New module generation for higher lifetime

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Abstract

In the past decades, IGBTs and free wheeling diodes have become the components that define the performance of power modules for frequency inverters. This reflects not only the electrical parameters of the silicon dies but also the performance of the used assembly technologies. The assembly technologies define in first order the lifetime of power modules. In this paper we present the first PrimePACK™ module built with a new set of joining technologies, called ".XT". The new technology will outperform the lifetime limitations known today. The discussed module has a nominal current of 900A and a blocking voltage capability of 1200V.

1. Introduction

1.1. Current situation of power electronics

Power modules are limited today internally by the used joining technologies for a further increase of lifetime and / or power density. All following module internal interconnections have to be changed to overcome these limits.

1.) Die front side connection: Today aluminium is the standard material used on the chip front side. Aluminium is used for bond wires as well as for the metallization layer on the chip front side.

The typical lifetime limiting failure mechanism is the bond wire lift off. It can be observed that the failure mechanism is a propagation of cracks inside the aluminium wire bond itself. In other words, the lifetime limitation is not caused by the bond process but by the material properties of aluminium.[2]

2.) Die to DCB connection: The common failure mode of the soldered die to DCB connection is the degradation of the solder joint. The degradation is driven by the mismatch of the expansion coefficients of the chip and the DCB during thermal swings in operation. This degradation leads to an increase of the thermal impedance (Zth). The increased impedance again accelerates the bond wire lift off.

Mandatory for a new connection technology is a higher stability of the joint.

3.) DCB to base plate connection: The base plate is the contact surface of the module to the heat-sink. The base plate itself can be seen as a thermal capacity as well as a thermal spreading layer to increase the contact area to the heat-sink. This results in a 70 % reduced thermal impedance for a pulse duration from 10 to 10000 ms compared with baseplate less modules as described in [4]. This leads to the conclusion that leaving out the base plate might be a feasible way to overcome the challenge of improving the DCB-base plate interconnection but not in all cases the (optimal) solution. A significant improvement of the connection is useful for modules used in high power and in high dynamic medium power applications.

1.2. Lifetime discussion

Lifetime of a power module can be defined as the amount of operating hours the module can operate in an application under specific load conditions. The joining technologies define the lifetime, basically once a failure mechanism occurs.

Different joining technologies are competing to set the new standard in future power modules. The ideal technology has to improve the lifetime significantly and has to meet the demands of electronics mass production. The optimal solution should also reflect the three decades experience on mounting and joining technologies of power module production.

The following example can illustrate this requirement. A clear advantage of the currently used wire bond process is the high degree of flexibility. Similar type of equipment can be used to produce different module designs simply by mechanical adaption and changes in the bond program of the machine. No essential change on the equipment is needed.

How to use the advantages of this? How to develop an overall approach for power modules?

1.3. Module lifetime and power density

Once the power cycling capability of a power module is improved, it can be used in two different ways.

The first way is to use the enhancement for a longer lifetime of the module. In the power cycling diagram (figure 1) this corresponds to a step from today's curve in vertical direction. The number of usable cycles is increased by a factor alpha at a given temperature swing (for example 40 K). This is a valuable characteristic in lifetime demanding applications.

The second way is to increase the power density especially for air cooled systems by means of an increased maximum junction operation temperature. The increase of the junction temperature leads naturally to increased temperature swings inside the module.[1]

The increased swing due to a higher allowed junction temperature can be indicated by a horizontal step from today's power cycling curve. The decrease of the useable cycles has to be compensated by new technologies.

2. PrimePACK.XT- benchmark in lifetime

2.1. Core features of .XT

The development of the .XT technology was based on the idea to develop a solution for the whole module system. Besides this .XT is a set of module internal mounting and joining technologies which does not stick to a special module type. .XT has the potential to be rolled out in several existing packages.

2.2. Description of the implemented technologies

Chip front side connection

In the former chapter we pointed out that flexibility in power module production is an important characteristic of the wire bond process. On the other hand, a comparison on material properties of aluminium against copper shows clearly that the electrical conductivity of copper is about 60% higher than aluminium. The yield strength of copper compared to aluminium is by a factor of 5 higher. These properties may give an indication how to overcome the challenge of the die's front side connection.

	copper	aluminium
electrical resistivity	1.7µOhm.cm	2.7µOhm.cm
thermal conductivity	400W/m.K	220W/m.K
CTE	16.5ppm	25ppm
yield strength	140MPa	29MPa
elastic modulus	110-140GPa	50GPa
melting point	1083°C	660°C

Table 1 Comparison of copper and aluminium properties

With Infineon's wafer fabrication and module package expertise it was possible to implement a copper front side metallization of the dies. Furthermore Infineon Technologies developed a bond process using copper as material of choice.

The new copper wire bond process can naturally provide the same flexibility as the current aluminium wire bond process today.

The achieved power cycling results are given in [3] and underline the potential of .XT.

Chip- Substrate connection

For the die to DCB interconnection a more reliable solution has been developed as well. The new chip mounting process combines a superior lifetime with the established knowledge of three decades of power semiconductor production. Infineon's new developed diffusion soldering process provides a high flexibility for the different configurations needed today (half bridges, chopper configuration ...). The thickness of the joint is about 10 µm and solely consists of high melting intermetallics phases.

Compared with soft solder joints the thickness could be reduced by a factor in the order of 5 to 8.

Substrate- base plate connection

As discussed above a more reliable solution for base plate modules is also needed. Investigations have shown that the end of life mechanism of the DCB to base plate connection is crack propagation inside the solder joint. The approach is to implement additional precipitations in the solder in order to stabilize the joint.

A more detailed description can be found in [3].

2.3. Power cycling capability

The power cycling (PC) capability of modules is described in power cycling diagrams. For a given maximum junction operation temperature the horizontal axis indicates the temperature swing of the junction. The ordinate indicates the achieved number of cycles.

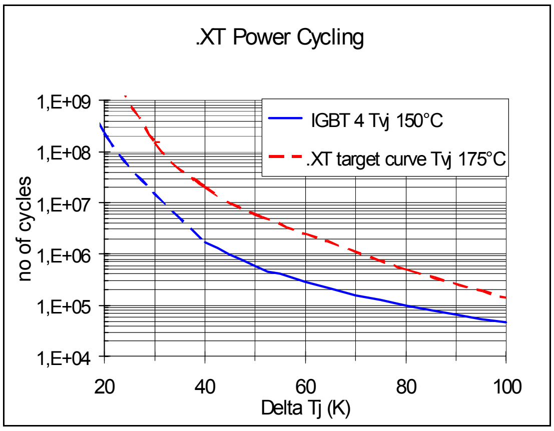

Fig. 1. PC diagram: Standard IGBT 4 Curve and IGBT4.XT power cycling limits for pulses with duration of about 1.5 seconds.

The power cycling curve of the .XT technology reports a higher power cycling capability compared to the IGBT4 power cycling curve. Besides this the target curve is already valid for an operation junction temperature up to 175°C.

3. Characteristics of FF900R12IP4LD

3.1. Electrical evaluation

The focus of the .XT technology is to improve the lifetime significantly. The customer should be able to replace the existing module like a FF900R12IP4D by the new FF900R12IP4LD. The target for the electrical development was to achieve the same electrical performance as of today's IGBT 4 and the corresponding diode.

The characterisation of the FF900R12IP4LD in our lab has shown the same losses per switching event, as the corresponding product in conventional technology.

	FF900R12IP4D	FF900R12IP4LD
Eon&Eoff [mJ]	280	280
Erec [mJ]	100	100
Vce sat [V]	2,1	2,1
Vf [V]	1,5	1,5

Table 2 Table of electrical module properties at 150°C

Also parameters like softness and maximum short circuit withstand remained unchanged.

4. Lifetime estimation for .XT

In the following chapter we compare the lifetime of two PrimePack™ modules. Both modules have the 4th IGBT generation of Infineon Technologies inside. One module, the FF900R12IP4D, is assembled with the current mounting and joining technology whereas the FF900R12IP4LD is assembled with the new .XT technology.

4.1. Lifetime estimation

For a given application a corresponding mission profile describes the specialities which have to be regarded in module lifetime estimations.
In the following analysis a cycle load profile with high amplitude and frequent motoring cycles has been used. The simulation was done by using a lifetime simulation tool developed by Infineon Technologies.
A typical application characterized by this load profile could be a commercial, construction & agriculture vehicle (CAV) like a digger or a city-bus with stop and go operation.
As thermal boundary conditions an ambient temperature of 60°C and a maximum junction temperature (Tvj max) of 150°C were chosen.

The new power cycling target for .XT, given in figure 1, is valid for a maximum junction temperature up to 175°C. In our lifetime simulation we will use the given values also for lower junction temperatures. This is a kind of worst case investigation since the power cycling capability improves with lower maximum junction temperature.

In order to compare the two modules we assume a needed operation time of 25000h. This corresponds to 12.5 years of field operation in this example.

The needed voltage and current pattern of the engine inside the vehicle is depicted in figure 2.

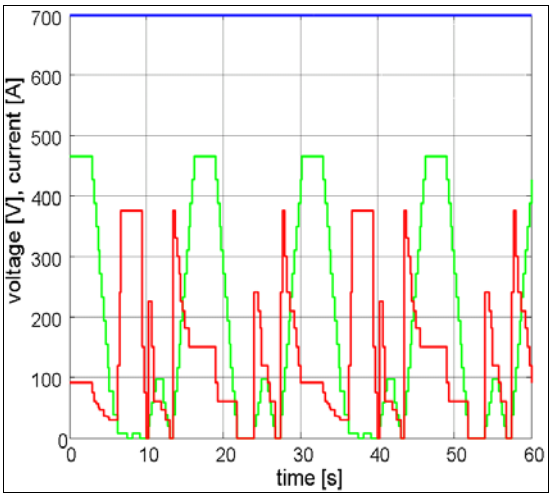

Fig. 2. Load profile with short pulses and high amplitudes. The blue line indicates the DC link voltage, whereas the green line is the voltage and the red line the current needed at the vehicles electric machine.

During inverter operation the losses depicted in figure 3 occur. Table 2 has shown the similarity of the losses for the FF900R12IP4D and the FF900R12IP4LD. This means that the calculated losses in figure 3 are valid for both types of modules.

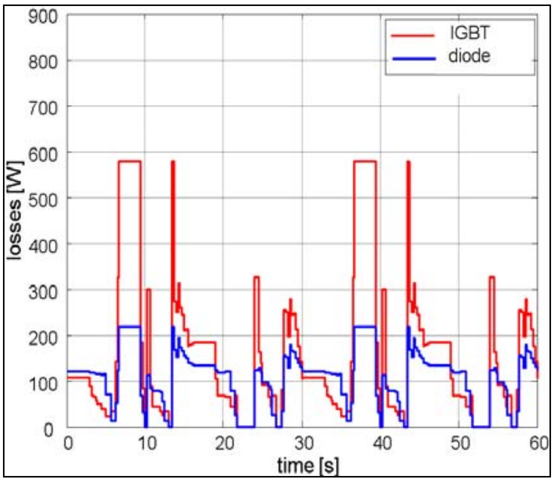

Fig. 3. Losses of the IGBT and the free wheeling diode

Together with the thermal network of the modules it is possible to derive the temperature swings for the IGBTs and diodes.

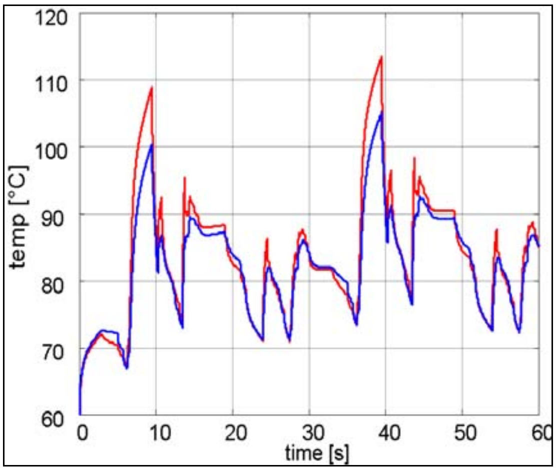

Fig. 4. Calculated junction temperatures of the IGBTs (red) and diodes (blue) based on the load profile.

In the next step the calculated temperature swings have to be considered using the power cycling curves. This was performed with a rain flow analysis. For the FF900R12IP4D the simulated number of cycles of 25000 operating hours has to be compared with the IGBT4 PC curve.

The ratio of the added cycles compared with the maximum cycles from the power cycling curve indicates the lifetime utilization.

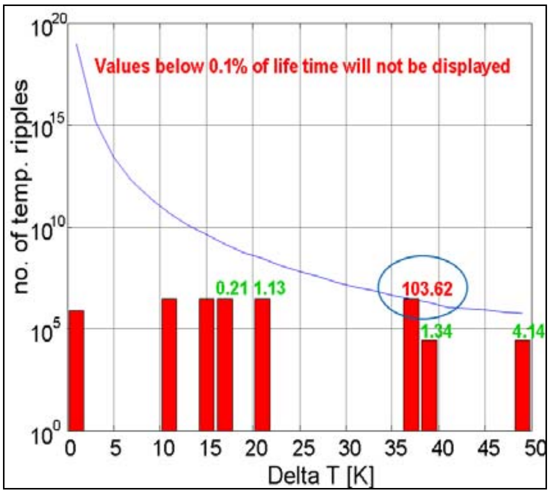

Fig. 5. Comparison of IGBT4 PC curve with needed lifetime of 25000 hours operation. The blue line is the PC curve. The red bars indicate the number of ripples for a temperature swing.

Load profile in this example was chosen in a way that needed cycles at 37 K exceeds the number of cycles provided by the IGBT4 PC curve as shown in Figure 5. The new module with .XT is able to withstand the applied load which is shown in figure 6. All ripples stay below the power cycling curve.

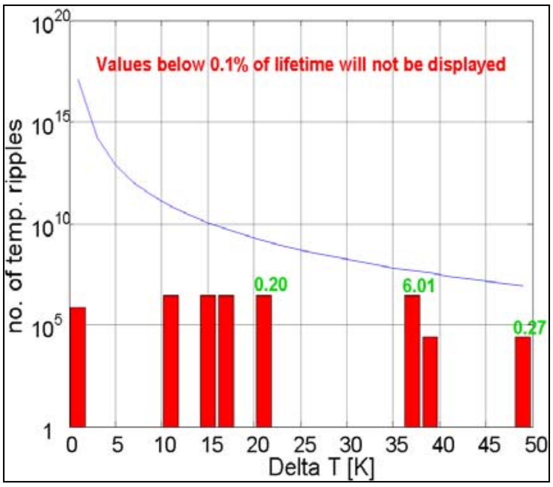

Fig. 6. Comparison of .XT power cycling curve with needed lifetime of 25000 hours operation

4.2. Comparison of lifetime estimations

The complete lifetime utilization can be compared if the integral of the singular contributions is computed. The calculation is done separately for the IGBT and the free wheeling diodes. Figure 7 depicts the achieved lifetime utilization.

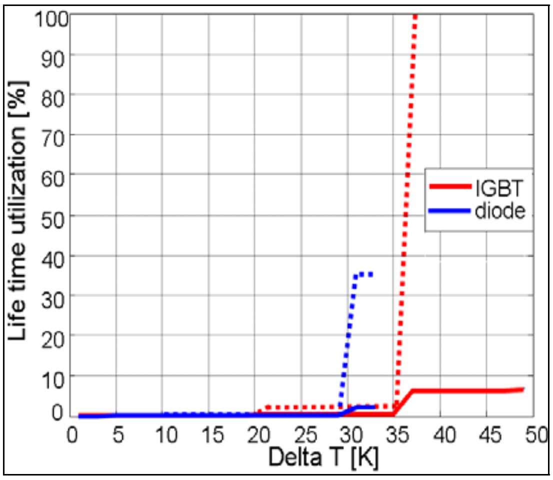

Fig. 7. Lifetime comparison of two modules. The dotted lines describe the utilization of the conventional technology. The IGBT with the standard technology defines the lifetime by reaching the 100 % limit. The continuous lines show the lifetime utilization of the .XT technology.

At the point where the module with conventional technology has reached its end of life, the module with the new .XT technology shows a lifetime utilization of about 10 percent. The increased power cycling capability of .XT transfers directly into a 10 times enhanced module lifetime. This corresponds to the first way discussed in 1.3. The second way to use the enhanced power cycling capability is to increase the output current. In order to compare the increased output current we fix the lifetime to 25000h like before and calculate the corresponding maximum current. Due to the higher current the ripples are shifted to higher temperatures. Figure 8 depicts the lifetime utilization with an increased output current of 125% compared with the standard module. The lifetime limit is now defined by the ripple at a swing of 54 K.

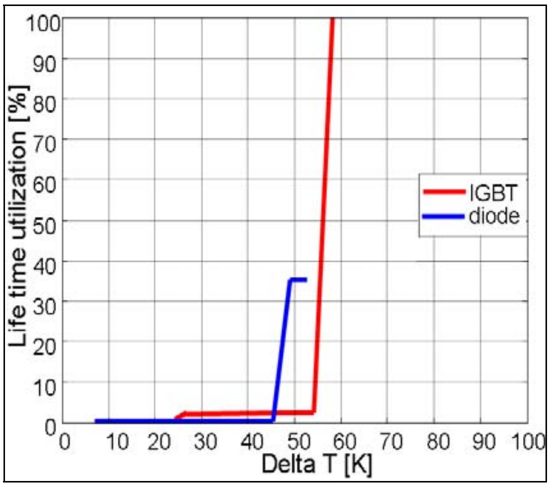

Fig. 8. Lifetime utilization of the FF900R12IP4LD with increased output current of 125% compared to the FF900R12IP4D after 25000h of operation.

5. Conclusion

The first product with the new mounting and joining technology .XT introduced by Infineon Technologies AG has been described. It was shown how the new power cycling target curve of the .XT technology pushes lifetime estimations beyond today's limits.

In our example the module lifetime was simulated to be ten times longer compared to the standard module.

The general trend in power electronics for demand of longer lifetime and / or higher power density is addressed by the development of the .XT technology by Infineon Technologies AG.

6. Literature

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