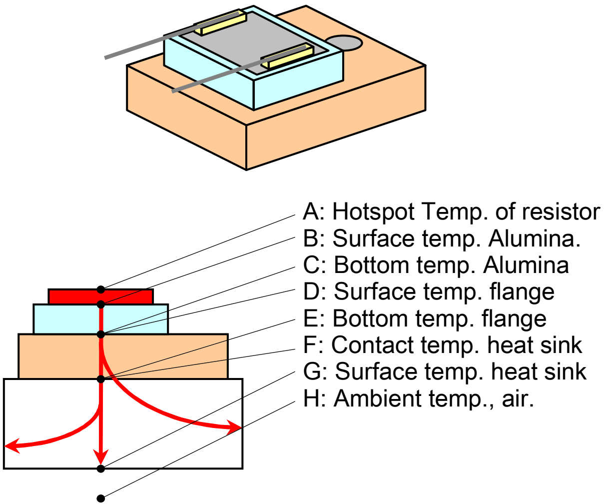

Figure 2. Structure and thermal conductivity of the TO220 resistor.

When thermal resistance is defined as follows:

Thermal resistance = 1 / Degree of thermal conductivity (K/W) (3)

Equation below is obtained.

Amount of heat transport = Temperature difference / Thermal resistance (W) (4)

Therefore, following analogy can be approved. Amount of heat transport = Electric current. Temperature difference = Difference in potential. Thermal resistance = Electric resistance.
These will help understanding of electric engineers.

Temperature rise test measures thermal resistance between two points, i.e. the degree of thermal conductivity, therefore, coefficient of thermal conductivity, sectional area of heat transmission, and length are unchanged. This will give the rectilinear relationship between heat (electric power) and temperature (difference) as shown by Figure 9. Curved relationship between heat and temperature is attributable to heat transfer by convection and radiation.

2. Heat flow of the TO220 resistor

Nikkohm Co., Ltd. provides the resistors represented by TO220 and TO247. As to the heat transfer of these resistors, providing electric power (heat) to the resistor film, most of heat flows out of the resistor by only means of the thermal conductance, because planate (and short) materials with a high coefficient of thermal conductivity are piled up like sandwich as shown by Figure 2.

Temperature difference between A and B points are negligible because the film is adequately thin. Temperature difference between C and D points are determined by coefficient of thermal conductivity of soldering. Temperature difference between E and F points are not negligible as it is coefficient of thermal conductivity of thermal conduction grease. Thermal resistance of commercially available heat sink is usually the temperature difference between the point F and the air temperature (ambient temperature) at the point adequately far from heat sink.

3. Thermal resistance

Larger temperature difference will result in larger thermal resistance between A and B points; and smaller temperature difference will result in no thermal resistance. Temperature difference will be zero when thermal resistance is zero. Larger the sectional area of heat flow is, smaller the temperature difference is. Shorter the heat flow distance, smaller the temperature difference is.

Figure 3 shows one of examples of the equivalent circuit in thermal resistance. As to the TO220 resistor, when the temperature of screw for connecting flange is occasionally measured by mistake, such measurements never make sense. Figure 3 shows the equivalent circuit of thermal resistance of the TO220 resistor.

Thermal resistance does not depend on quality of materials but physical properties (coefficient of thermal conductivity), heat breakthrough area and thickness of materials. Figure 4 shows thermal resistance of each material where thickness is equal. The expression such that “Copper can conduct heat efficiently” and “Aluminum nitride can conduct heat efficiently” is not correct.

4. Heat flow of the power chip resistor

As the power chip resistor is not equipped with the structure to actively diffuse heat out of resistive elements such as heat conductor on the rear surface, it is considered

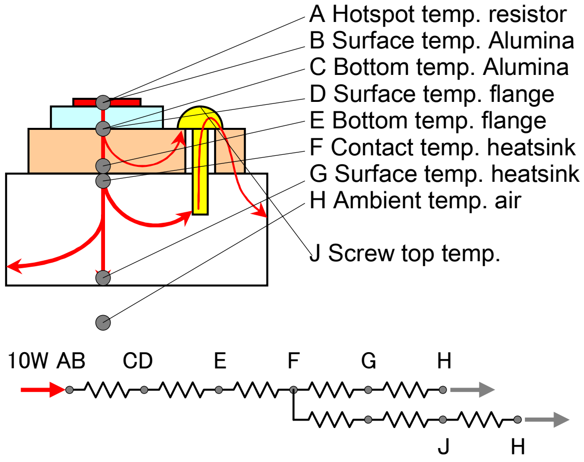

Figure 3. Heat flow and equivalent circuit of thermal resistance of the TO220 resistor

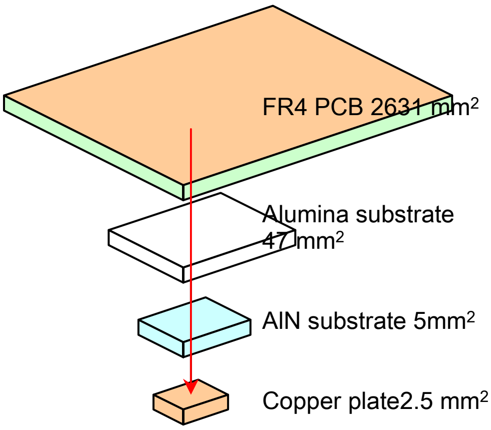

Figure 4. FR4, Alumina substrate, Aluminum nitride substrate, Copper flange. The thermal resistance is same regardless of dimensions if each material is same in thickness.

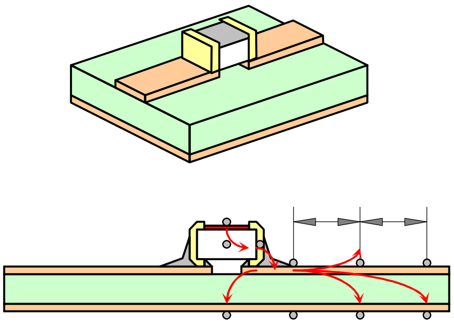

Figure 5. Heat flow of the chip resistor

that most of heat will be conducted from terminals to the wiring of printed board through soldering. And as the size is quite small, thermal conductivity generated by convection and radiation on the surface is small enough to be neglected.

The chip resistor is mounted on the surface of printed board. As printed board has multilayer structure, the internal conditions of insulating body cannot be identified uniquely. Therefore, it is required that maximum temperature of resistor film, ceramic substrate temperature, electrode temperature, solder temperature, and the temperature of copper-foiled wiring at the close distance; and thermal resistance ranging from maximum temperature of resistor film to the copper-foiled wiring should be clearly specified when the chip resistor is mounted. Substrate employed by users determines the thermal structure design ranging from the copper-foiled wiring to ambient temperature of the resistor. Perform temperature rise test to find the thermal resistance with G10 double copper-foiled substrate in 1.6mm thickness as shown by Figure 5. Thin printed board pattern in 0.2mm width exists, however, employ the width of recommended foot pattern of the chip resistor.

5. Heat flow of high-frequency resistor

Circuit width of the printed board is wider than that of the precise chip resistor where high-frequency chip resistors are mounted on the printed board. Since the high-frequency resistor can efficiently conduct heat from the electrode terminals to the copper-foiled circuit, measure temperature rise at each point taking the heat flow as shown by Figure 5 into consideration.

Some of power type high-frequency resistors, power type termination, and power type attenuator have electrodes on the rear surface for the purpose of heat release and special impedance matching as shown by Figure 6. Electrodes on the rear side should be connected to the ground conductor of printed board.

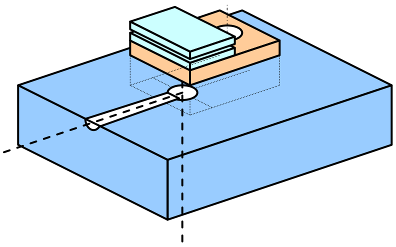

Figure 8. Mounting method of thermocouple when measuring temperature on the rear side of flange
Temperature of resistor flange is measured after grooving on the heat sink face that the resistor is attached and inserting thermocouple into the groove.

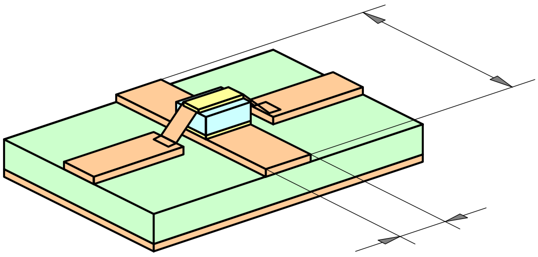

Figure 6. Measurements of heat flow of the power type high-frequency resistor with the ground and heat release conductor attached on the rear side of printed board. Copper foil for ground used in high-frequency circuit is connected to the rear side of printed board by the through-hole method. Specify the dimensions of copper foil on the surface of printed board dimensions.

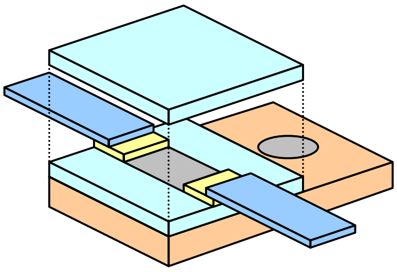

Figure 7. Flanged high-frequency resistor.
This resistor measures heat flow as well as TO220.

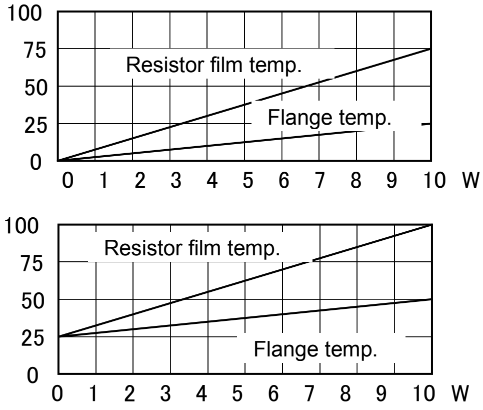

Figure 9. The measurement results of temperature rise. Both upper and lower expressions can be used, however, when the upper expression is used, the note “0℃ is equivalent to 24.5℃ at the room temperature” should be inserted.

In most cases as shown by Figure 6, copper foil for grounding and heat radiation located orthogonal to signal copper foil is thermally and mechanically connected to the ground copper foil on the rear side of printed board by through-hole method.

Given the high thermal resistance at through-hole, Figure 6 specify and standardize horizontal and vertical dimensions (area) of copper foil for grounding and heat radiation on the surface of printed board, measure the maximum temperature of resistor film and the temperature of copper foil for grounding and heat radiation, and then find the thermal resistance between the maximum temperature of resistor film and temperature of copper foil for grounding and heat radiation to make a specification.

Some of power type high-frequency resistors, power type termination, and power type attenuator equipped with copper flange for the purpose of heat release and impedance matching are shown in Figure 7. This flanged termination measures the temperature rise as well as TO220, and finds the thermal resistance between the maximum temperature of resistor film and the center point on the rear surface of flange to describe on the product specifications.

6. Measurements of temperature rise

The measurement results of temperature rise are expressed as shown in Figure 9. Temperature difference between resistor film and flange, i.e., thermal resistance represents thermal performance of the resistor.