Thermal Reliability Test Solutions of Power Devices

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- Introduction to Thermal Reliability of Power Devices

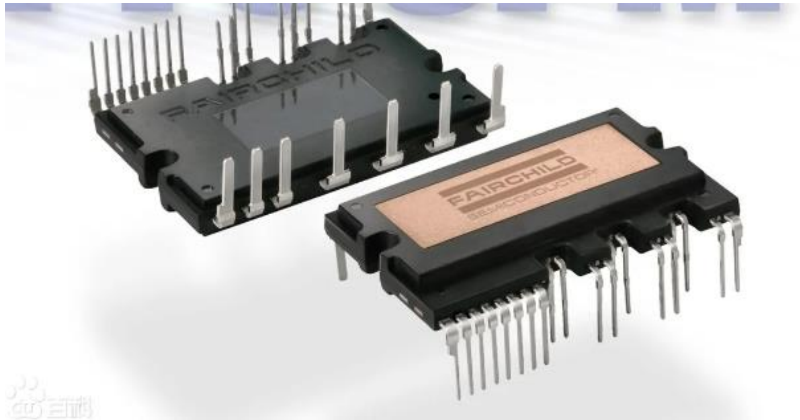
- Micred's Solution for Thermal Resistance and Power Cycle Testing of Power Devices

- The Effect of Applying Different Cycle Strategies in Power Cycles on Test Lifetime

Part I Introduction to Thermal Reliability of Power Devices

Types


HybridPACK™ solutions


FAIRCHILD
FAIRCHILD


HybridPACK™ DSC


EasyPACK™ family

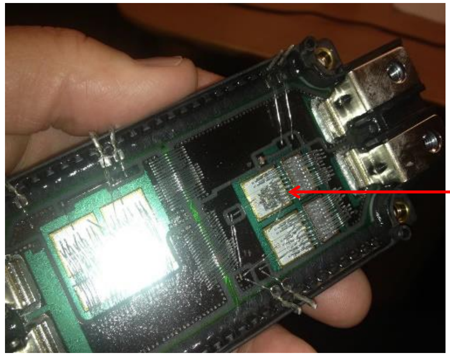
High power module device

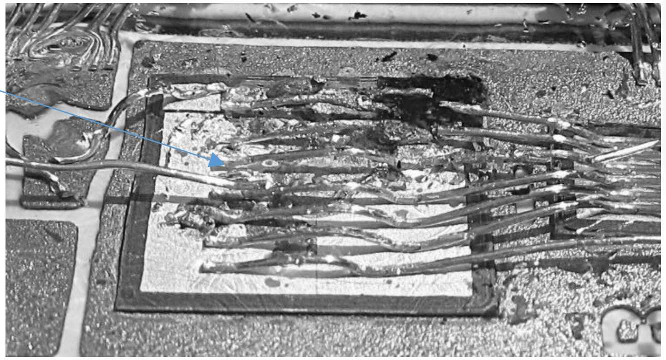
- Automotive and transportation
- Power generation and conversion
- Thermal testing and power cycling (reliability)

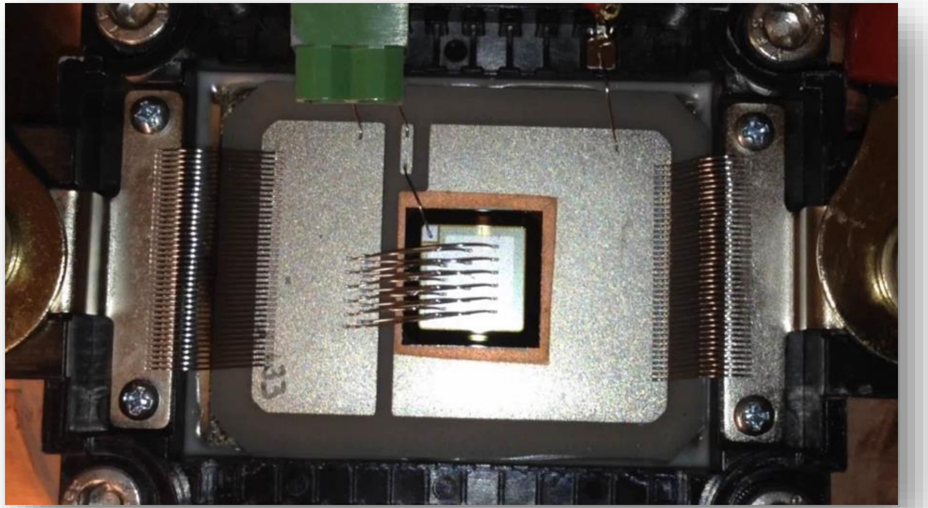
Application of Structural Functions - Reliability and Service Life

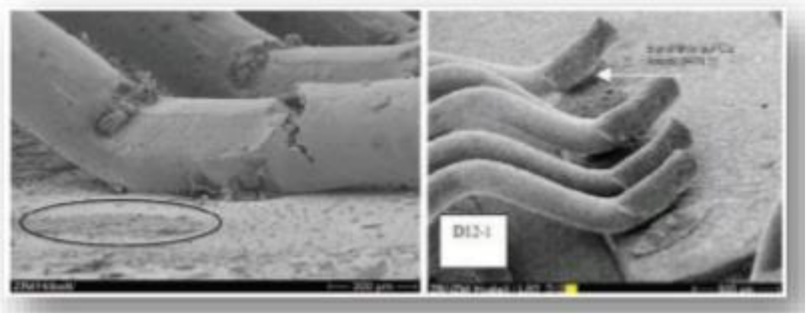
Reliability - Monitoring system or component degradation over time

- Determine where the defect occurs in the hot stack
- Identifying changes in failure over time
- This analysis is completed before the component completely fails

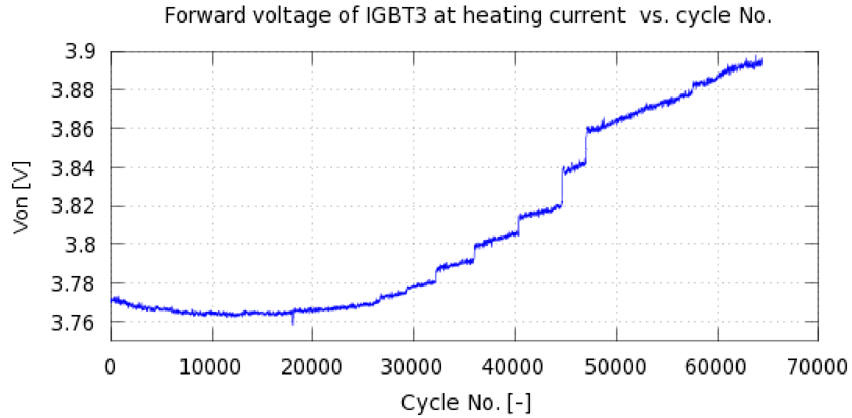






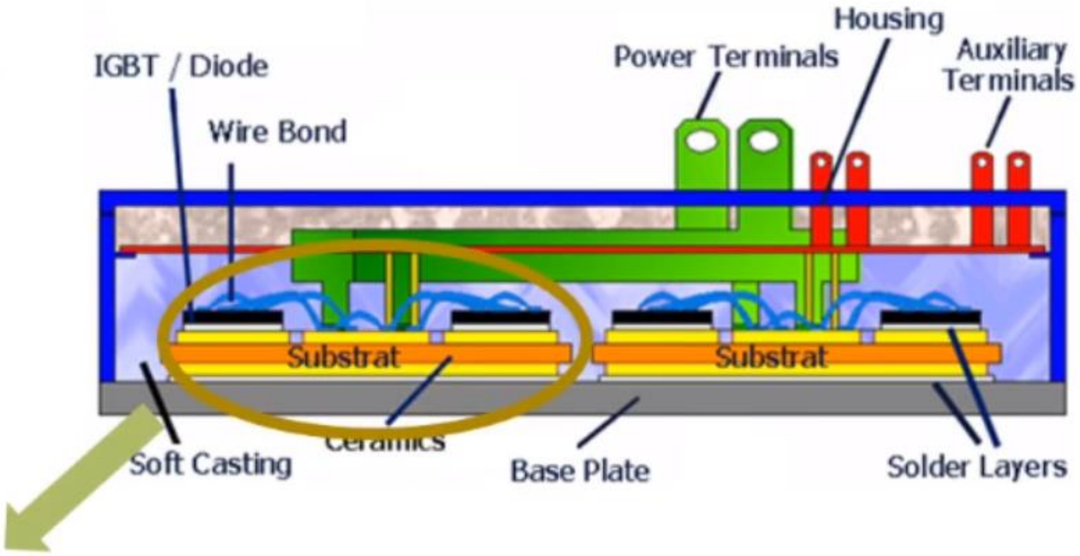


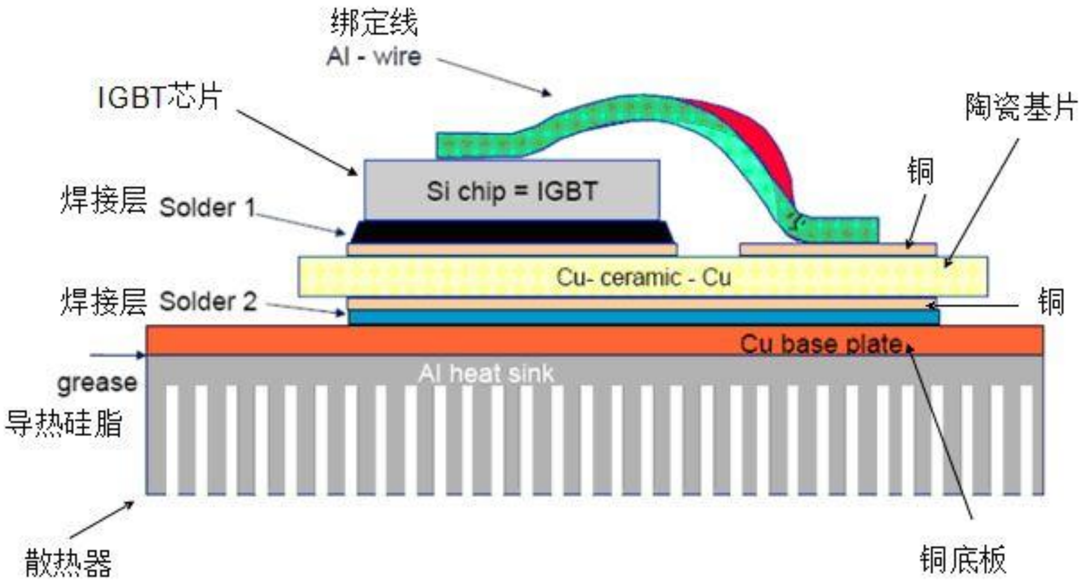
Technology Market及Siemens PLM

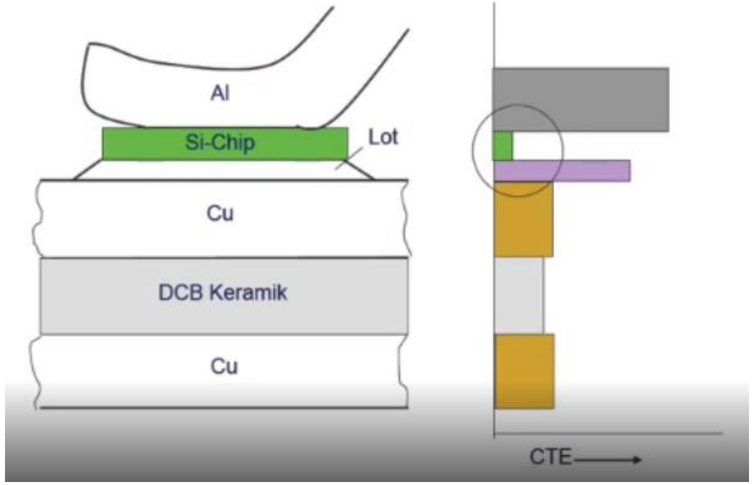


Bond wire degradation over increasing cycles

Power cycle damage to IGBT modules

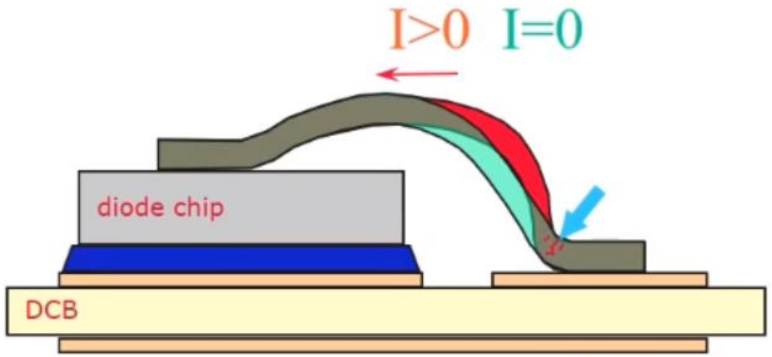


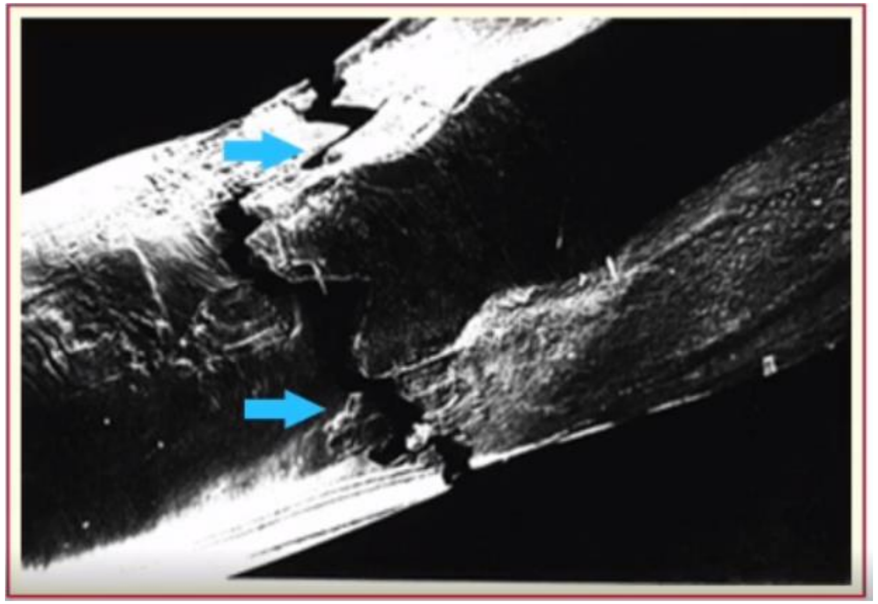




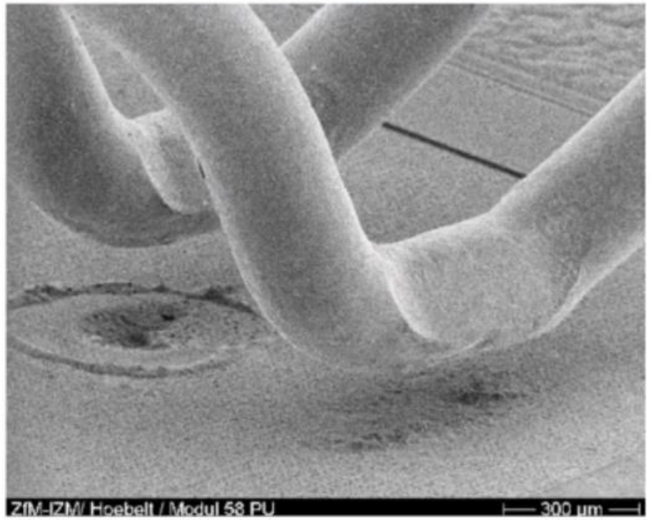
Fragile areas where typical power electronic devices are prone to defects

The bonding line falls off and breaks





IGBT standard module, ΔT 100K
failed between 10791 und 13000 cycles



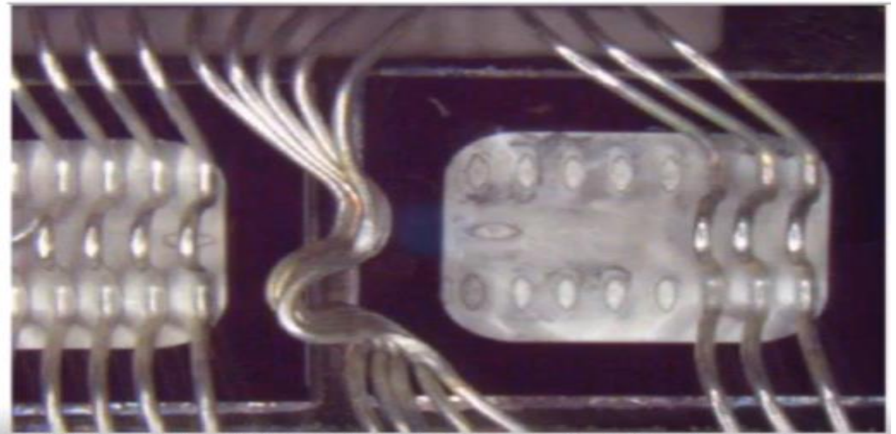


Bild 1: 2438H03 System2 Substrat2 D4 (ohne PI)
Bond Lift Off der Stitchbonds und Querbonds

Fragile areas where typical power electronic devices are prone to defects

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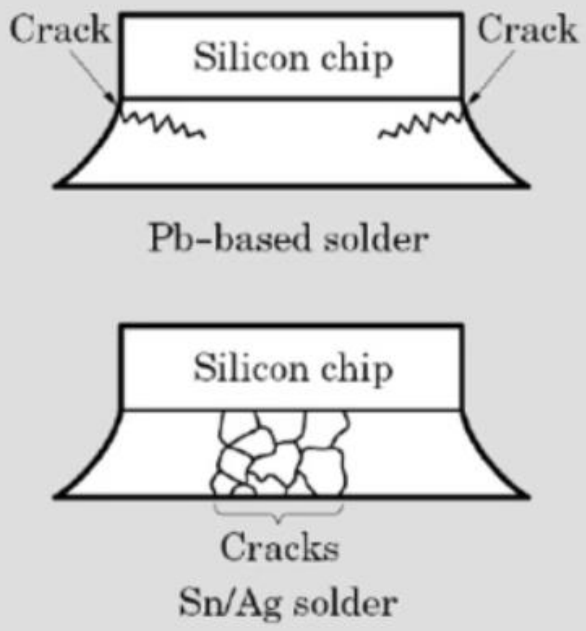
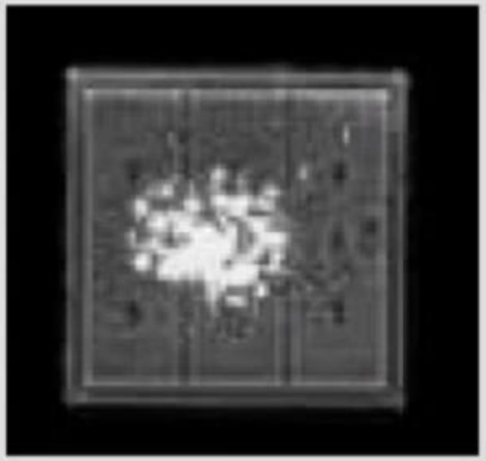
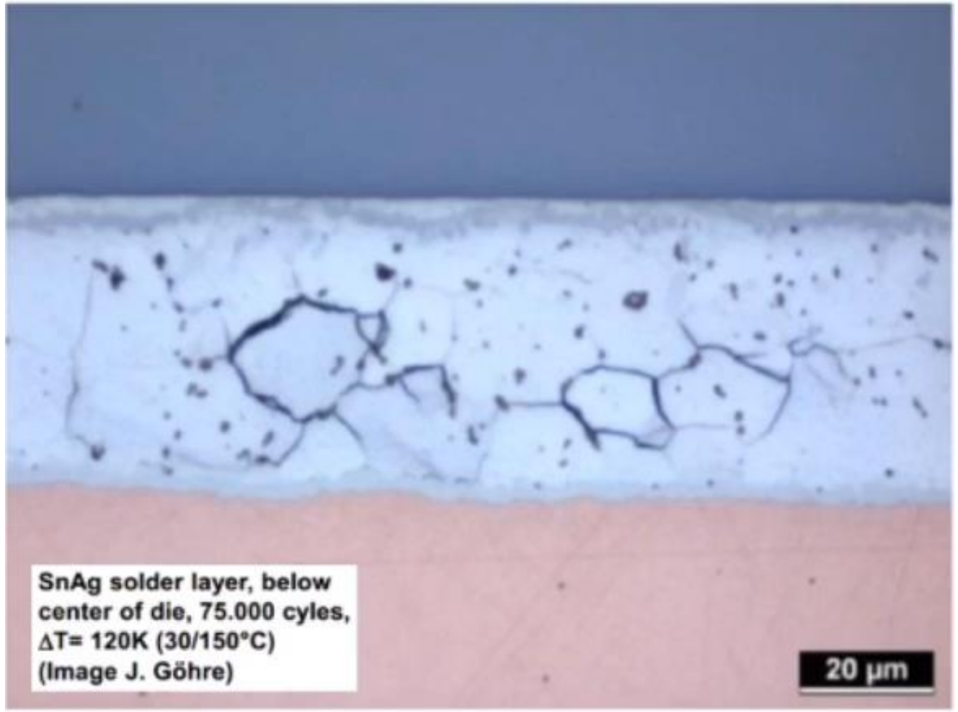
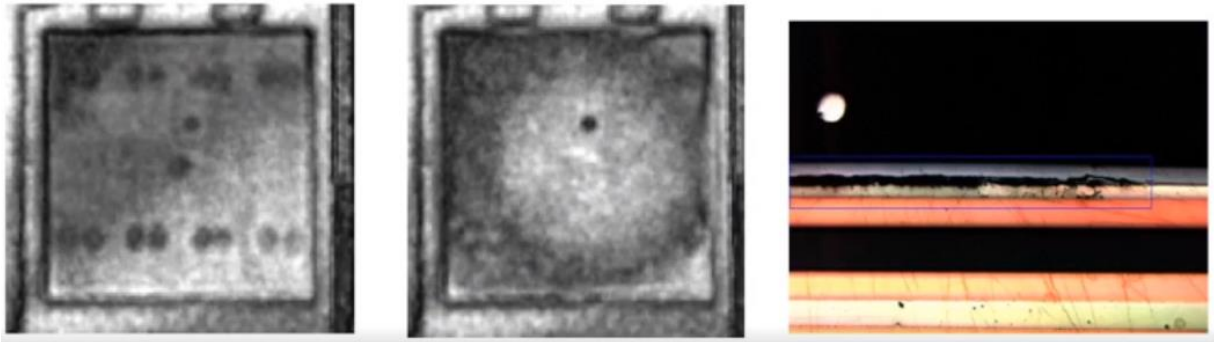




Failure form of Sn/Ag solder (acoustic image of Sn/Ag solder interface)



Chip solder layer cracking



comparison of unstressed (left) and stressed (middle and right) lead-free chip solder layer T_{jmax}= 125° C, ΔT= 80K, 600.000 cycles, Images from Infineon

Fragile areas where typical power electronic devices are prone to defects

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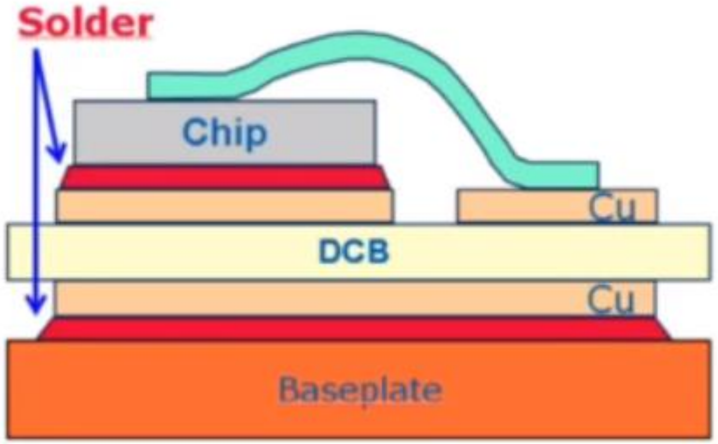
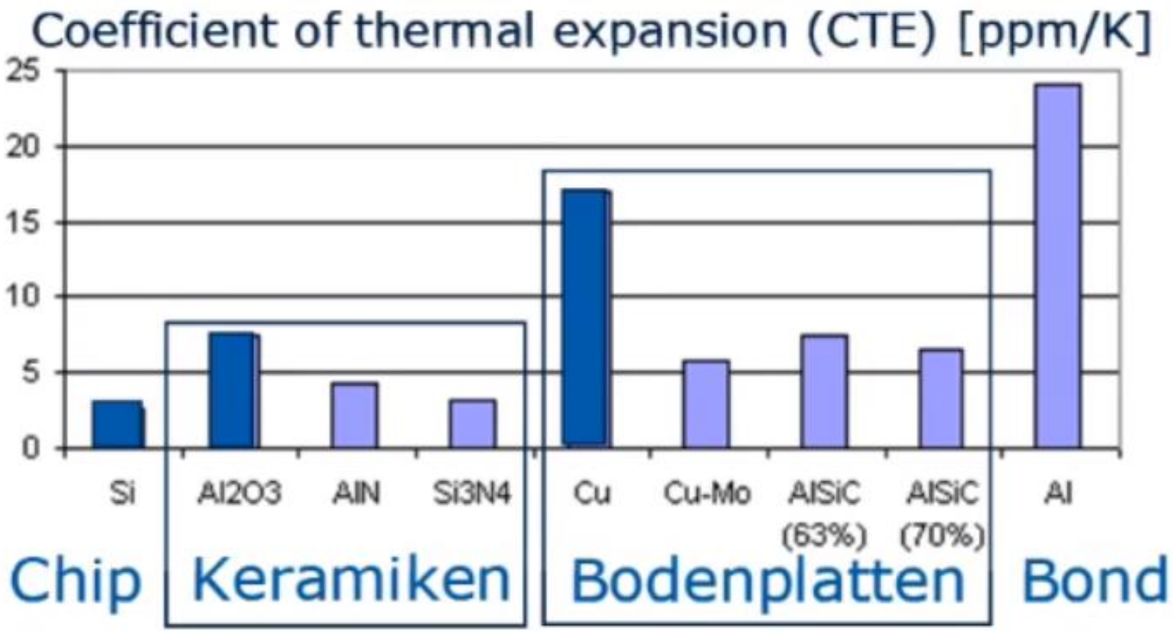
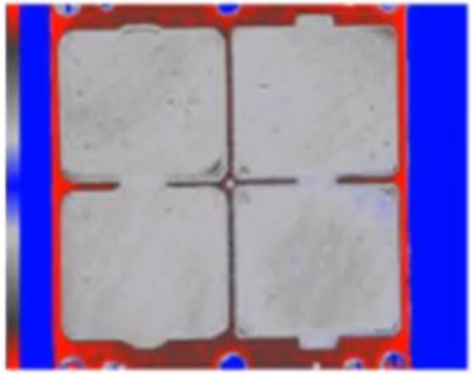
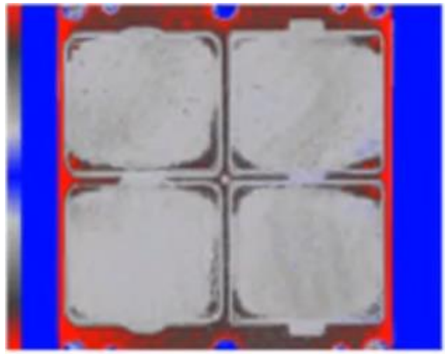
Cracking of substrate welding layer



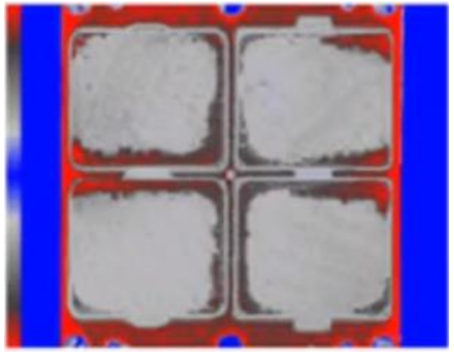




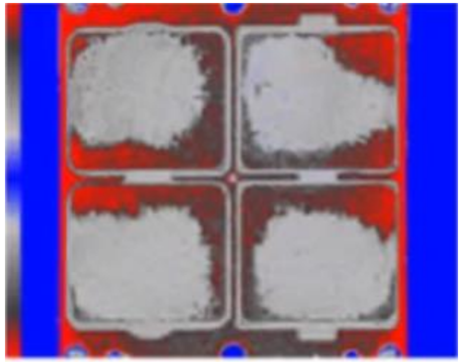
200 cycles (Cu)



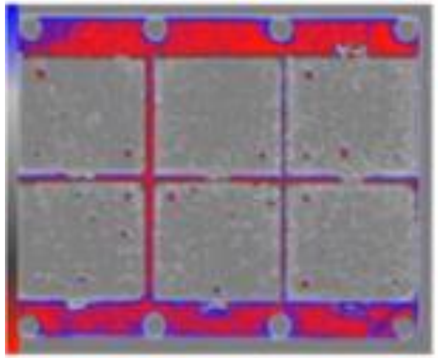
1000 cycles (Cu)



2000 cycles (Cu)



4000 cycles (Cu)

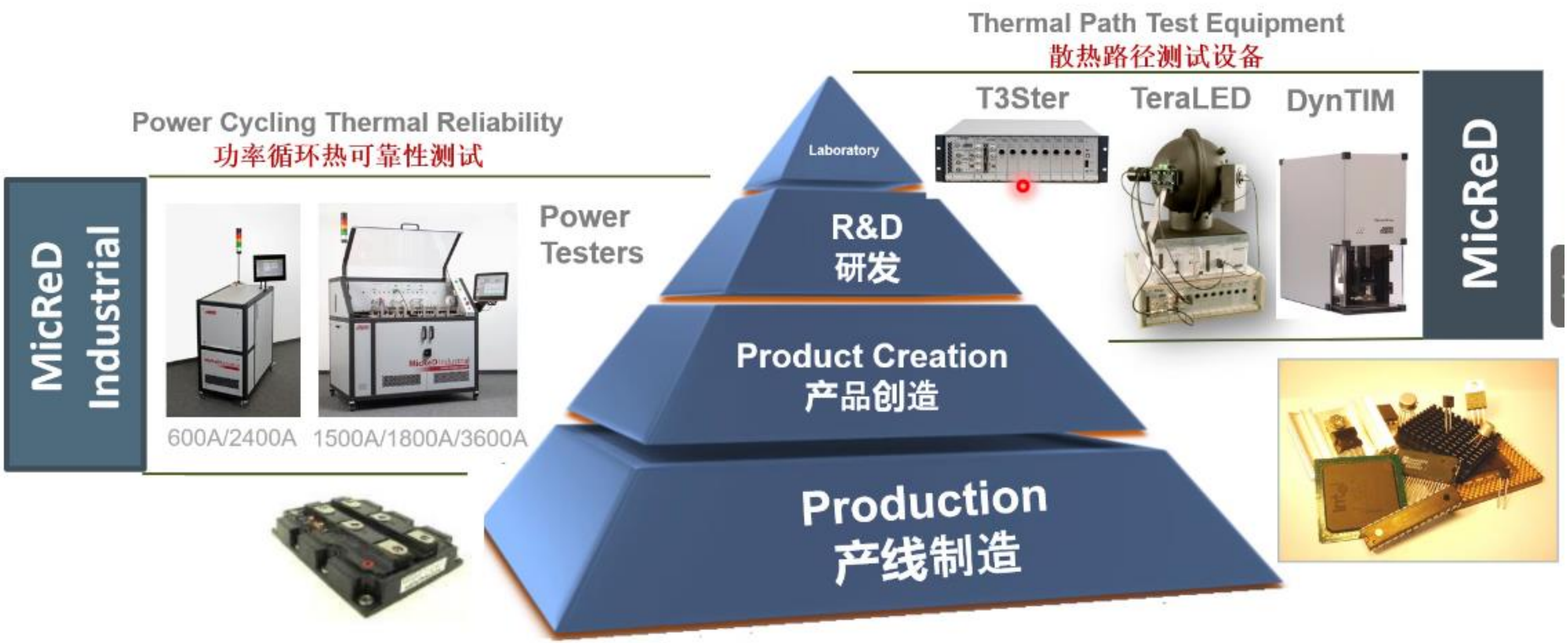


20 000 cycles (AlSiC)

Part II Micred's Solution for Thermal Resistance and Power Cycle Testing of Power Devices

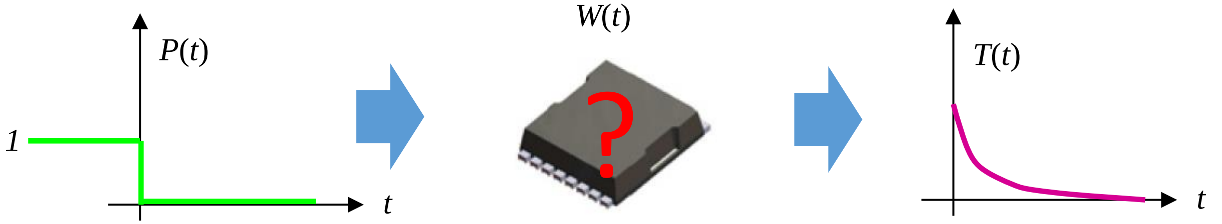
MicReD - 提供热测试的解决方案

SIEMENS
Ingenuity for life



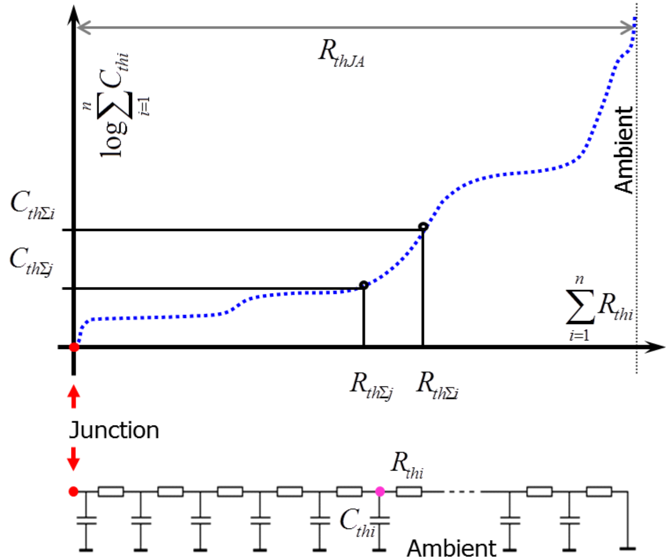
Transient thermal testing--Origin of structural functions

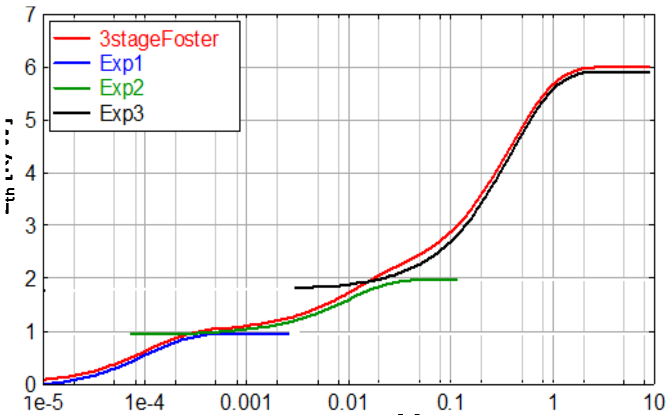
Transient thermal testing



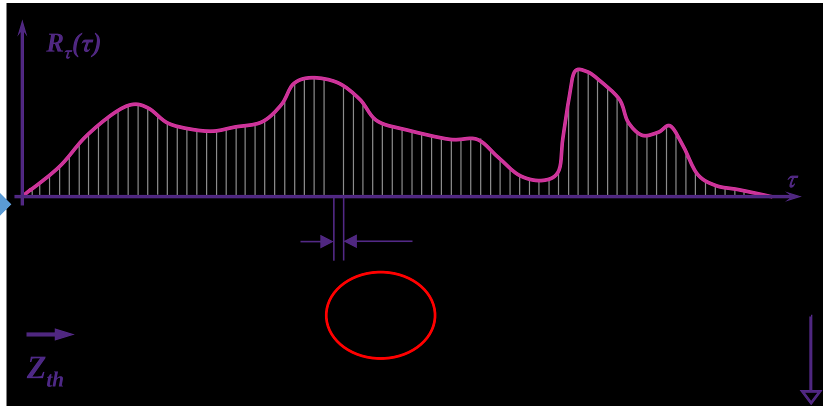
Provide constant heating power to the DUT, and then cool it down

Structural function curve

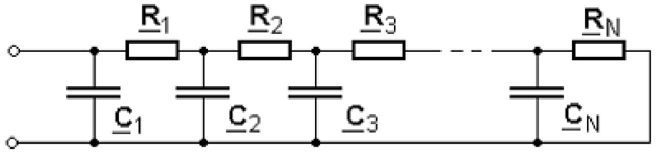




Thermal impedance curve



Time constant spectrum



Foster to Cauer model transformation

Siemens Simcenter MicReD Power Tester

- Uses T3Ster Transient thermal testing technology
- Structure Functions

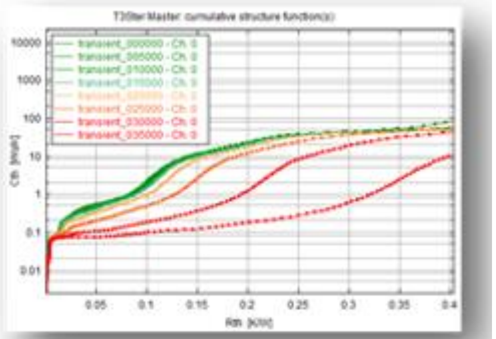
- High Power applications， Power current
- 600A, 1500A, 1800A, 2400A, 3600A

- Automated Power Testing and Power Cycling tests

- For diode MOSFETs, IGBTs and else Power devices

Siemens Simcenter MicReD Power Tester

- Industrial implementation of Mentor’s industry-unique MicReD T3Ster technology
- Provides fully automated power testing / cycling
- Simple touch-screen user interface
- For MOSFET, IGBT and generic two-pole devices
- Records diagnostic information during test:
  - Current, voltage and die temperature sensing
  - “Structure Function” identifies changes / failures in package structure
- Supports package development, reliability testing, and batch checking of incoming parts before production



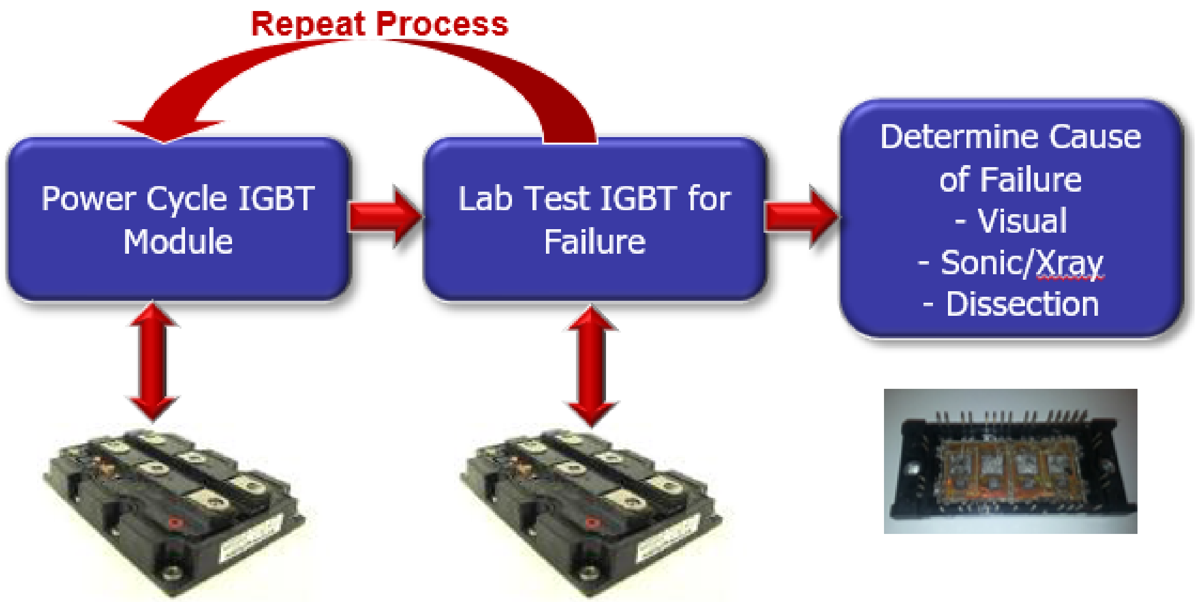
Structure Function

Touch Screen Controls

Traditional Process

- Traditional Process:
  - Run set number of power cycles
  - Take to lab and test for failure
  - Repeat power cycling/lab testing cycle until failure
  - Take to lab and determine reason for failure

- Issues:
  - Repetitive cycle/lab test process = long times
  - No “real time” indication of failure in progress – only post mortem
  - Failure cause requires lab analysis – typically internal to package



Operational principle

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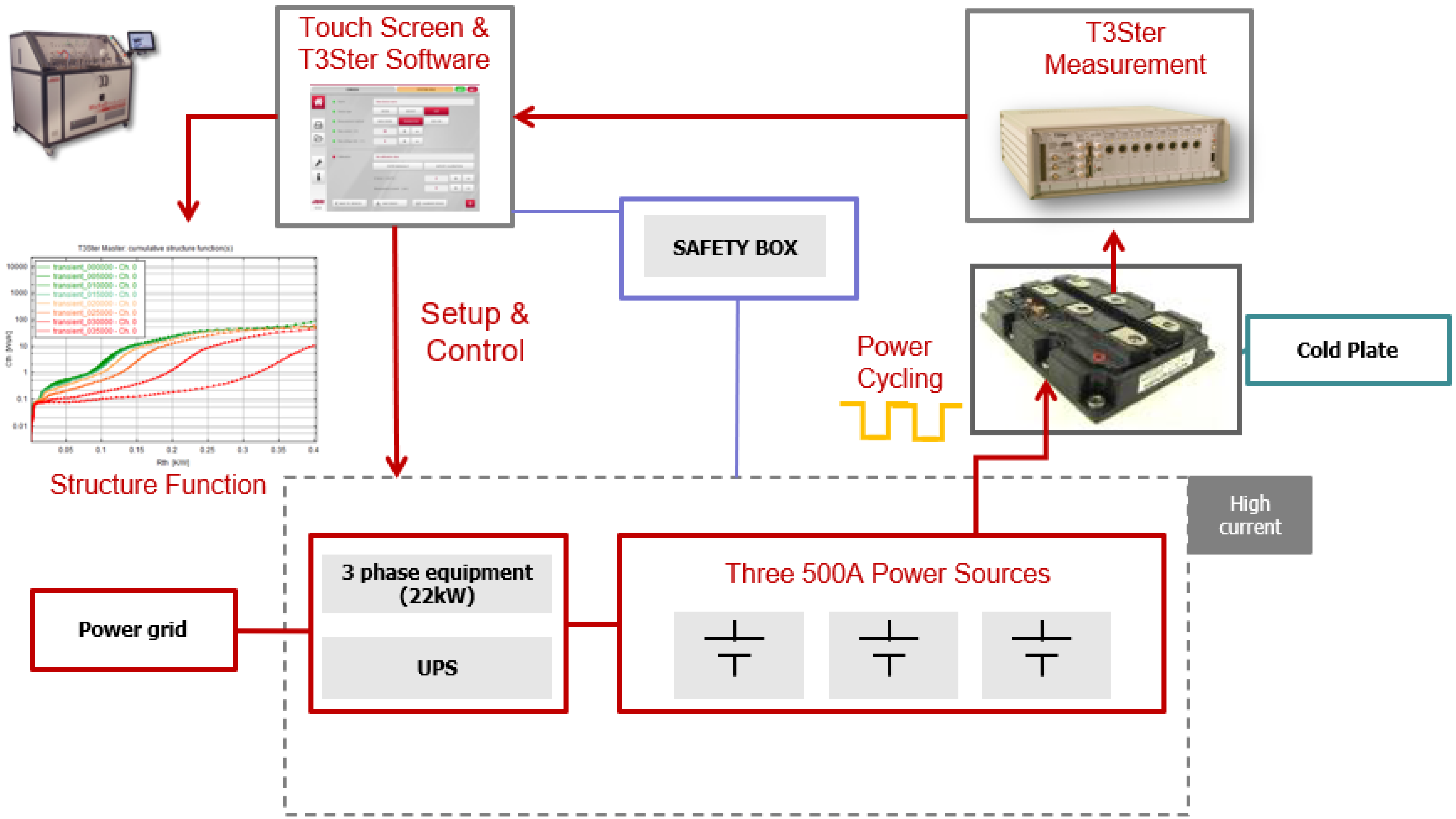

Implementing Thermal Reliability and Life Prediction of Power Semiconductor Modules Based on Power Tester

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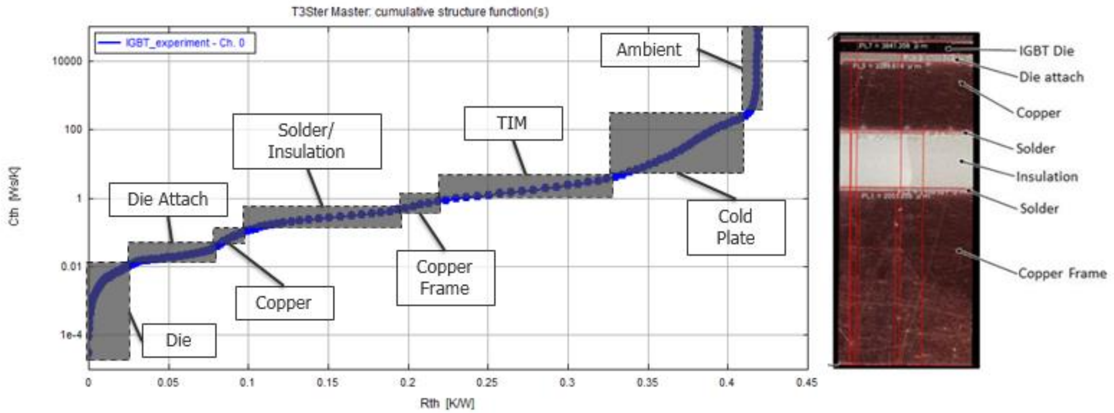
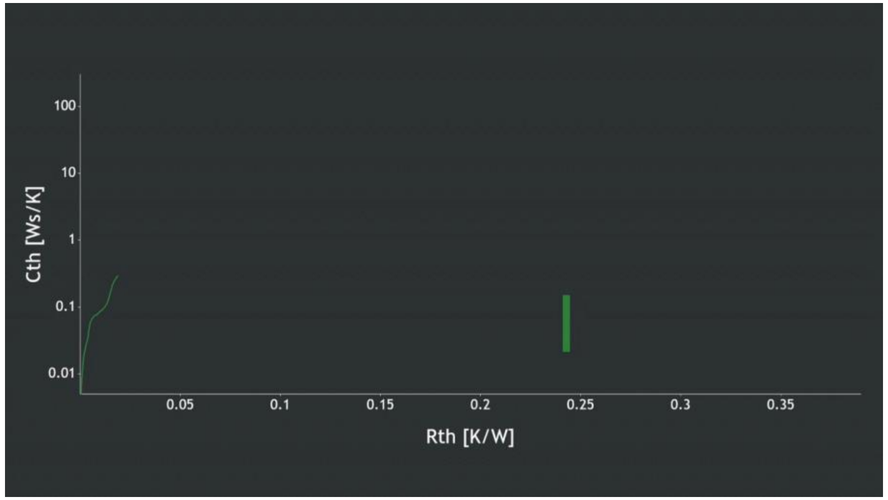
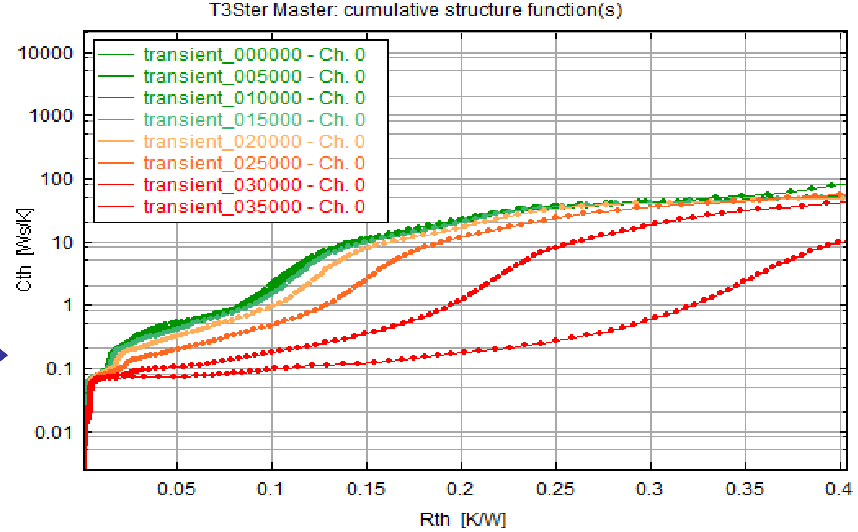


Power Tester is a powerful tool for testing the thermal resistance (Rth) and thermal reliability (Power cycling) of power semiconductors, as well as predicting their lifespan





Die attack degradation can be displayed in real-time through the structure function curve in power cycle testing

Comparison of structural function curves collected periodically in power cycle testing

The top 10 main advantages of Simcenter POWERTESTER

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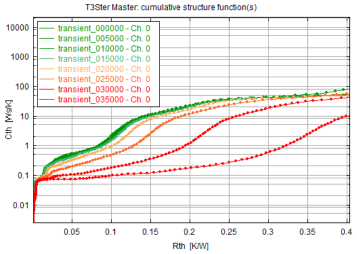
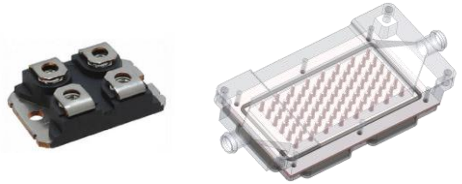
10. Understand the causal relationship between failure mechanism and damage

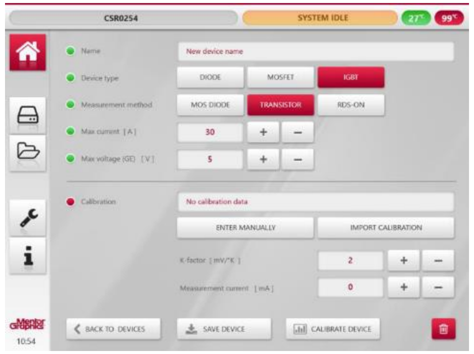


1. Solutions for different industries - a wide range of available hardware options

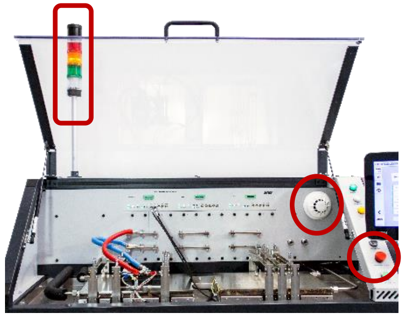
2. combining Rth and PC



3. The operation interface is simple and convenient

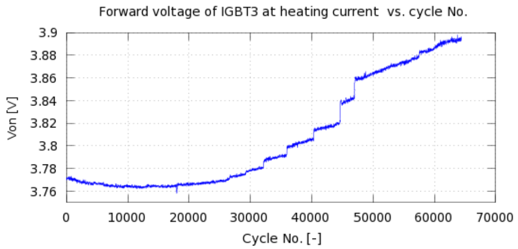


9. Safety features and high reliability design

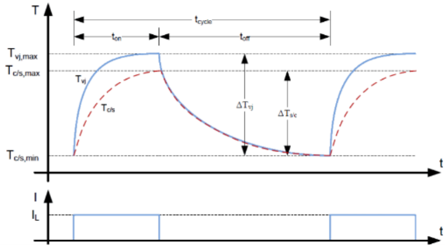


8. Easy operation

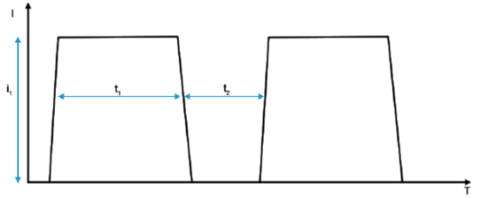
7. Remote monitoring



6. High precision monitoring and precise testing results



5.Support PCsec & PCmin



4.power cycle application strategies (compliant with AQG-324 standard)

PartIII The Effect of Applying Different Cycle Strategies in Power Cycles on Test Lifetime

Power cycle testing application strategy

- Constant current

—Degradation has immediate impact on resulting temperature swing, no compensation

—Most severe strategy

- Constant current, change of the cold-plate's HTC

—Changes the flow rate of the coolant liquid in sync with the cycles

—Helps to create a temperature swing at the case to induce failures in the base plate solder

—For longer cycle times

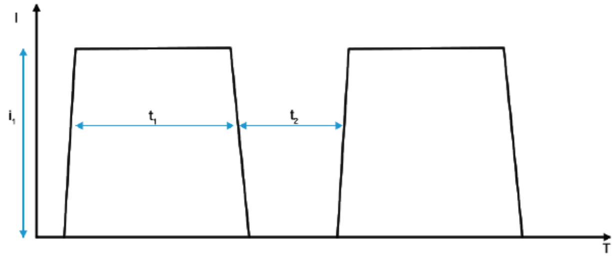
- Constant power, PV

—Constant ton and toff

—Power losses are held constant by controlling the driving current

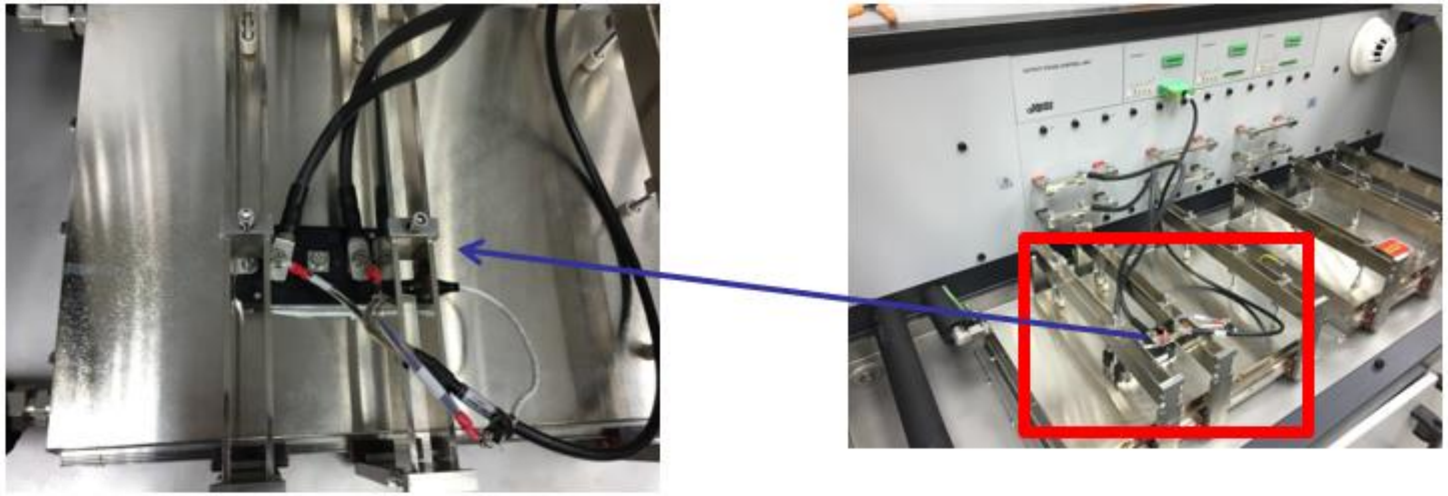
- Constant ΔTj=Const

—Driving current control

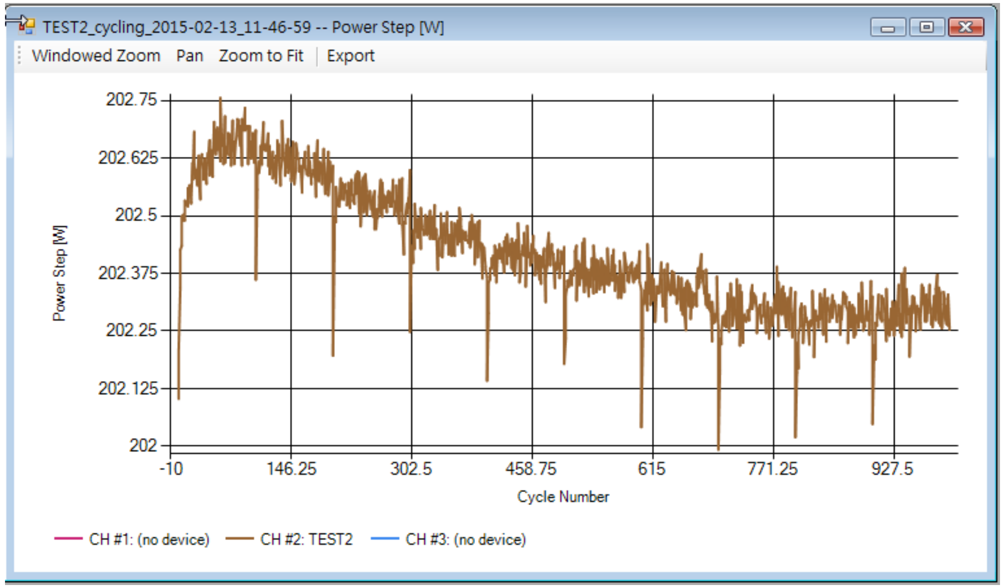


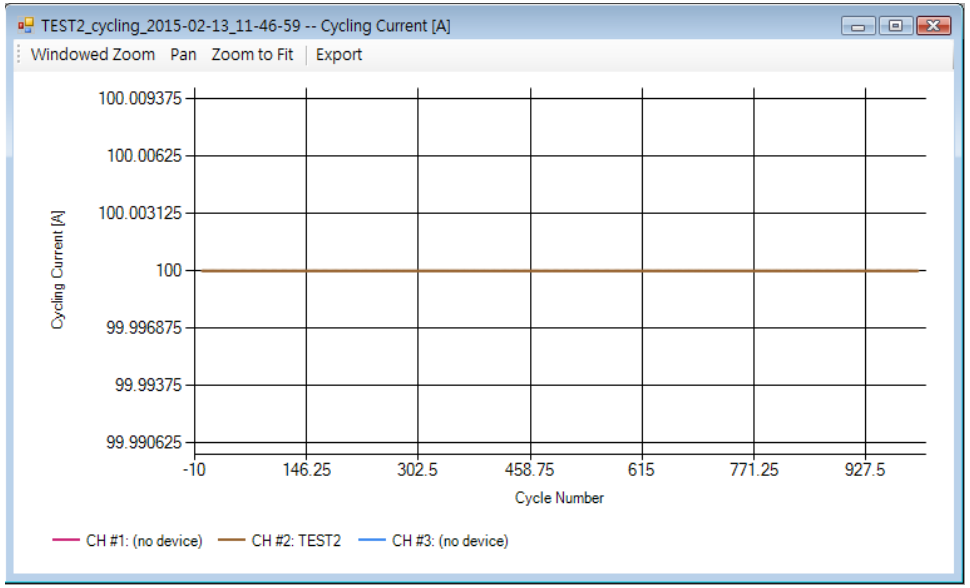
IGBT measurement of Power Tester(1) – constant current

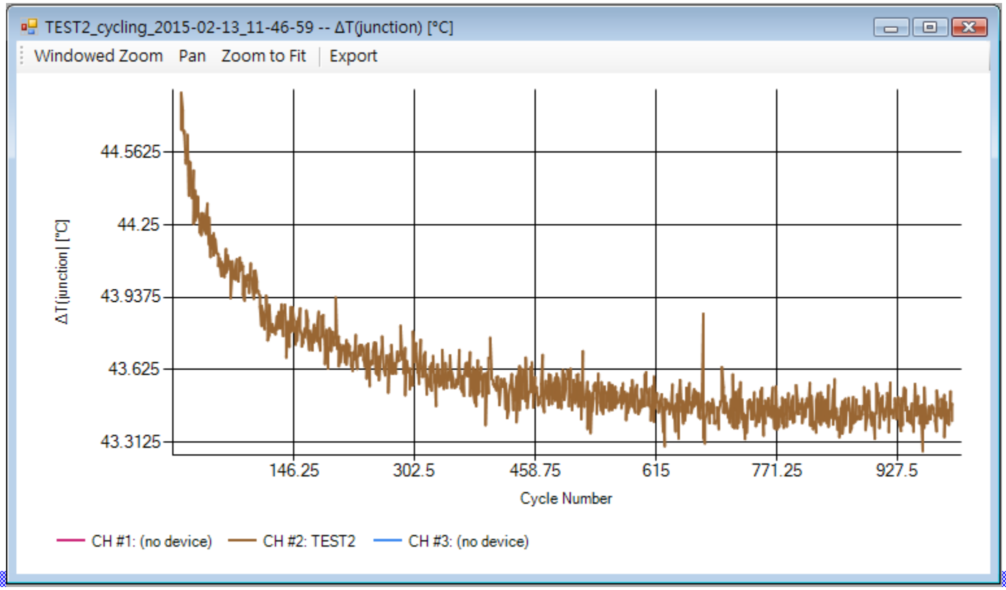
- Base plate temperature: 25°C
- Input power: 200W @ 100A
- Constant current regardless of the voltage change
- The number of cycles:1000 cycles
- Transient test after every 100 cycles

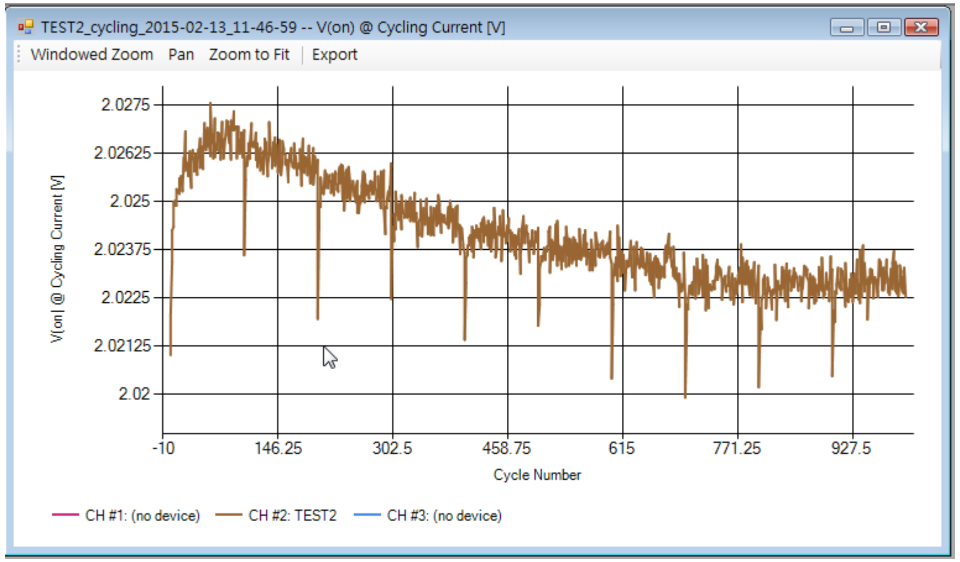


IGBT measurement of Power Tester(1) – constant current

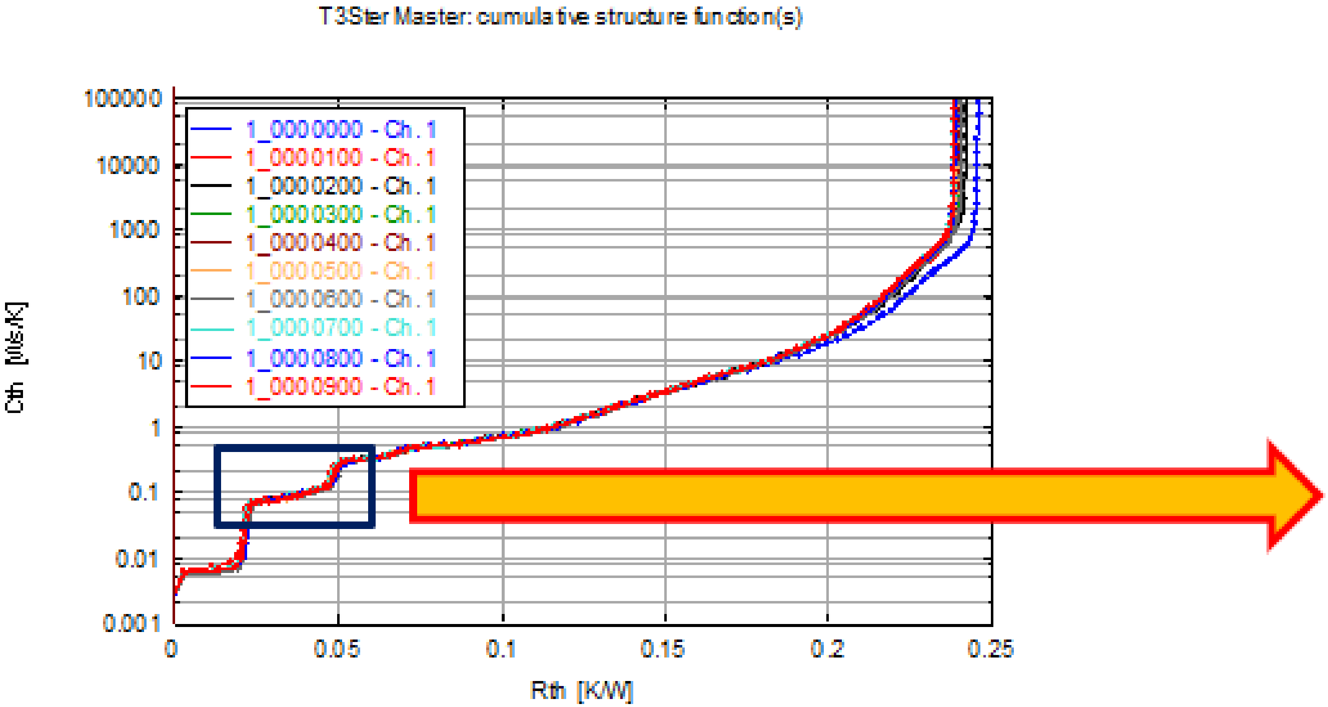


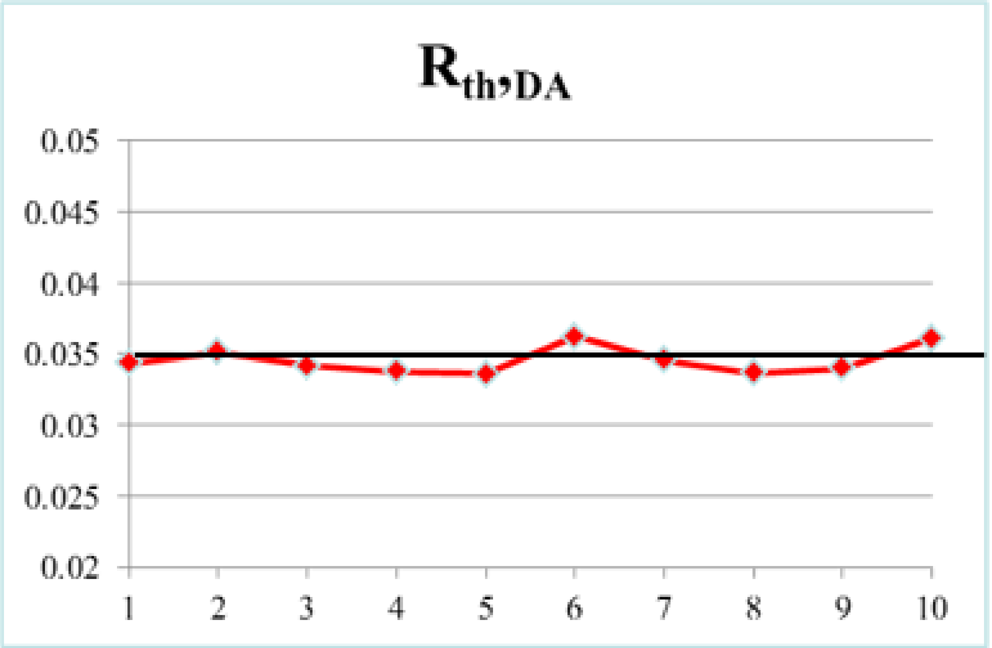






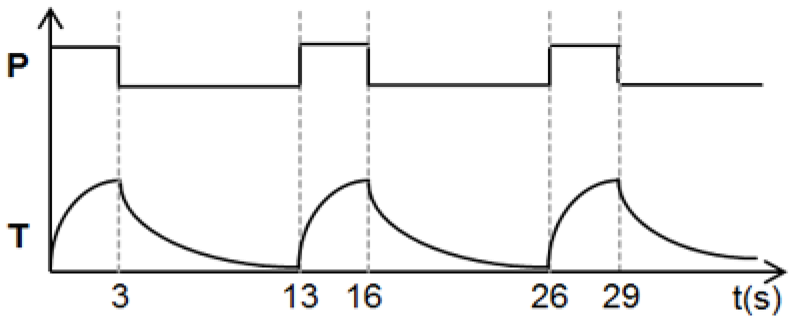
IGBT measurement of Power Tester(1) – constant current

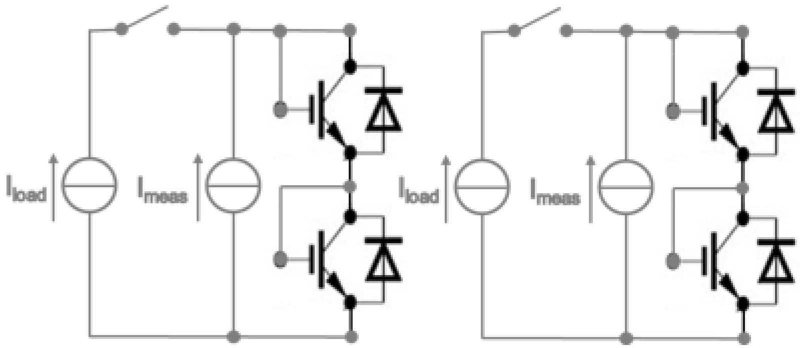




IGBT measurement of Power Tester(2) – constant current

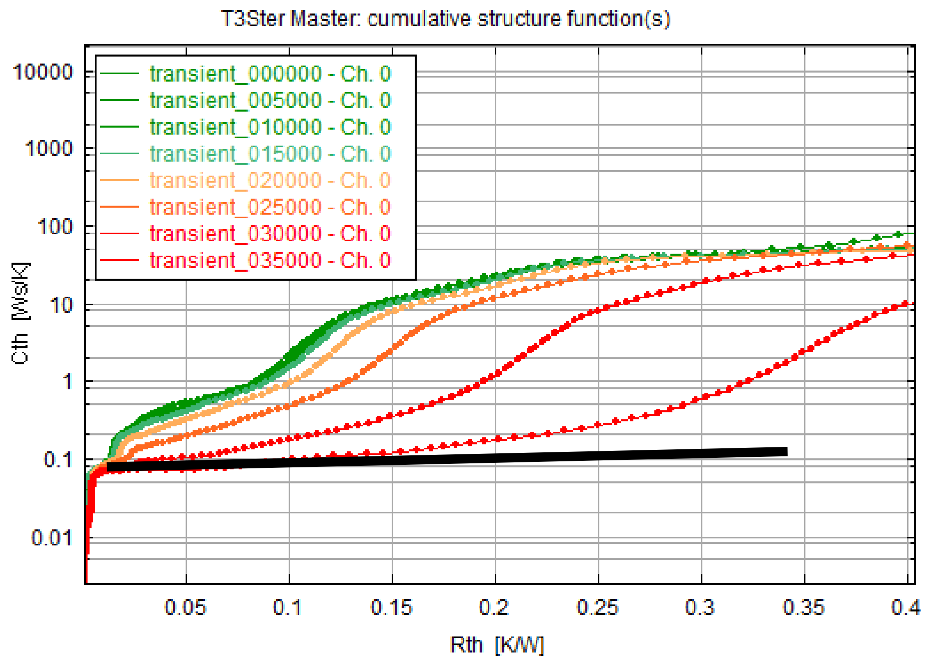
- Base plate temperature: 25°C
- Targeted junction temperature: 125°C
- Input power: 200W @ 25A

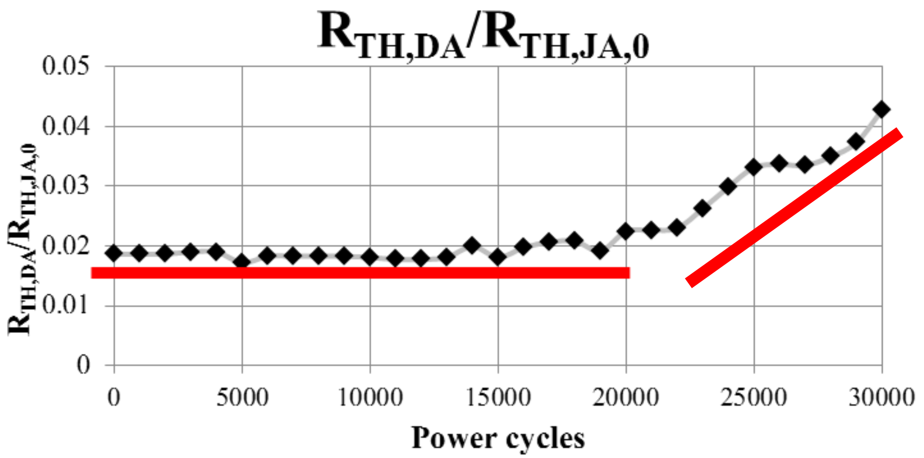




- **Constant current regardless of the voltage change**
- Transient test after every 200 cycles

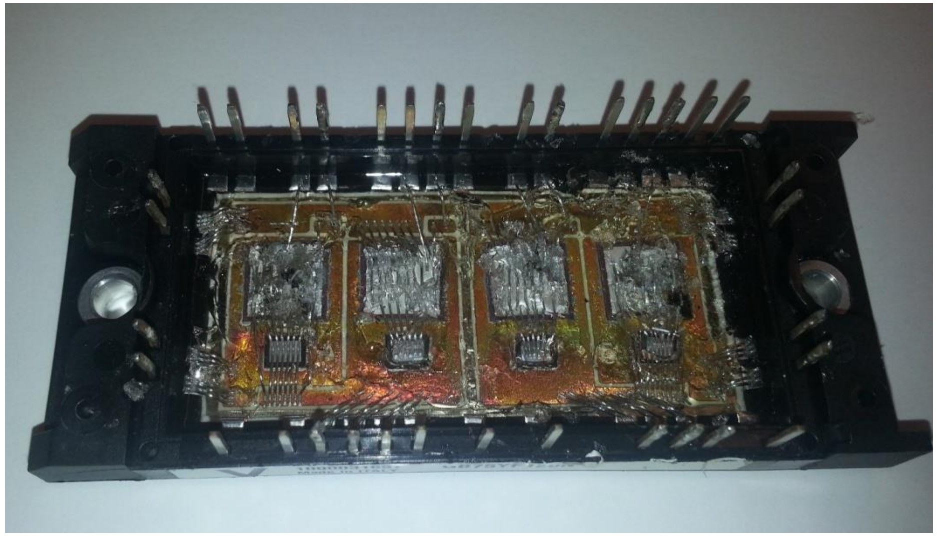
IGBT measurement of Power Tester (2) – constant current

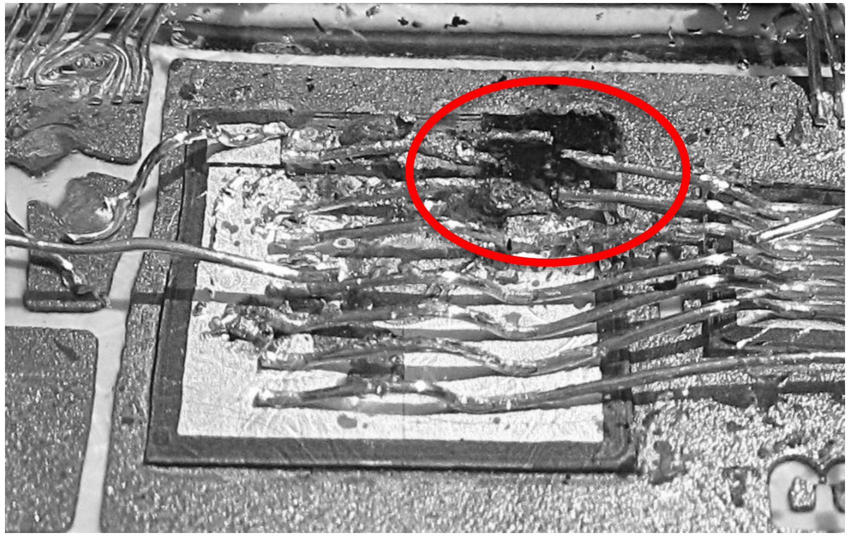




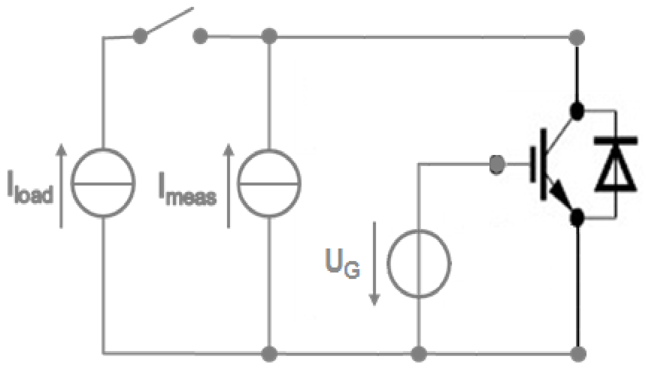
IGBT measurement of Power Tester(2) – constant current

- Broken bond-wires and burnt areas on the chip surface





- Devices mounted on temperature controlled cold plate
- Base plate temperature: 25 °C
- Various control strategies*
- Transient test after every 250 power cycles



Power cycling strategy	Device	Initial parameters (avg(1..1000 cyc))				Cycles-to-failure
		I [A]	P [W]	DT [°C]	$T_{j,max}$ [°C]	
Const. I	A4	**90.0**	389.6	120.1	156.9	21570
	B4	**87.2**	379.1	119.9	157.2	24837
	C4	**89.1**	388.2	119.8	157.2	24892
Const. P	A3	93.7	**399.1**	119.9	158	29226
	B3	90.4	**399.1**	119.7	156	31081
	C3	90.3	**399.1**	118.9	155	29340
Const. ΔT	A2	91.2	411.1	**119.9**	155	35406
	B2	90.5	396.8	**110.9**	144.5	57329
	C2	91.1	382.1	**119.3**	152.5	39149

IGBT measurement of Power Tester(3)-Different Strategies to compare

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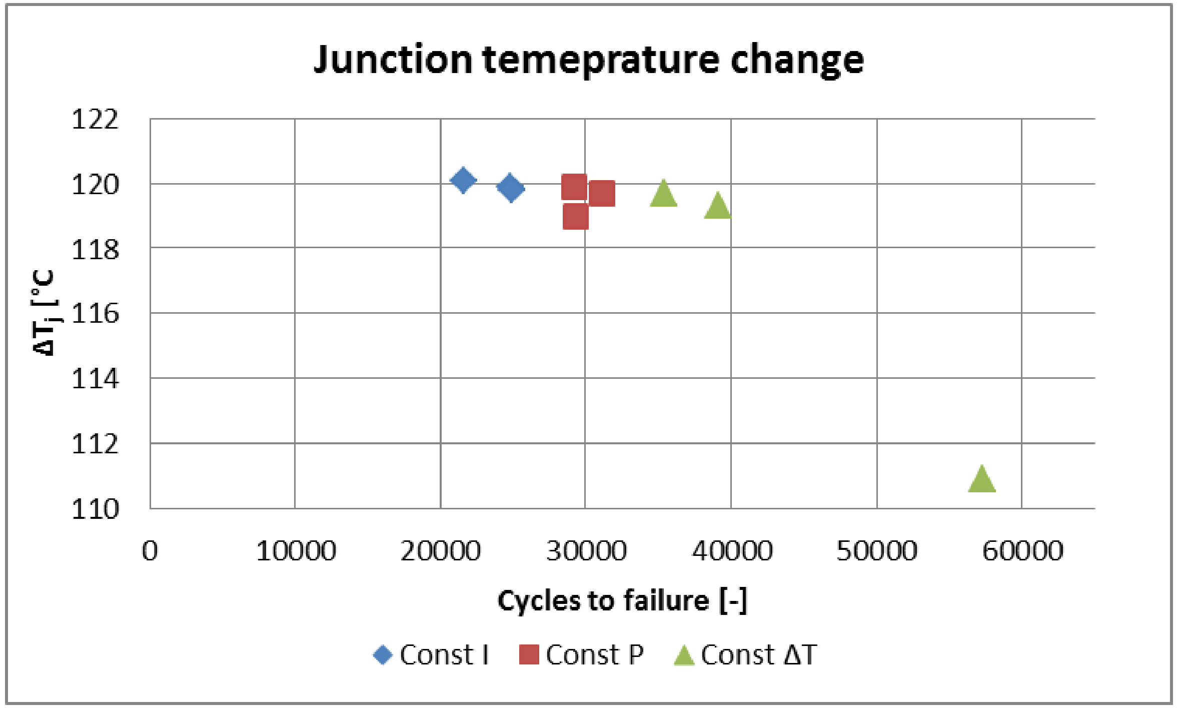

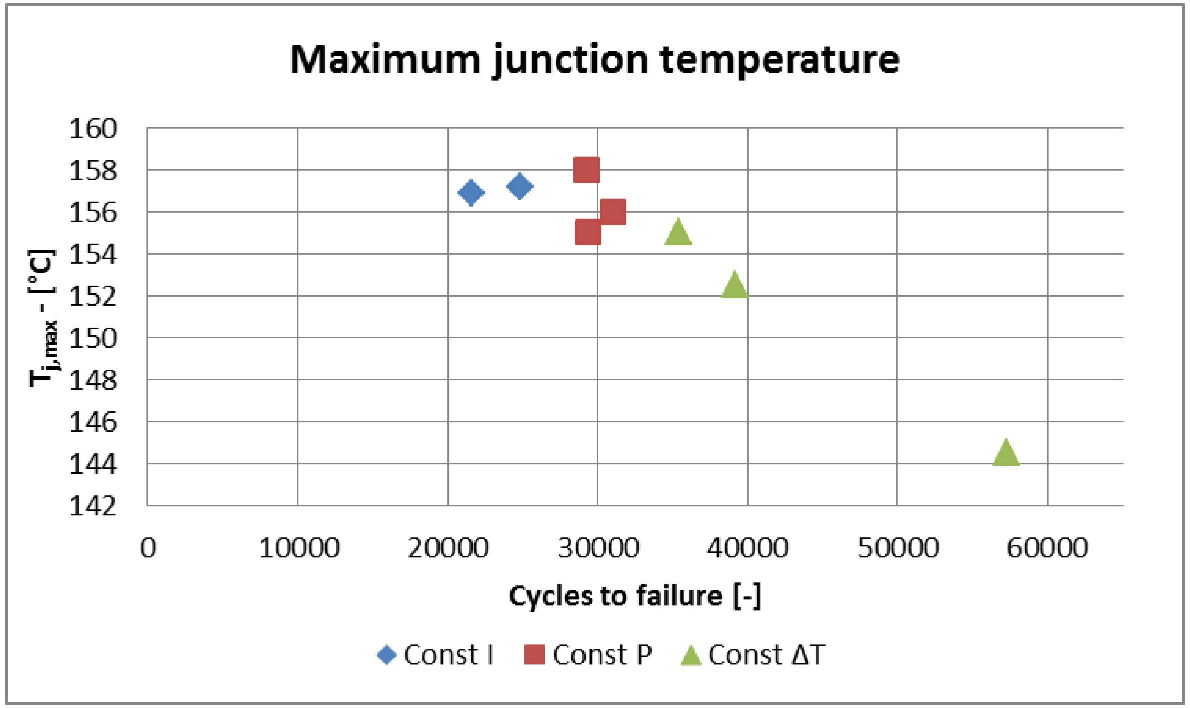

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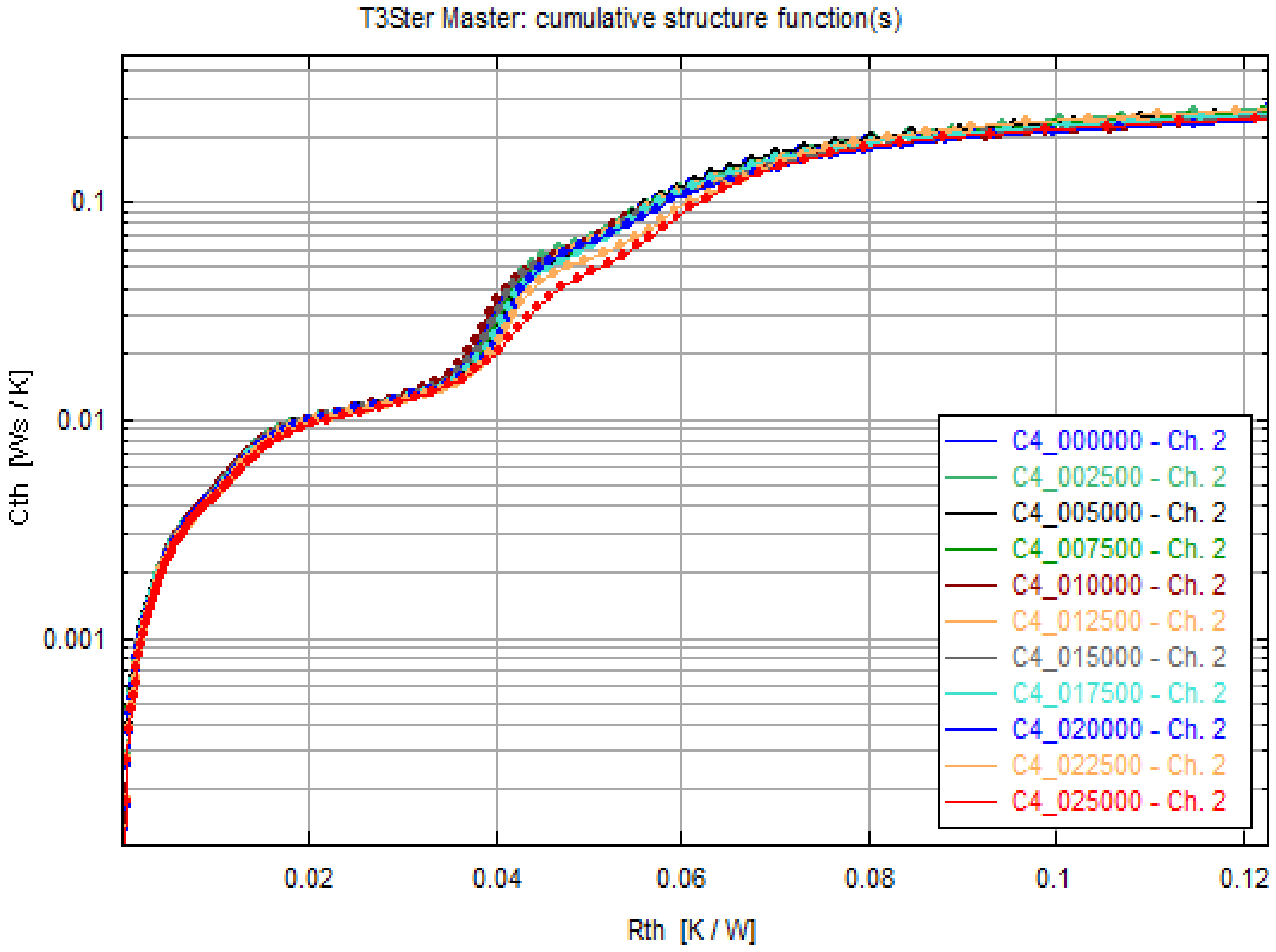
Structure functions to identify die attach degradation



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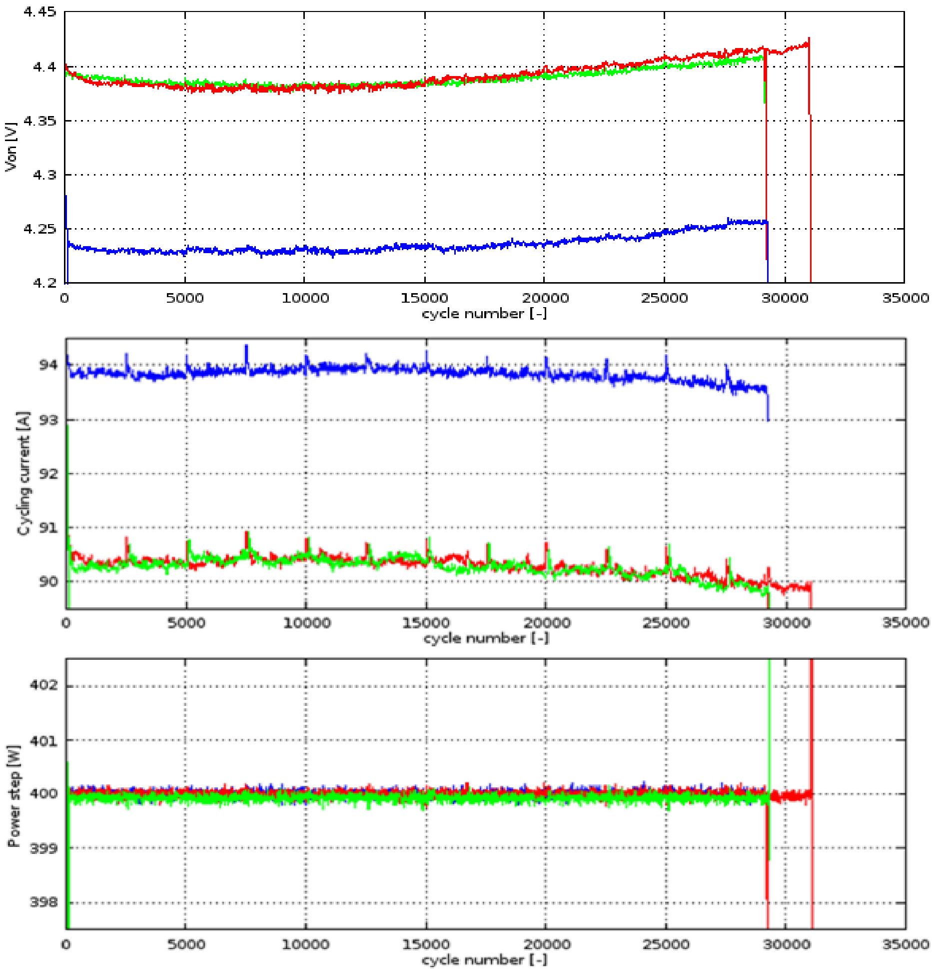
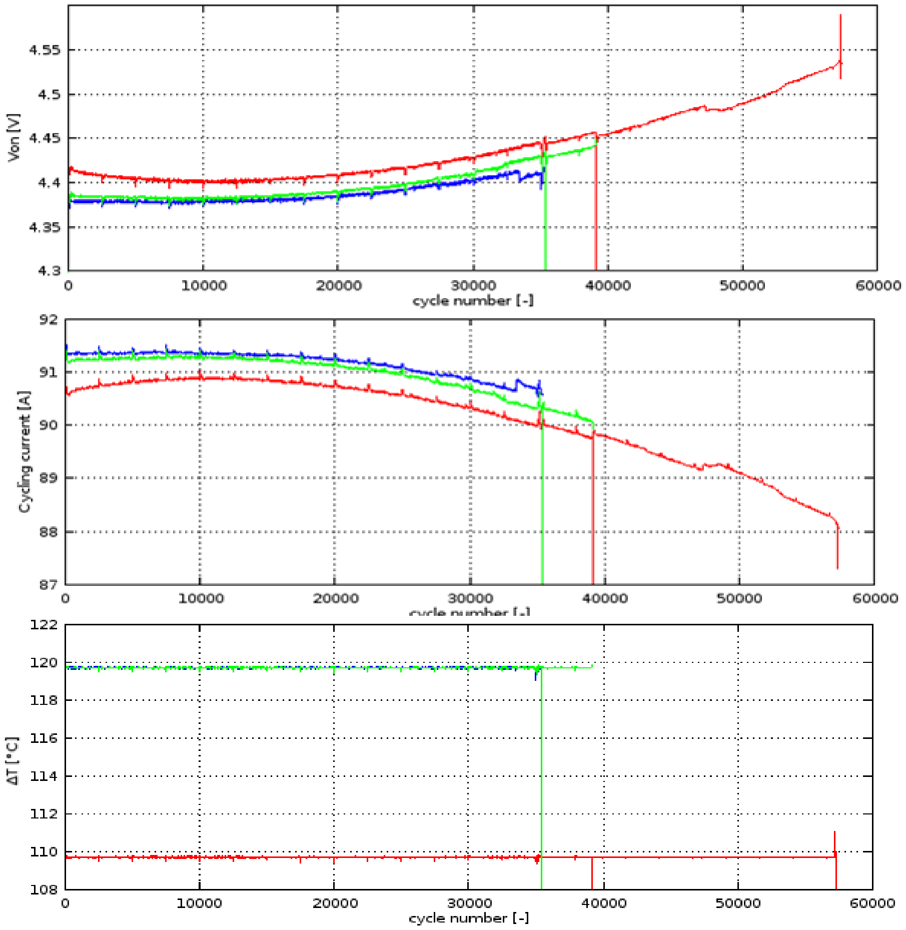
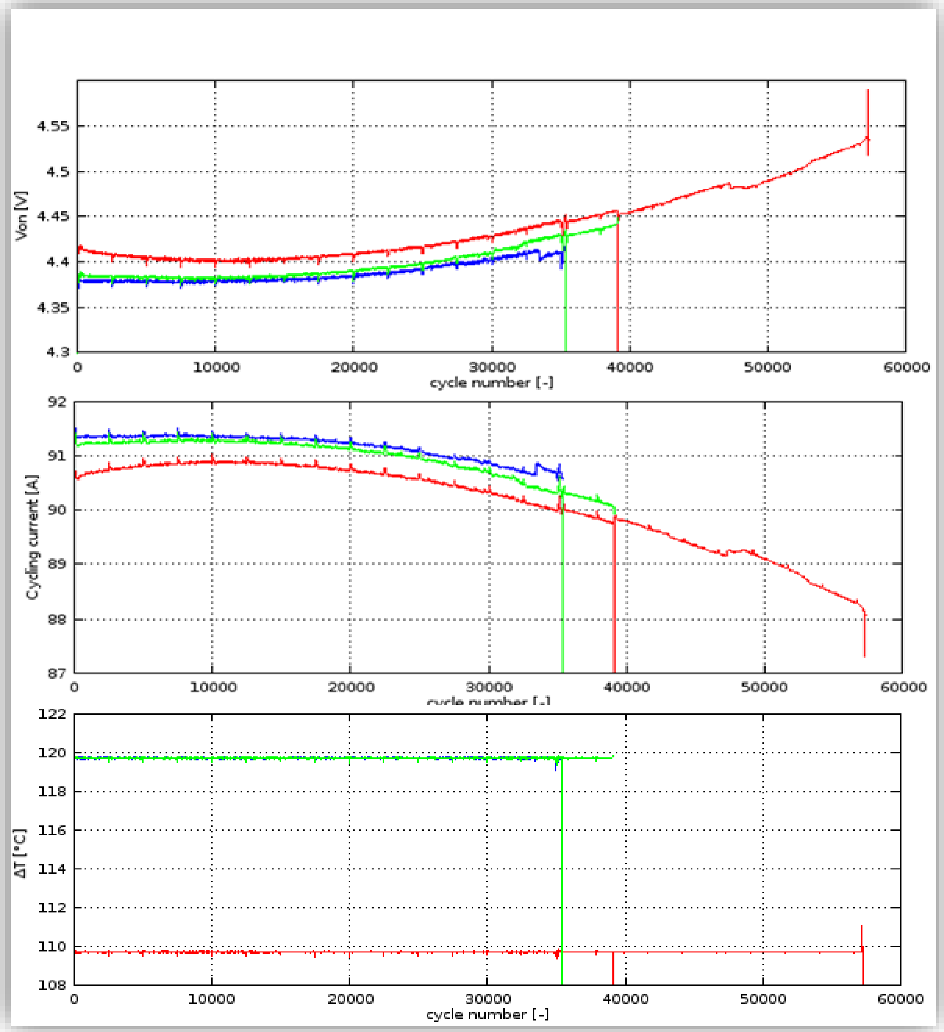
Cycling number vs. electric parameters for constant ΔP (left) and constant ΔT (right)





Effect of temperature differences on lifetime



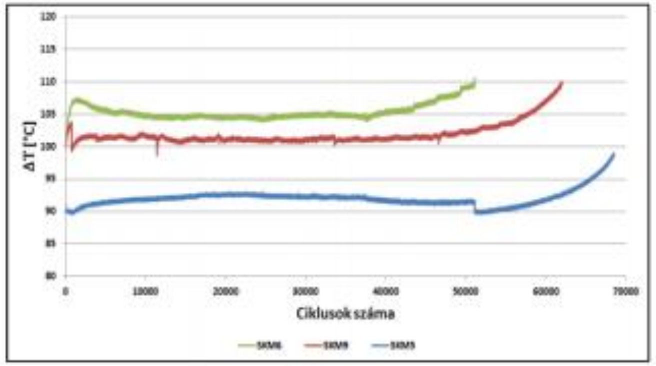
- The same parameters used for IGBT cycling
- ΔTj is kept constant, but 10ºC difference between two cases

Significant difference in the lifetime

- 120ºC: ~36000 cycles
- 110ºC: ~58000 cycles

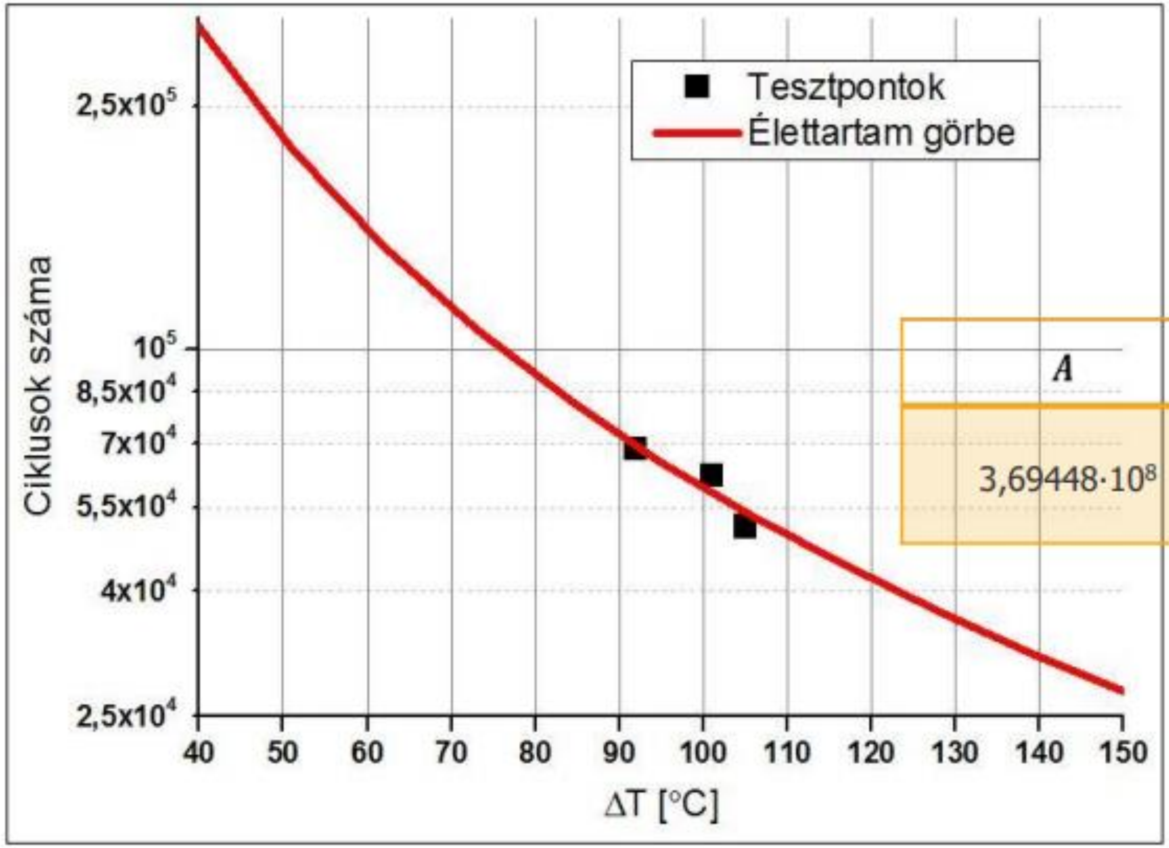
- 2 points of the lifetime curve are available

Accelerated Life Test



	Average ΔT [°C]	Cycle number to failure [-]
SKM6	105	51104
SKM9	101	61969
SKM5	92	68465

- 3 samples were cycled at pre-set boundary conditions: 110°C, 100°C, 90°C



A	α
$3{,}69448 \cdot 10^{8}$	-1,89743

- Curve fitting following the Coffin-Manson model

$$N_f = A \cdot (\Delta T_j)^{\alpha}$$

Life prediction

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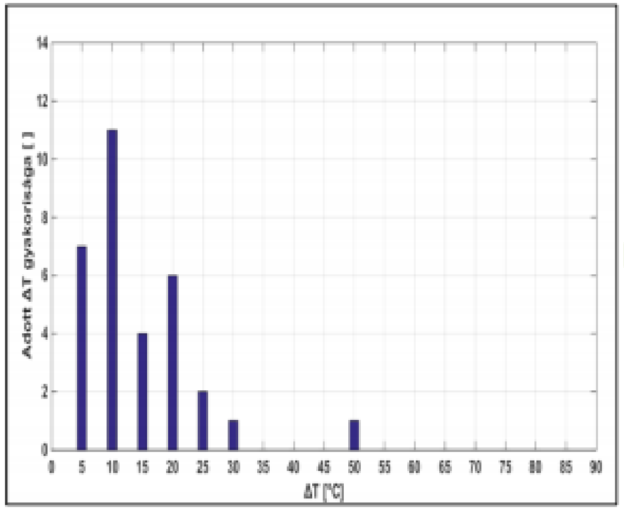
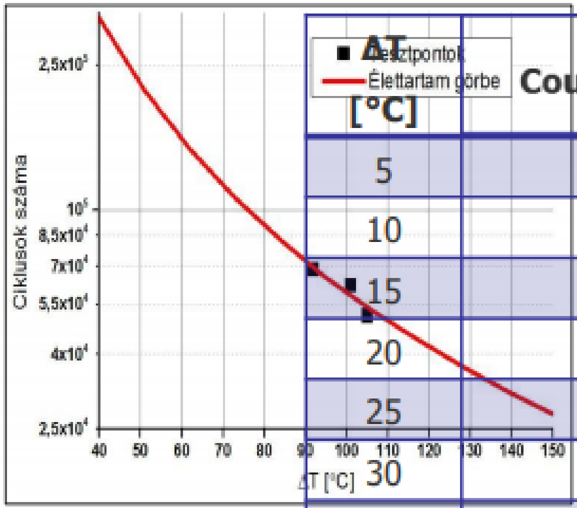


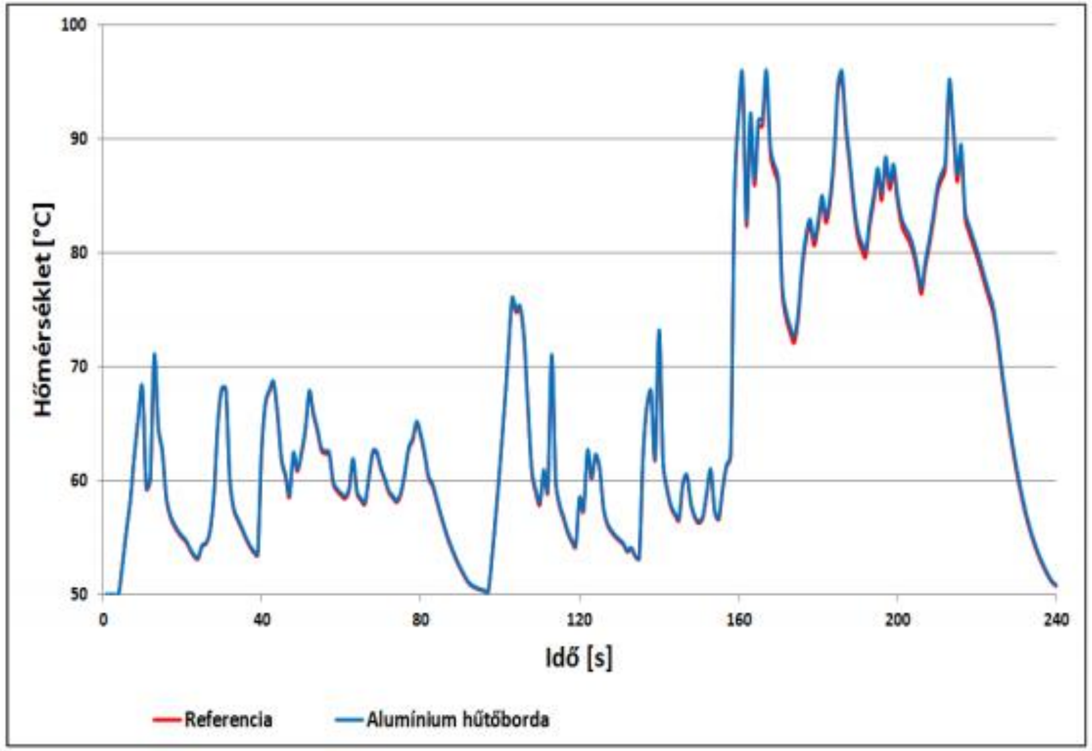


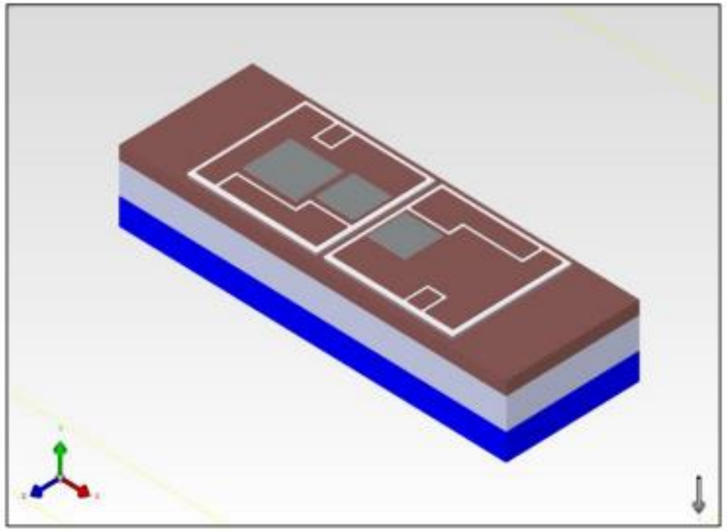
ΔT [°C]	Count (w_i)	Cycle number (N_i)
5	7	17430372
10	11	4678680
15	[illegible]	2167716
20	6	1255856
25	2	822356
30	1	581860
50	1	220737

- $N_{f\_sum} = \frac{1}{\sum_{k=1}^{n} \frac{w_i}{N_{f\_i}}}$
- $t_{operation} = N_{f\_sum} \cdot t_{cycles}$

N_{f_sum}	t_{ciklus} [s]	$t_{operation}$ [h]
55382	240	**3692**

Copper vs. Aluminum
Difference< 2%





	$N_{f\downarrow sum}$	t_{cycle} [s]	$t_{operation}$ [h]
Copper	54171	240	**3611**
Aluminum	53128	240	**3541**

Life prediction – optimizing cooling systems (with different heat dissipation media)

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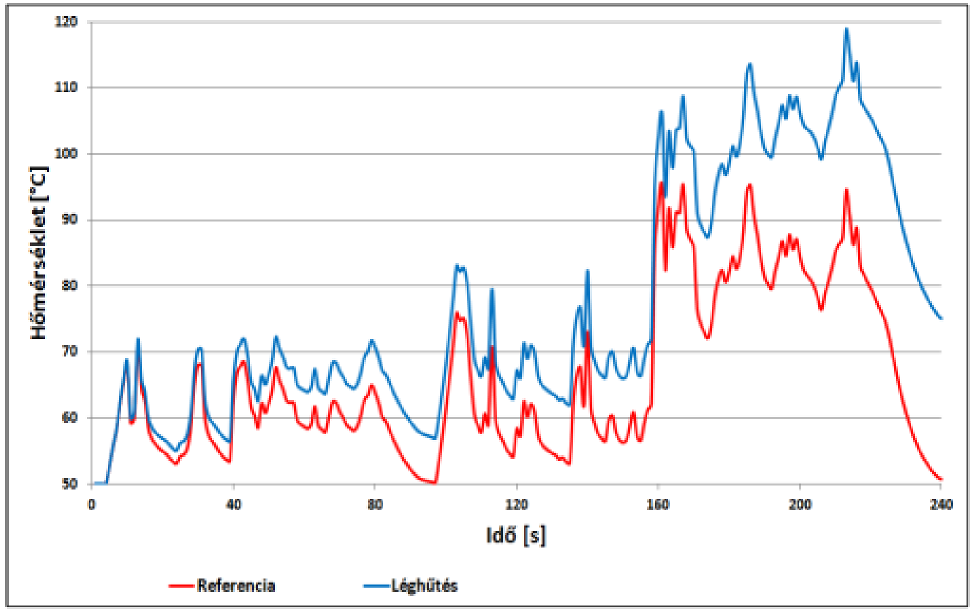
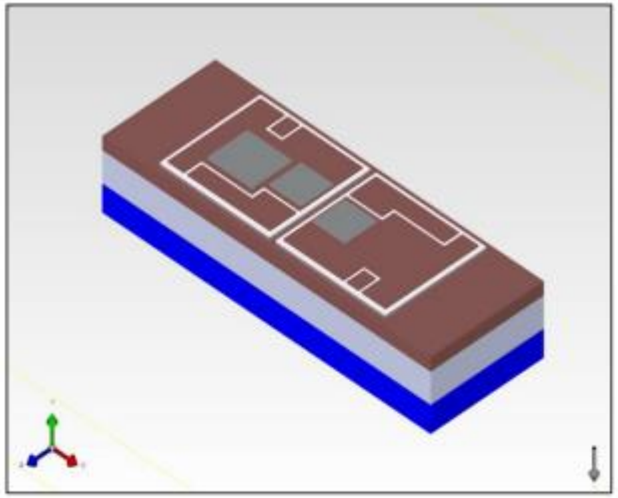
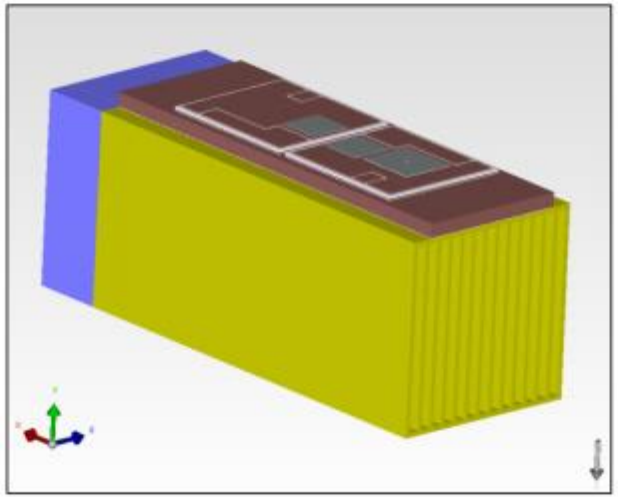
- Liquid vs. air cooling
- Copper cold-plate
- Difference~ 12%





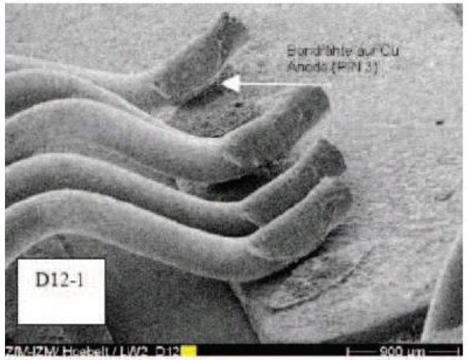


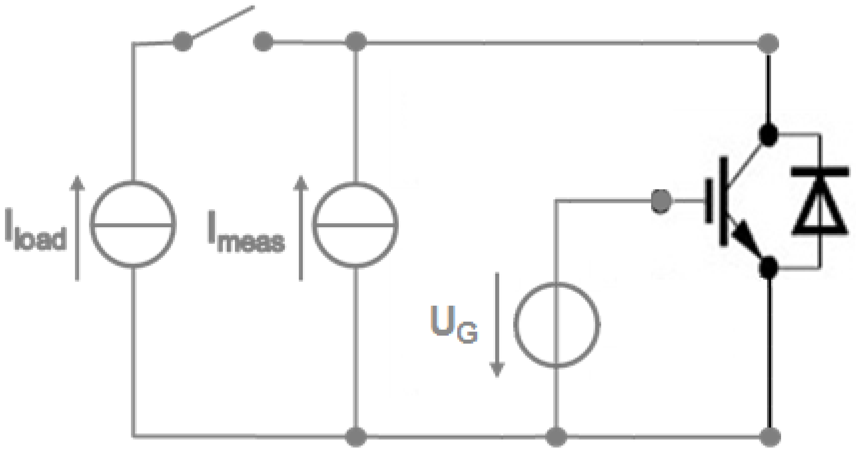
	$N_{f,sum}$	t_{cycle}[s]	$t_{operation}$ [h]
Liquid	54171	240	**3611**
Air cooling	47986	240	**3199**

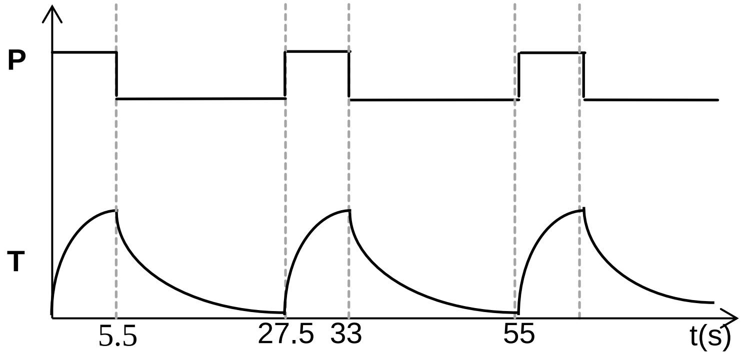
IGBT measurement of Power Tester (4)– Wire Bonding broken check

- $I_{D\ max}$=160A
- Device driven is saturation mode, V_{GS}=15V
- Target ΔT = 100°C
- Constant timing and current regardless of the voltage change

I_{load}	160 A
P	~530 W
ΔT	~100 °C
$T_{Heating}$	5.5 s
$T_{Cooling}$	22 s
Tmax	135 °C







IGBT measurement of Power Tester(4)- Wire Bonding broken check

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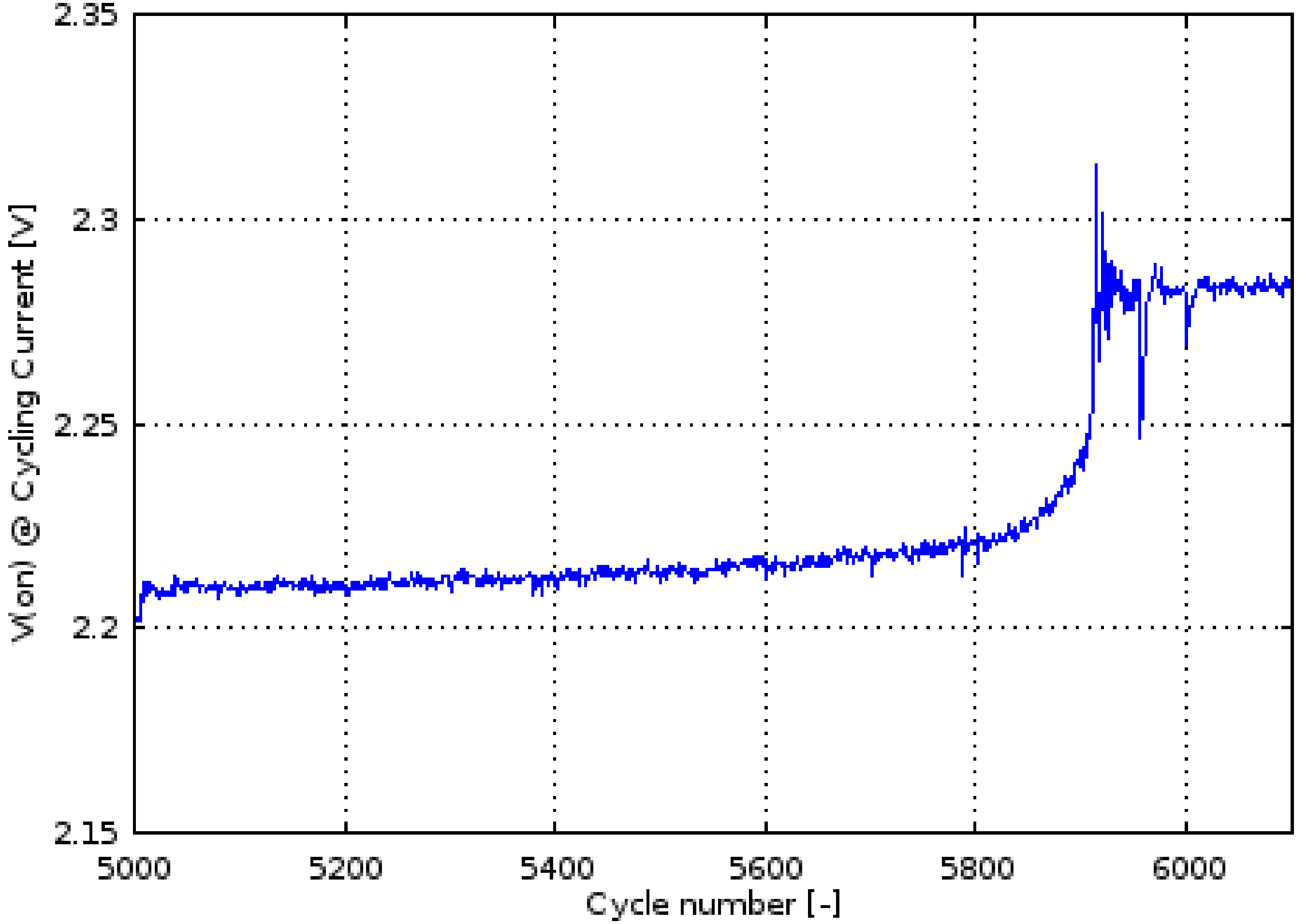
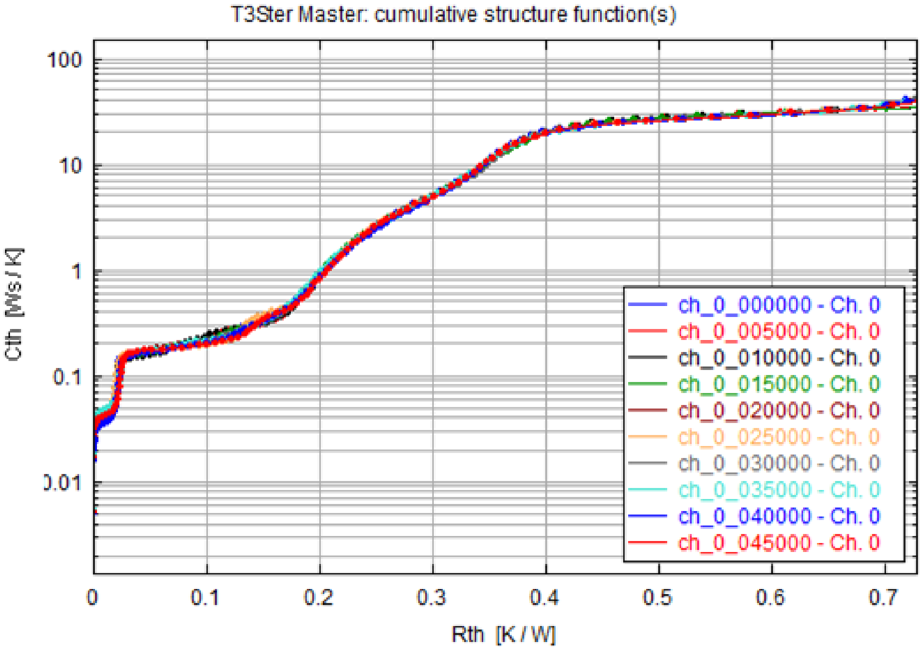
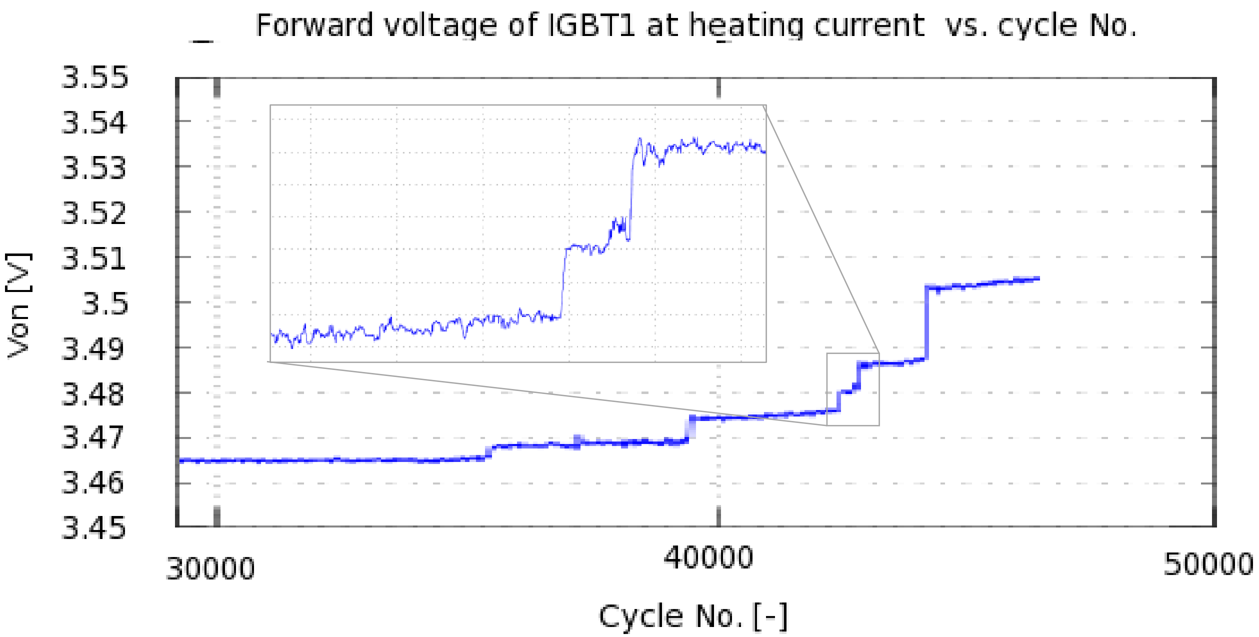
- Firs voltage drop increasing gradually
- Then stepwise voltage elevation can be observed

Bond wire degradation







We could verify that there was no structural change

IGBT measurement of Power Tester(4)- Wire Bonding broken check

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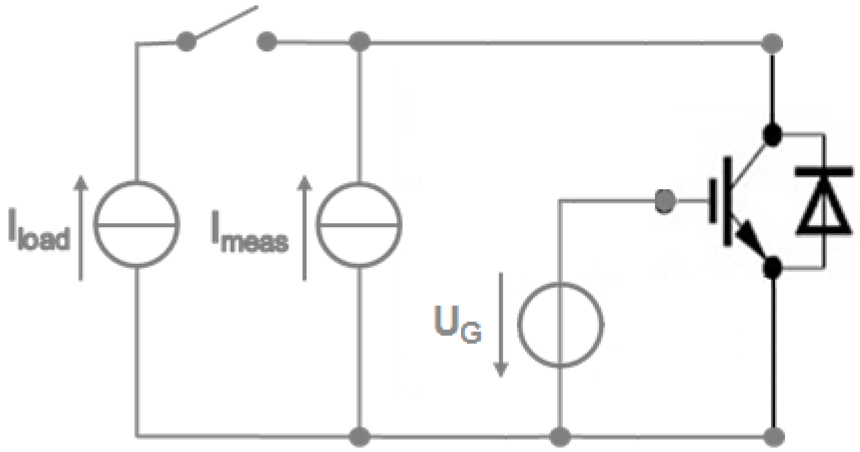
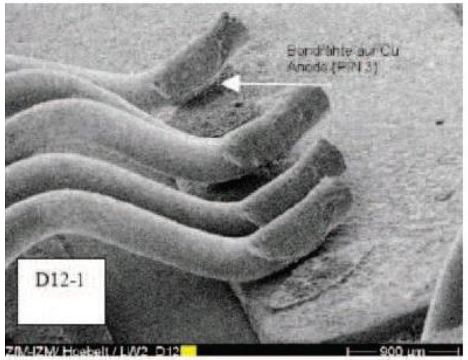
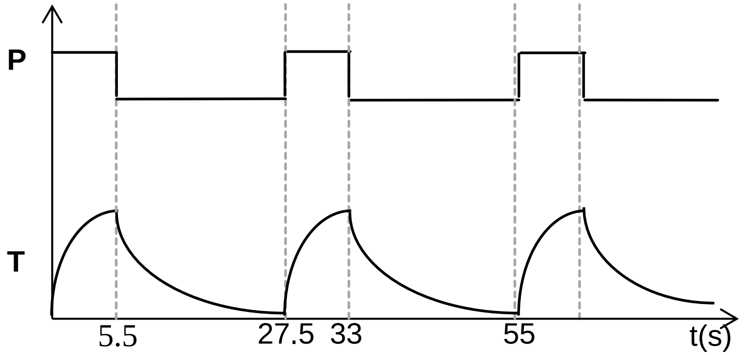
- $I_{D\ max}$=160A
- Device driven is saturation mode, V_{GS}=15V
- Target ΔT = 100°C
- Constant timing and current regardless of the voltage change

I_{load}	160 A
P	~530 W
ΔT	~100 °C
$T_{Heating}$	5.5 s
$T_{Cooling}$	22 s
Tmax	135 °C







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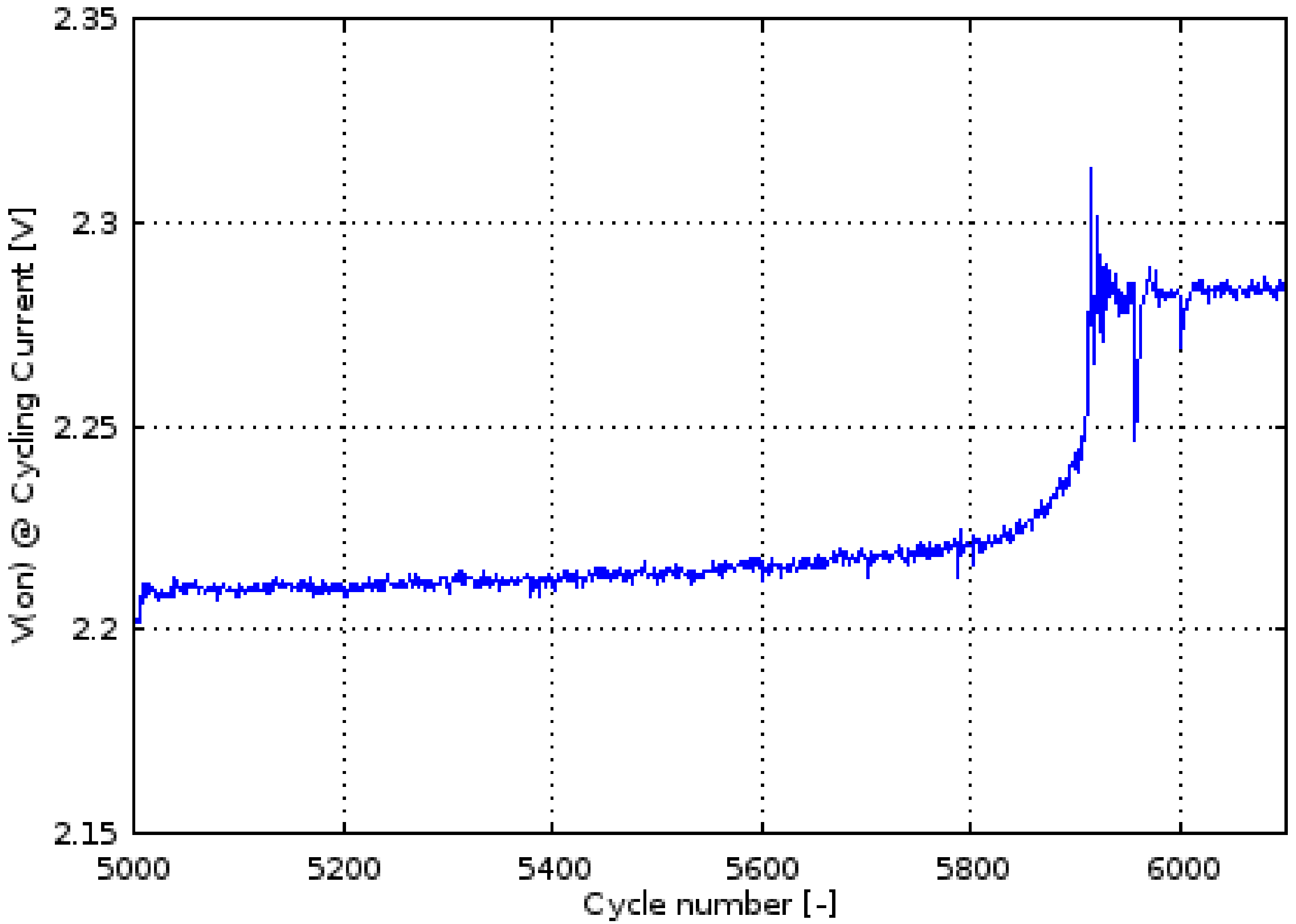
- Firs voltage drop increasing gradually
- Then stepwise voltage elevation can be observed

Bond wire degradation



IGBT measurement of Power Tester(4)- Wire Bonding broken check

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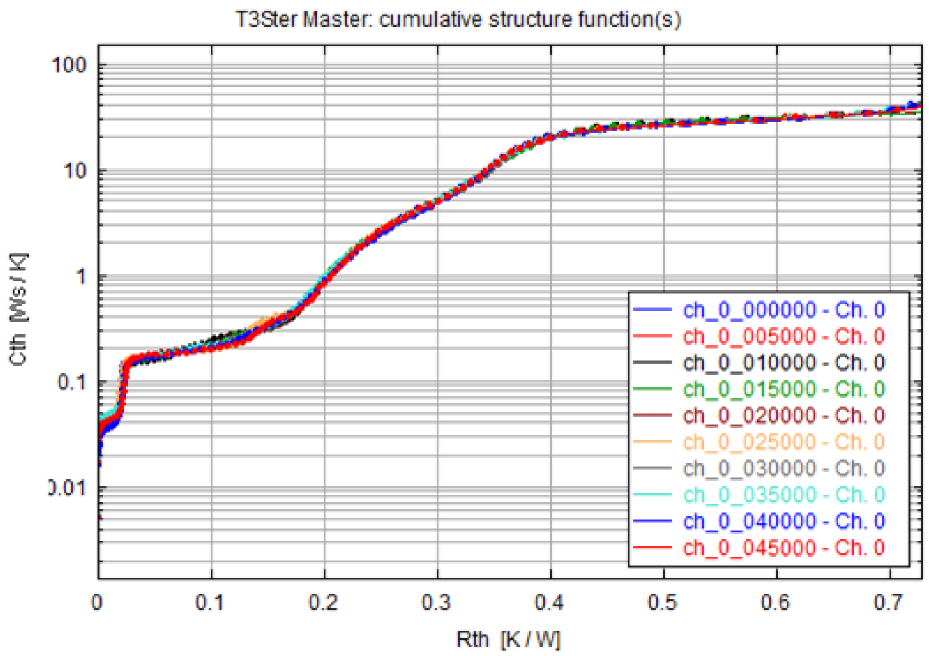
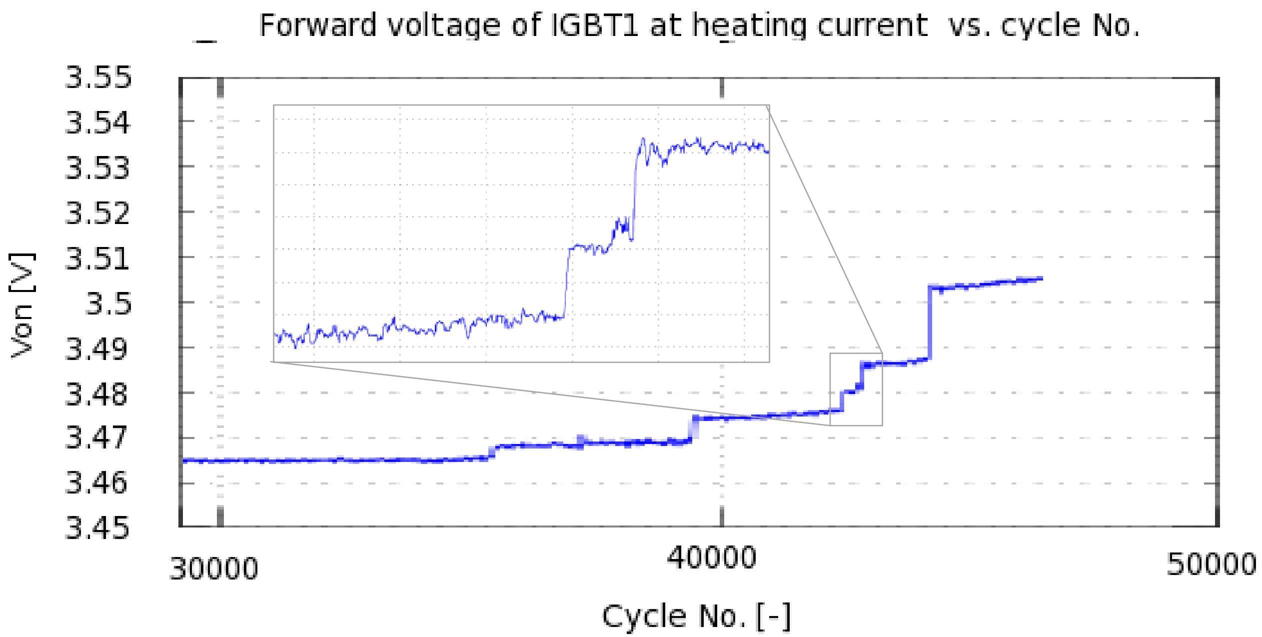
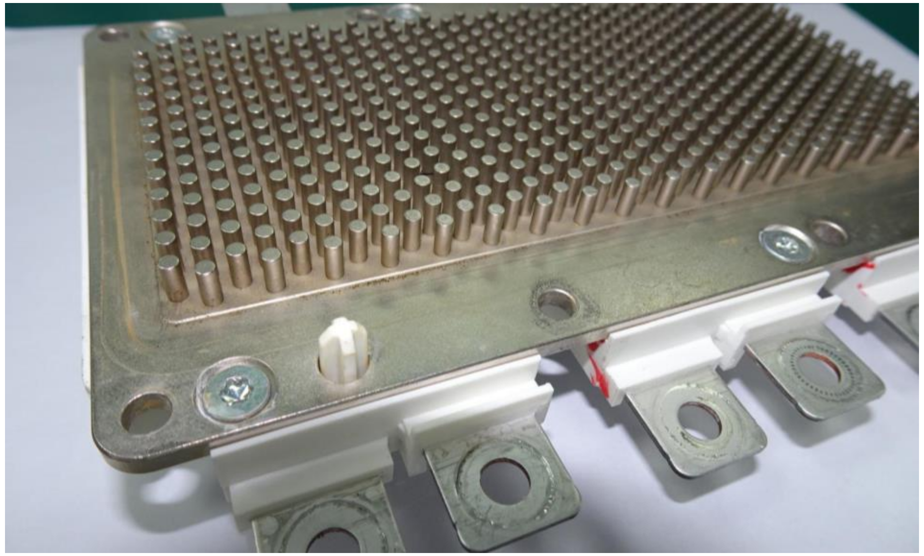




We could verify that there was no structural change

HPD Module Thermal Resistance Test Environment and Conditions(5)



Thermal resistance, junction to cooling fluid	per IGBT	$\Delta V/\Delta t$ = 10 dm³/min, T_F = 75°C	R_{thJF}
Temperature under switching conditions	t_{op} continuous for 10s within a period of 30s, occurence maximum 3000 times over lifetime		$T_{vj\ op}$

[1] Verified by characterization / design not by test.
[2] Cooler design and flow direction according to application note AN-HPD-ASSEMBLY. Cooling fluid 50% water / 50% ethylenglycol.
[3] For Tvjop > 150°C: Baseplate temperature has to be limited to 125°C.

HPD Module Thermal Resistance Test Environment and Conditions(5)

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Item	Coolant Medium	Flow Rate（dm^3/min）	Coolant Temperature（℃）
1	50% Deionized water & 50% Ethylene glycol	10	55/65/75
2	50% Deionized water & 50% Ethylene glycol	10/15	75
3	Deionized water / 50% Deionized water & 50% Ethylene glycol	10	75

HPD Module Thermal Resistance Test Environment and Conditions(5)

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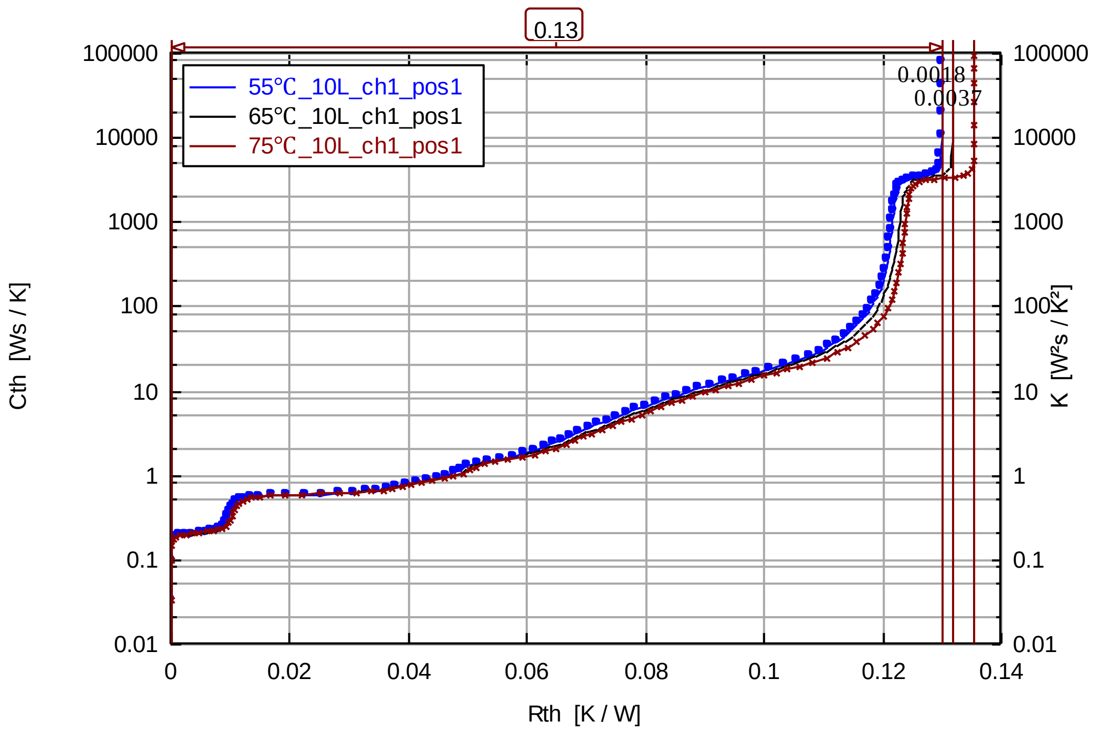
1. Constant coolant medium, coolant flow rate, thermal resistance test under different coolant temperature conditions



DUT	Test Channel	Test Interface	55℃, 10 dm³/min, 50% Deionized water & 50% Ethylene glycol	65℃, 10 dm³/min, 50% Deionized water & 50% Ethylene glycol	75℃, 10 dm³/min, 50% Deionized water & 50% Ethylene glycol	Change in thermal resistance for every 10℃ decrease in the cooling medium
1	CH1	POS1	0.1300	0.1318	0.1357	-2.12%
		POS2	0.1256	0.1267	0.1324	-2.59%
2	CH2	POS1	0.1308	0.1333	0.1352	-1.64%
		POS2	0.1267	0.1279	0.1345	-2.92%
3	CH3	POS1	0.1301	0.1322	0.1362	-2.26%
		POS2	0.1296	0.1329	0.1375	-2.91%

When the coolant temperature drops from 75° C to 55° C under test specification conditions, the module thermal resistance value Rth(j-fluid) decreases by 1.5%~3% for every 10° C the temperature decreases.

HPD Module Thermal Resistance Test Environment and Conditions(5)

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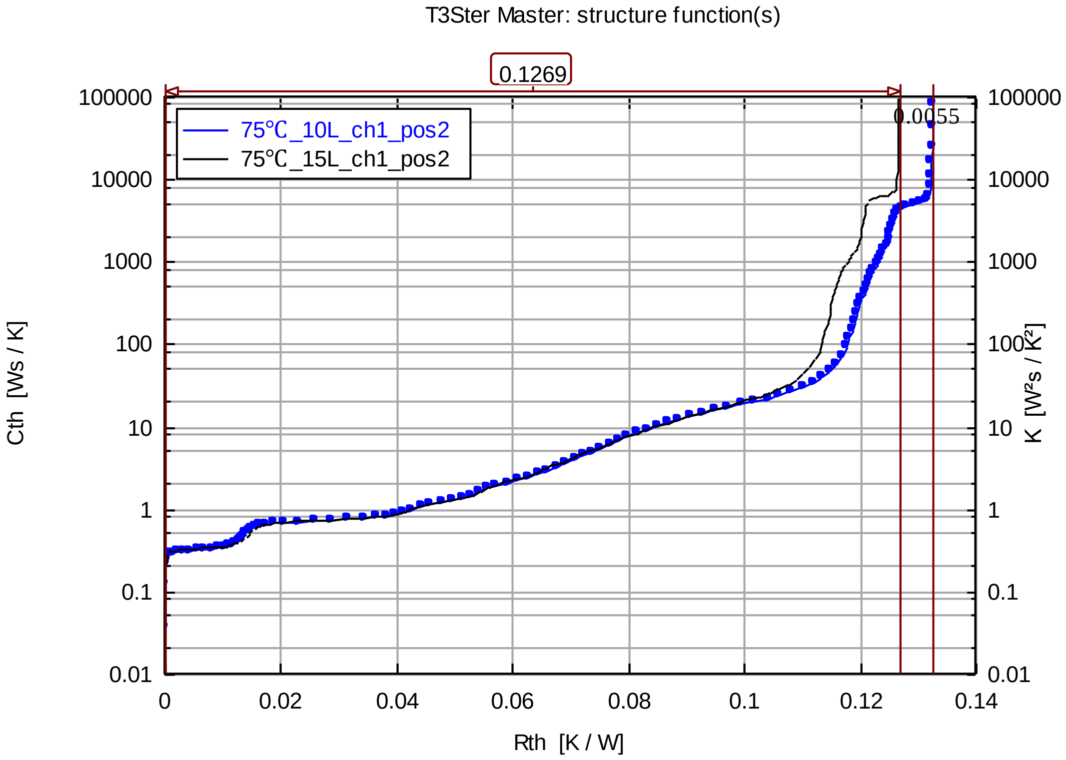
2. Thermal resistance test under constant coolant medium, coolant temperature, and different coolant flow rates



DUT	Test Channel	Test Interface	75℃, 15dm³/min, 50% Deionized water & 50% Ethylene glycol	75℃, 10dm³/min, 50% Deionized water & 50% Ethylene glycol	The cooling medium was lowered by 5 dm³/min to test the change of thermal resistance
1	CH1	POS1	0.1306	0.1357	-3.76%
		POS2	0.1269	0.1324	-4.15%
2	CH2	POS1	0.1293	0.1352	-4.36%
		POS2	0.1288	0.1345	-4.24%
3	CH3	POS1	0.131	0.1362	-3.82%
		POS2	0.1322	0.1375	-3.85%

When the coolant flow rate increases from 10dm3/min under test specification conditions to 15dm3/min, the module thermal resistance value Rth(j-fluid) decreases by 3.5%~4.5%

HPD Module Thermal Resistance Test Environment and Conditions(5)

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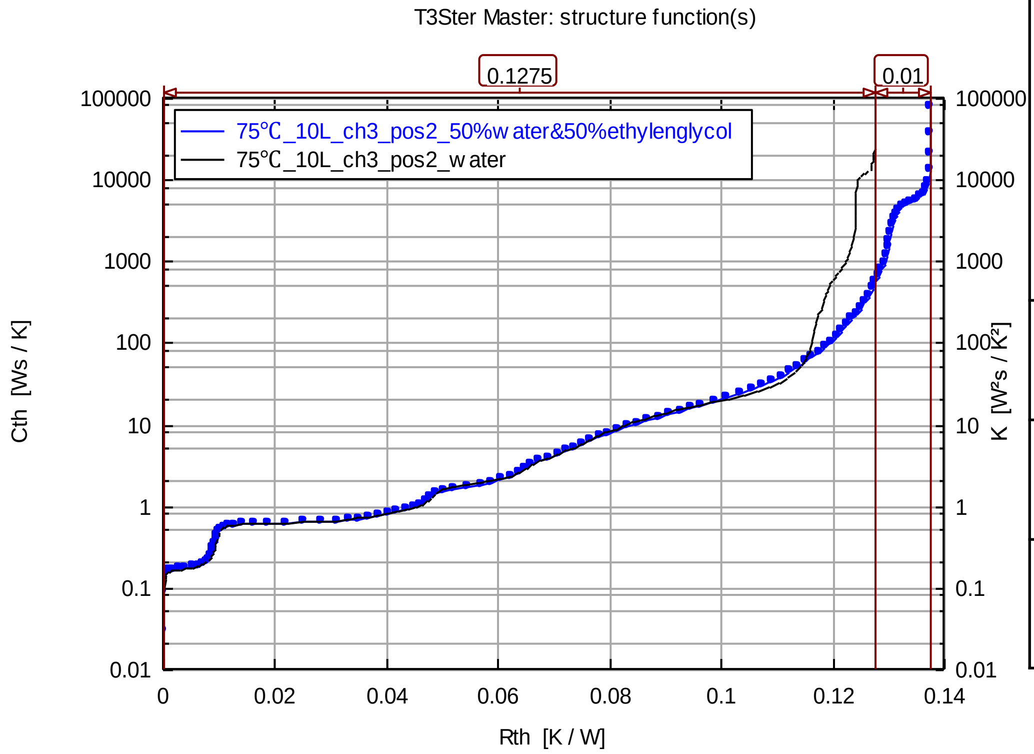
3. Constant coolant temperature, coolant flow rate, and thermal resistance test under different coolant medium conditions



DUT	Test channel	Test Interface	75℃, 10 dm^3/min, Deionized water	75℃, 10 dm^3/min, 50% Deionized water & 50% Ethylene glycol	Variation of thermal resistance in different medium test
1	CH1	POS1	0.1258	0.1357	-7.30%
		POS2	0.1247	0.1324	-5.82%
2	CH2	POS1	0.1239	0.1352	-8.36%
		POS2	0.1269	0.1345	-5.65%
3	CH3	POS1	0.1271	0.1362	-6.68%
		POS2	0.1275	0.1375	-7.27%

When the cooling medium is changed from 50% water & 50% ethylene glycol mixture to deionized water, the module thermal resistance value Rth(j-fluid) decreases by 5%~8%

HPD Module Thermal Resistance Test Environment and Conditions(5)

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To sum up, in actual application, the thermal resistance value of the device can be measured according to its usage environment, so that its temperature changes in the entire application environment can be more accurately obtained, and targeted improvements can be made. Avoid unnecessary losses.

Thermal testing and analysis of joints（器件结合部）
Testing and Analysis of Heat Dissipation Materials（散热材料）
Testing and parameter evaluation of cooling components(散热部件)
Thermal performance testing of packaging substrate materials（封装基板材料）
PCB heat dissipation performance evaluation（PCB散热性能）
Electronic device packaging aging experiment/life testing（封装老化与寿命检测）

Contact

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