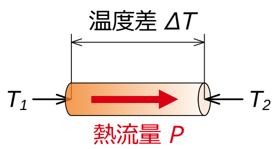
功率器件

热模型是什么

在 SPICE 模型中，有一类模型是用来进行热仿真的热模型。使用热模型进行热仿真是为了在热设计的初期阶段制定粗略的评估而实施的。本应用笔记对热模型进行说明。

热阻的定义

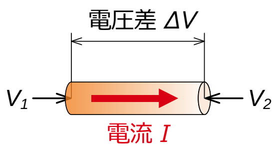
首先，对热阻的定义进行说明。热阻是对热量传递的难易程度进行数值化的表示。如果使用图表和公式进行说明，如 Figure1 所示，任意 2 点之间的温度差ΔT 除以 2 点之间流动的热流量 P(单位时间流动的流量、消耗功率)等于该 2 点之间的热阻 Rth。



$$热阻R_{th} = \frac{T_1 - T_2}{热流量P} = \frac{温度差\Delta T}{热流量P} \quad [℃/W]$$

Figure 1. 热阻的定义

上述图表和公式看起来很熟悉，是因为热阻的计算方法类似于用于电阻计算的欧姆定理。Figure2 是用图表和公式列出的欧姆定理的描述方法。将欧姆定理中的电参数换成热参数，即可用来描述热阻。



$$电阻R = \frac{V_1 - V_2}{电流I} = \frac{电压差\Delta V}{电流I} \quad [V/A]$$

Figure 2. 欧姆定理

热模型是什么

SPICE 中的热模型是指能够将暂态热阻特性通过电路进行仿真计算，也就是将暂态热阻转换成等价的电路进行仿真的模型。

首先结温 Tj 能够通过公式（1）进行计算。

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

R_{thJA}：从 PN 结到周围环境温度之间的热阻 [℃/W]
P_C：器件功耗 [W]
T_A：周围环境温度 [℃]

其次根据上述热阻定义，将热回路转换为电路，得到公式(2)。

热回路		电路
R_{th} [℃/W]	→	R [Ω]
P_C [W]	→	I [A]
T_A [℃]	→	V_{BIAS} [V]

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

R：使用电阻替代热阻[Ω]
I：使用电流替代器件功耗 [A]
V_{BIAS}：使用偏置电压替代周围环境温度[V]

接下来 Figure 3 代表仿真电路， Figure 4 代表器件构成。由公式（1）（2）可知，将器件的功耗 P_D 作为电流 I 施加到 Tj 端子上，再将周围环境温度 T_A 作为偏置电压 V_{BIAS} 施加到 Ta 端子上，由此便可以在 Tj 端子上得到了具有 RC 时间常数的电压。这个电压就是结温。另外，连接到 Tc 端子的电阻 R1 代表外壳和散热器之间的热阻 RthCF，R2 代表散热器和周围环境温度之间的热阻 RthFA。另外，RthCF 中还包含有热界面材料（TIM:Thermal Interface Material）的热阻和接触热阻。另外 C1 是散热器的热容量，R2 和 C1 构成散热器模型。

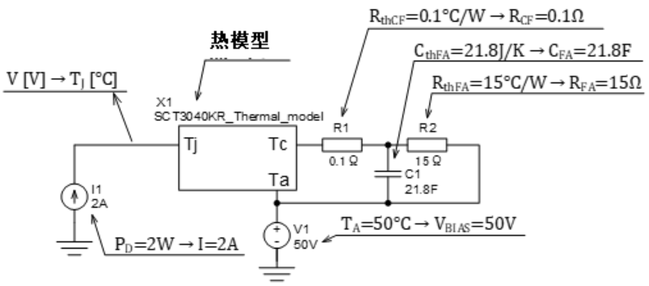


Figure 3. 仿真电阻的一例

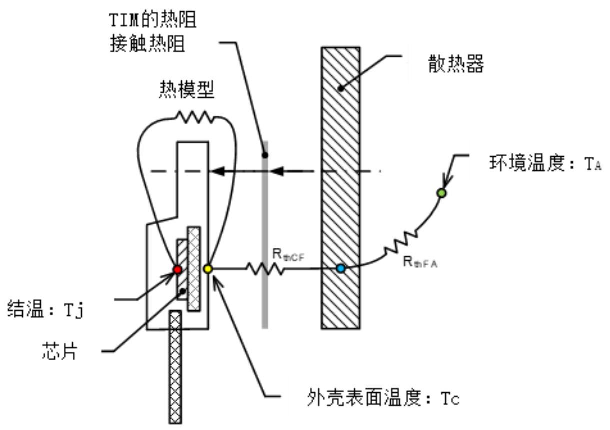


Figure 4. 器件构成

实际的热模型

因为物体有热容量，所以即便器件的功耗增加了，温度也不会马上上升。热容量代表温度变化的难易度，热容量越大温度上升越慢。热容量的定义是将某个物体的温度提高 1K（开尔文）所需要的热量，热容量的单位是 J/K（焦耳每开尔文）。有些国家也使用 W・s/K（瓦秒每开尔文）（相当于 J/K）进行定义。另外，对于相对温度来说单位 K 与℃相当。

因为需要将该热容量转换为电气模型，所以在热模型中通过电容器的容量来代表热容量。热模型的电路如 Figure 5 所示。

图 5 被称为 Cauer 型 RC 热网络，通过将电压（=周围环境温度）施加到 Ta 端子上，将电流（=器件功耗）施加到 Tj 端子上，Tj 端子上会产生具有 RC 时间常数的电压（=温度）。

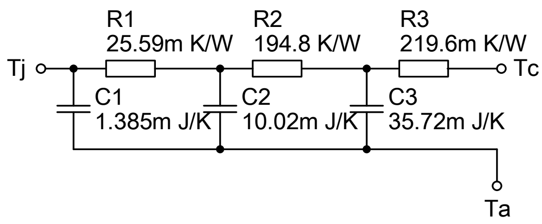


Figure 5. 热模型的一个例子，Cauer 型 RC 热网络
ROHM SiC MOSFET: SCT3040KR

接下来 Figure 6 表示 SPICE 热模型的网络列表。在 Subckt 中描述了 R 和 C 的数值。

```
* 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)}
********* ********* ********* ********* ********* *********
  --- 中略 ---

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. 网络列表的一例
ROHM SiC MOSFET: SCT3040KR

热模型的制作方法是，首先将器件安装到无限大散热板（冷板）上，用暂态热特性测量仪（T3Ster *1 等）进行实测。接着根据实测数据计算结构函数，用来描述器件封装的热阻和热容量。Figure 7 是结构函数的一个例子。因为由暂态热特性测量仪所得到的结构函数是将三维的温度分布影响、以及热阻和热容量按照细分的结构网络进行描述的，因此其描述结果并不像 Figure 8 中的实际测量安装图中的芯片和芯片键合之间那样，各个部分之间存在明确的边界界限。因此 Figure 5 中所列出的 RC 参数，与 Figure 8 中所画出的各要素的热阻和热容量，并不是一一对应的关系。另外，Figure 5 所举出的例子中 RC 是 3 段构成的，也有 4 段以上构成的情况。

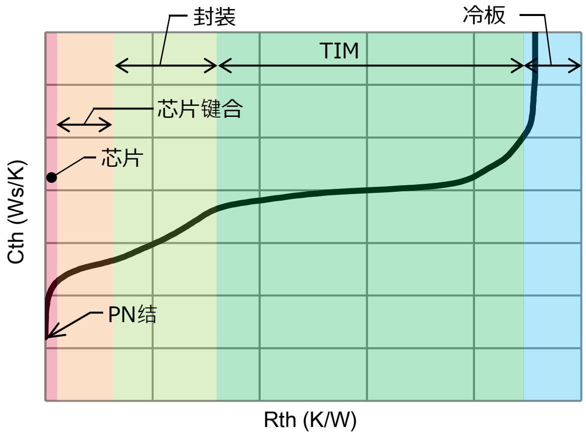


Figure 7. 结构函数的一例

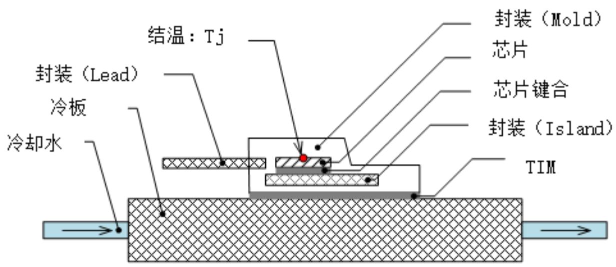


Figure 8. 实际测量安装图的一例

“热模型”的要点如下。

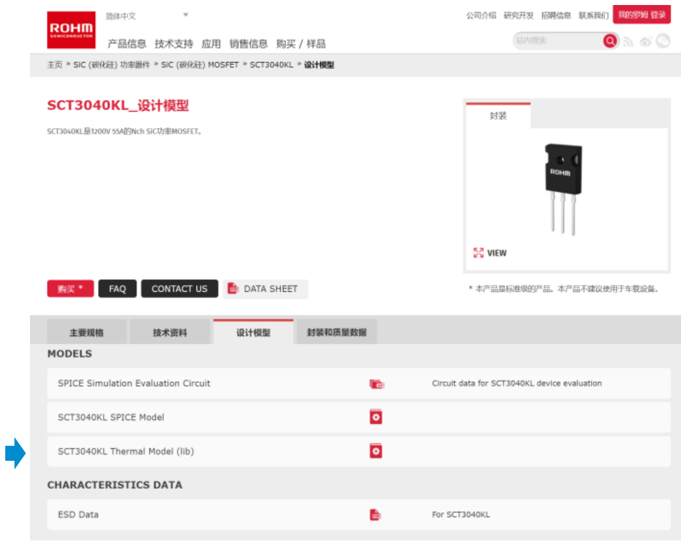
· SPICE 模型中有用于进行热仿真的热模型。

· 热模型是为了将热回路的计算转换成等价的电路计算，所准备的暂态热阻的等价电气模型。

· 通过将芯片功耗 Pc 转换成电流 I，施加到热模型上，可以将 PN 结温度 Tj 作为电压进行监测。

热模型的下载方法

热模型可以从罗姆的主页得到。从每个产品页面中选择“模型和工具”选项卡，“设计模型”项目中有“热计算模型”，请从这里下载文件。



*1: T3Ster 是 Mentor Graphics Corp. 的产品。

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