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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.

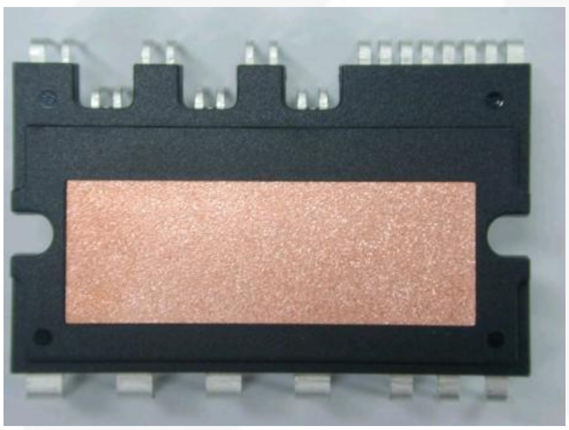


Figure 1. Fresh Sample

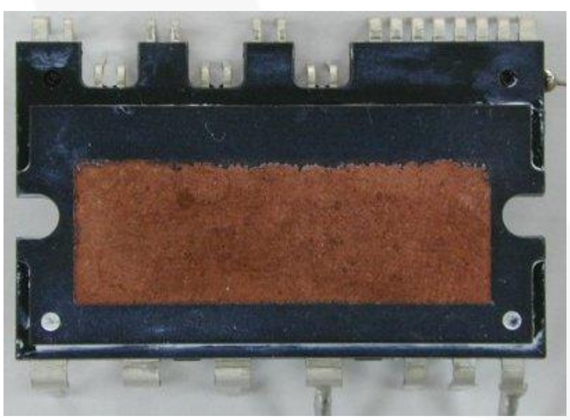
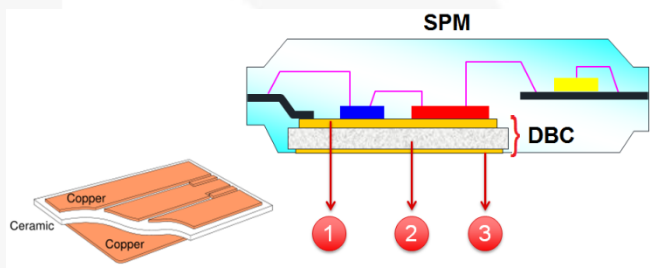


Figure 2. Oxidized Sample

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.



		SPM 3 Package
1	Top Cu	0.30mm
2	Ceramic	0.63mm
3	Bottom Cu	0.20mm

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°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.

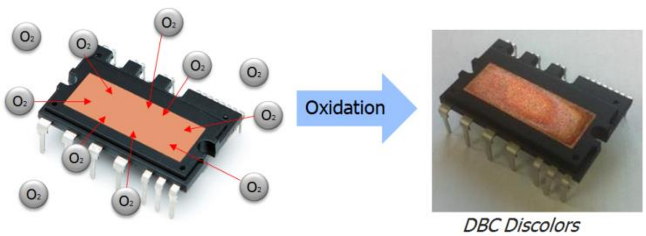


Figure 4. DBC Oxidation Process

Oxidation starts with the formation of Cu2O, which is red or pink in color, when copper atoms initially react with oxygen molecules in the air. [3]

$$2Cu + O_2 \rightarrow Cu_2O \quad (1)$$

Cu_2O can be further oxidized to CuO which is black in color.

$$2Cu_2O + O_2 \rightarrow 4CuO \quad (2)$$

In the case of SPM products, a very thin Cu_2O 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 oxidization. It is better to keep the devices in an environment with humidity of 50+25/-20%RH and temperature of 24±5°C.

Thermal Performance

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

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

where

$R_{th,}$ conduction is thermal resistance of solid conductor in [°C/W]

L is thickness of solid conductor in [m]

A is heat dissipation area of solid conductor in [m^2]

k is thermal conductivity of solid conductor in [W/m°C]

R_{thjc} is thermal resistance from junction-to-case and related to the package structure. R_{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 W/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 µm in SPM package.

R_{thjc} and R_{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_{thjc}, and 0.0013% of the R_{thjs} when the thickness of copper oxide is 100 nm and thermal conductivity is 10 W/m°C. Contribution of copper oxide layer to R_{thjc} and R_{thjs} is so small that the copper oxide layer does not affect the thermal performance of SPM package.

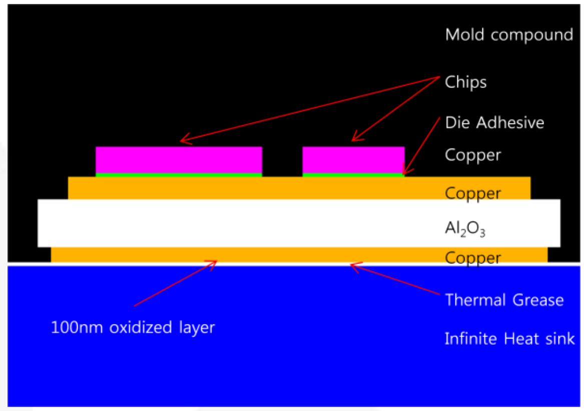


Figure 5. Cross Section View of SPM Package

Table 1. Details of R_{thjc}

R_{thjc}	100.00%
R_{th_chip}	9.78%
$R_{th\_adhesive}$	6.15%
R_{th_Top} Cu	2.52%
$R_{th\_Al_2O_3}$ Substrate	80.64%
R_{th_Bottom} Cu	0.91%
$R_{th\_OxideLayer}$	0.0021%

Table 2. Details of R_{thjs}

R_{thjs}	100.00%
R_{th_chip}	5.80%
$R_{th\_adhesive}$	3.65%
R_{th_Top} Cu	1.50%
$R_{th\_Al_2O_3}$ Substrate	47.85%
R_{th_Bottom} Cu	0.54%
$R_{th\_OxideLayer}$	0.0013%
$R_{th\_thermal}$ Grease	40.67%

Actual measurements of thermal resistance were also performed with the FSBB30CH60 and FSBB20CH60 to prove the software analysis. Measured R_{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.

Conclusion

The exposed DBC copper layer of the SPM package can be oxidized during storage or the manufacturing process. The oxide layer formed is very thin on the outer surface. But the impact of the oxidation on thermal resistance is negligible, and there is no degradation of isolation voltage of the package. The oxidized copper layer does not affect thermal performance, electrical characteristics and product reliability.

References

[1] *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.*

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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