

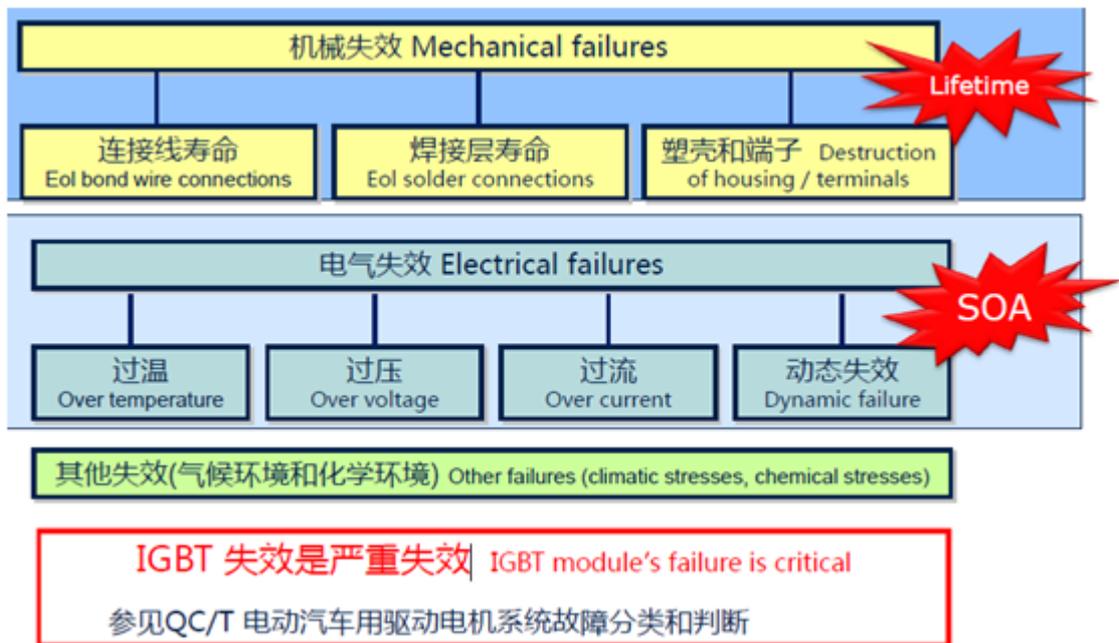
# IGBT 模块应用中的寿命和可靠性

系统寿命与可靠性关系：

可靠性：产品在一定条件下无故障完成规定功能的能力或可能性



IGBT 模块的失效模式：



功率周次 Power cycling：

功率周次用于评估绑定线和 Die 焊层的机械寿命

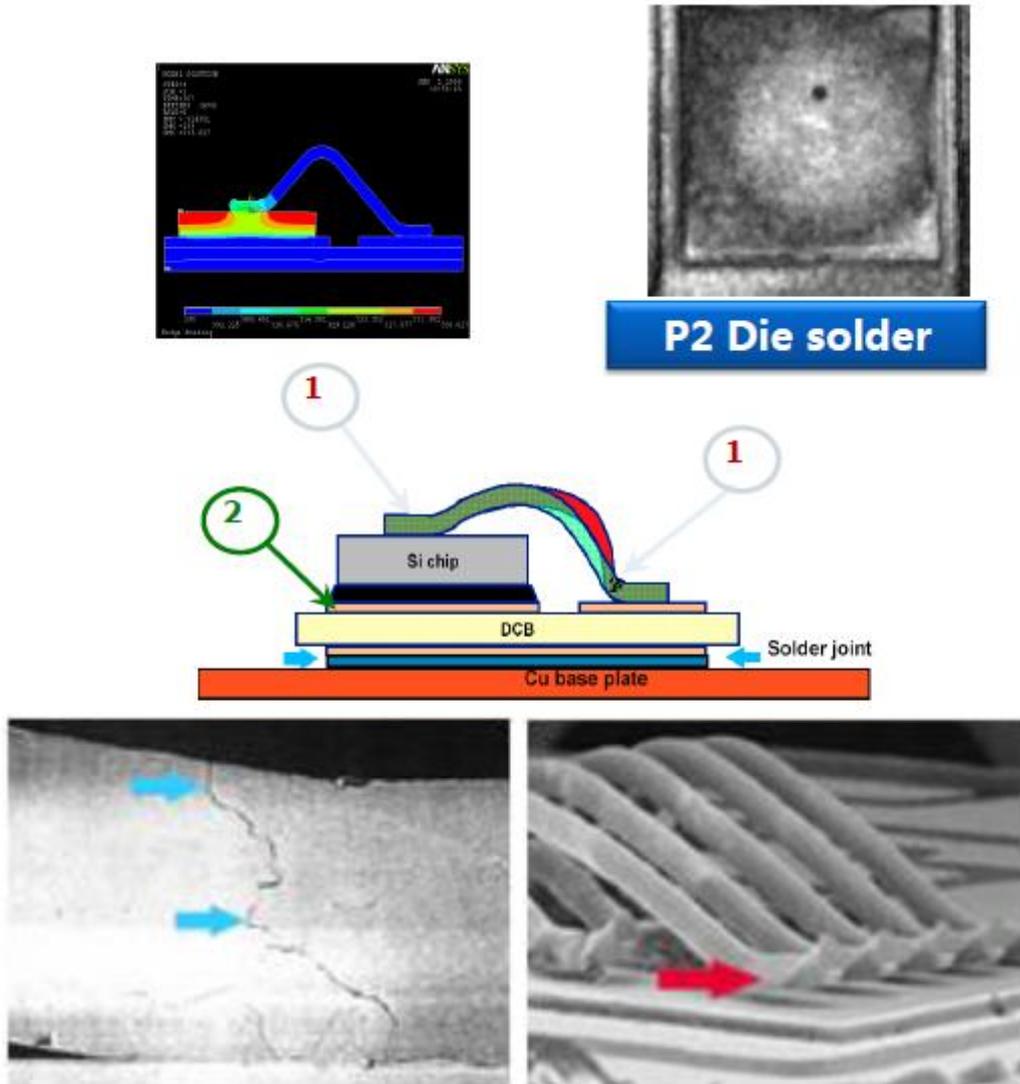
Power cycling can estimate the bonding wire and die solder's lifetime

测试方法：加载自加热，周期 $\leq 3$ 秒，测试 $\Delta T_{vj}$

Test method: Self heating by load,  $T_{\text{cycle}} \leq 3$  seconds, measure  $\Delta T_{vj}$

失效判据：饱和压降  $V_{\text{cesat}}$  增大+5%

Failure criteria:  $V_{\text{cesat}}$  increase more than 5%



温度周次 Thermal cycling

温度周次用于评估 DCB 下焊接层的寿命

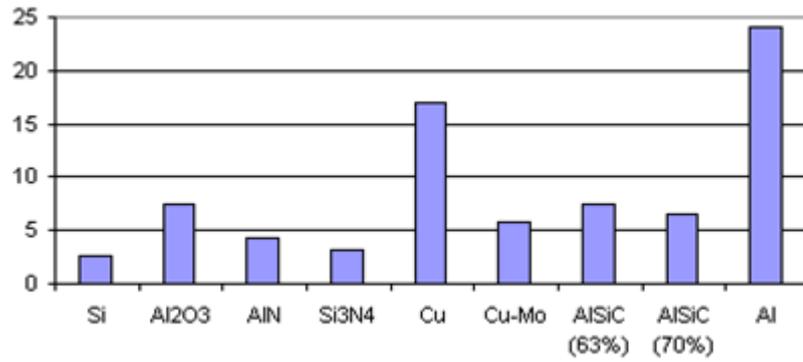
Thermal cycling can estimate DCB solder's lifetime

测试方法：通电加热，周期 5 分钟，测量 $\Delta T_c$

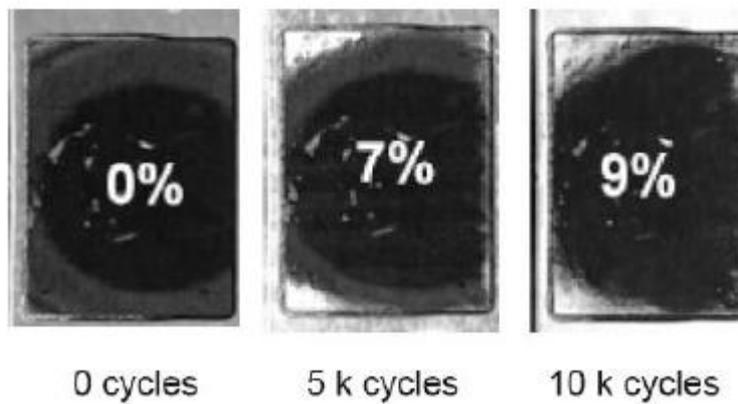
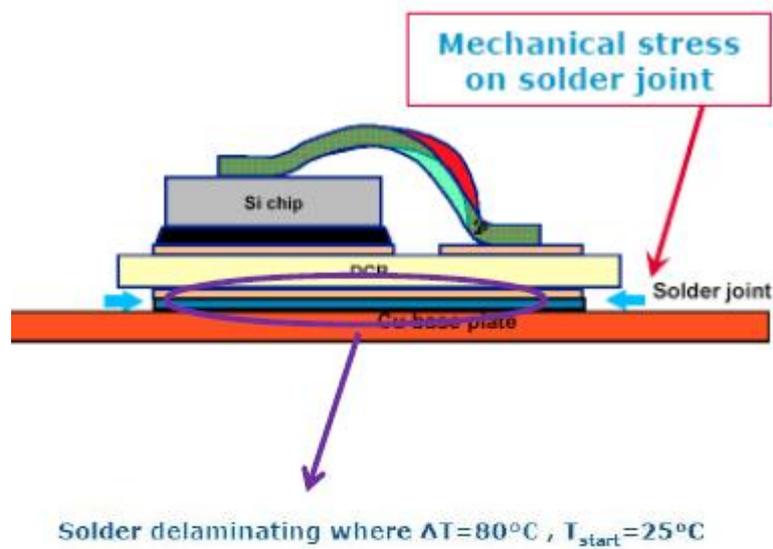
Test method: Self heating by load, 5 min/, measure  $\Delta T_c$

失效判据：热阻  $R_{thjc}$  增大+20%

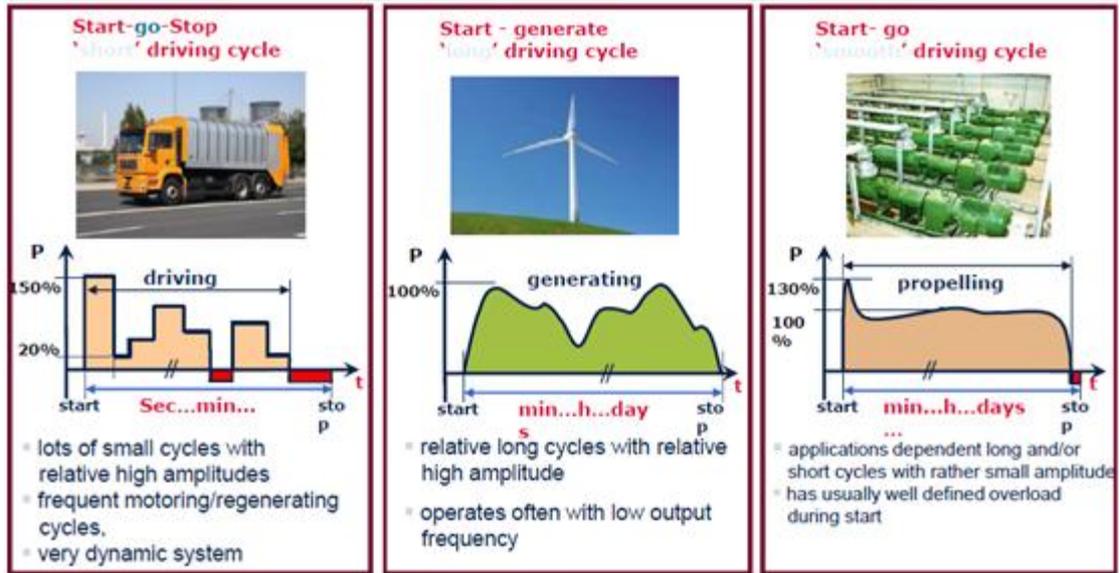
Failure criteria:  $R_{thjc}$  increase 20%



失效机理是两种材料不同的膨胀系数  
 (Different material' s CTE) [ppm/K]



不同应用下 IGBT 模块的寿命  
 Lifetime of IGBT module in different application

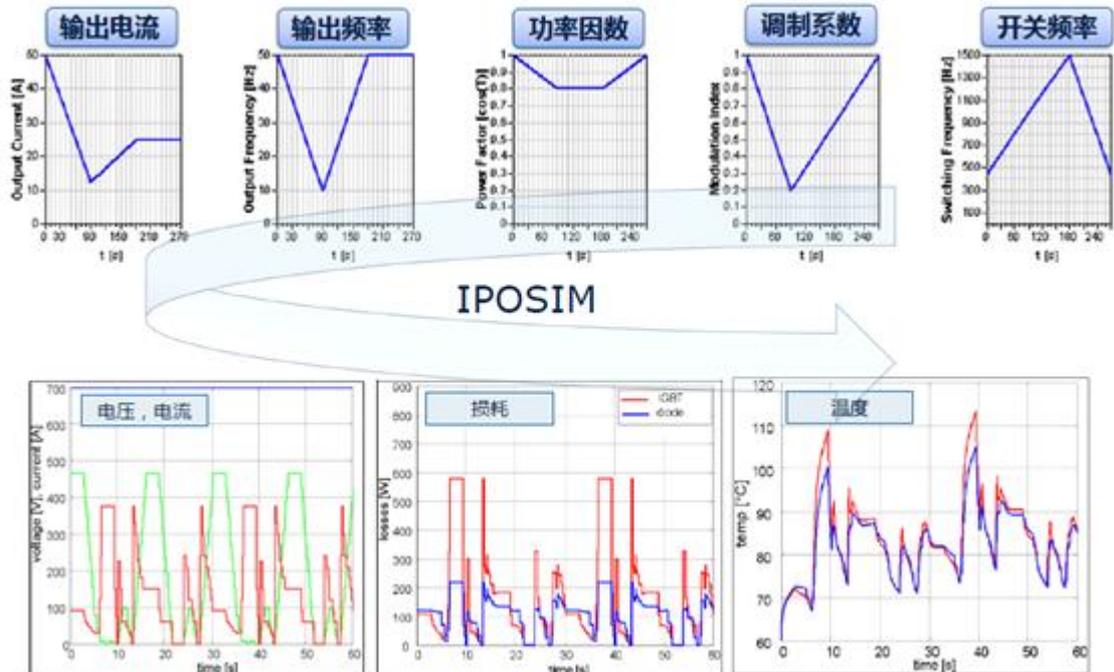


There are many applications and similar types of power modules.  
 Main objective is: how to select an active device in order to reach desired system lifetime?

Is it possible to have power module suiting to all applications?

由周期内系统工况变化获得温度变化

Get the temperature profile by power profile in a cycle



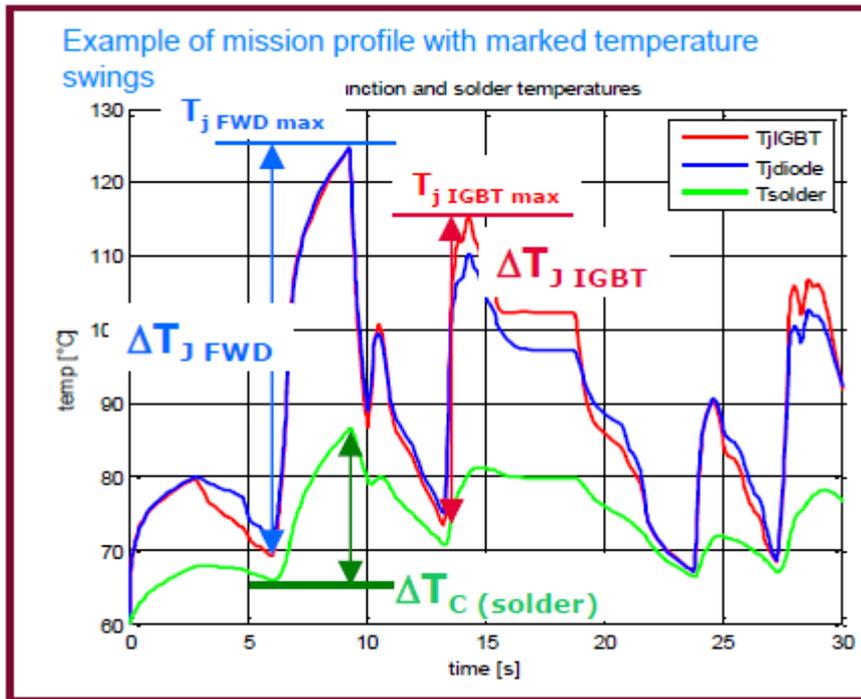
温度变化导致的失效模式

Failure modes with  $\Delta T$

There are two key factors in the selection of the appropriate power module:

1) thermal:  $T_{vj\ op} < T_{vj\ max}$

2)reliability: wear out mechanisms which determine module lifetime as result of module reliability curves and thermal stresses



Note: RBSOA and other electrical phenomena are not covered in the presentation.

Factors and impacts:

$$1) T_{jFWD\ max} \leq T_{vj\ op}$$

$$T_{jIGBT\ max} \leq T_{vi\ op}$$

Nowadays  $T_{vj\ op} = 150^{\circ}\ C$

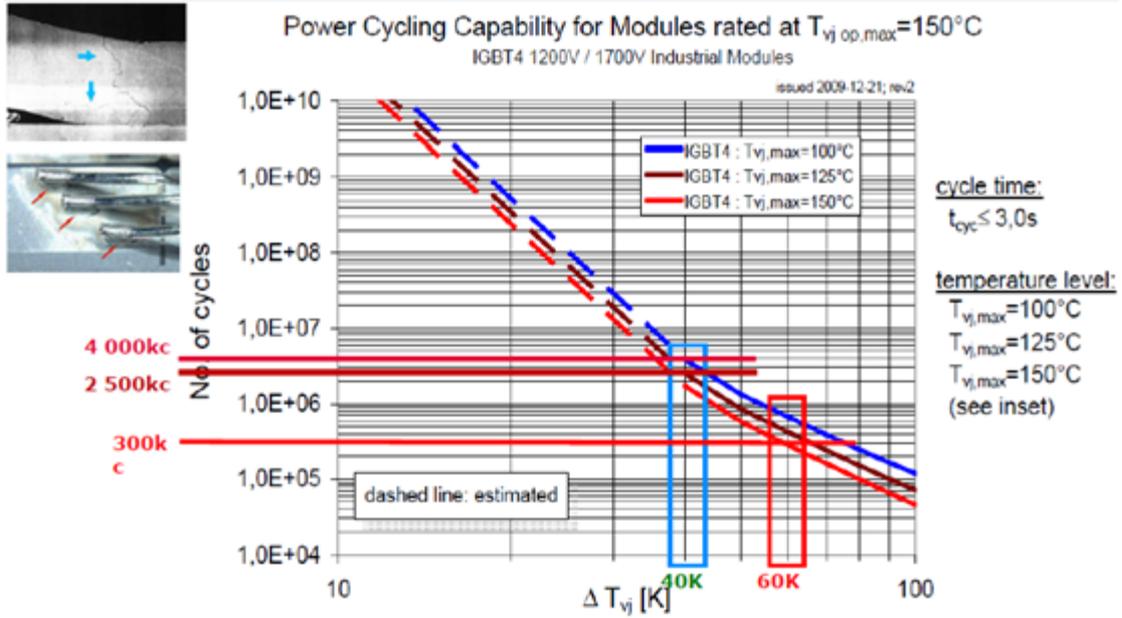
2)  $\Delta T_{jFWD}$  &  $\Delta T_{jIGBT}$  refer to Power Cycling reliability curves

$\Delta T_C$  refers to Thermal Cycling reliability curves

Reliability curves are always given by power module manufacturer

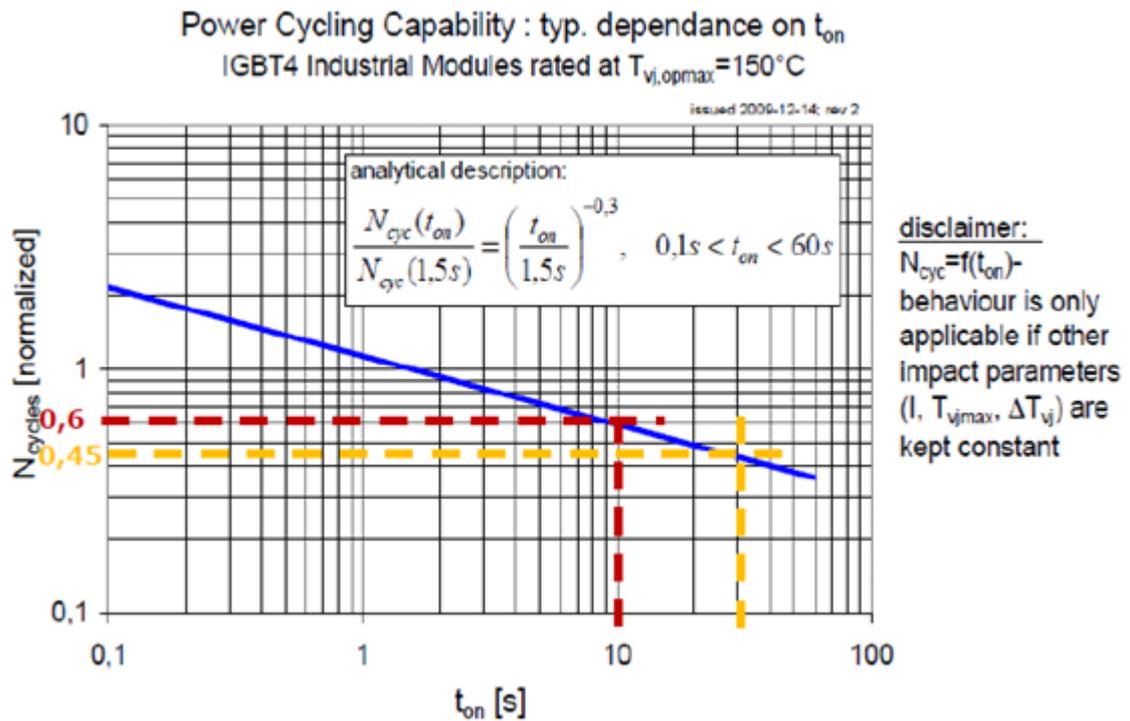
绑定线老化——功率周次曲线

Bond wire degradation - PC curve



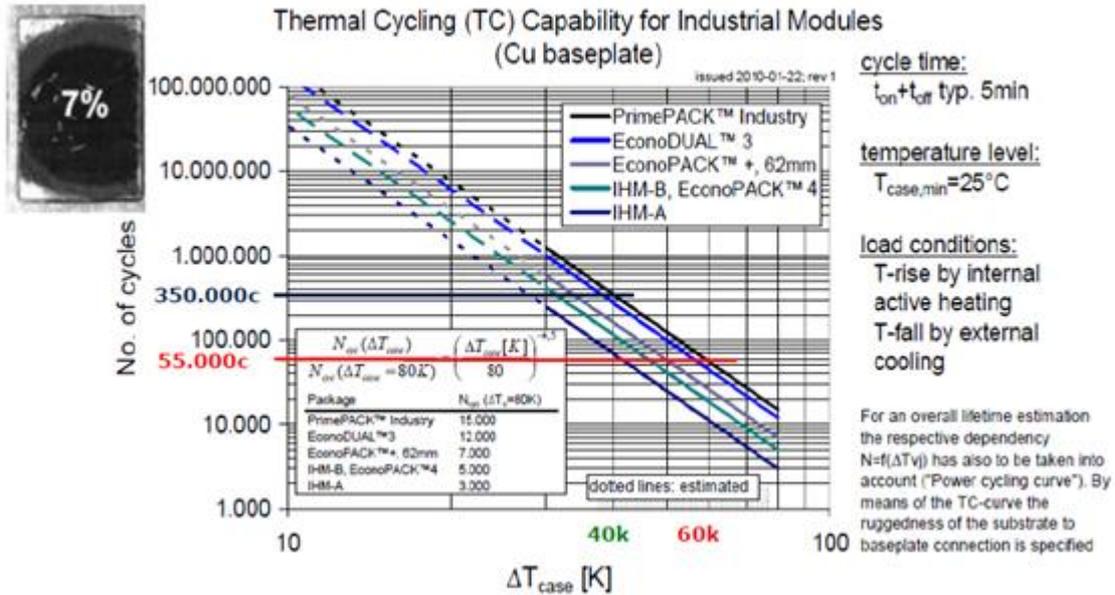
功率周次曲线修正因数

PC curve correction factor



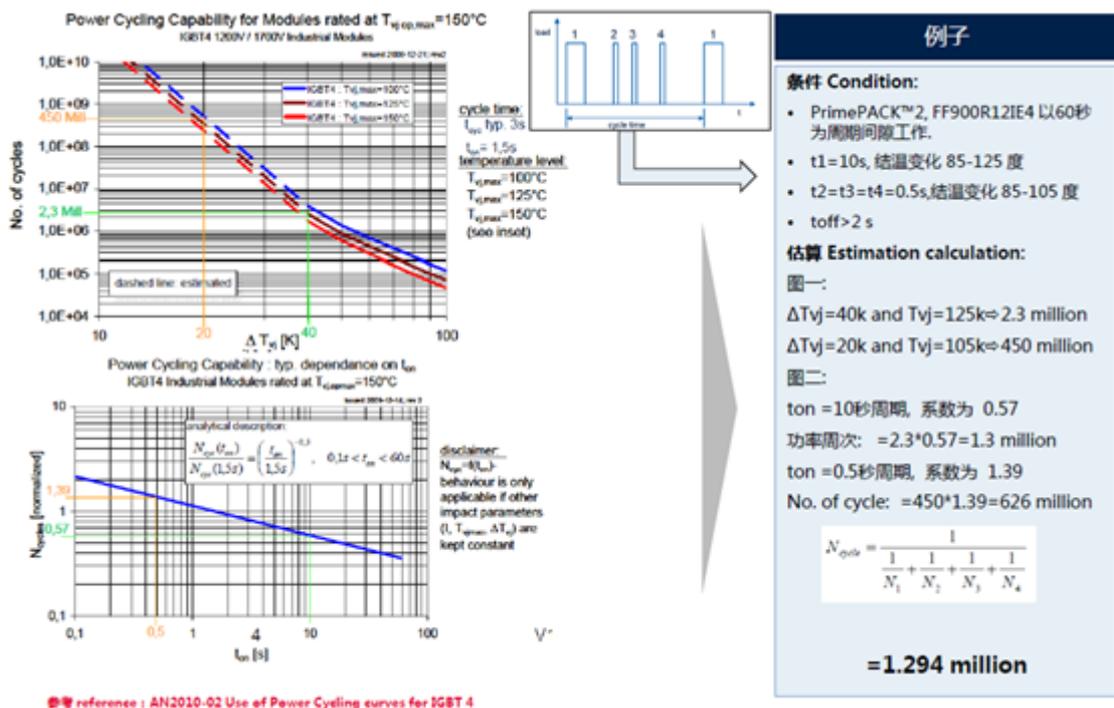
基板焊层老化——热循环曲线

Solder on baseplate degradation - TC curve



功率温度循环 (PC) 次数评估计算

No. of cycle estimation calculation with Power cycling curve



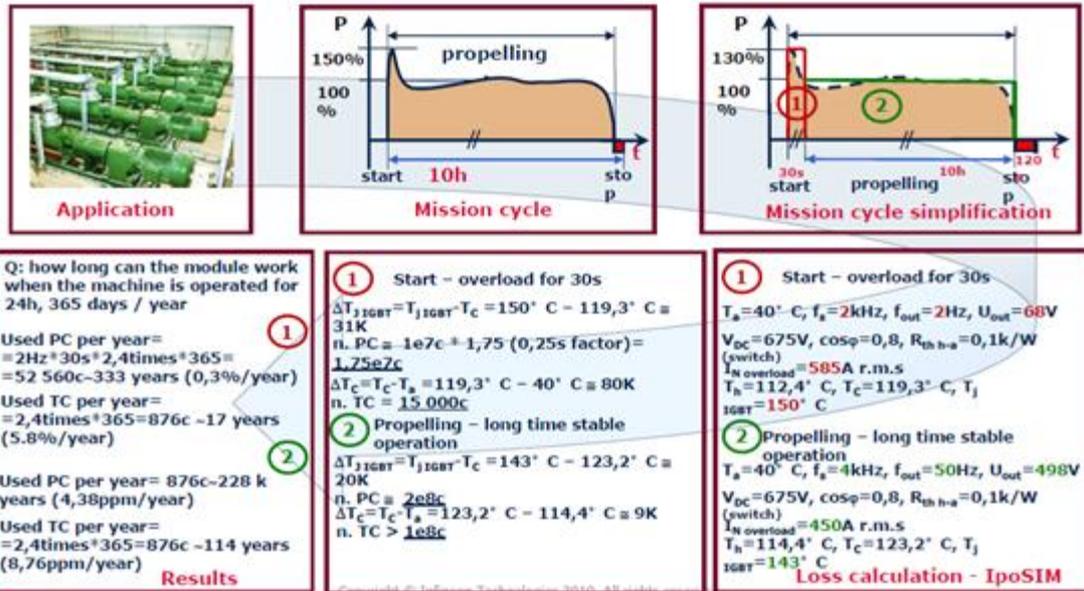
实例: 稳态周期系统的寿命估算

Simple mission cycle -- example of lifetime estimation

For relative simple mission cycles the module lifetime based on the three presented reliability

curves and power losses converted into a junction and case temperature swing can be easily

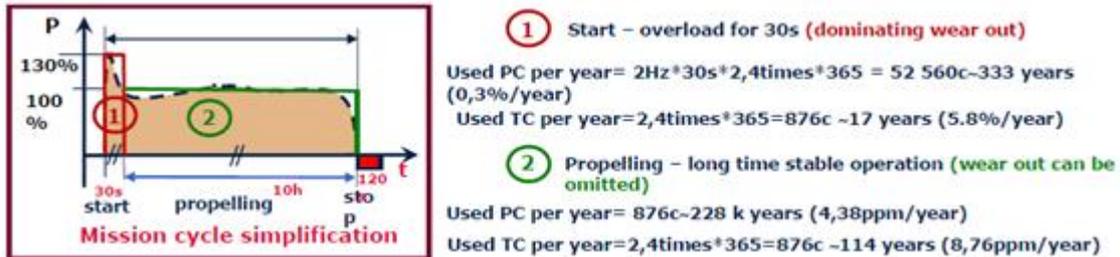
estimated. PrimePACK™ module in use: FF900R12IP4D



实例：稳态周期系统的寿命估算

Simple mission cycle -- example of lifetime estimation

Question from last page: how to estimate the power module lifetime under the mission cycle,  
 has to be repeated again. Let's calculate the module wear out as a function of mission cycle and time.



Final lifetime module estimation:

wear out / year =  $0,3\% + 5,8\% + 4,38\text{ppm} + 8,76\text{ppm} \approx 6,1\%$

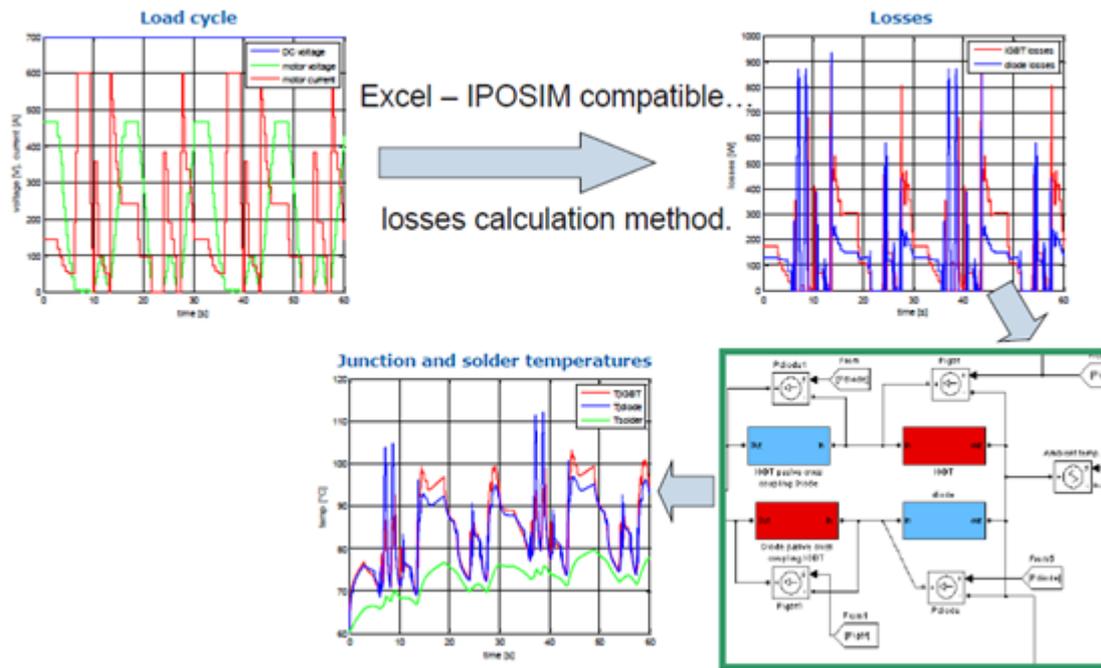
As reliability curves are given for 100% lifetime the module can work in the example application

for :  $100\% / 6,1\% \approx 16,4\ \text{years}$

Note: These calculations are made for IGBT only. FWD has to be calculated separately.

动态负载周期的寿命估算方法

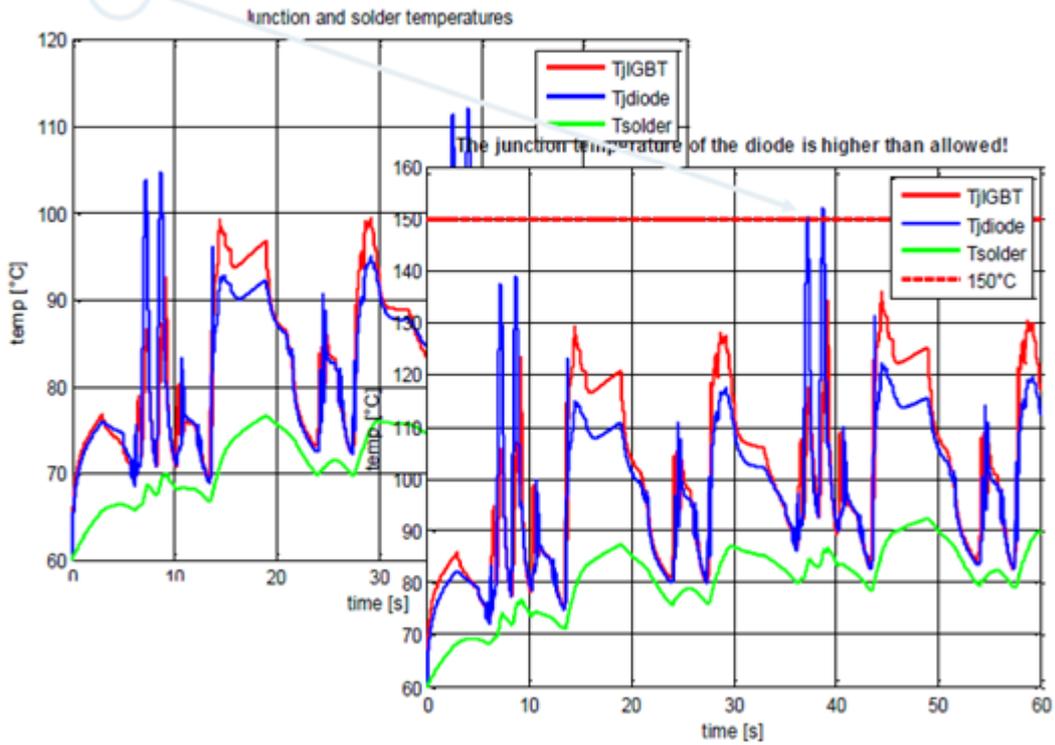
Dynamic load cycle - lifetime estimate



Matlab calculates losses for given number of the load cycles and applies them to the thermal networks specific for selected module in Simulink. As a result the junction temperature profile for IGBT, Diode and the profile of the solder temperature is obtained.

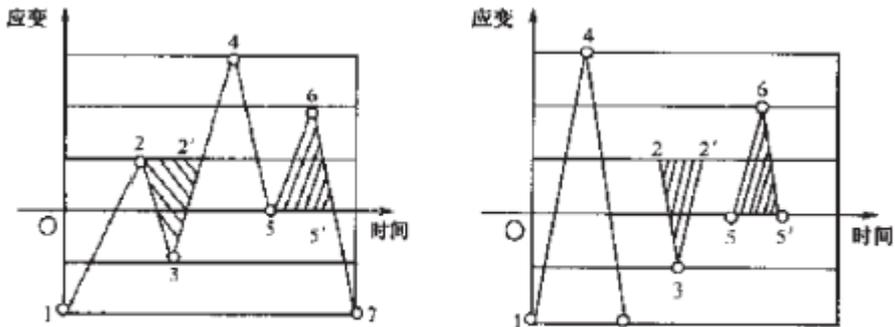
In that case, the simulation will be stopped. Over the graph the information says, which element has higher temperature than allowed. If its below..

## If the temperature exceeds the limit

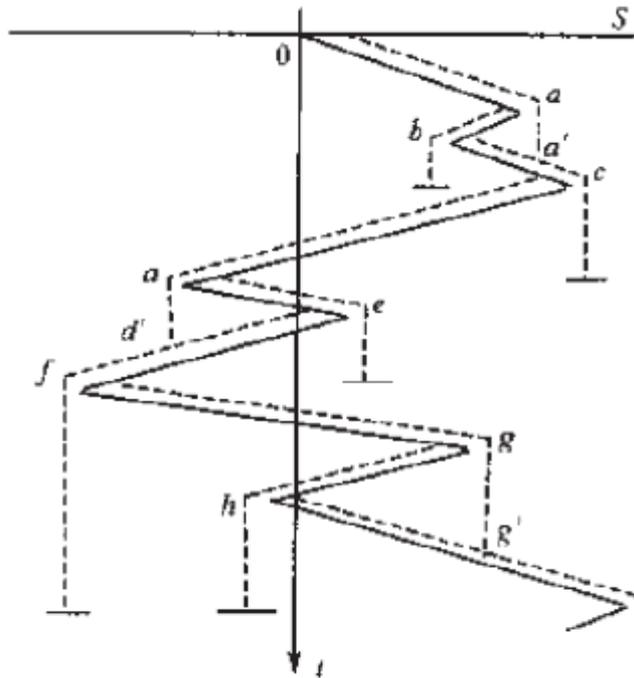


雨流计数法——随机负载谱转化为变幅或恒幅的负载谱

- 把负载变化周次种类减少
- 根据有限的试验数据推算整个寿命周期的变化规律，获得典型谱

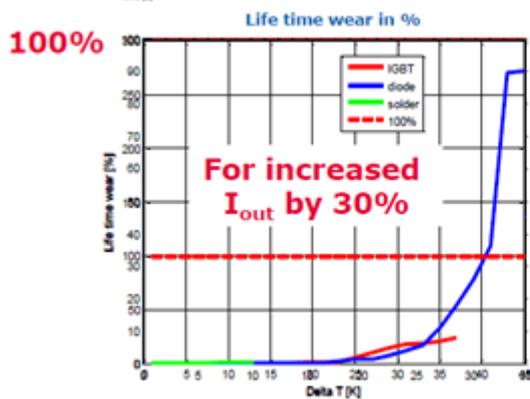
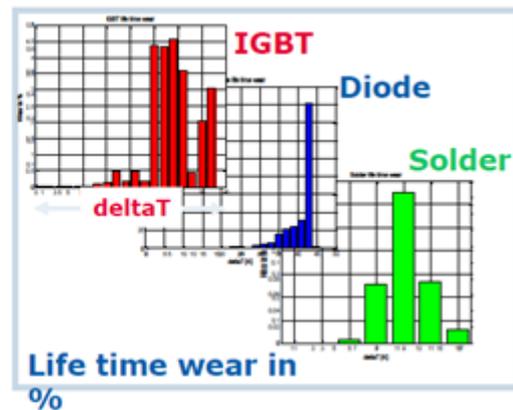
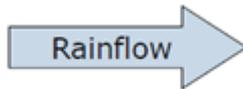
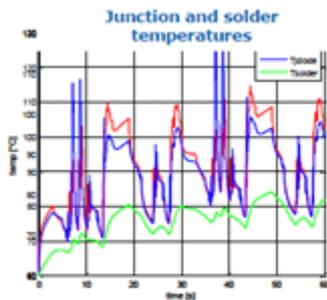


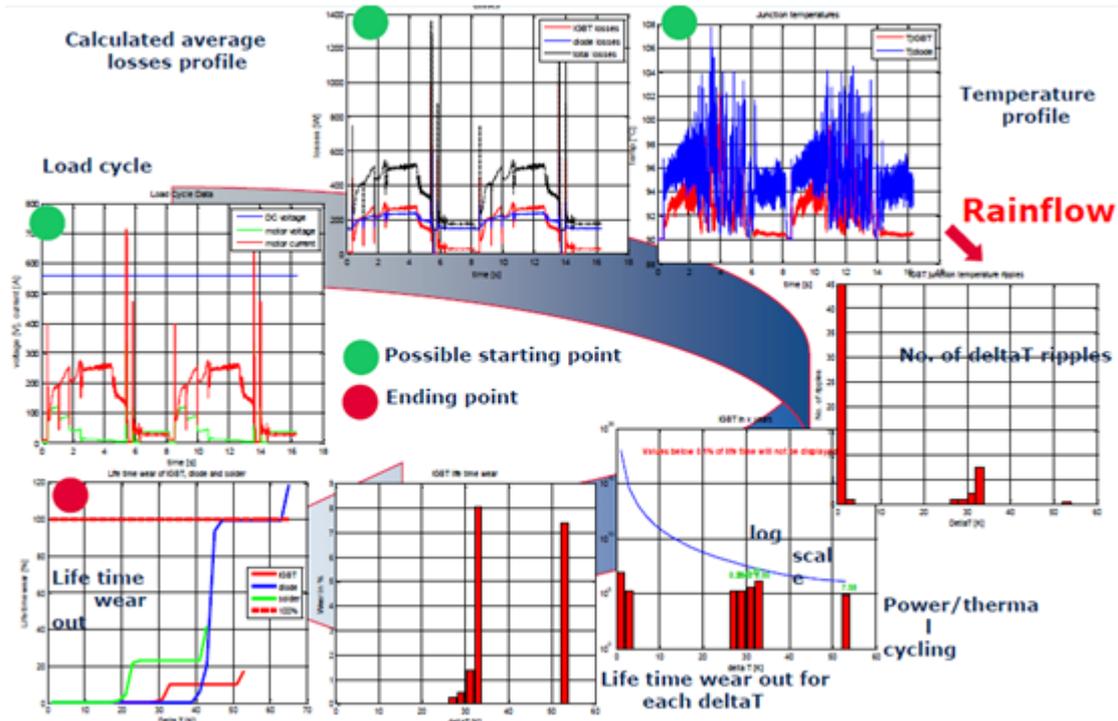
温度时间的简化谱



雨流计数法

From the temperature profile analysis the life time (and wear of the life time in %) for each element and solder will be calculated. The graphs will show the life time wear for each  $\Delta T$ . The sum of the percents is calculated and also shown on the graph.

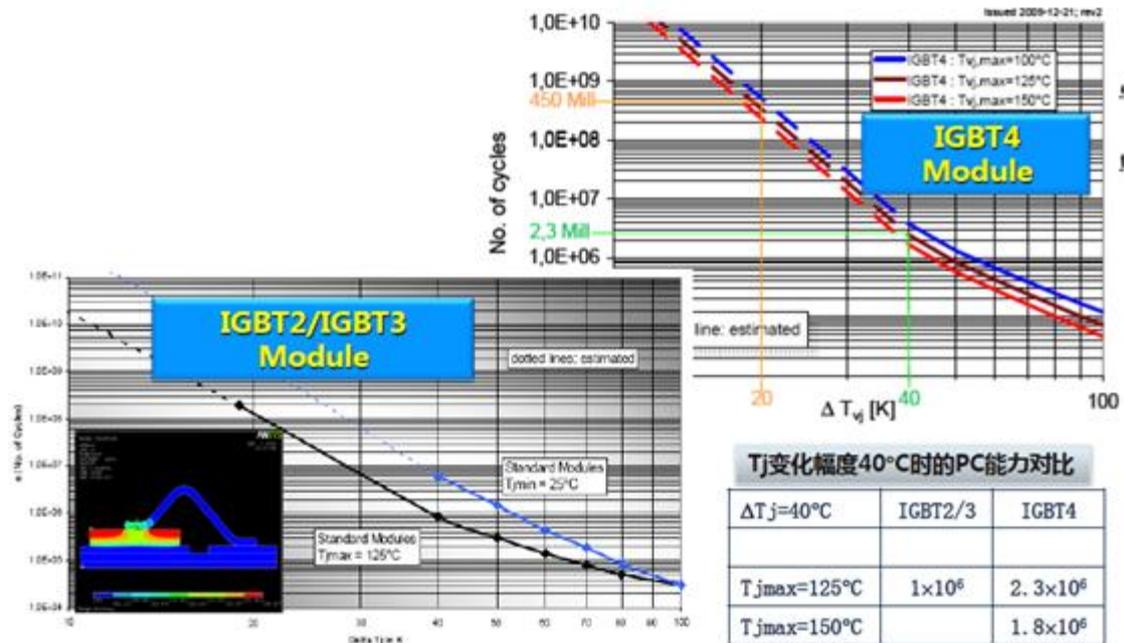




IGBT4 模块的性能提升

High performance of IGBT4 module

IGBT4 模块的 150 度最高允许工作结温，源于内部焊线工艺的改进，使其可靠性指标-功率周次（PC）数大幅增加！



铜绑定线 Copper Bonding Wire--- EconoDUAL™3 600A

真正实现 EconoDUAL™3 最大输出电流能力

--- @  $TC = 100^{\circ}C$ ,  $T_{vj} = 175^{\circ}C$

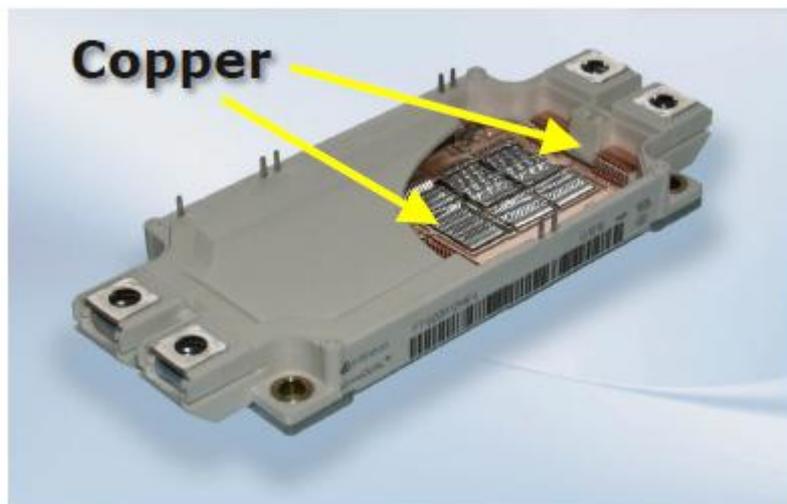
降低引线电阻  $R_{CC}$  ‘EE’

保证功率周次，满足风力发电，电动汽车需求

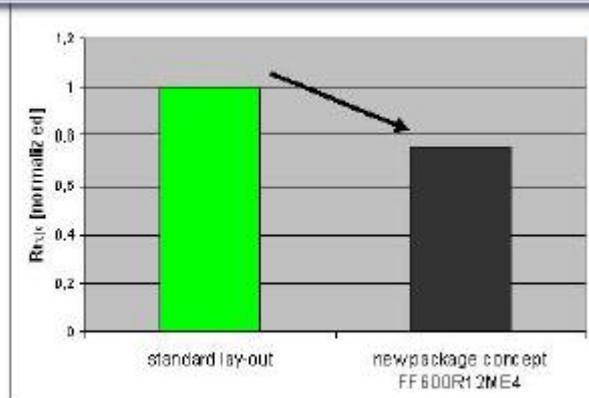
提供焊接/PressFIT 两种兼容版本

提供 650V, 1200V, 1700V IGBT4 全系列，便于现有设计的功率升级

	<b>Aluminium (standard)</b>	<b>Copper (Ifx new)</b>	<b>Copper vs. AL</b>
<b>Electrical resistivity</b>	2.7 $\mu$ Ohm*cm	1.7 $\mu$ Ohm*cm	 <b>-40%</b>
<b>thermal conductivity</b>	220 W/m*K	400 W/m*K	 <b>+80%</b>



特别 DCB 改善了结对壳的热阻降低 22%\*  
Special DCB can decrease 22% R\_thjc



\*模块实测 600A-EconoDUAL™ 3!

PressFIT 端子压接技术

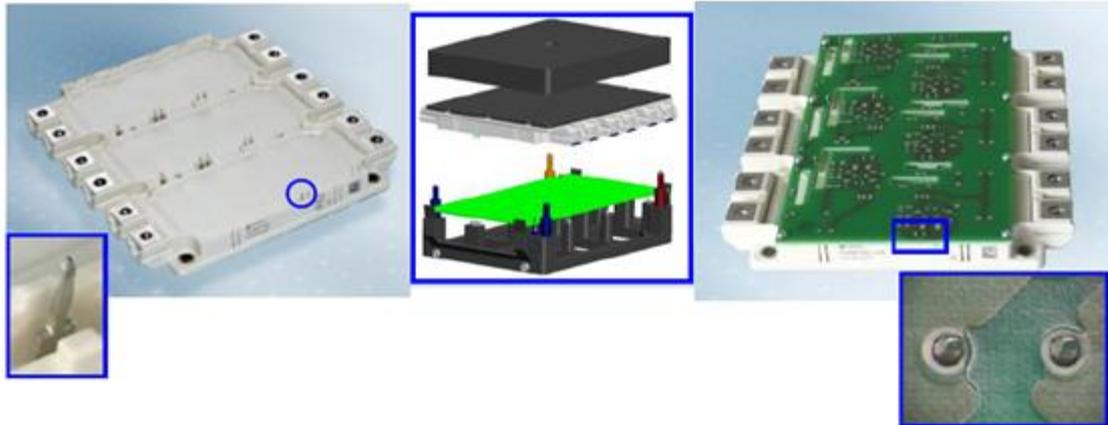
Press + FIT = PressFIT

PressFIT Technology

无铅 以达到 RoHS 环保要求

简易无焊接安装 节约生产组装的成本和时间

高可靠性 减少工人焊接端子中失误导致的过温和静电损坏  
可靠性已在多个高端客户的产品中得到验证

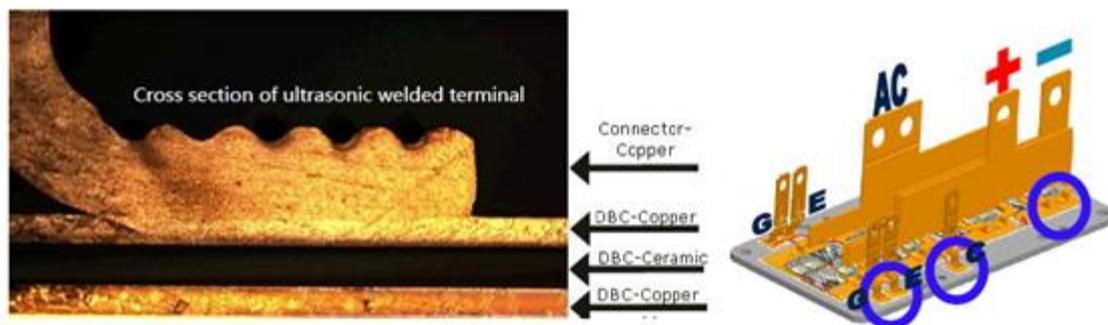


超声波焊接的功率端子 Ultrasonic welded terminals

功率端子采用超声波焊接

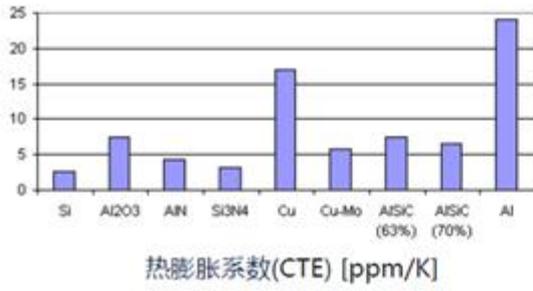
Internal terminal connections ultrasonic welded

- 可增加模块端子的鲁棒性 Increased mechanical robustness
- 可增加模块端子电流通过能力 Higher terminal currents possible
- 无焊料可增加热传导能力 maximum temperature even reduced



已应用在以下的模块封装中：PrimePACK, IHM-B Traction series, EconoPACK™4

模块基板和衬底材料的选择以提高温度周次



TST 温度冲击试验结果

