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# AN-9190

## Impact of DBC Oxidation on SPM® Module Performance

### Introduction

SPM® modules with Direct Bonded Copper (DBC), substrates aim for high thermal performance. The backside of the DBC substrate is formed by a bare copper layer which is supposed to contact external heat sink through thermal grease or any other Thermal Interface Material (TIM). The surface of the copper layer may get oxidized when it is exposed to the atmosphere during storage or the manufacturing process. Figure 1 and Figure 2 show examples of fresh and oxidized copper layer of SPM 3 series modules.

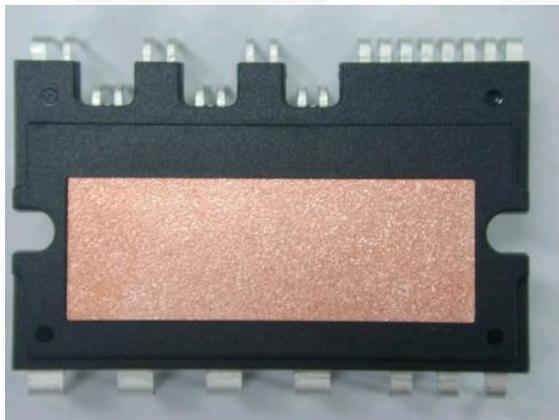


Figure 1. Fresh Sample

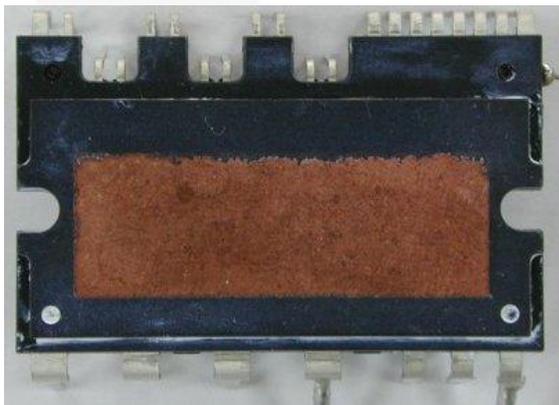


Figure 2. Oxidized Sample

The objective of this document is to clear up the concerns on any performance degradation due to the DBC oxidation by illustrating the effect of copper oxide layer on the thermal and electrical characteristics of SPM products and

proving that there is no impact on the performance of the module.

### What is DBC?

As seen from Figure 3, the DBC substrate is composed of a thin ceramic layer with a sheet of copper bonded to both sides by a high-temperature oxidation process. It is commonly used in power modules because of its excellent thermal conductivity. The top copper layer can be chemically etched using printed circuit board technology to form an electrical circuit, while the bottom copper layer is usually kept plain.

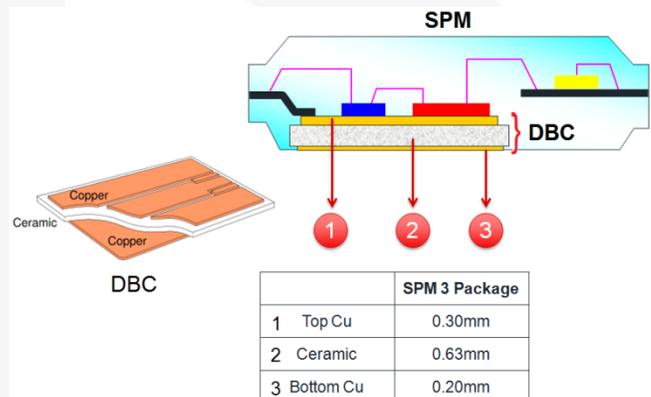
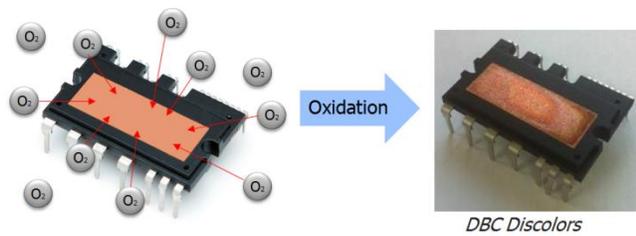


Figure 3. Structure of DBC

Alumina ( $Al_2O_3$ ) or Aluminum nitride (AlN) are used as ceramic material. AlN has much better thermal conductivity ( $> 150 W/mK$ ) than  $Al_2O_3$  (24-28 W/mK) but is much more expensive. The DBC substrates have excellent electrical insulation and good heat spreading characteristics.[1]

### What is Copper Oxidation?

The copper oxide consists normally of  $Cu_2O$  or  $CuO$ . The oxide layer is formed very thin and non-uniformly. For example, the thickness of oxide is known to reach around 125 nm when the copper surface is exposed to air at  $200^\circ C$  for 1 hour.[2] Actual measurements performed with special equipments show that thickness of oxidation layers of typical oxidized samples are from 1.8 nm to 14 nm.

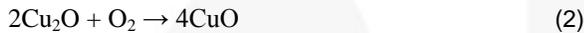


**Figure 4. DBC Oxidation Process**

Oxidation starts with the formation of  $\text{Cu}_2\text{O}$ , which is red or pink in color, when copper atoms initially react with oxygen molecules in the air. [3]



$\text{Cu}_2\text{O}$  can be further oxidized to  $\text{CuO}$  which is black in color.



In the case of SPM products, a very thin  $\text{Cu}_2\text{O}$  layer can be generated if exposed to air for a long time. It is known that the storage in a high temperature and high humidity setting would accelerate Cu oxidation. It is better to keep the devices in an environment with humidity of 50+25/-20% RH and temperature of  $24 \pm 5^\circ\text{C}$ .

## Thermal Performance

Thermal characteristics of semiconductor packages are represented as thermal resistance,  $R_{\text{thjc}}$  and  $R_{\text{thjs}}$ . The thermal resistance by conduction is expressed as following:

$$R_{\text{th,conduction}} = \frac{L}{kA} \quad (3)$$

where

$R_{\text{th,conduction}}$  is thermal resistance of solid conductor in [ $^\circ\text{C}/\text{W}$ ]

$L$  is thickness of solid conductor in [m]

$A$  is heat dissipation area of solid conductor in [ $\text{m}^2$ ]

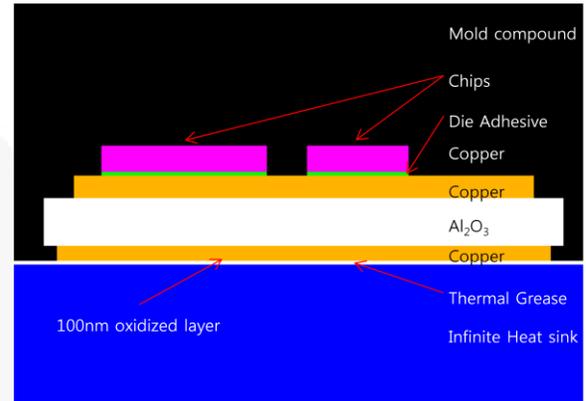
$k$  is thermal conductivity of solid conductor in [ $\text{W}/\text{m}^\circ\text{C}$ ]

$R_{\text{thjc}}$  is thermal resistance from junction-to-case and related to the package structure.  $R_{\text{thjs}}$  is thermal resistance from junction-to-sink and includes the thermal resistance of the contact between package and external heat sink.

Figure 5 shows a general cross sectional view of an SPM package mounted on a heat sink. Thermal grease with a thermal conductivity of  $1 \text{ W}/\text{mK}$  is commonly used in order to reduce the thermal resistance of the contact. The thickness of thermal grease is assumed to be around  $50 \mu\text{m}$  in SPM package.

$R_{\text{thjc}}$  and  $R_{\text{thjs}}$  of the SPM package is expressed as the sum of thermal resistances of each layer as shown in Table 1 and Table 2 respectively. These results are generated by FloTherm, thermal analysis software based on the dimensions and properties of the each material. The thermal resistance of copper oxide layer is 0.0021% of the  $R_{\text{thjc}}$ , and 0.0013% of the  $R_{\text{thjs}}$  when the thickness of copper oxide is

100 nm and thermal conductivity is  $10 \text{ W}/\text{m}^\circ\text{C}$ . Contribution of copper oxide layer to  $R_{\text{thjc}}$  and  $R_{\text{thjs}}$  is so small that the copper oxide layer does not affect the thermal performance of SPM package.



**Figure 5. Cross Section View of SPM Package**

**Table 1. Details of  $R_{\text{thjc}}$**

$R_{\text{thjc}}$	<b>100.00%</b>
$R_{\text{th\_chip}}$	9.78%
$R_{\text{th\_adhesive}}$	6.15%
$R_{\text{th\_Top Cu}}$	2.52%
$R_{\text{th\_Al}_2\text{O}_3 \text{ Substrate}}$	80.64%
$R_{\text{th\_Bottom Cu}}$	0.91%
<b><math>R_{\text{th\_OxideLayer}}</math></b>	<b>0.0021%</b>

**Table 2. Details of  $R_{\text{thjs}}$**

$R_{\text{thjs}}$	<b>100.00%</b>
$R_{\text{th\_chip}}$	5.80%
$R_{\text{th\_adhesive}}$	3.65%
$R_{\text{th\_Top Cu}}$	1.50%
$R_{\text{th\_Al}_2\text{O}_3 \text{ Substrate}}$	47.85%
$R_{\text{th\_Bottom Cu}}$	0.54%
<b><math>R_{\text{th\_OxideLayer}}</math></b>	<b>0.0013%</b>
$R_{\text{th\_thermal Grease}}$	40.67%

Actual measurements of thermal resistance were also performed with the FSBB30CH60 and FSBB20CH60 to prove the software analysis. Measured  $R_{\text{thjc}}$  with oxidized samples and non-oxidized samples showed similar values and the difference is smaller than measurement tolerance 5%. According to the test result and simulation outcome, it can be concluded that Oxidation of DBC does not have any impact on thermal resistance.

## Isolation Voltage

DBC oxidation does not have any impact on electrical characteristics of SPM products because all electrical components such as IGBT's, diodes, IC's, bootstrap diodes, lead-frame, and bonding wires are totally isolated from the external copper layer of the DBC.

There is no degradation of isolation voltage. It is the ceramic layer in the middle of the DBC that provides the high level of isolation. Therefore, the oxidized copper layer does not have any impact on the isolation voltage level of SPM products.

## References

- [1] [http://en.wikipedia.org/wiki/Power\\_electronic\\_substrate](http://en.wikipedia.org/wiki/Power_electronic_substrate).
- [2] S. Cho, K. Paik, and Y. Kim, "The effect of the oxidation of Cu-Base Lead Frame on the Interface Adhesion between Cu Metal and Epoxy Molding Compound", *IEEE Transactions on Components, Packaging, and Manufacturing Technology-Part B*, Vol20, No2, May1997, pp167~175.
- [3] [http://en.wikipedia.org/wiki/Copper%28I%29\\_oxide](http://en.wikipedia.org/wiki/Copper%28I%29_oxide).

## Related Resources

[FSBB30CH60C – Product Folder](#)

[FSBB30CH60D – Product Folder](#)

[FSBB10CH120D – Product Folder](#)

[FSBB10CH120DF – Product Folder](#)

[FNA23512A – Product Folder](#)

[FNA22512A – Product Folder](#)

[FNA21012A – Product Folder](#)

[AN-9086 — SPM® 3 Package Mounting Guidance](#)

[RD-404 — Reference Design of FSBB10CH120D](#)

[RD-354 — Reference Design of 1200V Motion SPM® 2 Series](#)

[AN-9075 - Users Guide for 1200V SPM® 2 Series](#)

[AN-9076 - Mounting Guide for New SPM® 2 Package](#)

[AN-9079 - Thermal Performance of 1200V Motion SPM® 2 Series by Mounting Torque](#)

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