Thermal measurement for D2PAK on PCB

Thermal design recommendation and guideline for SMD packages

About this document

Scope and purpose

This application note analyzes the thermal performance of 1700 V CoolSiC™ MOSFETs in TO-263 packages. These MOSFETs were soldered on the following printed circuit board (PCB) boards: 2-layer board with 1 oz. copper, 2-layer board with 2 oz. copper, 4-layer board with 1 oz. copper and 4-layer board with 2 oz. copper. The design of via matrix, diameters of vias, and the assembly of heat sinks were varied in each design. In this way, the temperature rises of SiC MOSFETs were tested. This investigation aimed to determine the best arrangement of MOSFETs on the PCBs for maintaining low temperature in the packages. The size and cost of the PCB were also considered. This application note allows customers and engineers to design their systems effectively taking advantage of the precise heat dissipation features presented in the experimental data.

Intended audience

Electronic engineers dealing with PCBs or other system designs.

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1 Introduction

Heat dissipation is a significant aspect of circuit design, especially in printed circuit board (PCB) layout. The interaction between transistors, packages and PCBs must be carefully designed to optimize heat dissipation. Heat sinks are not necessary for 1700 V CoolSiC™ MOSFETs in a surface-mount device (SMD) TO-263 package, which has reduced system complexity and cooling efforts in the PCB design. Therefore, using 1700 V CoolSiC™ MOSFET will save space and lower the cost of the PCB

Generally, the capability of the SMD to dissipate heat is weaker than the though-hole device , so customers may be concerned about the thermal transmission properties of this product. Hence, its thermal performance is investigated and evaluated in this application note.

1.1 Aim

In the following experiment, the temperature increases of a 1700 V SiC MOSFET in a TO-263 package were detected by studying different cases of PCB heat dissipation. From the test data, the effects of copper thickness, MOSEFT current, via diameters, via matrix size, and the existence of solder mask and heat sinks were analyzed. The investigation intended to determine the most suitable heat dissipation method under different constraints for customers and engineers.

1.2 Independent variables

This section introduces the important factors that influence the thermal performance of the MOSFET.

1.2.1 PCB layers

The thermal dissipation ability can be improved by the addition of PCB layers, as this increases the amount of copper placed on a board. In PCB design, the number of layers is an important parameter that needs to be considered. Using more layers also helps to minimize the electromagnetic interference between layers. So, the interference between signals decreases, and the life cycle of the PCB is extended. Additionally, the multilayer PCBs reduce the layout difficulty for complex circuits. On the other hand, building more layers will increase the cost of production.

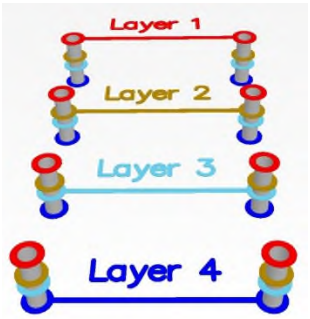

Figure 1 Vias in PCB layers

1.2.2 Copper thickness

The thickness of copper also influences the thermal transmission. It is measured using the unit ounce (oz.). An ounce (oz.) is a unit of weight that can be converted into grams (g) as follows: 1 oz. ≈28.35 g.

In the PCB industry, 1 oz. represents the thickness of copper, spread out evenly over an area of 1 square foot (FT^2). It is the weight per unit area to represent the average thickness of the copper foil.

$$1\mathrm{FT}^2 = 0.09290304m^2;\ \rho_{Cu} = 8.9\ \frac{g}{cm^3}$$

$$\text{thickness(t)} = \frac{mass(m)}{area(S)\cdot\ density(\rho)} = \frac{28.35g}{0.09290304m^2 \cdot 8.9\ \frac{g}{cm^3}} \approx 35\mu\text{m}$$

So, 1 oz. represents 35 µm copper thickness, 2 oz. represent 70 µm copper thickness.

1.2.3 Via size

Moreover, another critical factor is the diameter of the through-hole via on the board. As the size of the through-hole via increases, the effect of heat dissipation becomes more significant. However, the solder climbing problem may occur in the reflow welding process when the diameter is too large.

As shown in Figure 2 below, there are two groups of through-hole vias in the test: the via under the pad (solder joint of device) and the via around the pad (solder joint of device).

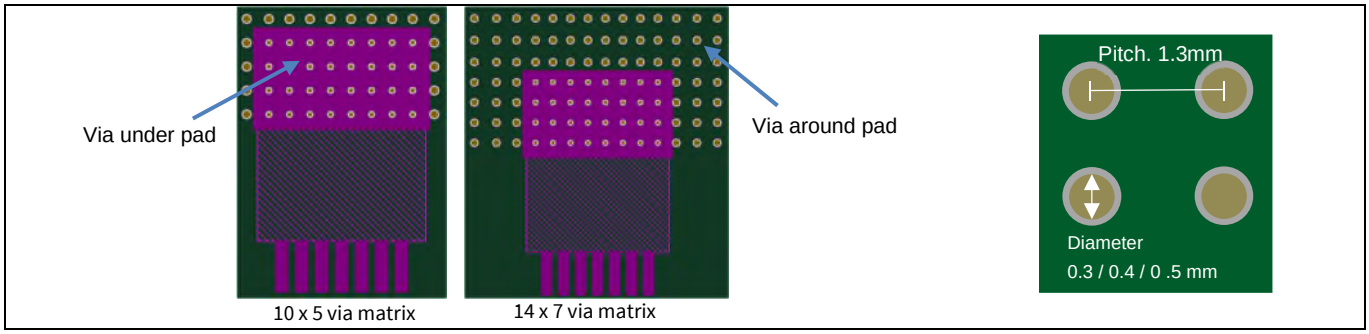

Figure 2 Via matrix number

1.2.4 Number of vias

Additionally, as vias help to transmit heat, increasing the number of vias will improve the performance. The via matrixs under the pad was kept the same in all measurement set-ups, while the number of outer vias was varied. Figure 2 displays an example of two different arrangements. The via pitch size is 1.3 mm in both cases. Apparently, the via matrix on the right side occupies a larger area. The area of copper around the pad increases as the via matrix grows, which causes the total copper size at the drain increases. If the area of copper under the pad is represented by S (67.45 mm^2), the total drain copper size of a 10x5 via matrix will be 1.6 S (112.52 mm^2). In comparison, a 14 x 7 via matrix uses 3.4 S (229.35 mm^2) area.

1.2.5 Heat sink

A heat sink is a device that transfers heat from heat-prone electronic components in electrical appliances to another medium, such as air. It can be made of aluminum alloy, brass or bronze in the form of plates, sheets, etc.

Figure 3 A variety of heat sinks on the market

Introduction

The efficiency of heat sinks depends on the thermal conductivity, k, of the materials. It measures the ability of heat conductance of a material. Table 1 lists the thermal conductivity of a range of materials. While silver has relatively high thermal conductivity and dissipates heat fast, using silver heat sinks will be expensive. Therefore, copper is commonly the best choice due to its reasonable price. Aluminum is also used when the requirements for thermal dissipation is not a priority, as its conductivity is much lower than with copper.

Table 1 The thermal conductivity of common materials

Material	k [W/(m·K)]	Material	k [W/(m·K)]	Material	k [W/(m·K)]
Si	150	Cu	401	Sn	64
SiO2	1.6	Brass	70-183	Pb	35
SiC	490	bronze	32-153	ABS	0.25
GaAs	46	Al	237	Glass	0.5-1.0
Au	317	Al2O3	45	FR4	0.2
Ag	429	AlN	150	Phenolic epoxy resin	0.2
Ni	90	Fe	80	air	0.01-0.04

2 Thermal measurement set-up

2.1 Measurement of power dissipation

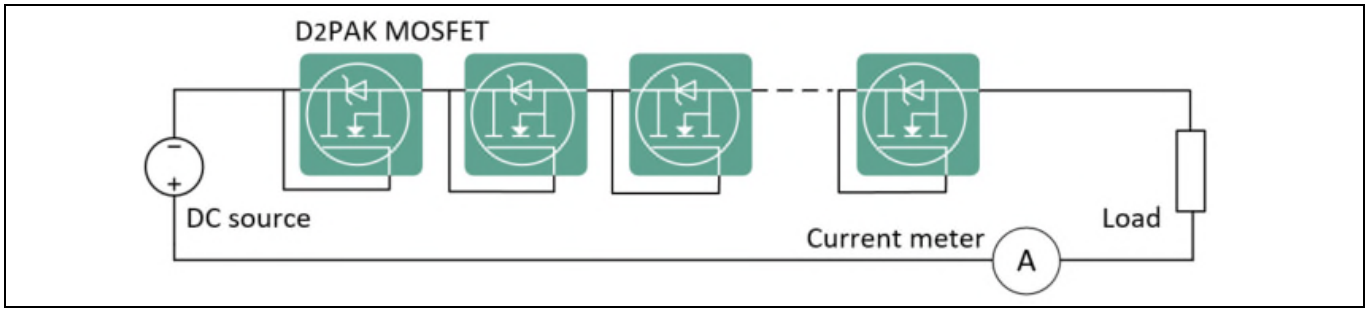

Figure 4 Measurement schematics

The circuit used for thermal measurements is shown in Figure 4. In the test, the following devices are used:

- DC Power Supply TPR3005-2DF
- DC Load Chroma 63110A
- Agilent Data Logger 34970A
- Digital Multimeter 34450A.

By using electronic loads, the current in the circuit was kept constant. The voltage drop of the volume diode was measured by the voltage meter. So, the power dissipation could be derived from the product of voltage and current.

2.2 Measurement of temperature rise

The temperature rise was measured using thermocouples and data acquisition instruments Figure 5 demonstrates the experimental set-up for temperature measurement.

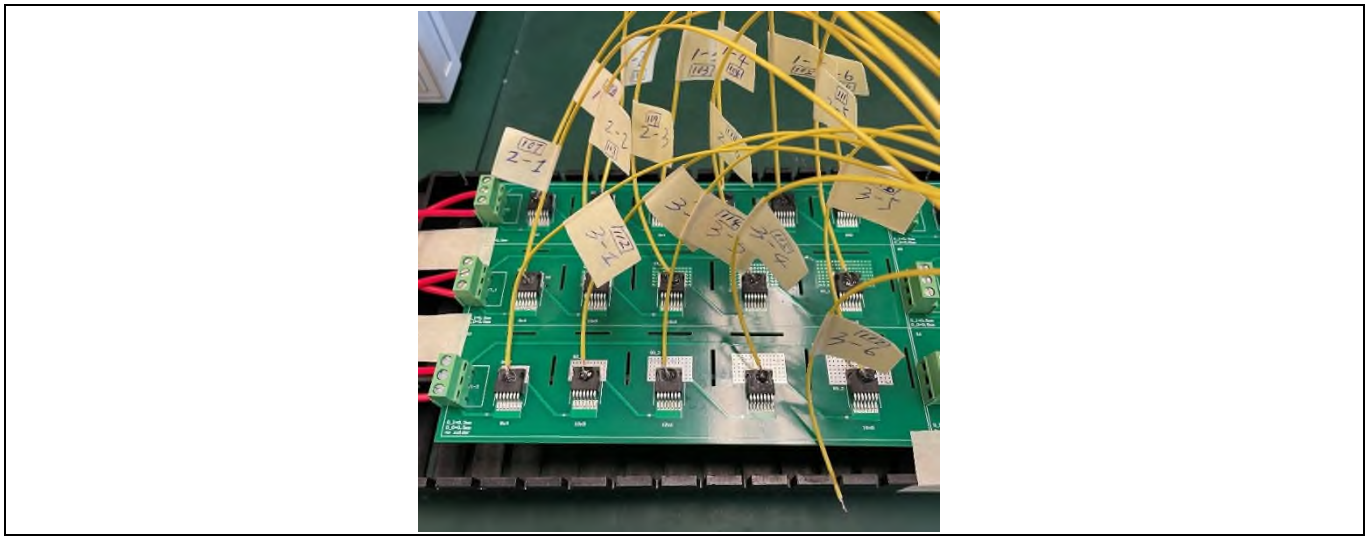

Figure 5 Temperature measurement set-up

Thermal measurement set-up

The J-type thermocouple used has high sensitivity, linearity and stability. The temperature range of the coverage measurement of a J-type thermocouple is -200 ~ 1200℃, although 0 ~ 750℃ is normally used. The tolerance is around 2℃.

To begin with, the open circuit temperature T_a was measured. Then, the circuit was closed and the temperature started to rise. 30 minutes later, the temperature T_c was recorded again when the heat dissipation was stabilized. The temperature rise was obtained from:

$$\Delta T_{c-a} = T_c - T_a.$$

Airflow reduces the accuracy of the measurement data, so the test platform was equipped with a windproof carton to get rid of this effect.

2.3 Temperature measurement point

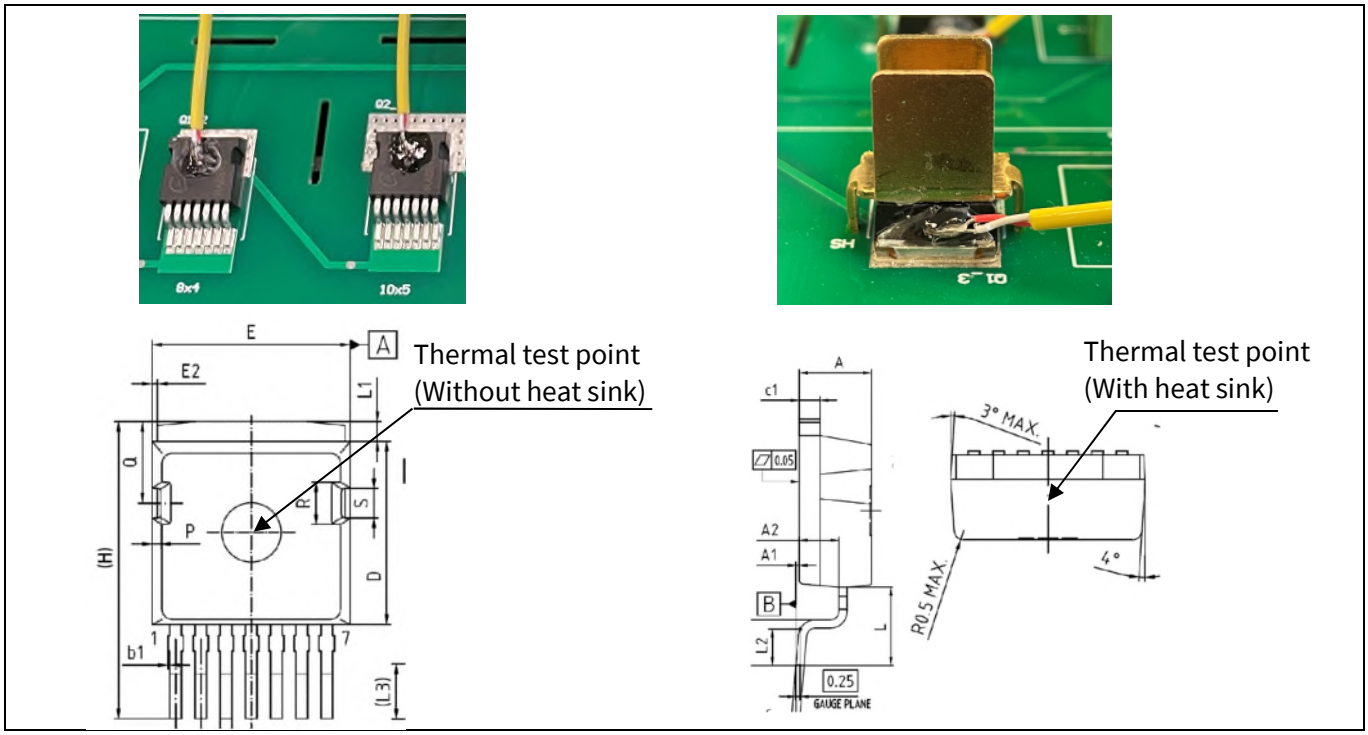

Figure 6 Temperature measurement point under two conditions

As shown in Figure 6, the measurement points are different in the two cases. The temperature is measured from the top of the packages without heat sinks attached. When a heat sink was presented, the measurement point was located at the side of the package.

3 Measurement parameters

3.1 Number of PCB layers and copper thickness

The difference between the four PCBs used in measurement are listed below:

- 2 layers with 1 oz. copper (2L1OZ)
- 2 layers with 2 oz. copper (2L2OZ)
- 4 layers with 1 oz. copper (4L1OZ)
- 4 layers with 2 oz. copper (4L2OZ)

3.2 Through-hole technology (THT) vias diameter

The diameters of the vias used in the experiment were 0.3 mm, 0.4 mm and 0.5 mm.

3.3 Via matrix size

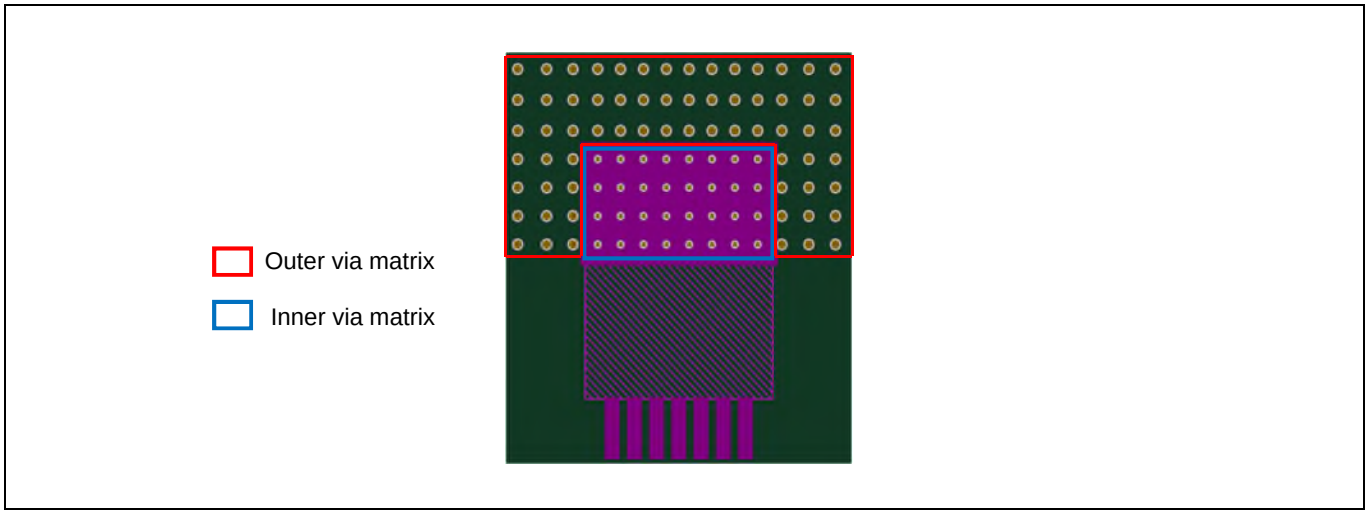

Figure 7 Outer and inner via matrix

Figure 7 above displays the boundary between the inner via matrix and outer via matrix. In order to check both the impact of the arrangement and diameters of the vias on the temperature change, the combinations of different sizes of outer via matrix and different diameters of inner vias were tested accordingly. The testing conditions are listed in Table 2, Table 3 and Table 4.

Table 2 Via matrix 1 (0.3 mm vias under the pad)

Via variants	1	2	3	4	5
Via matrix inner	8x4	8x4	8x4	8x4	8x4
Diameter inner	0.3 mm	0.3 mm	0.3 mm	0.3 mm	0.3 mm
Via matrix total	8x4	10x5	12x6	14x7	16x8
Diameter outer	n.a	0.5 mm	0.5 mm	0.5 mm	0.5 mm
Via pitch	1.3 mm	1.3 mm	1.3 mm	1.3 mm	1.3 mm
Total drain copper size	67.45 mm^2	112.52 mm^2	163.94 mm^2	229.35 mm^2	309.92 mm^2
Related ratio	S	1.67 S	2.43 S	3.4 S	4.6 S

Table 3 Via matrix 2 (0.4 mm vias under the pad)

Via variants	1	2	3	4
Via matrix inner	8x4	8x4	8x4	8x4
Diameter inner	0.4 mm	0.4 mm	0.4 mm	0.4 mm
Via matrix total	8x4	12x6	14x7	16x8
Diameter outer	n.a.	0.5 mm	0.5 mm	0.5 mm
Via pitch	1.3 mm	1.3 mm	1.3 mm	1.3 mm
Total drain copper size	67.45 mm^2	163.94 mm^2	229.35 mm^2	309.92 mm^2
Related ratio	S	2.43 S	3.4 S	4.6 S

Table 4 Via matrix 3 (0.5 mm vias under the pad)

Via variants	1	2	3	4
Via matrix inner	8x4	8x4	8x4	8x4
Diameter inner	0.5 mm	0.5 mm	0.5 mm	0.5 mm
Via matrix total	8x4	12x6	14x7	16x8
Diameter outer	n.a.	0.5 mm	0.5 mm	0.5 mm
Via pitch	1.3 mm	1.3 mm	1.3 mm	1.3 mm
Total drain copper size	67.45 mm^2	163.94 mm^2	229.35 mm^2	309.92 mm^2
Related ratio	S	2.43 S	3.4 S	4.6 S

3.4 Heat sink

Two kinds of heat sinks were tested as shown in Table 5 below.

Table 5 Two kinds of heat sink

Heat sink	HS1	HS2
		
Material	copper	Aluminum
Size (mm)	17 x 14.5 x 10 x 0.8	8.8 x 8.8 x 5
URL links	https://item.taobao.com/item.htm?spm=a230r.1.14.33.5a7c54dap97EQn&id=543677256194&ns=1&abbucket=20#detail	https://item.taobao.com/item.htm?spm=a1z10.3-c.w4002-21214618245.49.36155473n100vU&id=581976481584

3.5 Existence of solder mask

The thermal conductivity of solder mask is around 0.2 according to Table 1 above. As the thickness of solder mask was only 20 µm, it is not certain to what extent the solder mask influences the thermal dissipation. So, the thermal impact of it must be checked through the configuration shown in Figure 8 below.

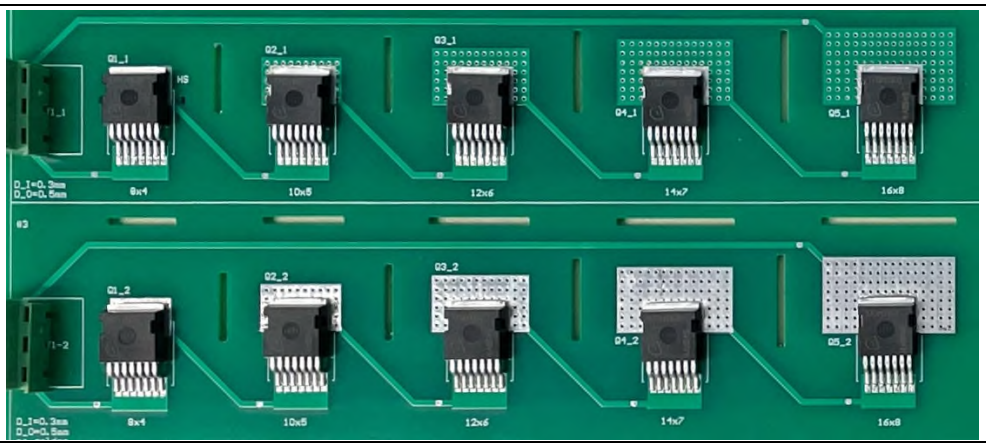

Figure 8 Thermal copper with and without solder mask

The diameter of the inner vias was 0.3 mm, and that of the outer vias was 0.5 mm.

Table 6 Parameters of inner and outer vias

Via variants	1	2	3	4	5
Via matrix inner	8x4	8x4	8x4	8x4	8x4
Diameter inner	0.3 mm	0.3 mm	0.3 mm	0.3 mm	0.3 mm
Via matrix total	8x4	10x5	12x6	14x7	16x8
Diameter outer	n.a.	0.5 mm	0.5mm	0.5 mm	0.5 mm
Via pitch	1.3 mm	1.3 mm	1.3mm	1.3 mm	1.3 mm
Total drain copper size	67.45 mm^2	112.52 mm^2	163.94 mm^2	229.35 mm^2	309.92 mm^2
Related ratio	S	1.67 S	2.43 S	3.4 S	4.6 S

3.6 Current

The current across the MOSFET body diode were set to the following values:

- 0.1 A
- 0.2 A
- 0.3 A
- 0.4 A
- 0.5 A

4 Test result and interpretation

The results are presented by charts in this chapter, based on the measurement plan described in the previous chapter. Then, conclusions are drawn from the test data.

4.1 The influence of different types of PCB

This first test measured the temperature rise of the PCBs with different via matrixes and currents. The trend of the temperature rise with different current was the same, so the data resulted from 0.3 A current was selected to be analyzed here. The diameter of the inner via was 0.3 mm, while the diameter of the outer via was 0.5 mm.

Table 7 Temperature rise ΔT of PCBs with different layers and via matrix at 0.3 A

Current is 0.3 A	Via matrix				
PCB variant	**8X4**	**10X5**	**12X6**	**14X7**	**16X8**
2L1OZ	46.84℃	42.06℃	36.71℃	35.03℃	29.37℃
2L2OZ	43.63℃	39.23℃	34.92℃	32.54℃	29.09℃
4L1OZ	40.25℃	35.46℃	33.09℃	30.70℃	28.78℃
4L2OZ	37.23℃	32.89℃	31.26℃	29.55℃	28.56℃

It is observed from Table 7 that there is a rising trend in ΔT in different via matrixes: 2L1OZ > 2L2OZ > 4L1OZ > 4L2OZ. As the size of the via matrix grows, the gap of ΔT between the 4 PCBs narrows. With the via matrix 8 x 4, the temperature rise of 4L2OZ is about 10℃ lower than that of 2L1OZ. With the via matrix 16x8, the temperature rise of 4 PCBs is almost the same.

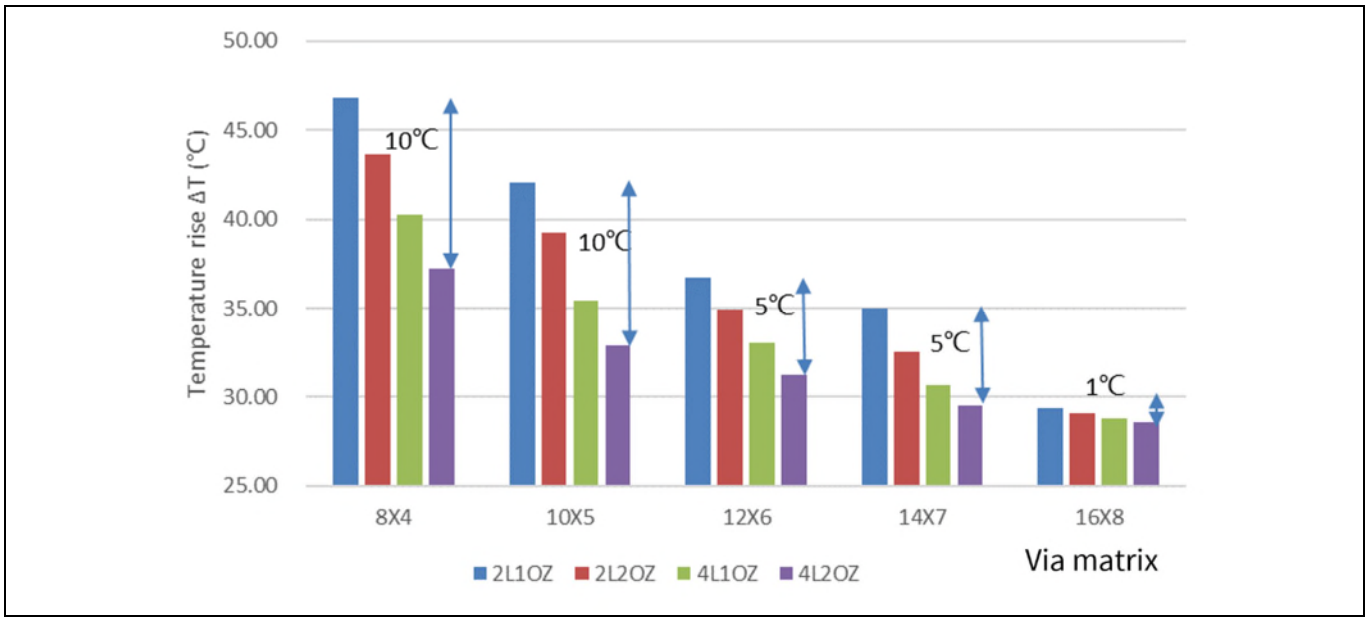

Figure 9 Temperature rise of different PCBs with different via matrix at 0.3 A

The reason for this is that the thickness of copper increases with the number of layers. As more copper is used in the PCB, the heat dissipation rate increases accordingly. When there are fewer vias presented, the copper is the main heat dissipation pathway. Due to the increase of the size of via matrix, the vias become the dominant heat dissipation pathway.

Therefore, when the via matrix is small, the heat dissipation can be increased by selecting the PCB with more layers or with greater copper thickness. But when the via matrix is large, increasing the number of PCB layers and copper thickness no longer produces a significant effect.

Conclusion 1 concerning PCB layer, copper thickness and number of vias

- When the total drain copper size is smaller than 3S (202.35 mm^2), adding PCB layers and copper thickness will improve thermal performance significantly. Also, adding PCB layers is more effective than increasing copper thickness.
- Otherwise, when the total drain copper size is greater than 3S (202.35 mm^2), the impacts of PCB layer and copper thickness is weakened. 1 oz. and 2 layers should be sufficient for cooling.

So, the top layer is very important. When the copper size is large enough, most of the heat is conducted by the top layer. Otherwise, we have to increase the number of PCB layers and copper thickness.

4.2 The influence of different current

This test measured the temperature rise under the current of 0.1 A to 0.5 A with different via matrixes. Because the trend was the same, the result of 4L1OZ PCB was selected for analysis here. The diameter of the inner via was 0.3 mm, while the diameter of the outer via was 0.5 mm. The data recorded in Table 8 below is displayed in Figure 10 below.

Table 8 Temperature rise under the current of 0.1 A to 0.5 A with different via matrixes on 2L1OZ PCB

PCB is 2L1OZ	Via matrix (℃)				
Current	**8X4**	**10X5**	**12X6**	**14X7**	**16X8**
0.1 A	14.64	13.08	11.67	10.68	9.47
0.2 A	29.62	26.83	24.33	22.65	19.49
0.3 A	46.84	42.06	36.71	35.03	29.37
0.4 A	59.67	52.24	46.31	43.24	37.82
0.5 A	73.14	65.88	59.96	56.68	50.69

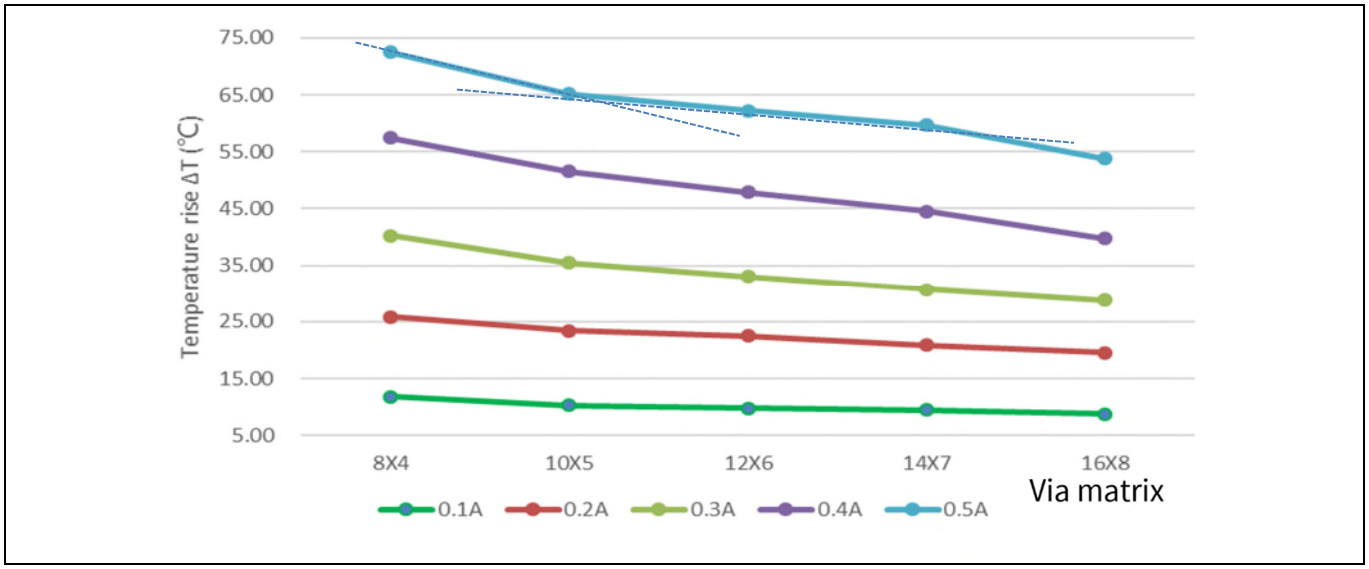

Figure 10 Temperature rise under the current of 0.1 A to 0.5 A with different via matrixes on a 2L1OZ PCB

It can be observed from the chart that if the current increases (which means the power increases), ΔT will increase. When the current is small, the difference between the temperature rises of various via matrixes is negligible. When the current is large, the difference is also large.

For a 2L1OZ PCB, at 0.1 A, the temperature rises with these 5 via matrixes are within 12 +/- 3℃. But at 0.5 A, the temperature change with an 8x4 via matrix is about 23℃ higher than 16x8. In other words, ΔT of 2L1OZ PCB is affected greater by the current, as the slope is steeper.

Therefore, when the current is small, the number of THT vias has little influence on the temperature rise. When the current increases, the number of THT vias has a greater influence on the temperature rise. It can also be seen from Figure 10 above that the temperature rise decreases with the growth of the via matrix at different currents.

Conclusion2 concerning current/power impact on the temperature rising:

Generally, power/current changing will not influence the total thermal resistance, as normally ΔT increases linearly with current.

4.3 The influence of solder mask

Solder mask affects the heat dissipation in some cases. This test measured and compared the temperature rise of different via matrixes on 4 types of PCB with/without solder mask. The diameter of the inner via was 0.3 mm, while the diameter of the outer via was 0.5 mm. The current was set to 0.3 A.

Table 9 Temperature rise in 2L1OZ/2OZ PCBs with/without solder mask at 0.3 A

	2L1OZ				2L2OZ			
Via matrix	**10X5**	**12X6**	**14X7**	**16X8**	**10X5**	**12X6**	**14X7**	**16X8**
With solder mask (℃)	42.06	36.71	35.03	29.37	39.23	34.92	32.54	29.09
Without solder mask (℃)	39.16	33.61	32.63	26.41	35.46	31.15	28.66	26.24
Temperature difference (℃)	2.90	3.10	2.40	2.96	3.77	3.77	3.88	2.85

The data in Table 9 above could be transferred to the Figure 11 below. The average temperature improvement was about 3 ~4℃.

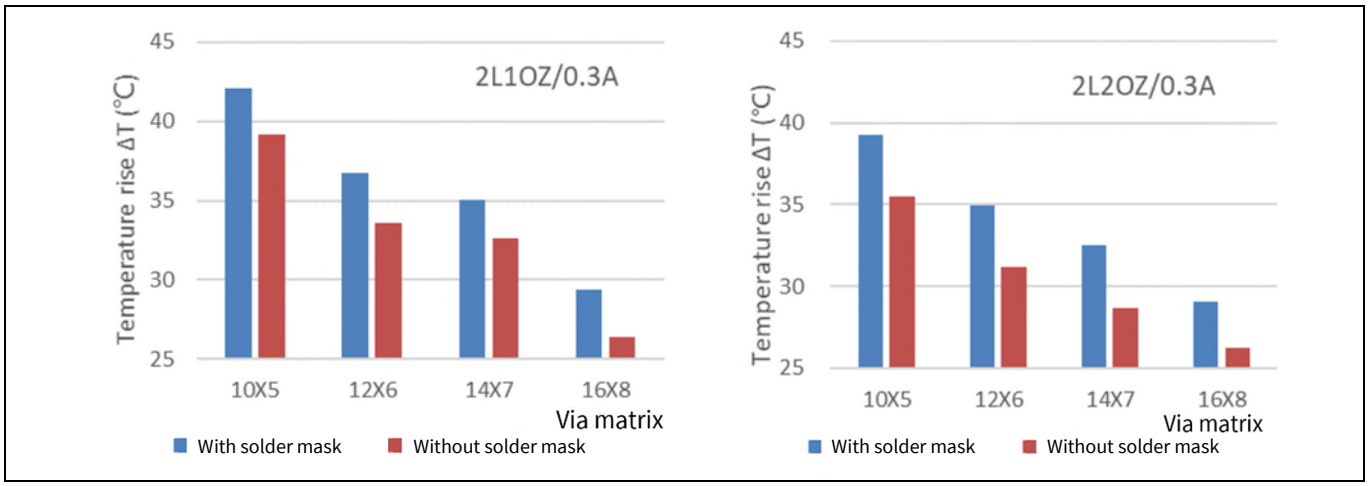

Figure 11 Temperature rise in 2L1OZ/2OZ PCBs with/without solder mask

The test results of 4L1OZ/4L2OZ PCBs are shown in Table 10 below.

Table 10 Temperature rise in 4L1OZ/2OZ PCBs with/without solder mask at 0.3A

	4L1OZ				4L2OZ			
Via matrix	**10X5**	**12X6**	**14X7**	**16X8**	**10X5**	**12X6**	**14X7**	**16X8**
With solder mask (℃)	35.46	33.09	30.70	28.78	32.89	31.26	29.55	28.56
Without solder mask (℃)	32.71	30.41	27.64	25.25	29.82	27.34	26.25	24.53
Temperature difference (℃)	2.75	2.68	3.06	3.53	3.07	3.92	3.30	4.03

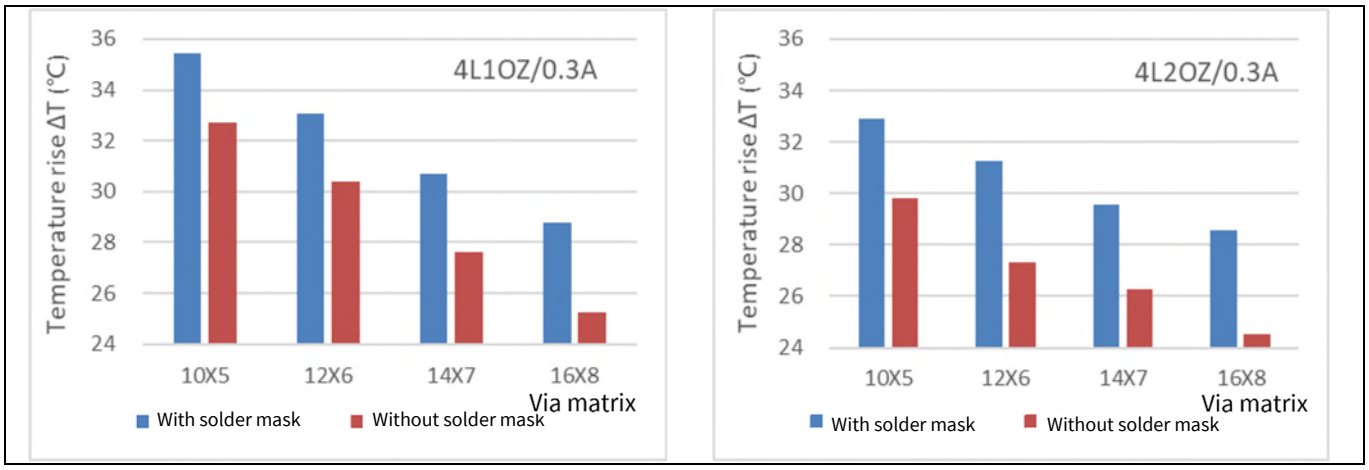

Figure 12 Temperature rise in 4L1OZ/2OZ PCBs with/without solder mask

The above charts show that the solder mask affects temperature rise. The temperature rise without solder mask is about 3-4℃ lower.

Table 11 Temperature rise in 4L1OZ PCB with/without solder mask at different currents

PCB type is 4L1OZ	0.1 A				0.3 A				0.5 A			
	10X5	12X6	14X7	16X8	10X5	12X6	14X7	16X8	10X5	12X6	14X7	16X8
With solder mask (℃)	10.22	9.79	9.40	9.17	35.46	33.09	30.70	28.78	65.18	62.20	60.65	53.76
Without solder mask (℃)	9.13	9.02	7.88	7.78	32.71	30.41	27.64	25.25	60.30	57.47	54.81	48.45
Temp. difference (℃)	1.09	0.77	1.52	1.39	2.75	2.68	3.06	3.53	4.88	4.55	5.84	5.31
Average (℃)	1.2				3				5.1			

Table 11 illustrates that the minimum difference between temperature rises with and without solder mask was about 1°C. The maximum difference was about 5°C.

Assuming the forward voltage was V_f=2.5 V, the total power at 0.3 A was $P = V_f \times I_f = 2.5\ V \times 0.3\ A = 0.75\ W$. The temperature difference was $\Delta T = 3℃$, the thermal resistance difference was $\Delta Rth_{ja} = \Delta T/P = 3℃/0.75\ W = 4\ ℃/W$.

Conclusion 3 concerning with / without solder mask

If the solder mask on the copper around the D2PAK device is removed, the total thermal resistance Rth_{ja} will decrease 4 ℃/W.

4.4 The influence of THT vias diameter

This part tested and analyzed the temperature rises with different diameters of THT vias on different kinds of PCB and with different currents.

The diameters of the inner vias were 0.3 mm, 0.4 mm and 0.5 mm, and the diameters of the outer vias were 0.5 mm. The current range was 0.1 A to 0.5 A.

At first, the temperature rises with different diameters of THT vias at 0.3 A current were analyzed.

4.4.1 Test on 2L1OZ / 2L2OZ at 0.3A

Table 12 Temperature rise in 2L1OZ/2L2OZ PCB at 0.3 A for different inner via diameters

Current at 0.3 A	2L1OZ (Unit: ℃)				2L2OZ (Unit: ℃)			
Via matrix	**8x4**	**12X6**	**14X7**	**16X8**	**8x4**	**12X6**	**14X7**	**16X8**
Inner via diameter 0.3 mm	46.84	36.71	35.03	29.37	43.63	34.92	32.54	29.09
Inner via diameter 0.4 mm	42.59	35.97	32.35	30.51	43.43	39.18	31.29	25.27
Inner via diameter 0.5 mm	44.85	39.76	37.44	31.04	40.98	38.53	34.66	29.95

The test results in Table 12 above could be transferred to Figure 13 below.

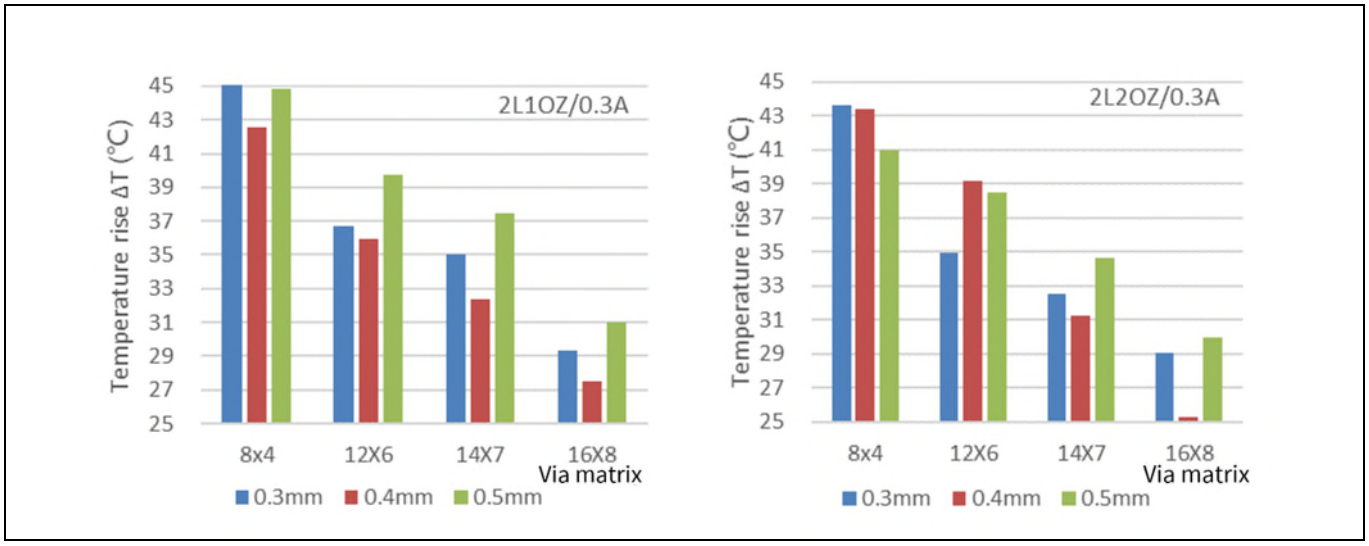

Figure 13 Temperature rise in 2L1OZ/2L2OZ PCB at 0.3 A

4.4.2 Test on 4L1OZ / 4L2OZ at 0.3 A

Similar thermal tests were carried out on the 4l1OZ and 4L2OZ to check their performance. The data is recorded in Table 13 below.

Table 13 Temperature rise in 4L1OZ/2OZ PCB at 0.3 A

Current 0.3 A	4L1OZ (Unit: ℃)				4L2OZ (Unit: ℃)			
Via rray	**8x4**	**12X6**	**14X7**	**16X8**	**8x4**	**12X6**	**14X7**	**16X8**
Inner via diameter 0.3 mm	40.25	33.09	30.70	28.78	37.23	31.26	29.55	28.56
Inner via diameter 0.4 mm	34.90	32.08	27.40	25.79	37.15	33.23	30.69	27.41
Inner via diameter 0.5 mm	36.29	32.87	30.06	29.82	39.33	35.47	32.26	29.43

The test results from Table 13 above could be transferred to Figure 14 below.

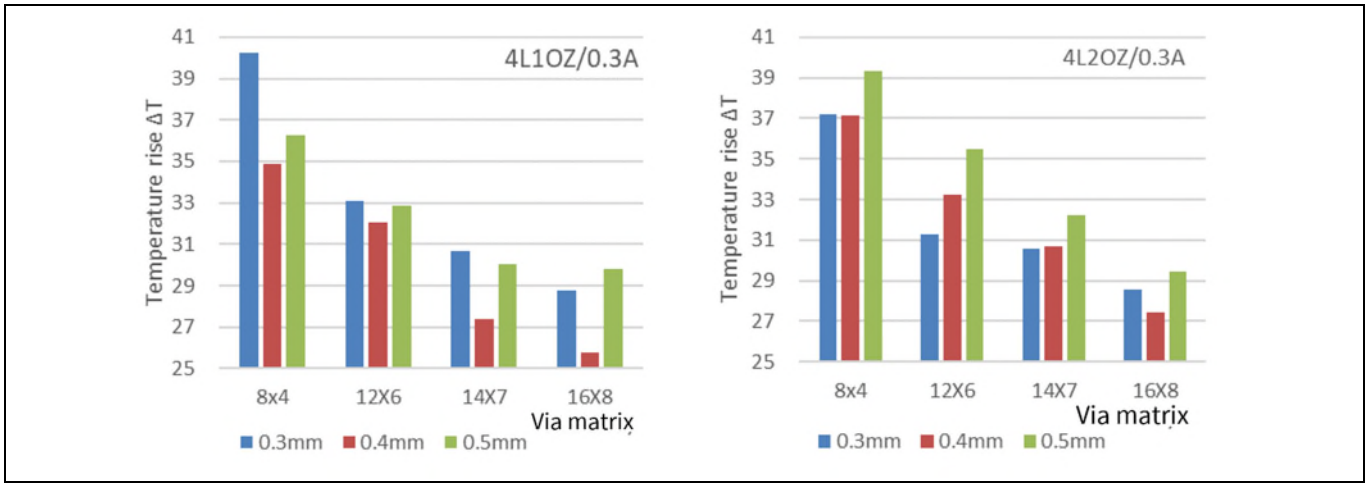

Figure 14 Temperature rise on 4L1OZ/2OZ PCB at 0.3 A

It can be observed from the above four figures that almost all via matrixes with a via diameter of 0.4 mm result in the lowest temperature rise on different PCBs. They have the most significant effect on the PCBs with 1 oz. copper thickness.

It should be noted that when the via matrix was small and a 2 oz. copper thickness PCB was applied, the 0.3 mm via diameter also had an advantage in heat dissipation. Sometimes it has better performance than the 0.4 mm one (for example, with the via matrix 12x6 on a 2 oz. copper PCB).

Moreover, the temperature rises with different diameters of THT vias under different currents are analyzed. Let us take a 4L1OZ PCB as an example:

Table 14 Temperature rise with 0.3, 0.4 and 0.5 mm inner via diameters at 0.1, 0.3 and 0.5 A on 4L1OZ

4L1OZ (Unit: ℃)	0.1 A				0.3 A				0.5 A			
	8x4	12X6	14X7	16X8	8x4	12X6	14X7	16X8	8x4	12X6	14X7	16X8
Inner via 0.3 mm	11.81	9.99	9.40	9.17	40.25	33.09	30.70	28.78	72.50	62.20	60.65	53.76
Inner via 0.4 mm	10.87	9.75	8.14	6.95	34.90	32.08	27.40	25.79	62.73	57.04	48.21	43.65
Inner via 0.5 mm	11.55	10.61	9.30	8.72	36.29	32.87	30.06	29.82	63.30	59.45	53.18	50.12

Table 14 further illustrates that under different current conditions, the 0.4 mm diameter had the advantage in heat dissipation. In other words, the temperature rises with the 0.4 mm via matrixes is lower. It is worth mentioning that this advantage is more significant in the case of high current.

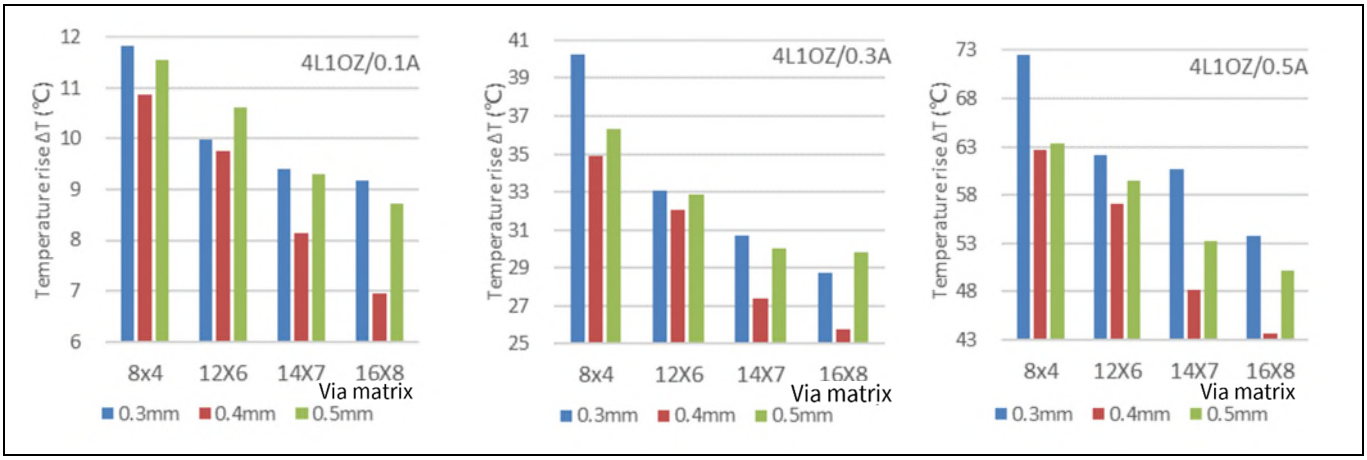

Figure 15 Temperature rise with 0.3, 0.4 and 0.5 mm diameters at 0.1, 0.3 and 0.5 A

According to the test result, we could conclude that 0.4 mm diameter produces the best thermal performance compared with 0.3 mm and 0.5 mm. It indicated that top-layer copper is very important for heat transmission, while the air inside the thermal vias is an inefficient thermal conductor. Hence, there is a trade-off between increasing the amount of copper and the volume of air through the vias.

Conclusion 4 concerning inner via diameters

0.4 mm inner via diameter results in the lowest temperature rise compared to 0.3 mm and 0.5 mm.

4.5 The influence of heat sink

Finally, the influence of the heat sink on temperature rise is considered. The experimental data is compared with the situation without a heat sink. The via matrix used in this test is 8 x 4, with no via matrix surrounding the pad. The diameter of the THT via was 0.4 mm. Figure 6 above and Table 5 above describe the heat sink assembly on the board. The measurement point was located at the side of the package in this test.

Table 15 Temperature rise of different heat sinks on 2L1OZ/2OZ and 4L1OZ/2OZ PCB at 0.1, 0.3 and 0.5 A

PCB type and current	0.1 A				0.3 A				0.5 A			
	2L1OZ	2L2OZ	4L1OZ	4L2OZ	2L1OZ	2L2OZ	4L1OZ	4L2OZ	2L1OZ	2L2OZ	4L1OZ	4L2OZ
Without heat sink (℃)	15.94	15.74	15.17	14.50	52.34	48.49	45.87	44.16	87.56	81.22	77.75	74.18
With heat sink HS1(℃)	14.19	12.54	12.10	12.01	44.94	44.18	42.67	41.09	79.02	74.75	67.93	64.00
With heat sink HS2(℃)	15.15	14.57	13.68	13.27	47.76	45.29	43.21	42.66	83.33	74.47	71.08	70.80

The test data in Table 15 above could be transferred to Figure 16 below.

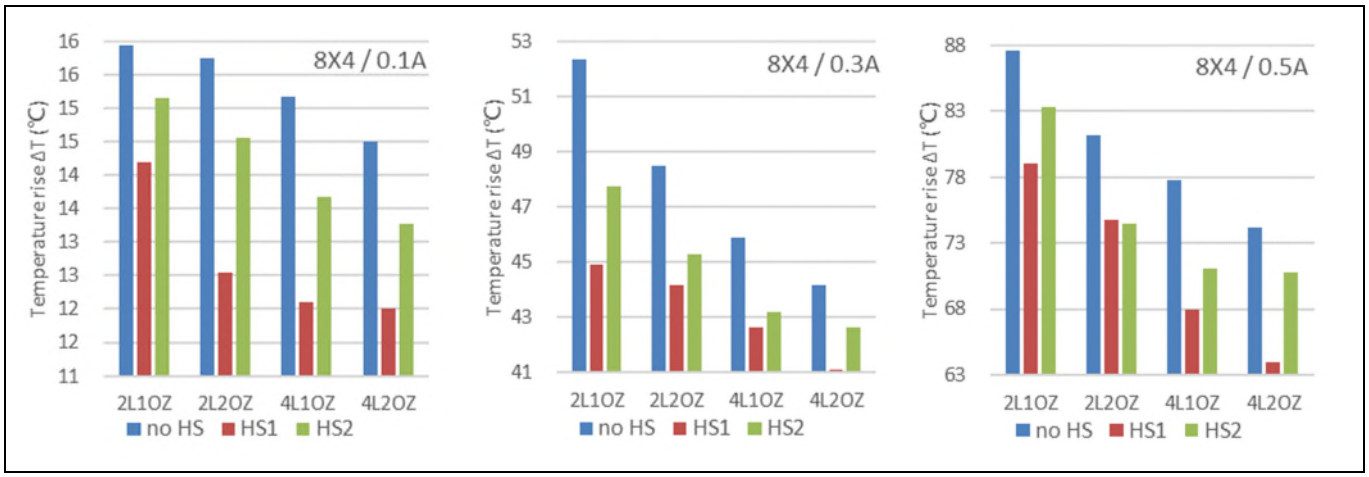

Figure 16 Temperature rise of different heat sinks at 0.1, 0.3 and 0.5 A

From the above chart, it is clear that heat sinks produce a positive effect on heat dissipation. Under large currents, adding a heat sink reduced the temperature rise by about 10℃.

Additionally, HS1 had better performance than HS2 in heat dissipation, since HS1 was made of copper while HS2 was made of aluminum.

Conclusion 5 concerning the selection of heat sink

Copper heat sinks help the heat dissipation to the largest extent.

4.6 Whether a heat sink is needed

This test compares the change of temperature rise under the two situations: increasing heat dissipation area and installation of heat sink. Finally, suggestions are made according to the heat dissipation requirements. Whether to increase the heat dissipation area or to install heat sinks can be justified by customers.

Take the 4L1OZ PCB as an example. A heat sink was installed on Group1. Via matrixes were modified in Group2. The diameter of the inner vias for both groups was 0.4 mm. The diameter of the outer vias in the Group 2 was 0.5 mm.

The temperature rises of the two groups cannot be compared directly because the measurement points of the two sets of data are different. So, we used the 4L1OZ PCB without outer via matrix and heat sink as a benchmark to compare the two groups of data. Th second column of Table 16 and Table 17 shows the temperature measured from the side and the center of the package on the same PCB layout.

Table 16 Temperature rise under the current of 0.1 A 0.3 A and 0.5 A with different heat sinks on 4L1OZ PCB

PCB type: 4L1OZ	Heat sink				
current	No HS	HS1		HS2	
0.1 A	15.17℃	12.10℃	ΔT= 3.07℃	13.68℃	ΔT=1.49℃
0.3 A	45.87℃	42.67℃	ΔT= 3.2℃	43.21℃	ΔT=2.66℃
0.5 A	77.75℃	67.93℃	ΔT= 9.82℃	71.08℃	ΔT=6.67℃

Table 17 Temperature rise under the current of 0.1 A 0.3 A and 0.5 A with different via matrixes on 4L1OZ PCB

PCB type: 4L1OZ	Via matrixes						
Via matrix	8X4 (67.45 mm2)	12X6 (163.94 mm²)		14X7 (229.35 mm²)		16X8 (309.92 mm²)	
0.1 A	10.87℃	9.75℃	ΔT=1.12℃	8.14℃	ΔT=2.73℃	6.95 ℃	ΔT=3.92℃
0.3 A	34.90℃	32.08℃	ΔT=2.82℃	27.40℃	ΔT=7.5℃	25.79 ℃	ΔT=9.11℃
0.5 A	62.73℃	57.04℃	ΔT=5.69℃	48.21℃	ΔT=14.52℃	43.65 ℃	ΔT=19.08℃

By subtracting the value of the 12x6, 14x7 and 16x8 via matrixes with 8x4 via matrix, the effect of increasing heat dissipation area on temperature rise can be found. In the same way, by subtracting the value of HS1 and HS2 with the value No HS, the effect of the heat sink on temperature rise can be found.

Based on the above analysis, the new data are as follows:

Firstly, the temperature of the 8x4 via matrix and the no-heat sink version was set to 0℃ for easier comparison. The negative number represents the amount of temperature decrease compared with '8x4 via matrix' or 'No HS.'

From the above tables, it can be concluded that the effect of installing the heat sink is greater than small heat dissipation area at 0.1, 0.3 and 0.5 A current. When the heat dissipation area increases, the heat dissipation will be better than the installation of heat sinks.

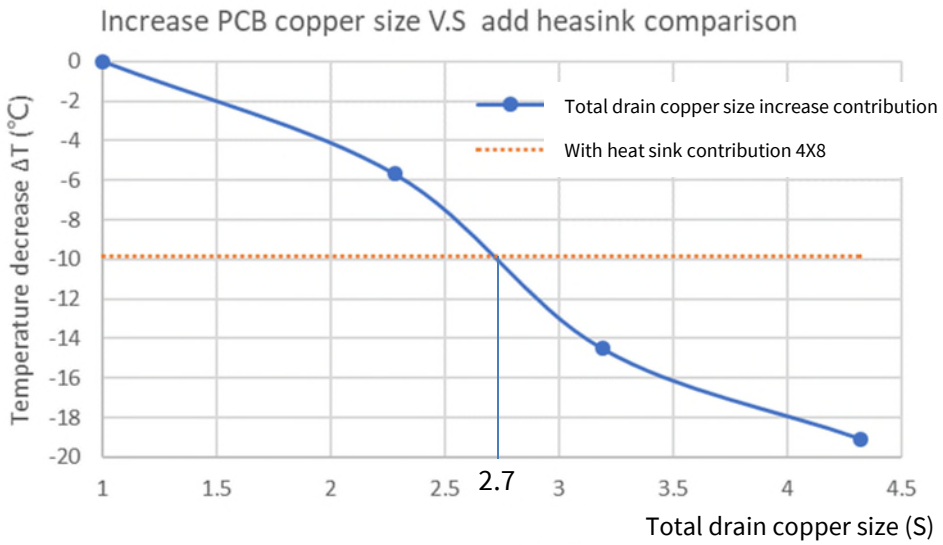

Figure 17 Thermal performance comparison of PCB copper size and HS1 at 0.5 A current

From the above figure, it can be seen more accurately that when the area is less than 2.7 S, the heat sink method is better. On the other hand, when the heat dissipation area increases, the more heat dissipation is better.

In other words, it is more effective to adopt the strategy of increasing the heat dissipation area in order to improve the heat dissipation greatly, when the heat dissipation area is large enough.

Conclusion 6 whether a heat sink is needed

Only when the total drain copper size is smaller than 2.7S (182.12 mm^2), it is necessary to consider adding a heat sink.

5 Conclusions

After testing the thermal behavior of a 1700 V SiC MOSFET in a TO-263 package under various conditions, we have summarized the key aspects for achieving the optimal cooling performance on PCBs. The test results show that the 4L2OZ board has a better cooling effect than the 2L1OZ board. However, the influence of the board type is less critical when the total drain copper area is greater than three times the copper area under the pad (≥200 mm^2). Also, it was found that 0.4 mm thermal vias under and around the pad led to lower temperature changes. The soldering mask around the pad increases the total thermal resistance R_{thja} by about 4°C/W. Moreover, a heat sink improves the thermal performance when the total drain copper area is limited to 2.7 times the copper area under the pad (< 182 mm^2). In this case, a copper heat sink is a better choice than an aluminum heat sink. The data shows that the MOSFET has excellent heat performance even without a heat sink, so the engineers should consider abandoning heat sinks in their design when the via matrix size is large.

6 References

[1] Datasheet: Infineon-IMBF170R1K0M1-DataSheet-v02_01-EN

[2] Application note: AN201708-Thermal Performance of surface mount semiconductor packages

[3] General Recommendations for Assembly of Infineon Packages [Online]. Available: https://www.infineon.com/dgdl/Infineon-General_Recommendations_for_Assembly_of_Infineon_Packages-P-v04_00-EN.pdf?fileId=5546d4625cc9456a015ccaf4a1fe3a32

Appendix: PCBs

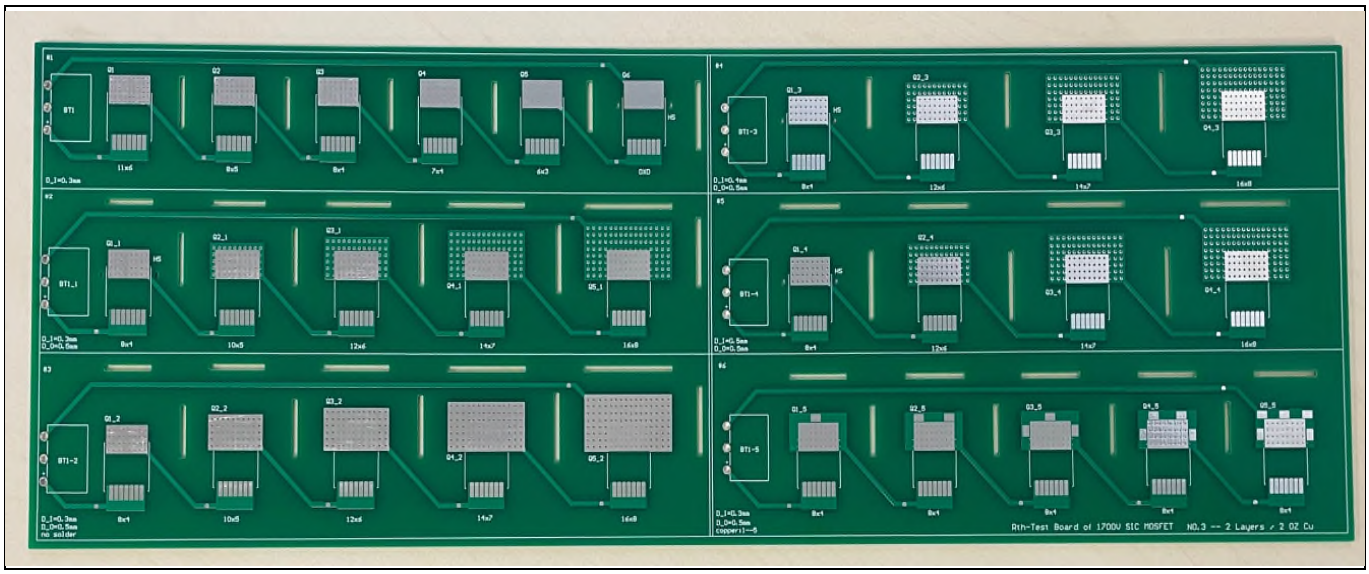

Figure 18 Tested PCBs

Revision history

Document version	Date of release	Description of changes
V1.0	2021/02/19	Initial creation
V1.1	2021/04/20	Updated
V2.0	2021/05/03	Updated

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