热设计

计算功耗时的注意事项 静态动作篇

在设计电源等会产生大功耗的电路时，我们需要通过模拟或计算确认 MOSFET 等器件的结温未超过绝对最大额定值，但如果此处使用的参数不合适，则会导致错误的设计值。本应用笔记将介绍用于计算热设计相关功耗的参数的注意事项。

结温的计算公式

MOSFET 的结温一般如公式 1 所示，用结到环境温度的热阻乘以器件的功耗，再加上环境温度求出。结到环境温度的热阻包括如 Figure1 所示的结到壳体的热阻，包含了 TIM（Thermal Interface Material）的壳体到散热器的接触热阻，以及散热器到环境温度的热阻。

$$T_J = \left(R_{thJC} + R_{thCH} + R_{thHA}\right) \times P_D + T_A \quad [°C] \qquad (1)$$

R_{thJC}: 结到壳体的热阻 [°C/W]
R_{thCH}: 壳体到散热器的热阻 [°C/W]
R_{thHA}: 散热器到环境温度的热阻 [°C/W]
P_D: 器件的功耗 [W]

T_A: 环境温度 [°C]

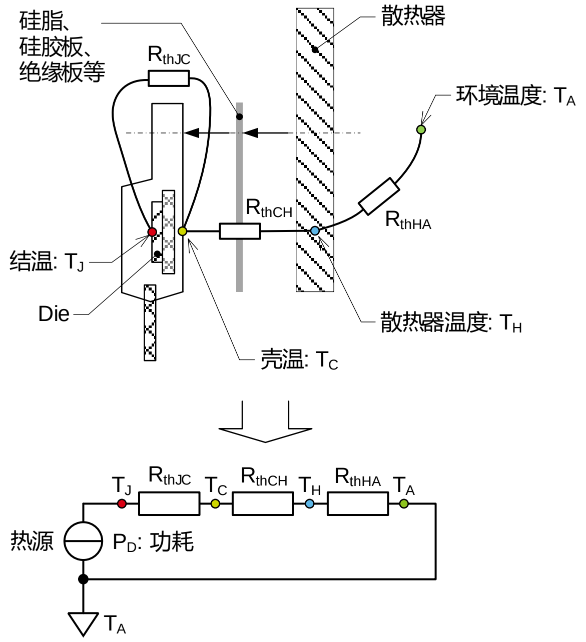

Figure 1.散热等效电路

使用参数的注意事项

器件功耗的求出方法因电路动作而异，在此为了简化说明，采用无开关动作的静态动作进行说明。

如公式（2）所示，MOSFET 导通时的功耗可以通过导通损耗求出，即通过将漏极电流的平方乘以漏极-源极间的导通电阻求出。

$$P_D = I_D^2 \times R_{DS(on)} \quad [W] \qquad (2)$$

I_D: 漏极电流 [A]
$R_{DS(on)}$: 漏极-源极间导通电阻 [Ω]

RDS (on) 可以参照规格书上的值，但应使用结温下的最大值，而非 25°C时的标准值。如果不使用结温下的最大值，则结温会被低估，最终导致错误的结果。

结温的计算方法

接下来将使用图表来说明计算结温的方法。以 N-channel SiC power MOSFET SCT4036KR 的规格书为例。

首先准备好计算所需的参数值。本例中，使用以下数值进行计算。

$I_D = 17$ [A]

$R_{DS(on)}$：后面会求出。

$R_{thJC} = 0.85$ [℃/W]　（来自规格书）

$R_{thCH} = 0.67$ [℃/W]

$R_{thHA} = 1.48$ [℃/W]

$T_A = 65$ [℃]

RthJC 使用规格书中记述的最大值（Figure2）。

●Thermal resistance

Parameter	Symbol	Values			Unit
		Min.	Typ.	Max.	
Thermal resistance, junction - case	R_{thJC} *9	-	0.65	0.85	K/W

Figure 2.
使用规格书上 RthJC 标准值的最大值

结温 T_J 一般用公式 1 计算，但求 PD 时使用的 RDS（on）必须使用结温下的值。由于目前 T_J 为未知数，所以无法决定 RDS（on）值使用多少度时的值。因此，首先需要计算各温度下 RDS（on）的最大值。

Figure3 是规格书上记载的 RDS（on）-结温的图表。可以使用图像数字化软件等读取数值。

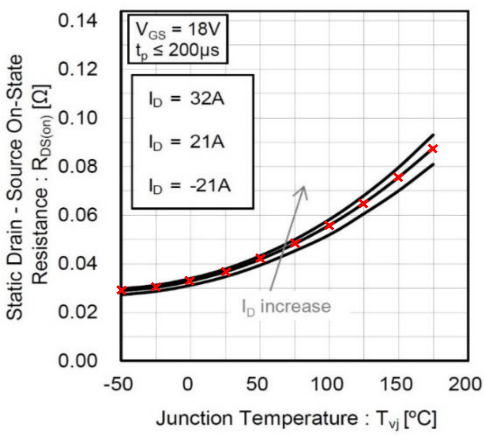

Figure 3.规格书中列出的 RDS（on）-结温图表

如 Figure4 所示将读取的值，用 Excel 做成图表。添加近似曲线并显示近似公式。

该图表是标准值，所以需要求出最大值。规格书上记载有如 Figure5 所示的导通电阻的规格。本例中，标准值为 36mΩ，最大值为 47mΩ，因此其比率为 1.3056 倍。接下来，使用刚才的近似公式求出各温度下的导通阻抗，将得到值乘以 1.3056 作为导通电阻的最大值。因为不需要低温，所以只计算高温部分即可（Figure6）。

Tj	Ron
-50	0.02887
-25	0.03013
0	0.03293
25	0.03675
50	0.04181
75	0.04819
100	0.05575
125	0.06493
150	0.07577
175	0.08768

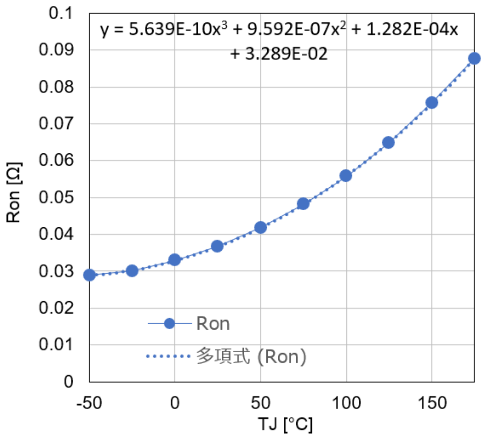

Figure 4.
用 Excel 将读取的数值图表化，并显示近似曲线和近似公式

Static Drain - Source on - state resistance	$R_{DS(on)}$ *8	V_{GS} = 18V, I_D = 21A, T_{vj} = 25°C	-	36	47	mΩ
		T_{vj} = 150°C	-	72	-	

Figure 5.规格书上导通阻抗的规格值

x	y	y×1.3056
Tj	Ron typ	Ron max
70	0.04676	0.06105
71	0.04703	0.06140
72	0.04730	0.06176
73	0.04758	0.06212
74	0.04786	0.06248
≈		≈
172	0.08619	0.11253
173	0.08670	0.11319
174	0.08721	0.11386
175	0.08772	0.11453

Figure 6.使用近似公式求出各温度下导通阻抗的最大值

接着求出各温度下的功耗。功耗的计算使用公式 2，各温度下的导通阻抗则使用 Figure6 中求得的值（Figure7）。

Tj	Ron	P_D
70	0.06104	17.64
71	0.06140	17.74
72	0.06176	17.85
73	0.06212	17.95
74	0.06248	18.06
≈		≈
172	0.11252	32.52
173	0.11319	32.71
174	0.11386	32.90
175	0.11453	33.10

Figure 7.使用公式 2 求出各温度下的功耗

接下来求出壳体的散热曲线。壳体的散热损耗 PC 可以通过公式 3 求出。

$$P_C = \frac{T_J - T_A}{R_{thJC} + R_{thCH} + R_{thHA}} \quad [W] \qquad (3)$$

T_J: 结温 [°C]

T_A: 环境温度 [°C]

R_{thJC}: 结到壳体的热阻 [°C/W]

R_{thCH}: 壳体到散热器的热阻 [°C/W]

R_{thHA}: 散热器到环境温度的热阻 [°C/W]

散热曲线呈直线变化，因此只需计算低温和高温两点即可（Figure8）。

T_J	$P_C = (T_J - T_A) / (R_{thJC} + R_{thCH} + R_{thHA})$
70	1.67
175	36.67

Figure 8.使用公式 3 求出散热曲线

将在前文中求得的功率损耗 PD 和散热损耗 PC 叠加显示在图表上（Figure9）。功率（发热）损耗 PD 和散热损耗 PC 相等（PD=PC）时的温度即为结温。图表中两曲线的交点即为结温，放大刻度读取温度（Figure10）。本例为 151.2℃，超过了器件的绝对最大额定值。

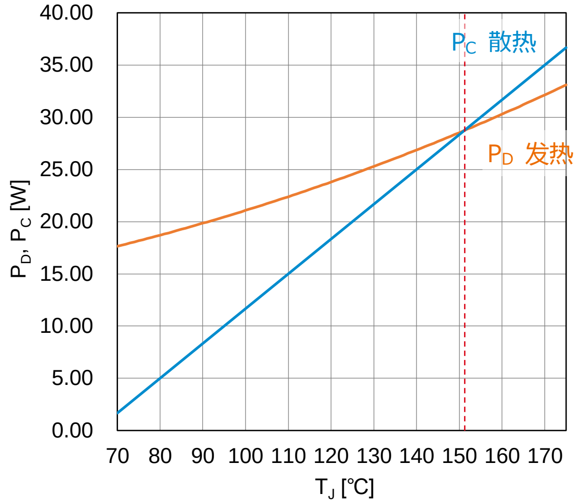

Figure 9.叠加显示功率损耗 PD 和散热损耗 PC

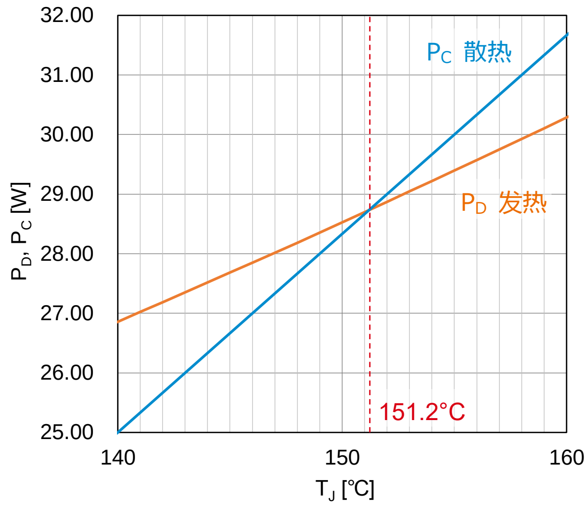

Figure 10.放大刻度以读取交点的温度

计算 PD 时使用的 RDS（on）如果使用了 25℃的最大值（Figure5）的话，请使用公式 1 和公式 2 计算结温为多少。

$$P_D = I_D^2 \times R_{DS(on)} = 17^2 \times 47 \times 10^{-3} = 13.58\ [W]$$

$$T_J = (R_{thJC} + R_{thCH} + R_{thHA}) \times P_D + T_A$$
$$= (0.85 + 0.67 + 1.48) \times 13.58 + 65 = 105.7\ [°C]$$

结果比正确计算的值低 45.5℃。像这样计算功耗时，如果不使用高温下的值，则可能会产生错误的估计，从而导致在实际设备中发生热故障。

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