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CRRC

IGBT Reliability introduction

September, 2019

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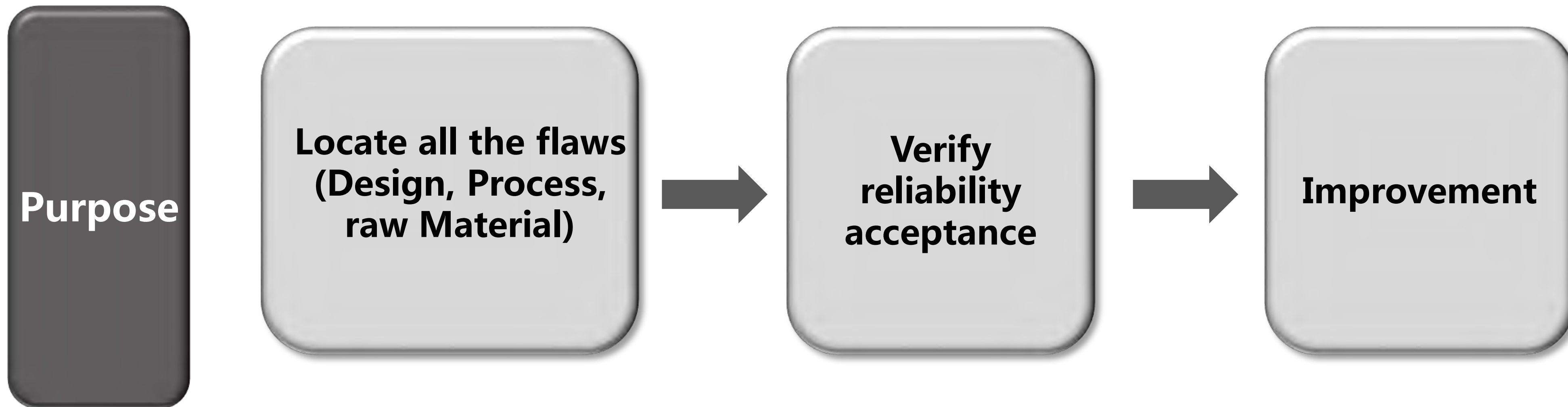
Part 2 Reliability Test Items

Part 3 Accelerated Test & lifetime Prediction

Part 4 Typical failure Mechanism

Part 1 Overview

1.1 Purpose of reliability test



1.2 Concept

- Reliability is created by design, manufacturing and test
- Locate flaws, Analyze root causes, Make Improvement
- Reliability test throughout life cycle, most important method to verify reliability of product
- Life test also belongs to reliability test, mainly for the products with wear-out characteristic

Part 1 Overview

1.3 Reliability test covers full life cycle

Design
- Reliability development
- Environmental stress screening
- Reliability improvement

Prototype
- Verification
- Life test

Production
- Environmental stress screening
- Acceptance Inspection

Application
- Verification
- Life test

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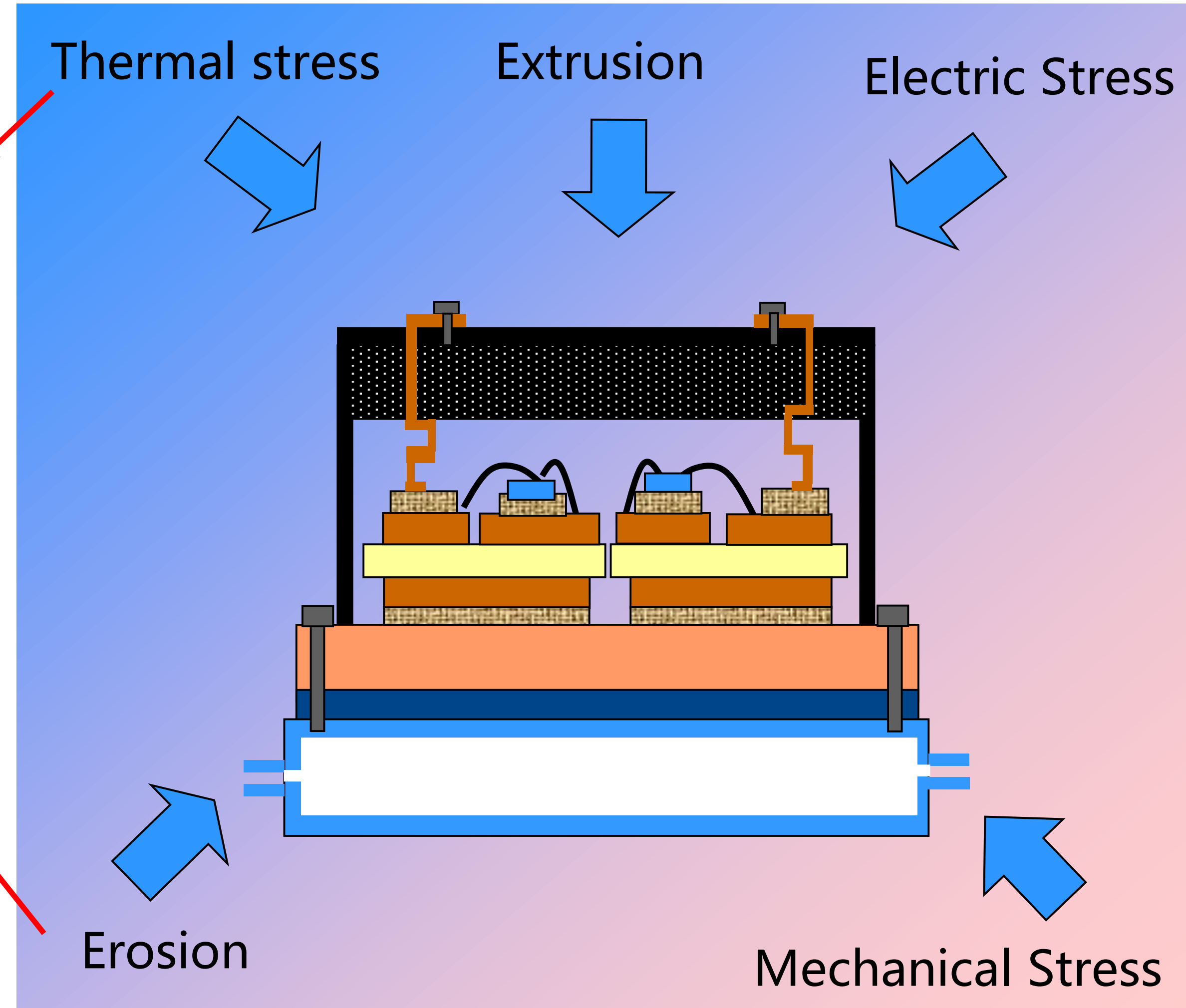
Part 2 Reliability Test Items

- High Temp Storage
- Low Temp Storage
- Temp Shock
- Thermal cycling
- Power Cycling
- Vibration
- Mechanical Shock
- THB/H3TRB
- Cyclic Damp Heat
- Salt-Mist
- HTRB
- HTGB



Part 2 Reliability Test Items

2.1 Test equipment and evaluation point

TS

Package

Thermal fatigue

LTS

Epoxy & Gel

Low temp Aging

HTS

Package

High Temp Aging

THB/H3TRB

Package

Damp-heat Aging

Part 2 Reliability Test Items

2.1 Test equipment and evaluation point

Passive cycling

Soldering

thermal fatigue

Mechanical Shock

Package

Mechanical stress

Vibration

Package

Mechanical strength, Resonate

Salt-Mist

Sealing Property,

Corrosion resistance

Part 2 Reliability Test Items

2.1 Test equipment and evaluation point

Power cycling

Wire-bonding, soldering

thermal fatigue

HTRB

Chip, package

electrical durability

HTGB

Gate Oxide、wire-bonding

Electrical Durability

Part 2 Reliability Test Items

2.2 IGBT test standard

NO	Standard	Subsection	Contents
1	IEC	IEC-60747-9	Semiconductor devices – Discrete devices –Part 9: Insulated-gate bipolar transistors (IGBTs)
2	JEDEC	JESD51-14	Single Thermal Conduction Path Semiconductor Rjc Thermal Resistance Test Using Transient Dual Interface Test Method
3	JEDEC	JESD51-1	Semiconductor device junction temperature test standard - electrical test method
4	ECPE	AQG324	Qualification of Power Modules for Use in Power Electronics Converter Units (PCUs) in Motor Vehicles
5	GB	GB/T29332	Power semiconductor device - discrete device – part 9 - (IGBT)
6	GB	GB/T 4937	Semiconductor device mechanical and climatic test methods
7	GB	GB/T2423系列	Electrical and electronic environment test
8	GJB	GJB 128B	Semiconductor discrete device test method
9	GJB	GJB 360B	Electronic and electrical component test methods

Part 2 Reliability Test Items

2.3 Qualification test for Locomotive IGBT module

	Qualification Test	Test Method	Test Conditions	Qualification Standard
Environmental Assessment	Passive Cycling	EN 50439-1:2004	△Tcase=80℃ T=45℃ To 125℃ Every Cycle= 4min	20000 cycles
	Thermal Shock	GB/T 2423.22-2002	-40℃ to +150℃ Every limited value, 2h Transfer time =30s	100 cycles
	Vibration	GB/T 2423.10-2008	F=5 to 500Hz G=10g	6 hours
	Mechanical Shock	GB/T 2423.5-1995	100g /6ms/ half sine	30 shocks
	Low Temp Storage	GB/T 2423.1-2008	Ta=-40℃	1000 hours
	High Temp Storage	GB/T 2423.2-2008	Ta=150℃	1000 hours
	Salt-mist	GB-T2423.17-2008	35±2℃ PH=6～7 Salt/water: 5%±0.1%	168 hours

Part 2 Reliability Test Items

2.3 Qualification test for Locomotive IGBT module

	Qualification Test	Test Method	Test Conditions	Qualification Standard
Environmental Assessment	Humidity	GB/T 2423.50-1999	Tj=85℃ RH=85% Vce=80V Vge=0V	1000 hours
Electrical Assessment	G-E Blocking /HTGB	GB/T 29332-2012	Tj=150℃ Vge=±20V	1000 hours
	C-E Blocking /HTRB	GB/T 29332-2012	Tj=150℃ Vce=0.8*Vces Vge=0V	1000 hours
	Power Cycling	EN 50439-1:2004	△Tj=60℃ Tj=+65℃ to +125℃ Cycle =1-3s	350k cycles

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Part 3 Accelerated Test & lifetime Prediction

Plastic outer

Bond wires

Bus-bar solder

Insulation paste

Die solder

FRD

IGBT

Current

Ceram

Copper clad layer of substrate

Substrate

Baseplate

Thermal flow

DBC solder

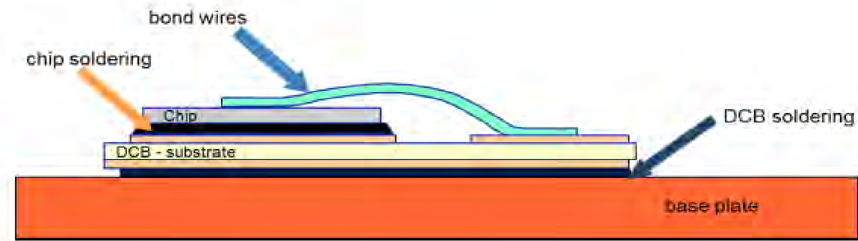
Heat conduction material

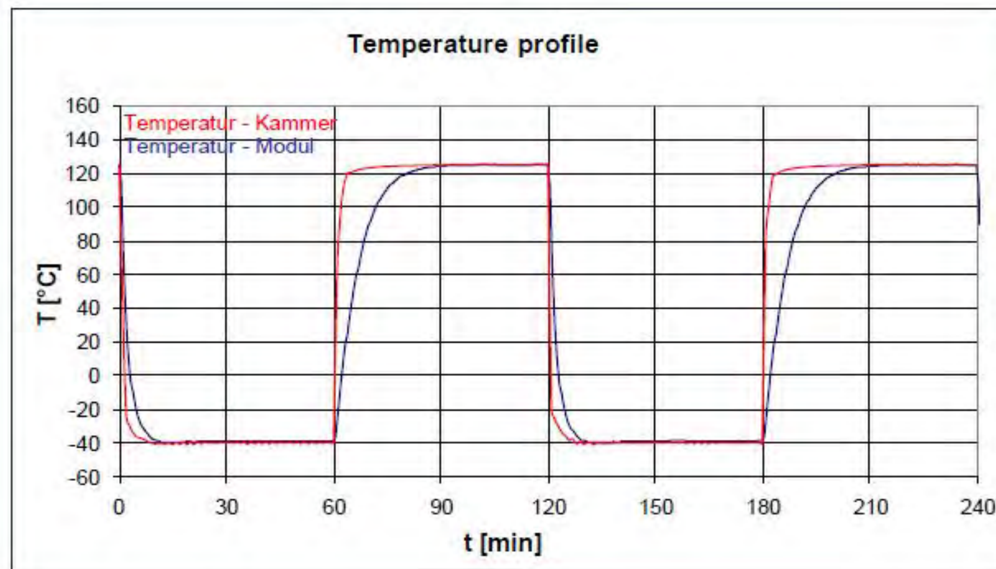
Heat dissipation material

- IGBT module package realizes electrical and thermal transmission and protection of the chip

Part 3 Accelerated Test & lifetime Prediction

3.1 Thermal shock test

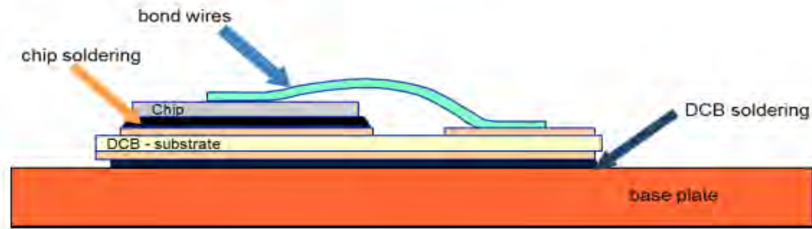


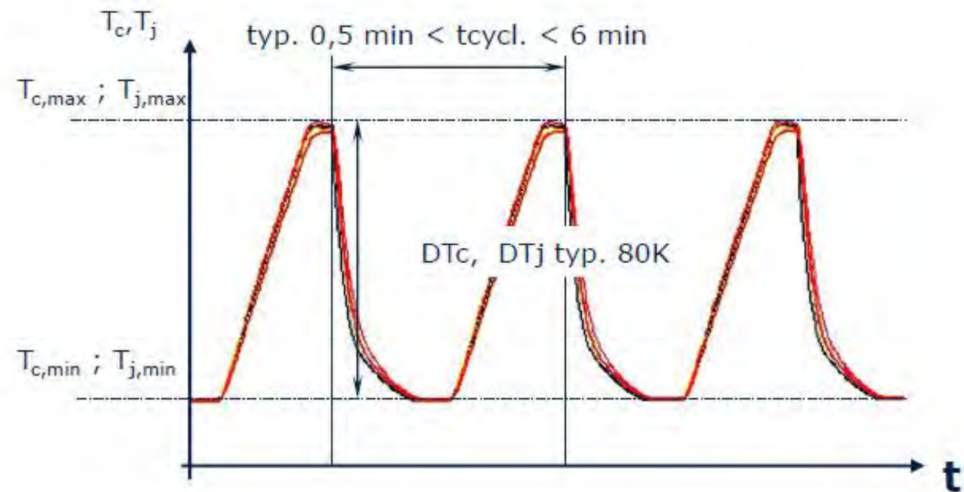


TST: 100cycles (Industry: 50cycles)

Part 3 Accelerated Test & lifetime Prediction

3.2 Thermal cycling test

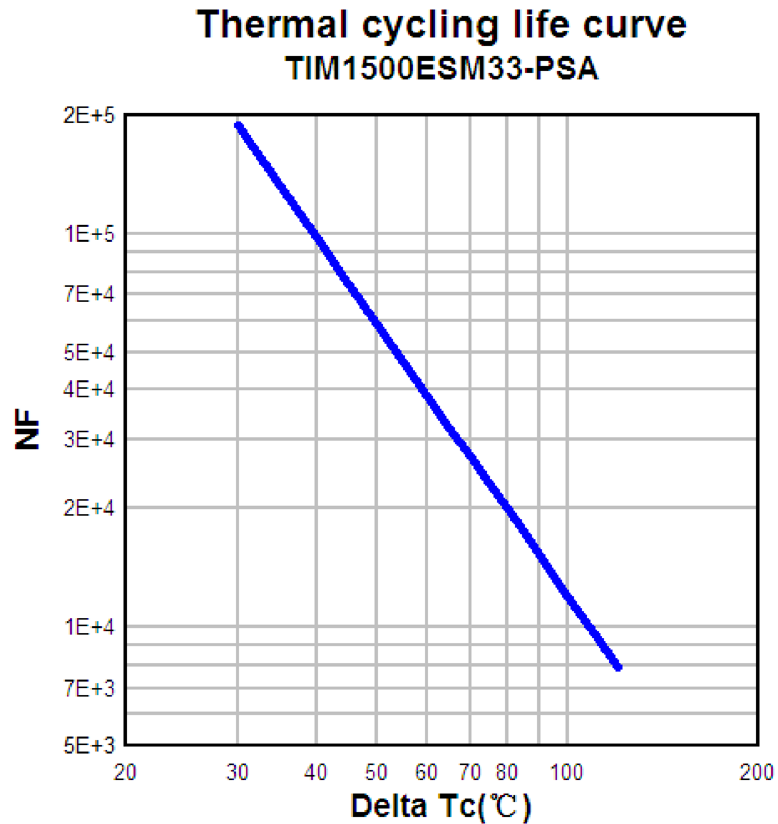


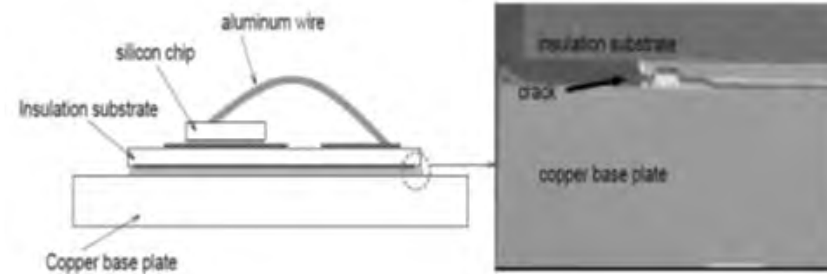


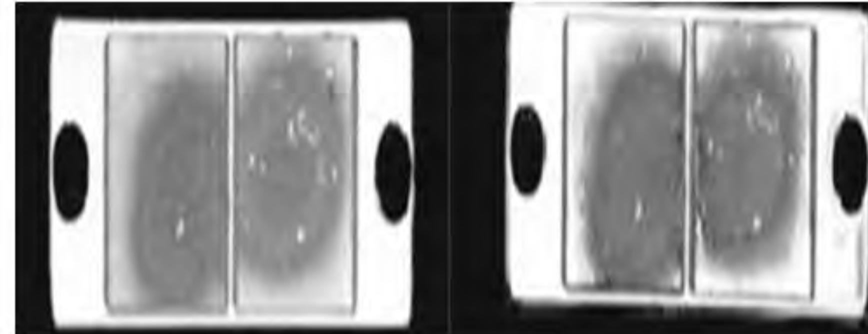
TC: 20000cycles (Industry: 12000cycles)

Part 3 Accelerated Test & lifetime Prediction

3.3 Failure mode of thermal cycling test



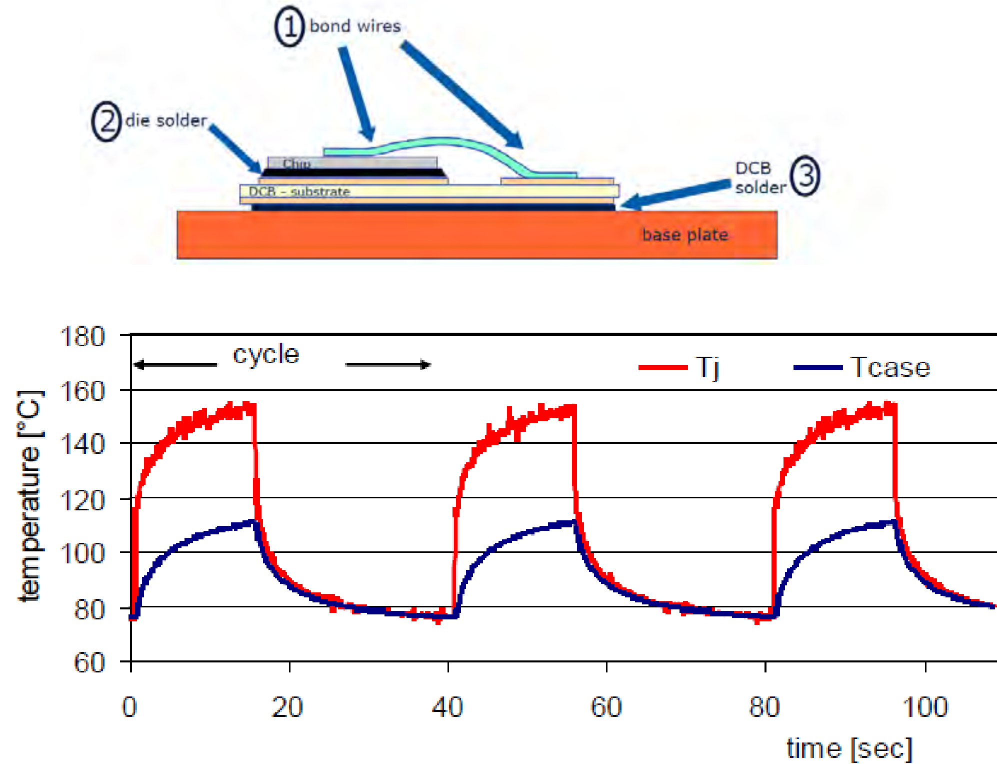




DBC solder\Die solder
\Bus-bar solder crack

Part 3 Accelerated Test & lifetime Prediction

3.4 Power cycling test



Reliability and failure modes

①PC on bond wires

②PC_{sec} on die solder(≤10s)

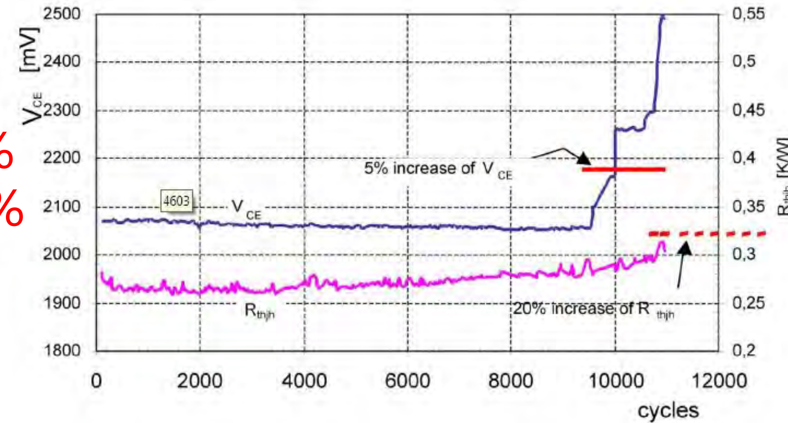
③PC_{min} on DBC solder(＞10s)

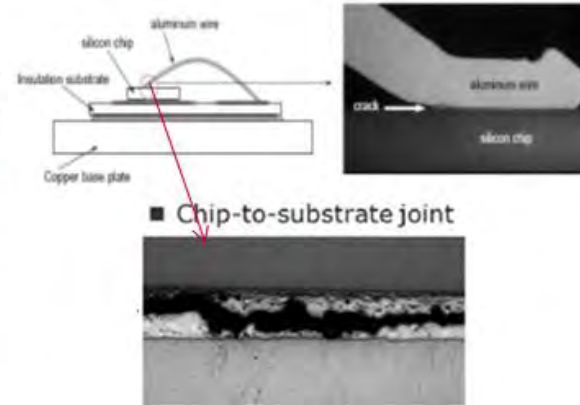
PC_{sec}: ΔT_j=80℃,350kcycles (Industry: 10kcycles)

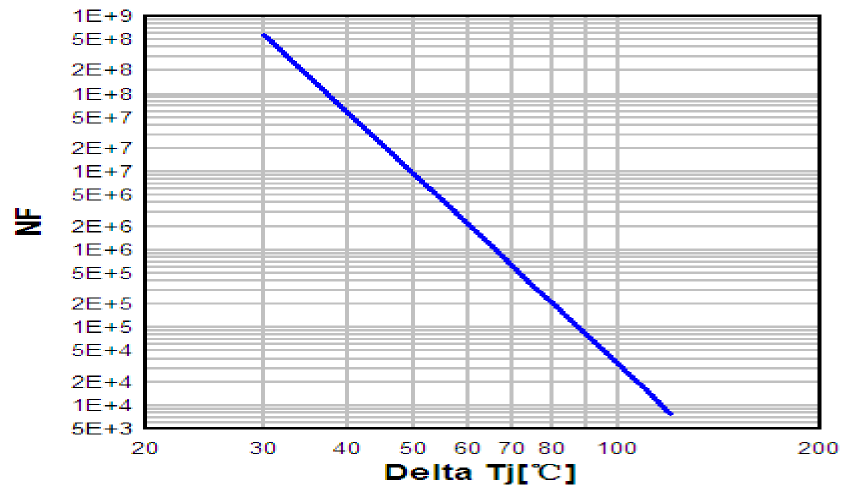
PC_{min}: ΔT_j=80℃,20kcycles (Industry: 12kcycles)

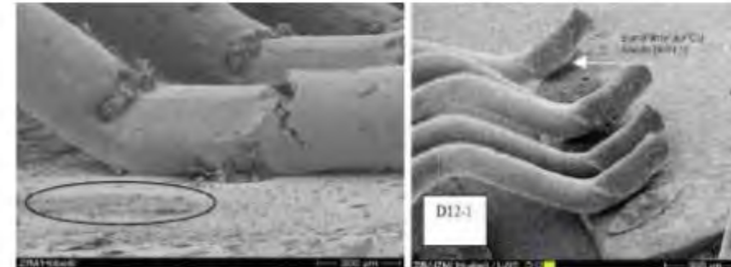
3.5 Failure mode of power cycling test

V_{CE} increase 5%
R_{th} increase 20%









Die solder crack/
bond wire crack or lift-off

3.6 Accelerated test model

Assessment Items	Accelerated test Model
High Temp Storage	Arrhenius Model
HTRB	Eyring Model
HTGB	Eyring Model
THB	Peck Model
Temp Cycling	Coffin-Manson Model
Power Cycling	Coffin-Manson Model

Accelerating Model	Equation	Accelerated category	Equation of Accelerating Factor
Arrhenius Model	$\lg t = a + b(\frac{1}{T})$	Temp	$AF = \exp\left[\frac{Ea}{k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$
Eyring Model	$t = Ae^{-Ea/kT} \times V^{-\beta}$	Temp, Voltage	$AF = \exp\left[\frac{Ea}{k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right] \times \left(\frac{V_2}{V_1}\right)^{\beta}$
Peck Model	$t = Ae^{-Ea/kT} \times RH^{-n}$	Temp, Mist	$AF = \exp\left[\frac{Ea}{k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right] \times \left(\frac{RH_2}{RH_1}\right)^{n}$
Coffin-Manson Model	$N_f = (\frac{\alpha}{\Delta T})^{\gamma}$	Change of Temp	$A_f = (\frac{\Delta T_T}{\Delta T_A})^{\gamma}$

Part 3 Accelerated Test & lifetime Prediction

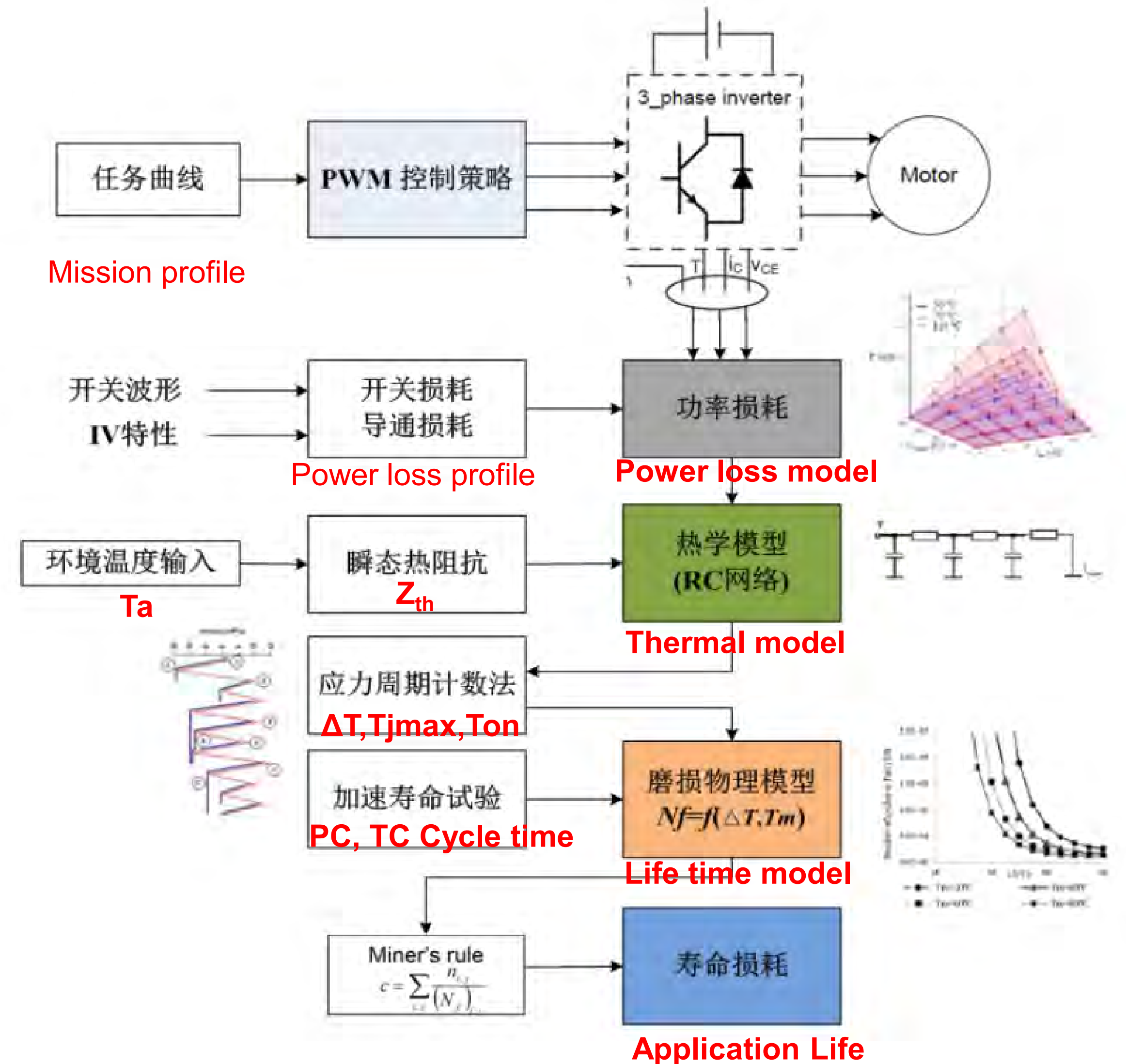
3.7 lifetime Prediction

Coffin Manson model（Simple）（Life time model）

$$Nf=(\alpha/\Delta Tj)^{\gamma}$$

Coffin Manson model(Hard）

$$Nf=K/\Delta T_j^{\beta 1}e^{(\beta 2/T_j+273)}t_{on}^{\beta 3}I^{\beta 4}V^{\beta 5}D^{\beta 6}$$



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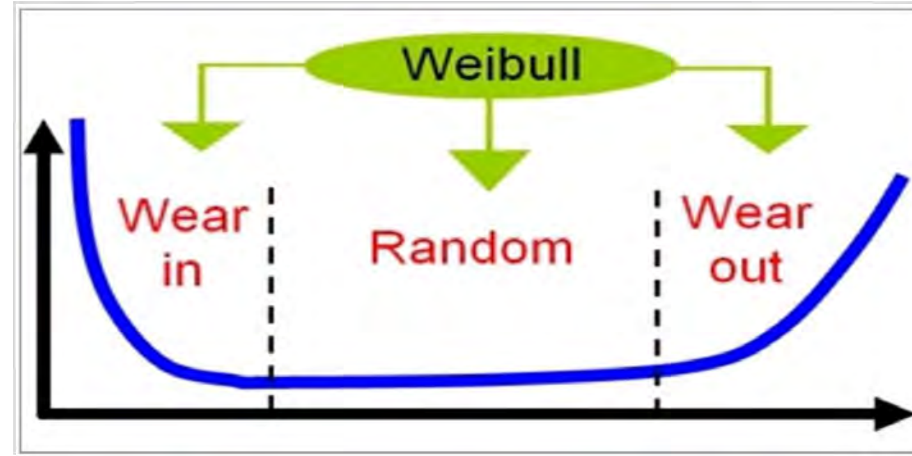
Part 4 Accelerated Test & lifetime Prediction

4.1 Bathtub curve



Defect **(Early stage Failure)**	Application **(Random Failure)**	Lifetime **(wear-out Failure)**
• Passivation Layer Breakdown • Terminal Breakdown • Cell Burn Down • Partial Discharge • Partial Over-heat • Exceed SOA •	• Voltage *: dv/dt Over stress* • Current *: di/dt* Over stress • Temp *: ΔT or dT/dt Over stress* • False trigger：Abnormal gate signal • Isolation V_{iso}：temp too high or over mechanical stress •	• Vcesat drift • Leakage current drift • accumulated damage by Surge current and di/dt • Accumulated damage by temp, ,ΔT and dT/dt • ......

Part 4 Accelerated Test & lifetime Prediction

4.2 Failure mode

Spontaneous Failures

Electrical failures

- Over-temperature
- Overvoltage
- Overcurrent
- Dynamic f.

Wearout Failures

Mechanical failures

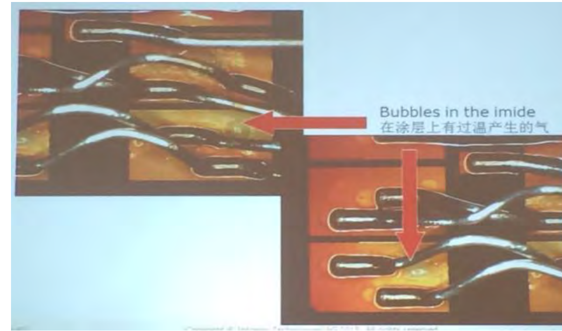
- Eol bond wire connections
- Eol solder connections
- Destruction of housing / terminals

Other failures (climatic stresses, chemical stresses)

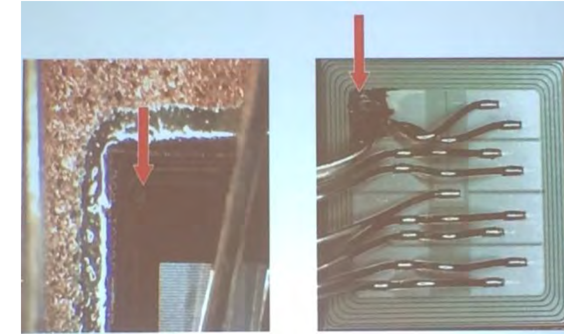
Part 4 Accelerated Test & lifetime Prediction

4.3 Spontaneous Failures

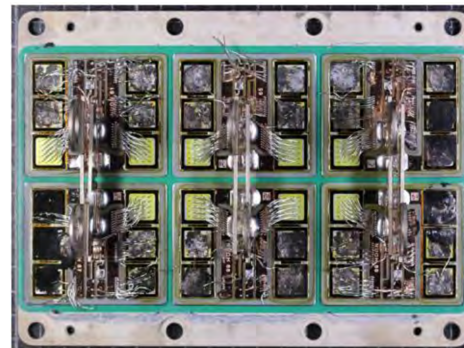
Over current



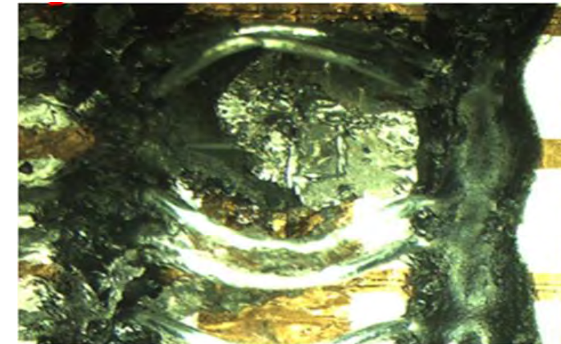
Over temperature



Over voltage of CE



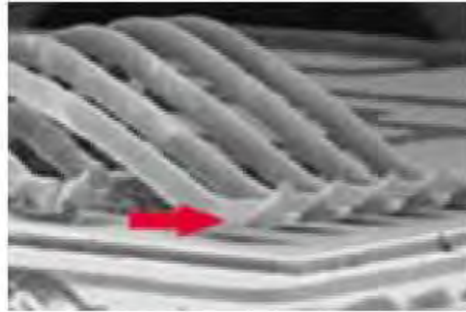
SCSOA Failure



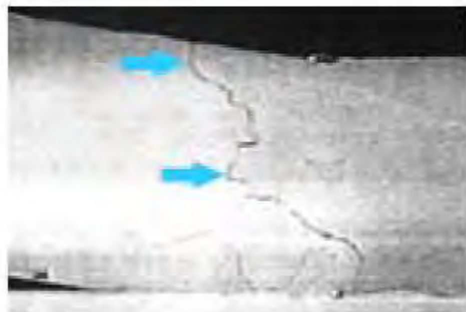
Over voltage of GE

Part 4 Accelerated Test & lifetime Prediction

4.4 Wear-out Failures



Bond-wire lift-off (left) and reconstruction of Al metallization (right)

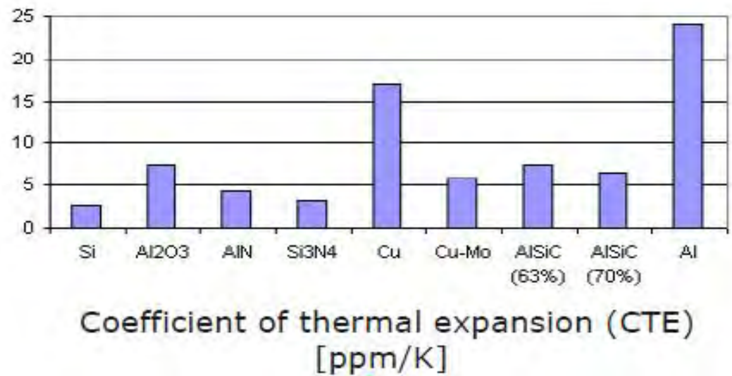


Bond-wire heel cracks

PC_{sec}/TC/V

Bonding Wire lift-off and crack failures

4.4 Wear-out Failures



Coefficient of thermal expansion (CTE) [ppm/K]

Thermal Shock Test Results

A — Cu base plate and Al_2O_3 DCB

600 Cycles high delamination

B — Cu base plate and improved Al_2O_3 DCB

1000 Cycles slight delamination

C — AlSiC base plate and Si_3N_4 DCB

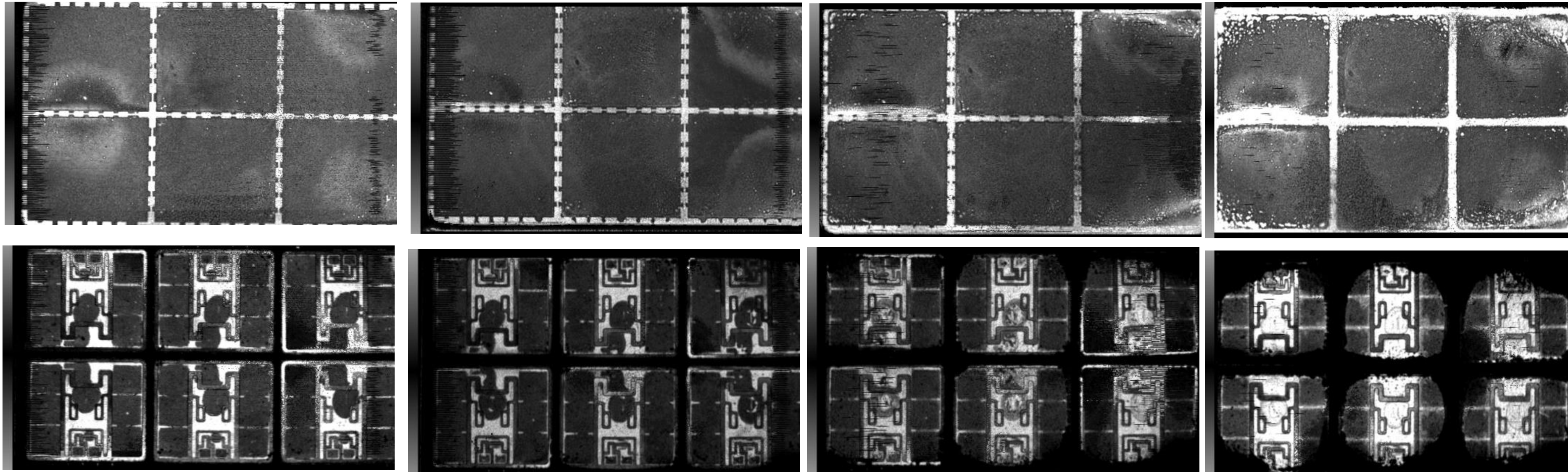
1000 Cycles no delamination

TS

DBC soldering wear-out failures

Part 4 Accelerated Test & lifetime Prediction

4.4 Wear-out Failures



0 cycles

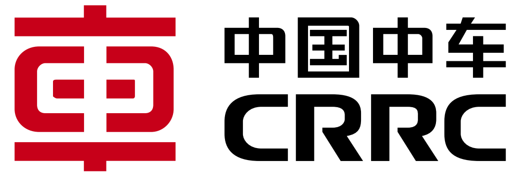
6000 cycles

12000 cycles

21000 cycles

TC/PC_{min}

Die soldering \DBC Soldering and terminal soldering wear-out



Thank you！