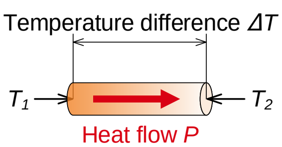
SiC Power Device

What is a Thermal Model?

Among SPICE models, there are models for performing simulations in relation to heat, which are referred to as thermal models. Simulations using the thermal models are performed to make a rough estimate during the initial stage of thermal design. This application note explains the thermal models.

Definition of thermal resistance

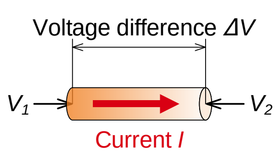
First, we explain the definition of thermal resistance. Thermal resistance is a quantification of how difficult it is for heat to be conducted. Using a diagram and equation, thermal resistance is represented as the quotient of the temperature difference between 2 given points by the heat flow between the 2 points (amount of flow per unit time, power consumption) P, as shown in Figure 1.



$$\textit{Thermal resistance } R_{th} = \frac{T_1 - T_2}{\textit{Heat flow } P} = \frac{\textit{Temperature difference } \Delta T}{\textit{Heat flow } P} \quad [°C/W]$$

Figure 1. Definition of thermal resistance

As these diagram and equation look familiar, they can be treated equivalently to Ohm's law. Figure 2 shows Ohm's law using a diagram and equation. It can be seen that the respective parameters are replaceable by heat and electricity.



$$\textit{Electric resistance } R = \frac{V_1 - V_2}{\textit{Current } I} = \frac{\textit{Voltage difference } \Delta V}{\textit{Current } I} \quad [V/A]$$

Figure 2. Ohm's law

What is a thermal model?

In a thermal model, a location corresponding to transient thermal resistance is replaced by an electrical circuit model, so that the transient thermal resistance characteristics can be calculated using an electrical circuit.

The junction temperature T_J can be calculated by Equation (1).

$$T_J = R_{thJA} \times P_C + T_A \quad [°C] \qquad (1)$$

R_{thJA}: *Thermal resistance between junction and ambient temperature* $[°C/W]$
P_C: *Power consumption of device* $[W]$
T_A: *Ambient temperature* $[°C]$

Replacing a thermal circuit with an electrical circuit according to the definition of thermal resistance described above yields Equation (2).

Thermal circuit		Electrical circuit
R_{th} [°C/W]	→	R [Ω]
P_C [W]	→	I [A]
T_A [°C]	→	V_{BIAS} [V]

$$V = R \times I + V_{BIAS} \quad [V] \qquad (2)$$

R: *Electrical resistance corresponding to thermal resistance* $[\Omega]$
I: *Current corresponding to power consumption of device* $[A]$
V_{BIAS} : Bias voltage corresponding to ambient temperature $[V]$

No. 62AN105E Rev.001
DECEMBER 2019

Next, the simulation circuit and the device configuration are shown in Figures 3 and 4, respectively. From Equations (1) and (2), a voltage with an RC time constant is generated in the Tj pin by applying the power consumption P_D of the device to the Tj pin as a current I and applying the ambient temperature T_A to the Ta pin as a bias voltage V_{BIAS}. This generated voltage represents the junction temperature. In addition, the resistance connected to the Tc pin is R1 that is thermal resistance between the case and the heat sink (R_{thCF}) and R2 that is thermal resistance between the heat sink and the ambient temperature (R_{thFA}). R_{thCF} includes the thermal resistance of the thermal interface material (TIM) and the contact thermal resistance. C1 is the heat capacity of the heat sink. R2 and C1 comprise the heat sink.

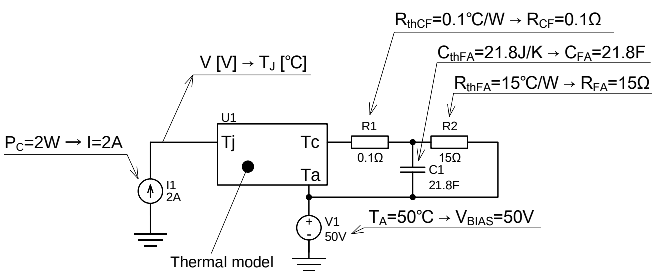


Figure 3. Example of simulation circuit

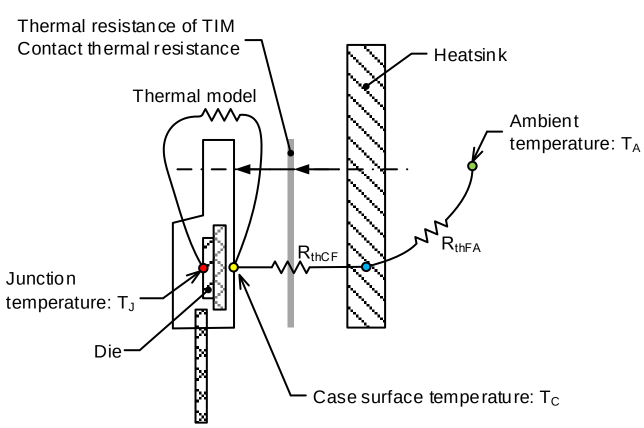


Figure 4. Device configuration

Actual thermal model

Due to heat capacity of objects, temperature will not increase immediately even when the power consumption of the device is increased. Heat capacity represents how easily temperature can change. The larger the heat capacity, the slower temperature rises. The heat capacity of an object is defined as the amount of heat required to raise the temperature of the object by 1 K (kelvin). The unit of heat capacity is J/K (joule per kelvin). In some countries, W·s/K (watt second per kelvin) is also used (equal to J/K). In addition, K and °C are considered equal when treating relative temperatures.

Since it is necessary to replace this heat capacity with an electrical model, heat capacity is treated as capacitance of a capacitor in thermal models. Figure 5 shows the circuit of a thermal model. This is referred to as a Cauer RC thermal circuit network. By applying voltage (= ambient temperature) to the Ta pin and applying current (= power consumption of the device) to the Tj pin, a voltage (= temperature) with an RC time constant is generated on the Tj pin.

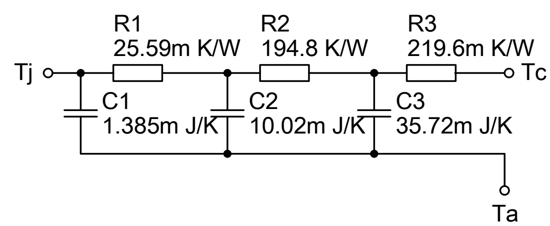


Figure 5. Example of thermal model: Cauer RC thermal circuit network

SiC MOSFET manufactured by ROHM: SCT3040KR

Next, Figure 6 shows the netlist of SPICE. As a subcircuit, values of R and C are described.

```
* SCT3040KR_T
* SiC NMOSFET with driver source Self-heating Thermal model
* 1200V 55A 40mOhm
* Model Generated by ROHM
* All Rights Reserved
* Commercial Use or Resale Restricted
* Date: 2019/07/09
*******************D G S DS Tj Tc Ta
.SUBCKT SCT3040KR_T 1 2 3 4  Tj Tc Ta
.PARAM T0=25 T1=-100 T2=300
.FUNC K1(T)      {MIN(MAX(T,T1),T2)}
********* ********* ********* ********* ********* *********
  --- Omitted ---

C21 Tj Ta 1.385m
C22 T2 Ta 10.02m
C23 T3 Ta 35.72m
R21 Tj T2 25.59m
R22 T2 T3 194.8m
R23 T3 Tc 219.6m
.ENDS SCT3040KR_T
```

Figure 6. Example of netlist

SiC MOSFET manufactured by ROHM: SCT3040KR

To create a thermal model, first mount the device on an infinite heatsink (cold plate) and perform actual measurement using transient thermal measurement equipment (e.g., T3Ster*). Next, calculate the structure function from the measurement data to express the thermal resistance and heat capacity of the package. Figure 7 shows an example of the structure function. The structure function obtained from transient thermal measurement equipment is represented as a network subdividing the effect of three-dimensional temperature distribution as well as the thermal resistance and the heat capacity. Therefore, each boundary is not so clear, for example, between the chip and the die bonding in the measurement mounting diagram shown in Figure 8. Thus, each device in Figure 5 does not correspond one-to-one with the thermal resistance and the heat capacity existing in each component in Figure 8. In addition, although the configuration has 3 RC stages in the example shown in Figure 5, it may have 4 stages or more.

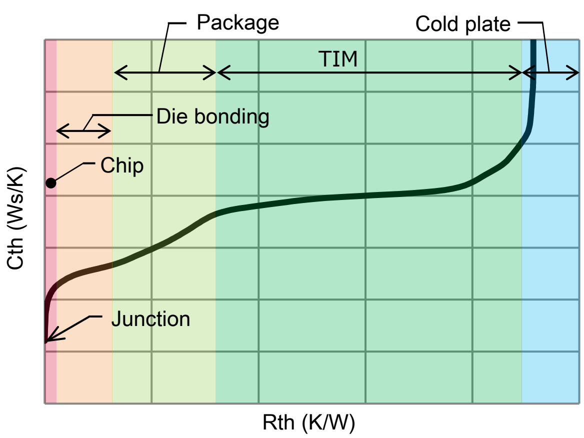


Figure 7. Example of structure function

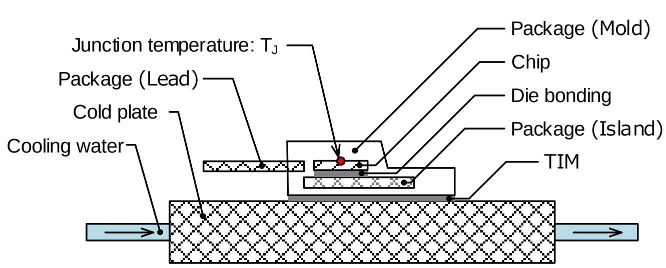


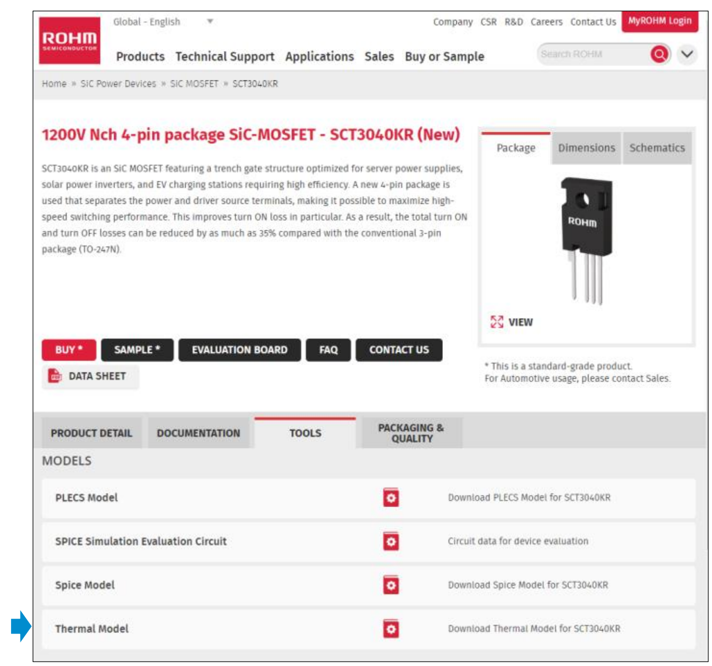
Figure 8. Example of diagram of measurement mounting

The key points of the “thermal models” are summarized as follows.

- Among SPICE models, there are thermal models for performing simulations in relation to heat.
- A thermal model is a model of an electrical circuit corresponding to the transient thermal resistance for performing calculations of a thermal circuit on an electrical circuit.
- By applying the power consumption P_C as current I to the thermal model, the junction temperature T_J can be monitored as voltage.

How to obtain thermal models

The thermal models are available from ROHM’s home page. On the page for the individual product name, select the “TOOLS” tab and download the file from “Thermal Model” in the items of “MODELS”.



* T3Ster is the product of Mentor Graphics Corp.

Notes

1) The information contained herein is subject to change without notice.

2) Before you use our Products, please contact our sales representative and verify the latest specifications :

3) Although ROHM is continuously working to improve product reliability and quality, semiconductors can break down and malfunction due to various factors.
Therefore, in order to prevent personal injury or fire arising from failure, please take safety measures such as complying with the derating characteristics, implementing redundant and fire prevention designs, and utilizing backups and fail-safe procedures. ROHM shall have no responsibility for any damages arising out of the use of our Poducts beyond the rating specified by ROHM.

4) Examples of application circuits, circuit constants and any other information contained herein are provided only to illustrate the standard usage and operations of the Products. The peripheral conditions must be taken into account when designing circuits for mass production.

5) The technical information specified herein is intended only to show the typical functions of and examples of application circuits for the Products. ROHM does not grant you, explicitly or implicitly, any license to use or exercise intellectual property or other rights held by ROHM or any other parties. ROHM shall have no responsibility whatsoever for any dispute arising out of the use of such technical information.

6) The Products specified in this document are not designed to be radiation tolerant.

7) For use of our Products in applications requiring a high degree of reliability (as exemplified below), please contact and consult with a ROHM representative : transportation equipment (i.e. cars, ships, trains), primary communication equipment, traffic lights, fire/crime prevention, safety equipment, medical systems, servers, solar cells, and power transmission systems.

8) Do not use our Products in applications requiring extremely high reliability, such as aerospace equipment, nuclear power control systems, and submarine repeaters.

9) ROHM shall have no responsibility for any damages or injury arising from non-compliance with the recommended usage conditions and specifications contained herein.

10) ROHM has used reasonable care to ensure the accuracy of the information contained in this document. However, ROHM does not warrants that such information is error-free, and ROHM shall have no responsibility for any damages arising from any inaccuracy or misprint of such information.

11) Please use the Products in accordance with any applicable environmental laws and regulations, such as the RoHS Directive. For more details, including RoHS compatibility, please contact a ROHM sales office. ROHM shall have no responsibility for any damages or losses resulting non-compliance with any applicable laws or regulations.

12) When providing our Products and technologies contained in this document to other countries, you must abide by the procedures and provisions stipulated in all applicable export laws and regulations, including without limitation the US Export Administration Regulations and the Foreign Exchange and Foreign Trade Act.

13) This document, in part or in whole, may not be reprinted or reproduced without prior consent of ROHM.

Thank you for your accessing to ROHM product informations.
More detail product informations and catalogs are available, please contact us.

ROHM Customer Support System

http://www.rohm.com/contact/