 DOI:10.30420/566414089

Different Zth model influence on discrete IGBT Tvj calculation in main inverter application

Hao Zhang[1], Gerardo Pantoja[2], Zhenbo Zhao[1],

[1] Infineon Technologies China Co., Ltd. Shanghai, China
[2] Infineon Technologies AG, Germany

Corresponding author: Hao Zhang, hao.zhang@infineon.com
Speaker: Hao Zhang, hao.zhang@infineon.com

Abstract

In the main inverter of xEV application, there is relatively little research and paper on IGBT discrete thermal resistance network modeling and the virtual junction temperature calculation. To address this gap, this paper focuses on the latest reflow solderable IGBT discrete products (TO247) and employs Ansys FEM 3D modeling to extract thermal resistance for the three different thermal resistance network (Zth) models. Furthermore, PLECS simulations for typical inverter conditions were used to make a comparison of different Tvj calculations, which based on the three Zth models of the discrete IGBT (between case and cooling water). This paper presents a detailed comparison of the results and methods used and introduces a novel model that aims to provide the most accurate virtual junction temperature calculations.

1 Introduction: the analysis of traditional TO247 ZthJW thermal networks

As found in many technical articles and application notes[1-4], a basic model for estimating the virtual junction temperature consists of using independent or self-heating networks to estimate the temperature of the IGBT and Diode in power module or discrete package.

In this approach thermal network elements are used in series representing the ZthJC, ZthCH and ZthHW as Fig.1 shown,

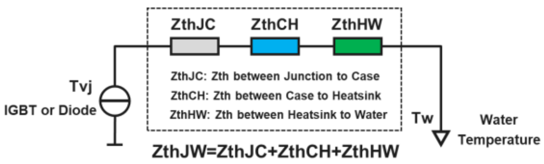


Fig.1 Typical Thermal Network of ZthJW

it provides enough accuracy when the intrinsic behavior of the topological switch is mainly using either the IGBT or the Diode during operation.

In main inverter of xEV application, the latest reflow solderable IGBT discrete and solution could provide lower system Rth and better cost performance, with replacing isolation and TIM layers replaced by the the DCB/AMB and solders as Fig.2 shown. The following sections of thermal network analysis, comparison and calculations are mainly based on the reflow solderable TO247 solution.

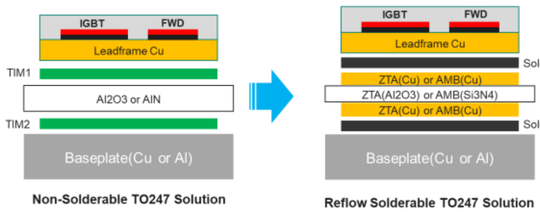


Fig.2 Reflow Solderable TO247 Solution

1.1 the structure of traditional TO247 ZthJW thermal network

The thermal network structure of traditional TO247 ZthJW from Chip Junction Temperature (Tvj) to Cooling Water Temperature (Tw) as presented in Fig. 3 below:

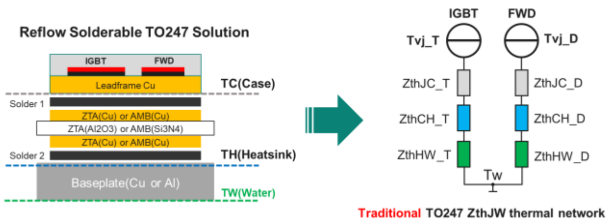


Fig.3. Traditional TO247 ZthJW Thermal Network

ISBN 978-3-8007-6414-3

 DOI:10.30420/566414089

In the traditional network identification method, a power source is placed in every IGBT or FWD and an ideal sink is placed below the heatsink. Then the temperature gradient is calculated using FEM method and based on the independent heating of the devices, the Zth(Rth) elements can be constructed for the different layers.

1.2 the limitation of traditional TO247 ZthJW thermal network

In a traction inverter application for example, the diode and IGBT will exchange the current in every switching instance due to the inductive behavior of the load.

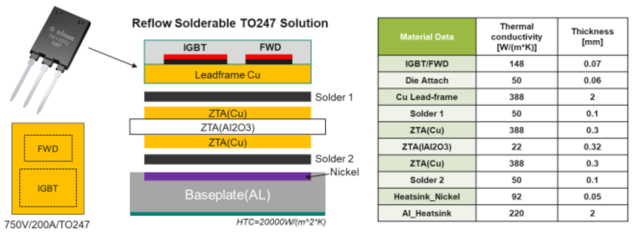
In this case the IGBT and the Diode which are placed in the same leadframe, the diode will start operation with the temperature produced by the energy dissipated in its own PN junction plus the additional heat transferred from the nearby IGBT.

As presented above, the traditional thermal network ZthJW of IGBT and FWD are independent. It does not consider the thermal coupling between IGBT and FWD.

A more complex network is needed to be able to calculate the temperature with accuracy.

1.3 Thermal coupling impact on TO247 ZthJC, ZthCH and ZthHW

In order to study the thermal coupling influence on the inside and outside of TO247 discrete, the 3D model of reflow solderable TO247 solution setup was created as Fig.4 below,



Material Data	Thermal conductivity [W/(m*K)]	Thickness [mm]
IGBT/FWD	148	0.07
Die Attach	50	0.06
Cu Lead-frame	388	2
Solder 1	50	0.1
ZTA(Cu)	388	0.3
ZTA(lAl2O3)	22	0.32
ZTA(Cu)	388	0.3
Solder 2	50	0.1
Heatsink_Nickel	92	0.05
Al_Heatsink	220	2

Fig.4. Traditional TO247 ZthJW Thermal Network

based on Ansys simulations results, the normalized influence by thermal coupling in the layer of RthJC, RthCH and RthHW are introduced in Fig.5.

for example, the RthJC_N of IGBT means, the ratio between the cross-heated(D2T) and the self-heated(T2T) thermal resistance, and the higher of the ratio the higher influenced on the thermal coupling in the layer (RthJC, RthCH or RthHW).

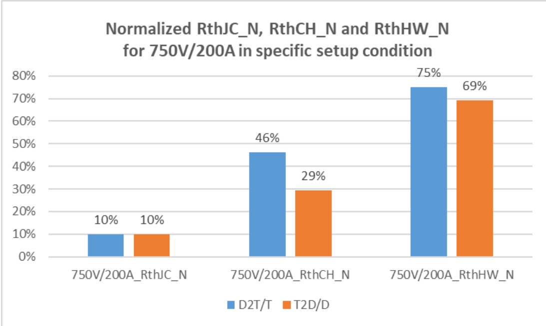


Fig.5. the normalized thermal coupling influence of RthJC_N, RthCH_N and RthHW_N based on Fig.4 reflow solderable TO247 solution setup

The above normalized results indicated that the thermal coupling influence on the layer of RthCH(29%~46%) and RthHW(69%~75%) is much more significant and important than that on RthJC(~10%).

Further, the RthJC may only take around 30% of the total RthJW for typical reflow solderable water cooling condition. (It would be even lower, if TO247 being used in air cooling conditions or still being mounted with TIM in the system, etc)

Overview, the influence by thermal cross inside the TO247 (RthJC) is relatively small ratio, if considering the proportion in total RthJW. So, the thermal cross of RthJC is ignored in this paper.

2 the new TO247 ZthJW thermal network A and B (per switch)

2.1 the structure of new TO247 ZthJW thermal network A (per switch)

As Fig.6, the ZthCH_TD and ZthHW_TD are the thermal resistance per switch in IGBT discrete thermal network, which can be extracted from the Ansys FEM simulations.

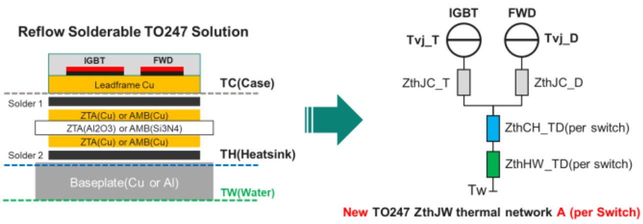


Fig.6. New TO247 ZthJW Thermal Network A (per switch)

2.2 the structure of new TO247 ZthJW thermal network B (full coupling)

As Fig.7, the ZthCH_T2D and ZthHW_T2D means the thermal resistance influenced by IGBT, and

ISBN 978-3-8007-6414-3

 DOI:10.30420/566414089

the ZthCH_D2T and ZthHW_D2T means the thermal resistance influenced by FWD.

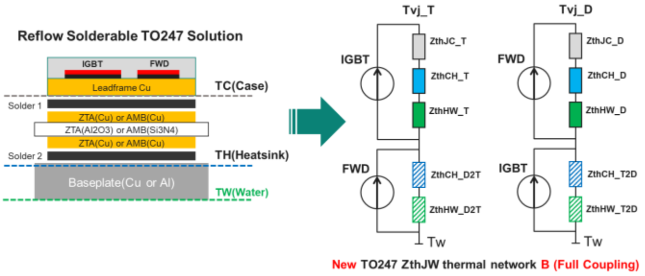


Fig.7. New TO247 ZthJW Thermal Network B (full coupling)

Both new thermal network A and B do consider the thermal coupling between IGBT and FWD on ZthCH and ZthHW, which need more quantitative analysis for the understanding of differences the two (A and B) and the traditional one in real applications.

3 System simulation analysis and comparison based on three ZthJW thermal network

3.1 Three ZthJW thermal networks (extraction from Ansys FEM simulations)

Based on above material data in Fig.4, the 3D model was built in Ansys, and some typical conditions are simulated below:

- Case1: Only IGBT chip heating
- Case2: Only FWD chip heating
- Case3: Both IGBT and FWD chips heating (typical drive mode)
- Case4: Both IGBT and FWD chips heating (typical generation mode)

some key Rth values for the above ZthJW thermal networks extracted from Ansys FEM simulations

Traditional	T (per IGBT)	D (per FWD)
RthCH /K/W	0.13	0.17
RthHW /K/W	0.12	0.13

Fig.8. TO247 ZthJW Thermal Network(traditional)

New A	T+D (per switch) Drive mode	T+D (per switch) Generation mode
RthCH /K/W	0.10	0.11
RthHW /K/W	0.11	0.11

Fig.9. TO247 ZthJW Thermal Network A

New B	T	T2D	D	D2T
RthCH /K/W	0.13	0.05	0.17	0.06
RthHW /K/W	0.12	0.09	0.13	0.09

Fig.10. TO247 ZthJW Thermal Network B

3.2 Inverter system simulations analysis and comparison by PLECS

As shown in Fig.11 and Fig.12, the PLECS simulation results based on three thermal networks at typical inverter and generator conditions as below. And the Tvj_T1x and Tvj_D1x are the simulation results by traditional thermal network, and the Tvj_T1y and Tvj_D1y are the simulation results by new thermal network A, and the Tvj_T1z and Tvj_D1z are the simulation results by new thermal network B.

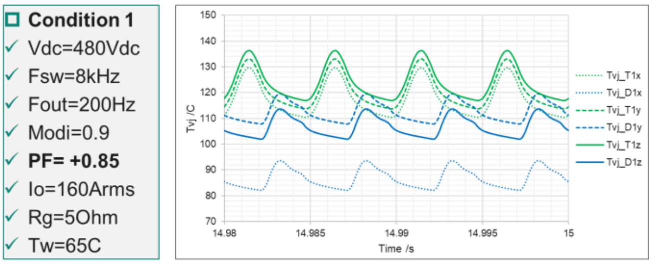


Fig.11. PLECS simulation results at typical inverter condition with three different models

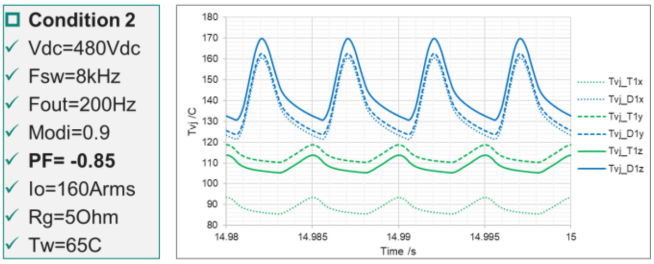


Fig.12. PLECS simulation results at typical generator condition with three different models

- **at inverter condition in Fig.11,**

1) The Tvj ripple of IGBT and FWD, almost the same for with and without consideration of thermal coupling influence of the three thermal networks.
2) The FWD Tvj.max would be much lower, if no consider about the thermal coupling A or B.
3) The IGBT Tvj.max is a little higher(accurate), when the network model considering the thermal coupling.

- **at generator condition in Fig.12,**

1) The Tvj ripple of IGBT and FWD, almost the same for with and without consideration of thermal coupling influence of the three thermal networks.
2) The IGBT Tvj.max would be much lower, if no consider about the thermal coupling A or B.
3) The FWD Tvj.max is higher(accurate), when the network model considering the thermal coupling.

ISBN 978-3-8007-6414-3

 DOI:10.30420/566414089

4 The ZthJW thermal network influenced by chip size and thermal stack from case to heatsink

In real applications, different size of the IGBT and FWD chip inside the TO247 IGBT discrete, or different kinds of thermal stack setup from case to heatsink may still have some influence on the above thermal coupling, which will be analyzed based on FEM Analysis in the last section.

4.1 Normalized RthCH and RthHW influenced by Different Chip Size

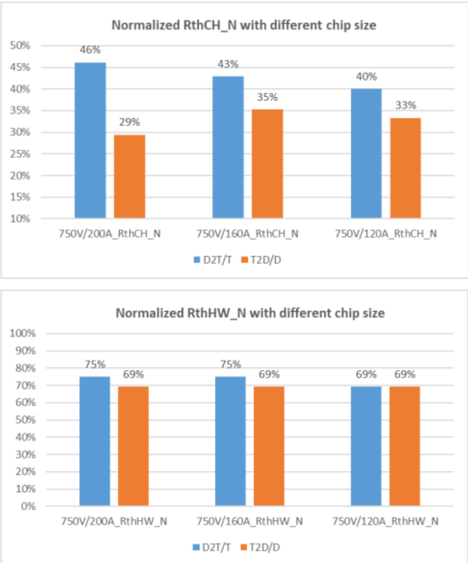
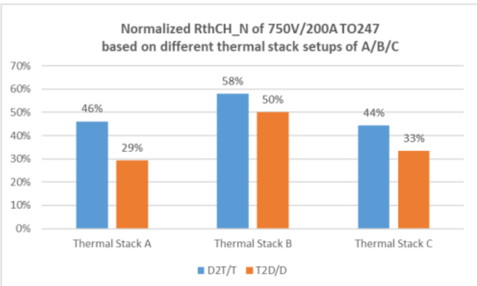


Fig.13. Normalized RthCH and RthHW influenced by Different Chip Size

As Fig.13 shown above, compared with different chip size from 120A to 200A, it seems the slightly influence on the normalized thermal coupling in layer of RthCH and RthHW.

4.2 Normalized RthCH and RthHW influenced by Different Thermal Stack



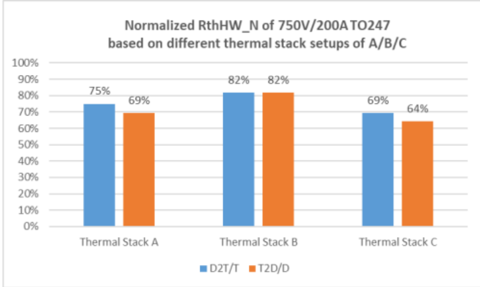


Fig.14. Normalized RthCH and RthHW influenced by Different Thermal Stack A/B/C

In Fig.14, the thermal stack A is based on the standard TO247 reflow solution with ZTA and Solder as Fig.4, and the thermal stack B the standard TO247 clip pressed solution with TIM and Al2O3 as Fig.2, and the thermal stack C is the high performance TO247 reflow solution with AMB and Solder. As the results shown, roughly the better Rth the less thermal coupling in RthCH and RthHW, and the reflow solution could reduce the thermal coupling influence.

5 Conclusion

Based on this paper, three thermal resistance Zth models are analyzed for discrete IGBT Tvj calculations in main inverter application, which shown that thermal coupling between IGBT and FWD should be considered for the better accurate Tvj calculation, especially for the thermal resistance between case and water.

6 References

[1] Thomas Hunger, Oliver Schilling: Numerical investigation on thermal crosstalk of silicon dies in high voltage IGBT modules, PCIM, Nuremberg, 2008.

[2] U. Scheuermann, R. Schmidt: Investigations on the VCE (T)- Method to Determine the Junction temperature by using the chip itself as sensor, proc. PCIM09, CD-ROM, Nuremberg, 2009.

[3] A 3D lumped thermal network model for long-term load profiles analysis in high power IGBT modules, IEEE Journal of emerging and selected topics in power electronics, Vol, PP, NO, 99, 2016.

[4] Hao Zhang, Matthias Lassmann, Koray Yilmaz, Lifeng Chen: Using Zth matrix model for more accurate Tvj calculation for IGBT power modules, PCIM, Shenzhen, 2021.

ISBN 978-3-8007-6414-3