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Junction Temperature Estimation Technologies of IGBT Modules in Converter-based Applications

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    - IGBT Structure
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Introduction

Packaging method

IGBT structure

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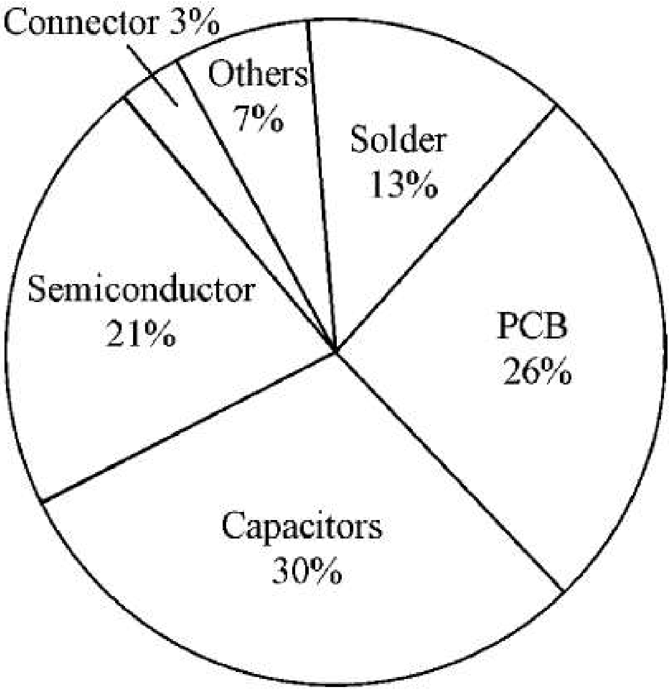
Introduction

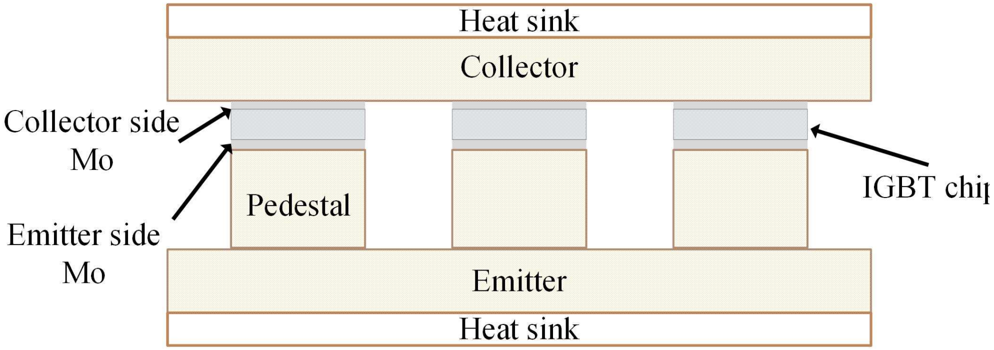
- The **semiconductor** and **soldering failures** in device modules totals 34% of converter system failures, according to a survey based on over 200 products from 80 companies.
- Figure also indicates that **capacitors** are fragile.



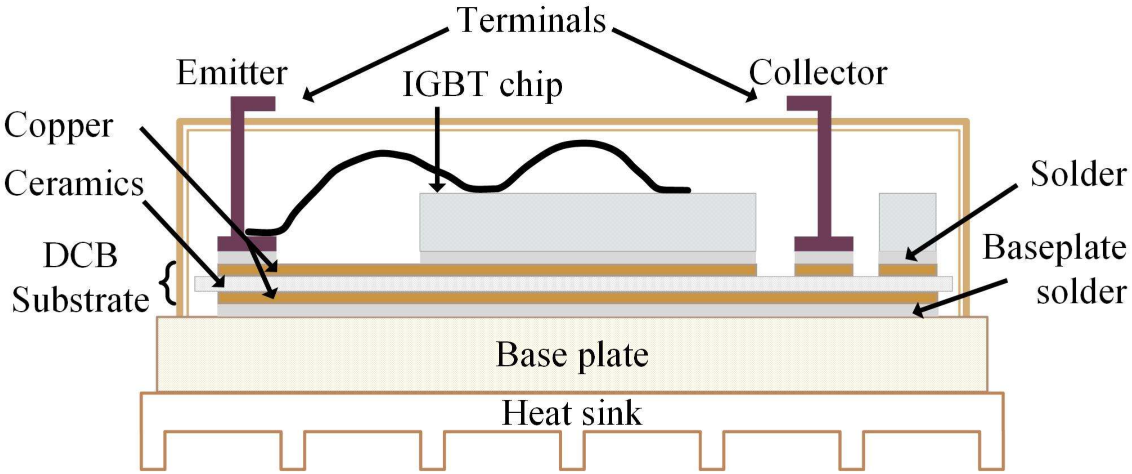
Failure distribution and ranking [7].

Introduction

Packaging method



Press-pack packaging



Wire-bonded packaging

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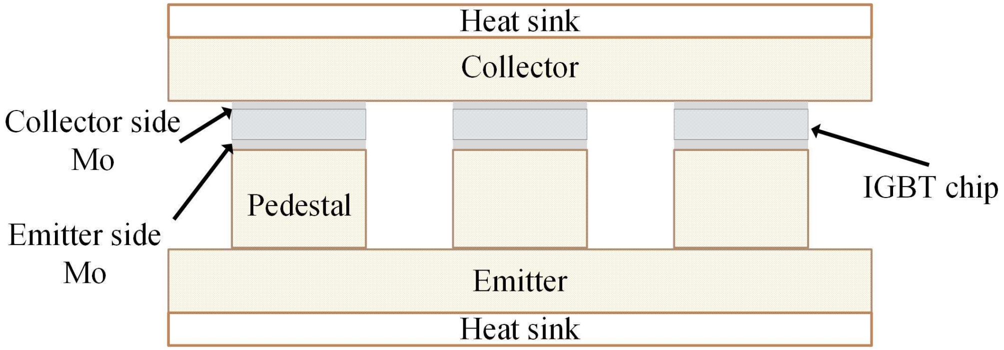
Introduction

Packaging method



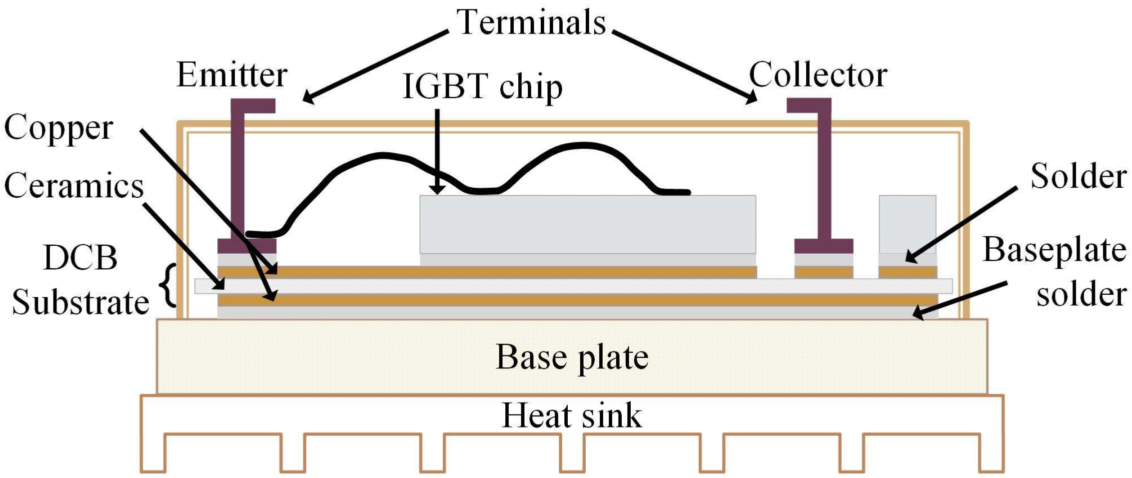
Press-pack packaging

- Widely used in high-voltage applications
  - Traction systems
  - Large motor drives
  - Power systems
  - Pulsed power applications
- Higher reliability due to better tolerance to thermal cycling
  - High cost
  - Limitations on the cooling methods

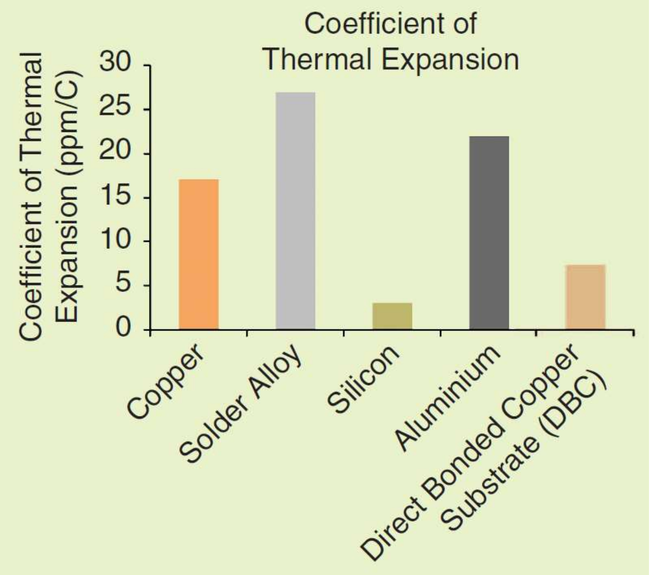
Introduction

Packaging method

- Widely used in voltage source converters
- Mismatch in CTE can lead to fatigue failure
  - Bond wire fatigue
  - Solder fatigue



Wire-bonded packaging



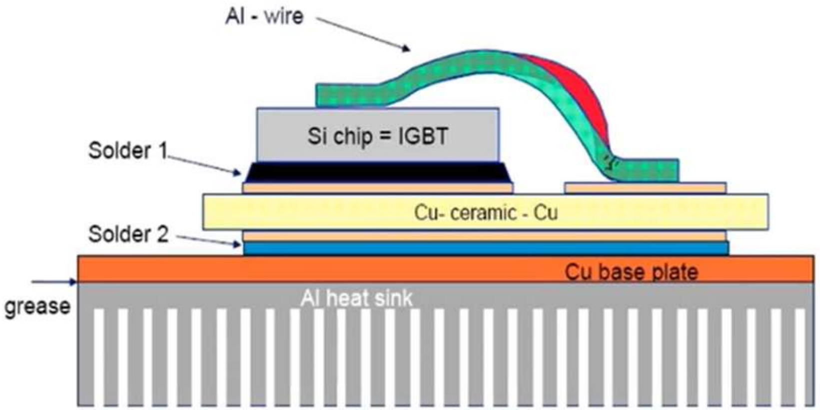
02

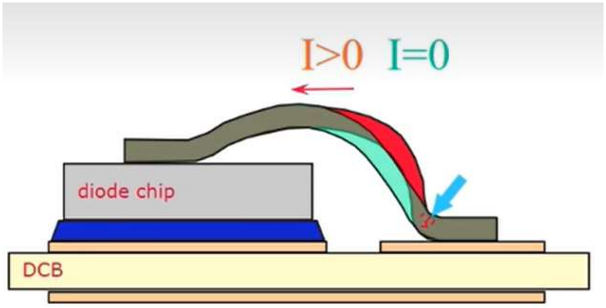
IGBT Health Monitoring

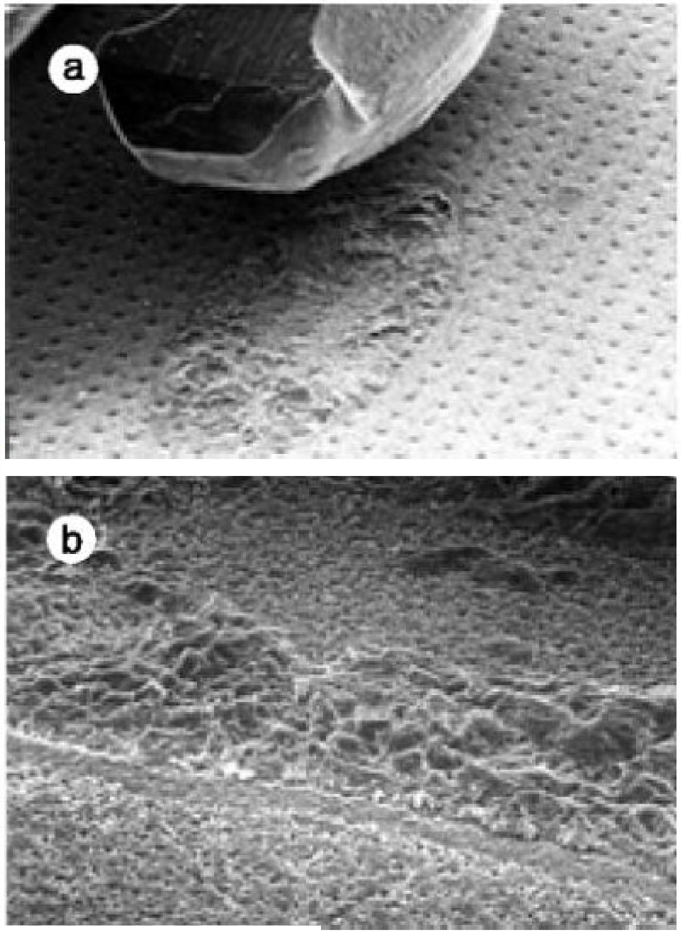
- Bond wire fatigue detection
- Solder fatigue detection

IGBT Health Monitor

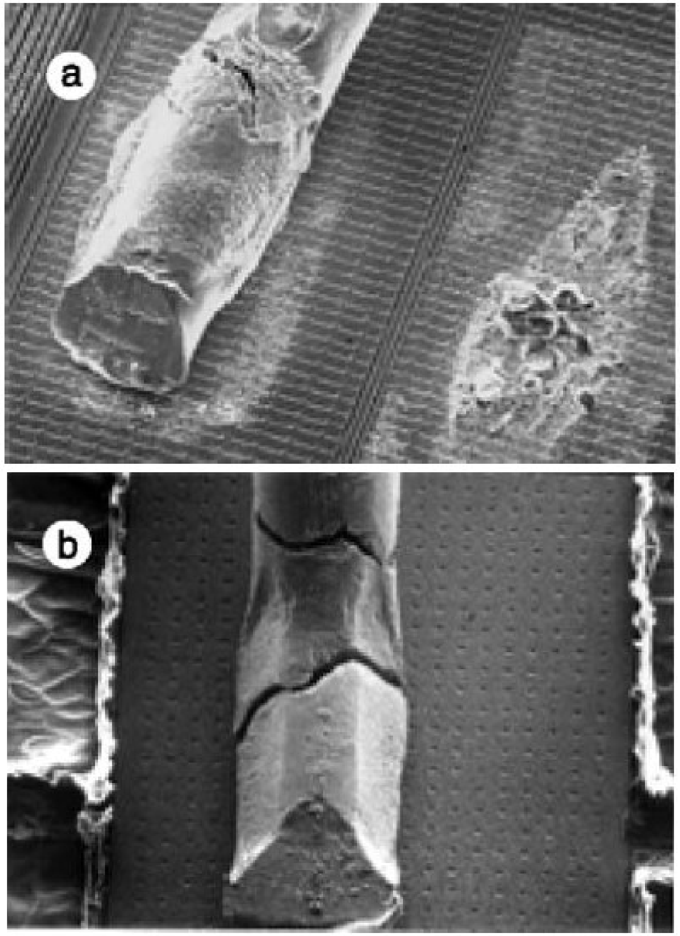
Bond Wire Fatigue







Bond wire lift off



Bond wire heel cracking

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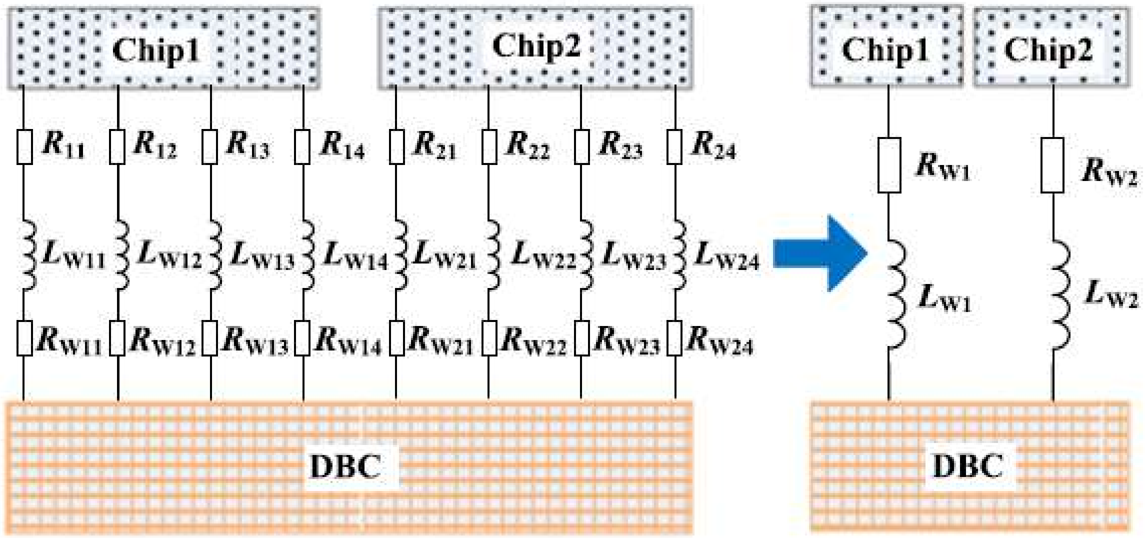
Bond Wire Fatigue



Equivalent resistance model of bond wires

Bond wire fatigue

- The contact of resistance R of the bond wire interface in a new module is almost zero, which is increased by the development of the aging process.

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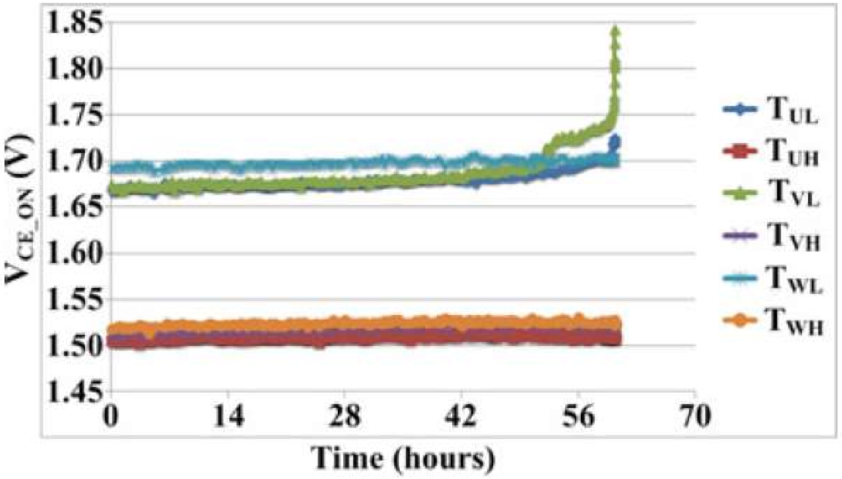
Bond Wire Fatigue

Vce_on measurement (on state voltage)(increase by 5%)

- Principle
  - The equivalent resistance of IGBT increases with bond wire lift-off, results in increases of Vce_on and VF.
  - Vce_on (5%) and VF (20%) is considered wear out failure.
- Limitations
  - Relatively small on-state voltage value
  - Changes with the collector current and junction temperature



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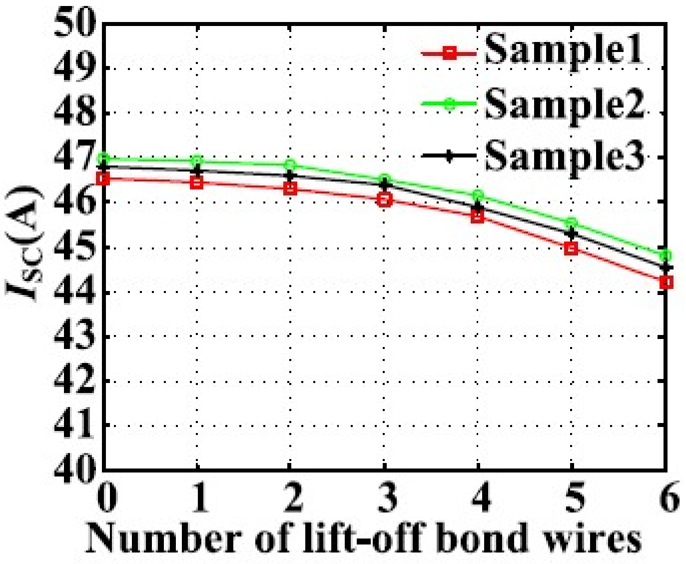
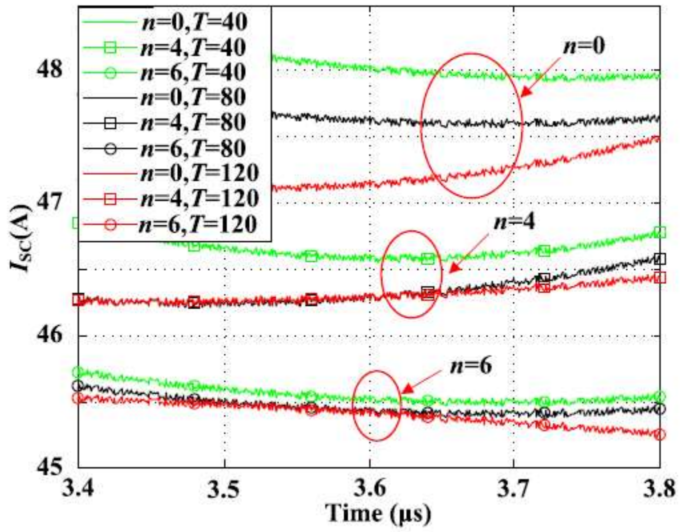
Bond Wire Fatigue

Short circuit(decrease by 4%)

- Principle
  - The IGBT module will have a short cricuit current when the driving voltage is lower.
  - The short circuit decrease with aging.
- Limitations
  - Require measurement of gate voltage
  - Changes with driving voltage and junction temperature.





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Bond Wire Fatigue

Other indicators

- Gate voltage
- Gate emitter threshold voltage
- Gate current

Conclusion

- Vce_on methods are mostly adopted.

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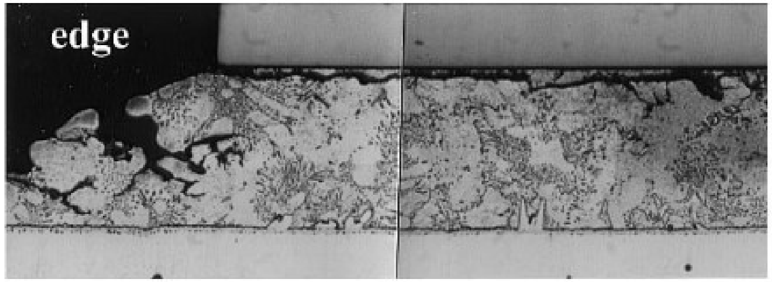
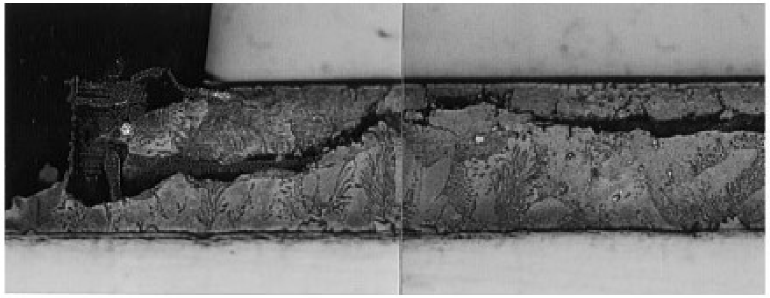
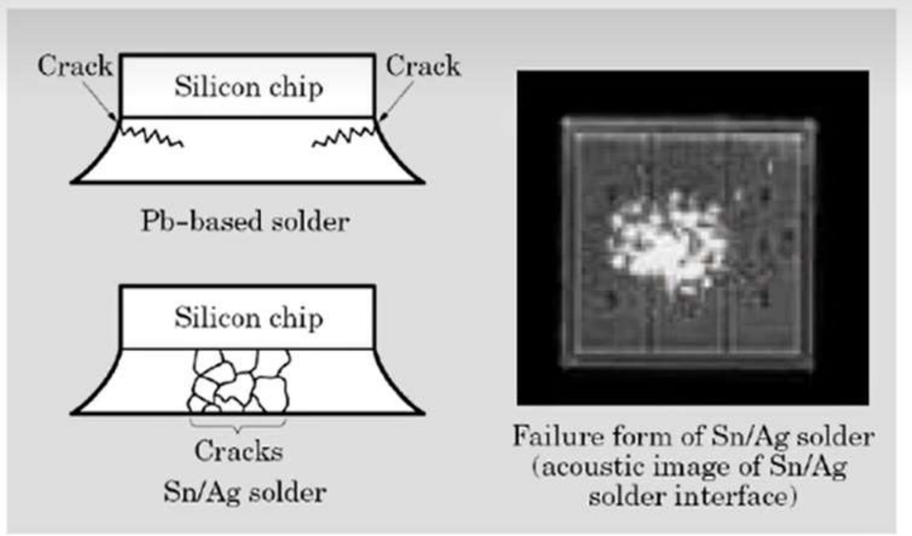
Solder Fatigue



Normal



Solder crack



Solder layer fatigue

- Fatigue includes fatigue between chip and DCB and between DCB and base-plate.
- Solder joint fatigue increases thermal impedance, therefore increase junction temperature
- **Thermal resistance** (20%), **junction temperature**, **case temperature** can be used as monitoring indicators.

$$R_{th(x-y)} = \frac{\Delta T_{xy0}}{P_L}$$

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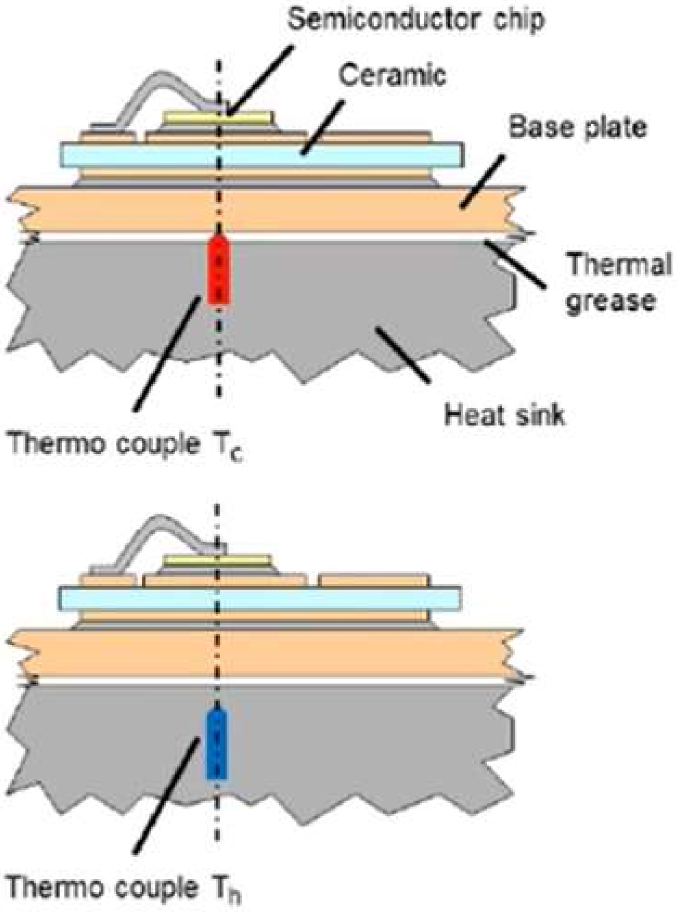
Monitoring-Direct measurement

Direct measurement (only used in Lab)

- Optical method
- Temperature sensors



Thermocouple

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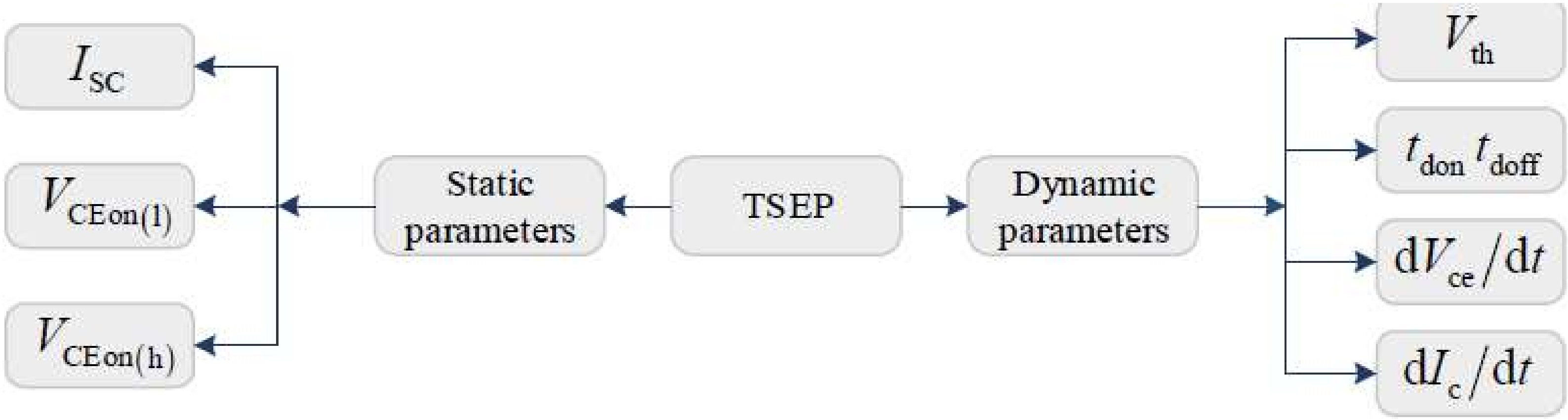
Monitoring-Junction temperature estimation



Classification of temperature sensitive electrical parameters (TSEP)

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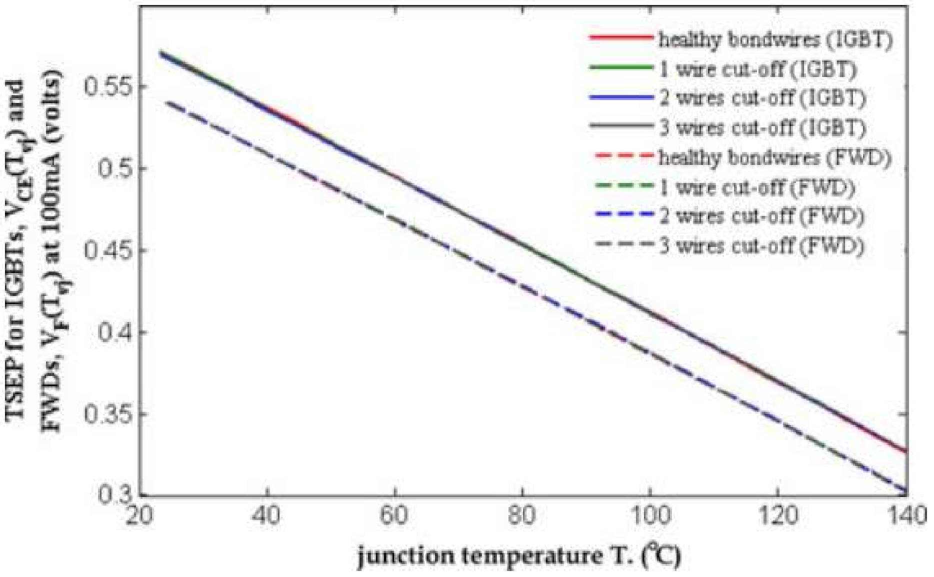
Monitoring-Junction temperature estimation

Vce_on at low current

- Principle
    - Inject a low current (0-100mA), obtain a low voltage.
- Limitations
    - Accuracy in Lab, but not applicable in applications.
    - Interrupt the converter application, only in Lab.



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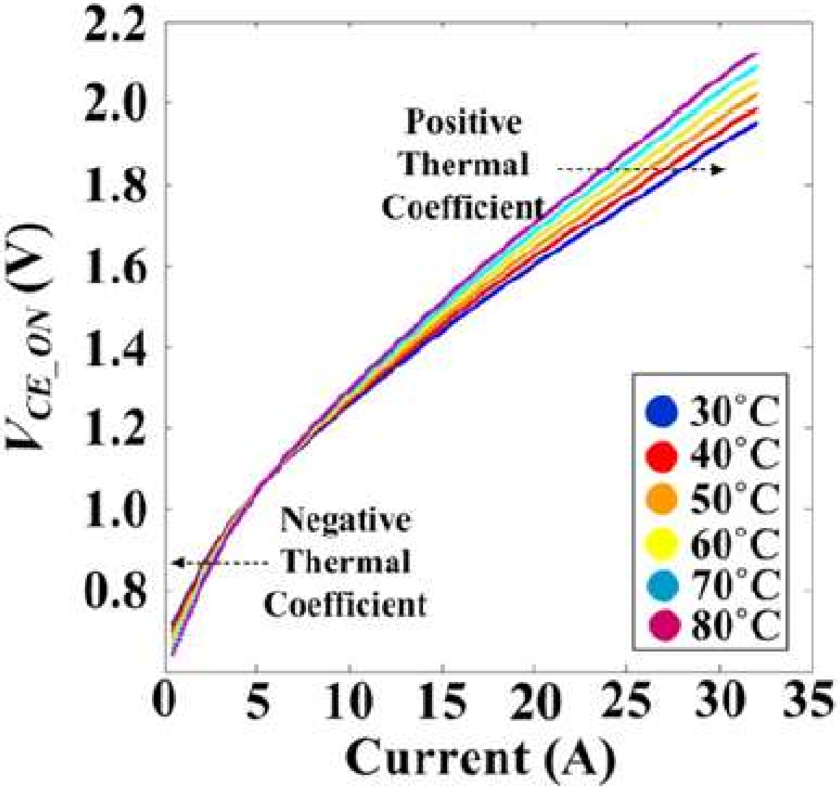
Monitoring-Junction temperature estimation

Vce_on at high current

- Principle
    - Give a load current, and observe the Vce
- Limitations
    - Vce change along with the ageing.



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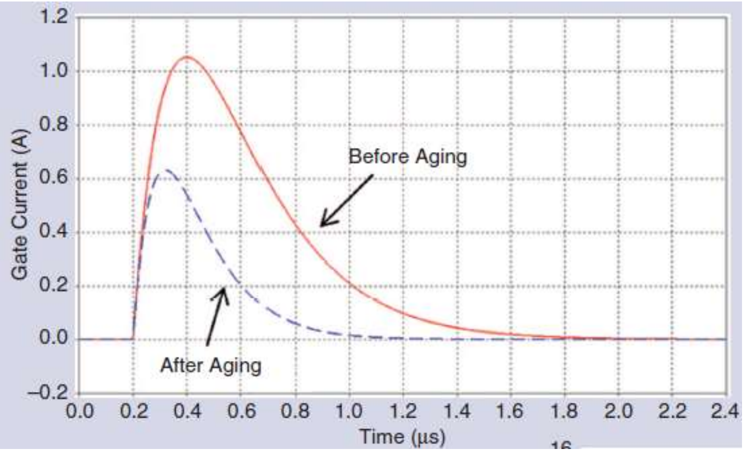
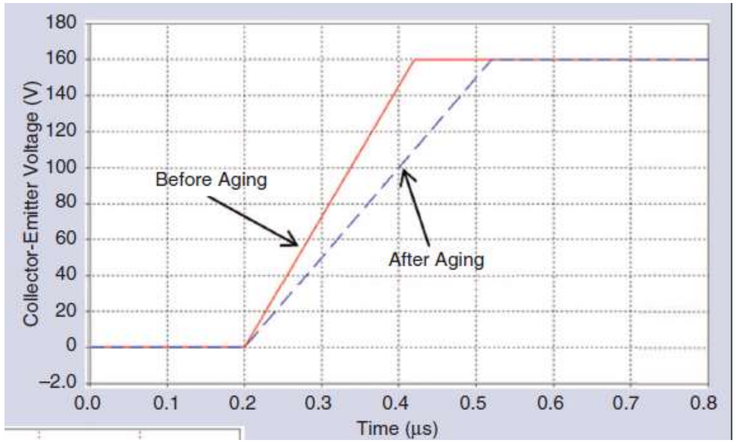
Monitoring-Junction temperature estimation

Dynamic characteristics

- Principle
    - The turn on delay, turn off delay and current slope during turn on can be selected as TSEP.
- Limitations
    - These measurements are constrained by the need for very fast current sensors in the range of several nanoseconds, or even picoseconds, per degree.





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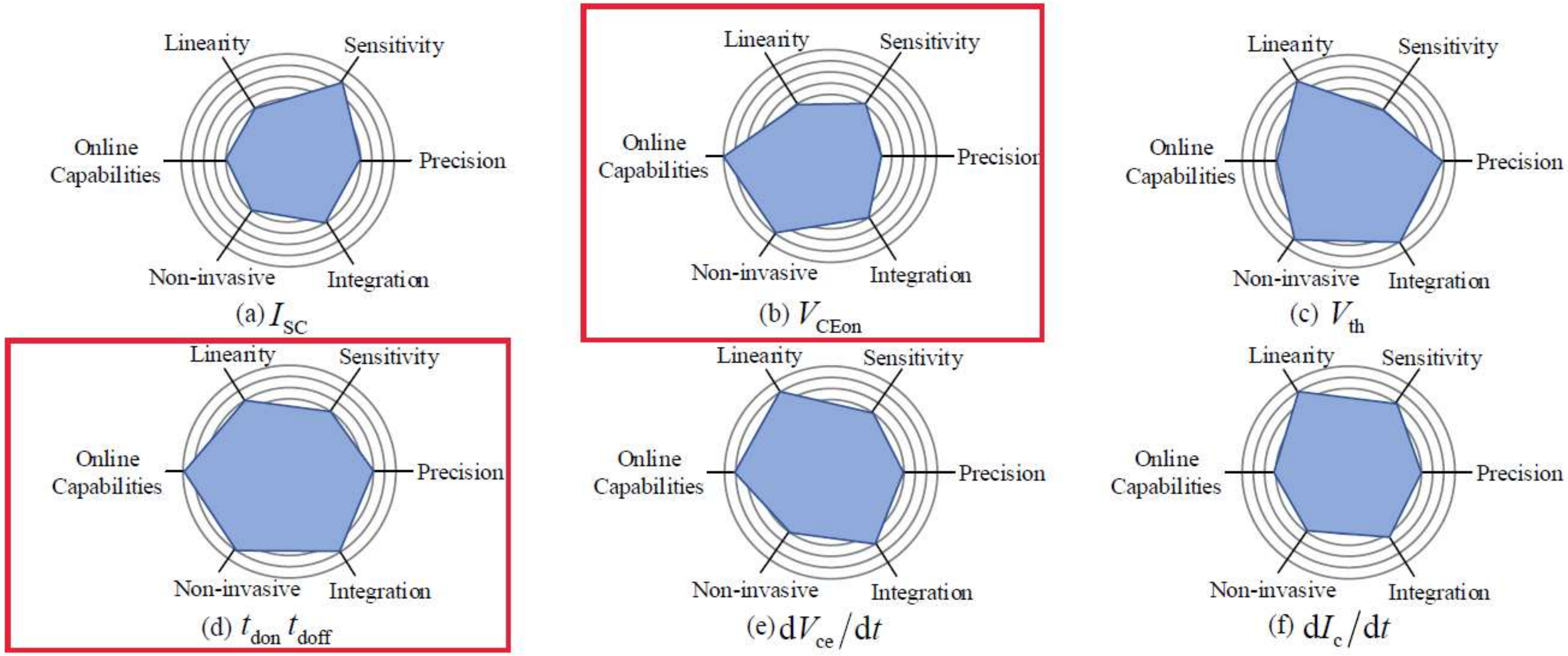
Monitoring-Junction temperature estimation

Other indicators

- Threshold voltage
- Dynamic TESP
    - d*V_ce*/dt
    - d*I_c*/dt



(a) I_{SC} (b) V_{CEon} (c) V_{th}

(d) t_{don} t_{doff} (e) dV_{ce}/dt (f) dI_c/dt

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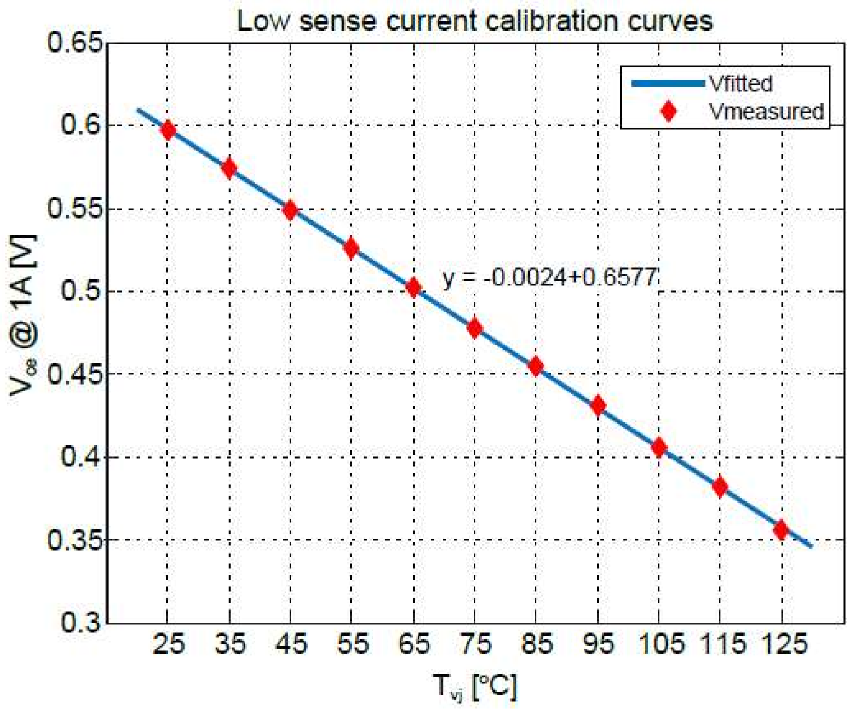
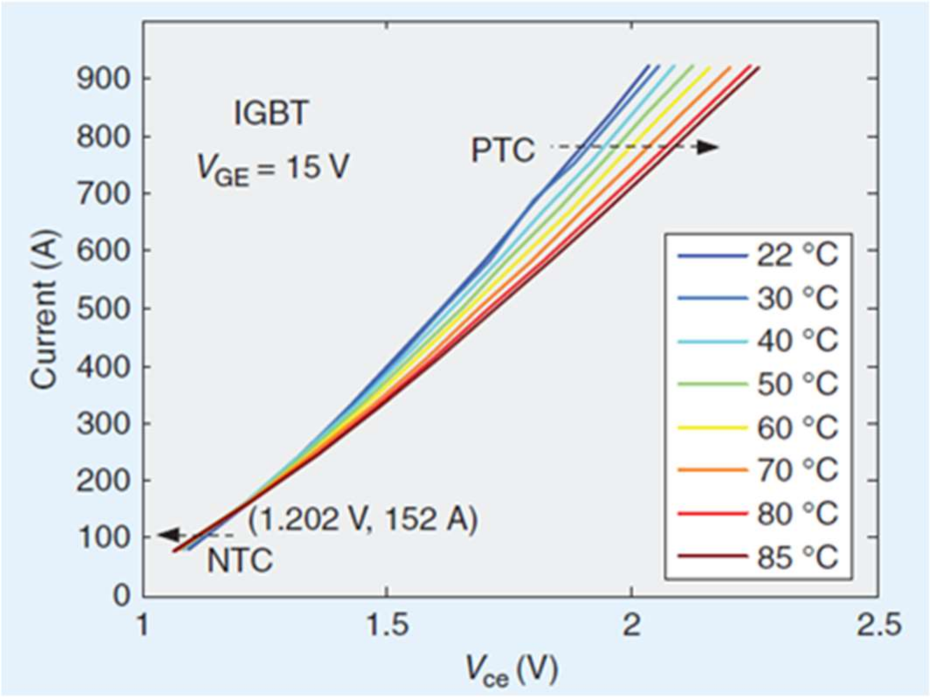
Calibration





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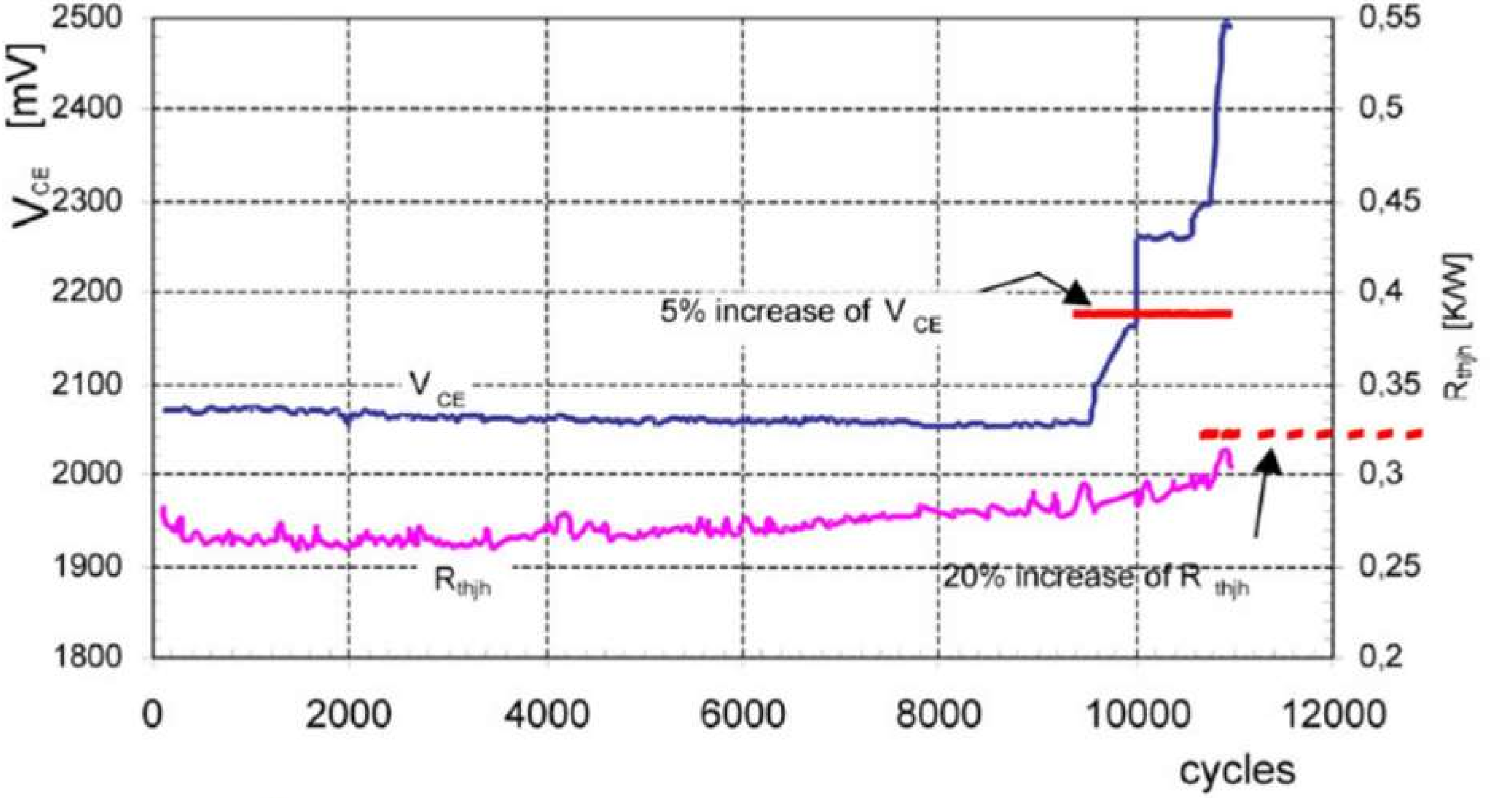
Calibration

- Step 1: Before the calibration
  - Keep the baseplate temperature homogeneously distributed as well as to maintain a steady temperature on the surface of the module.
  - The converter is kept at the same liquid temperature level. In this way, initially, it is assumed that the baseplate temperature and the chip temperature will be at same level.
- Step 2: Start the calibration
  - In one calibration process, constant temperature initialization, give a current from 0 to 890 A in a short period of time (200us), record the Vce, and temperature as soon as the IGBT is turned off.

IGBT Health Monitoring

Conclusion



03

IGBT Lifetime Prediction

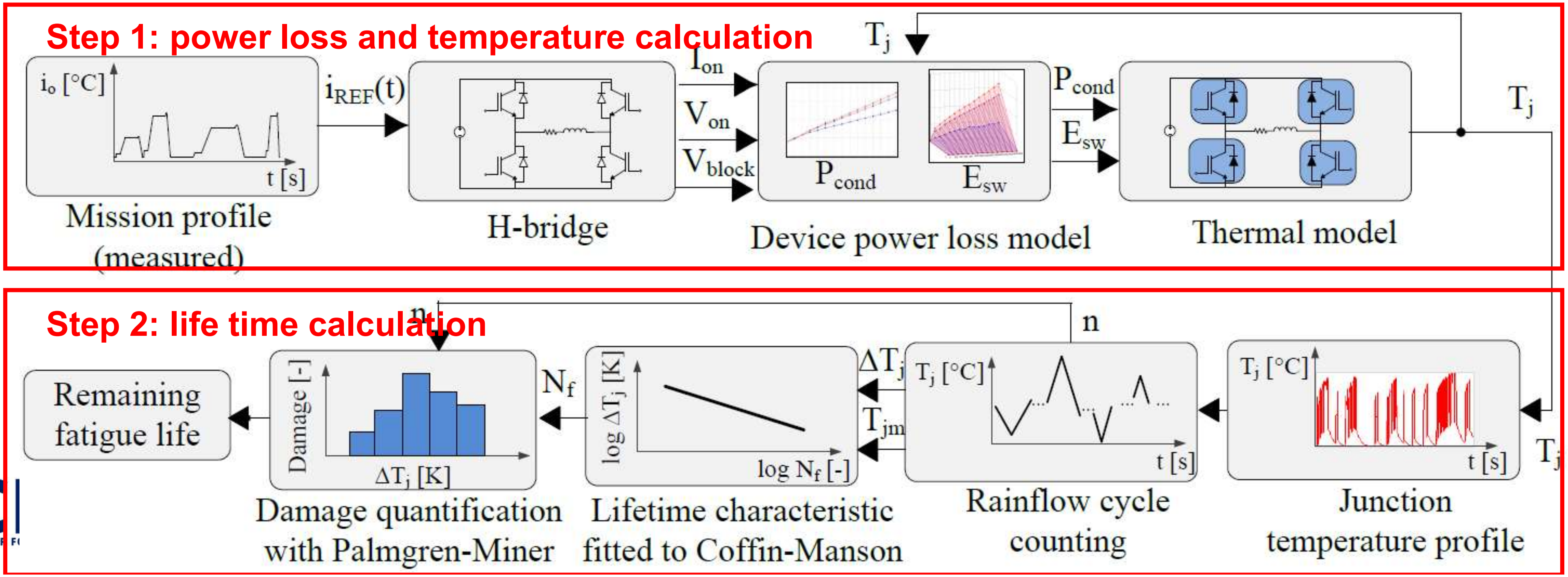
Power loss and temperature calculation

Lifetime calculation

IGBT Lifetime Prediction

Mission/Load profile

- Principle
    - The lifetime of IGBT depends on the temperature swing of junction.
    - Calculate the junction temperature by Mission/Load profile



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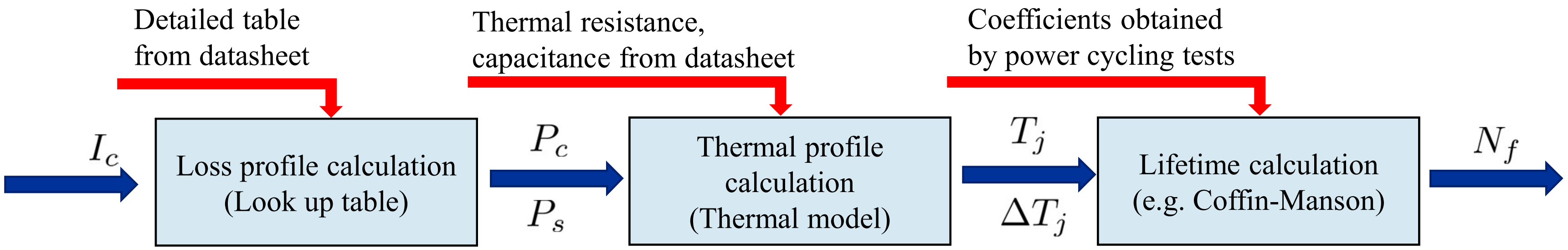


Detailed table from datasheet

Thermal resistance, capacitance from datasheet

Coefficients obtained by power cycling tests

I_c

Loss profile calculation (Look up table)

P_c

P_s

Thermal profile calculation (Thermal model)

T_j

ΔT_j

Lifetime calculation (e.g. Coffin-Manson)

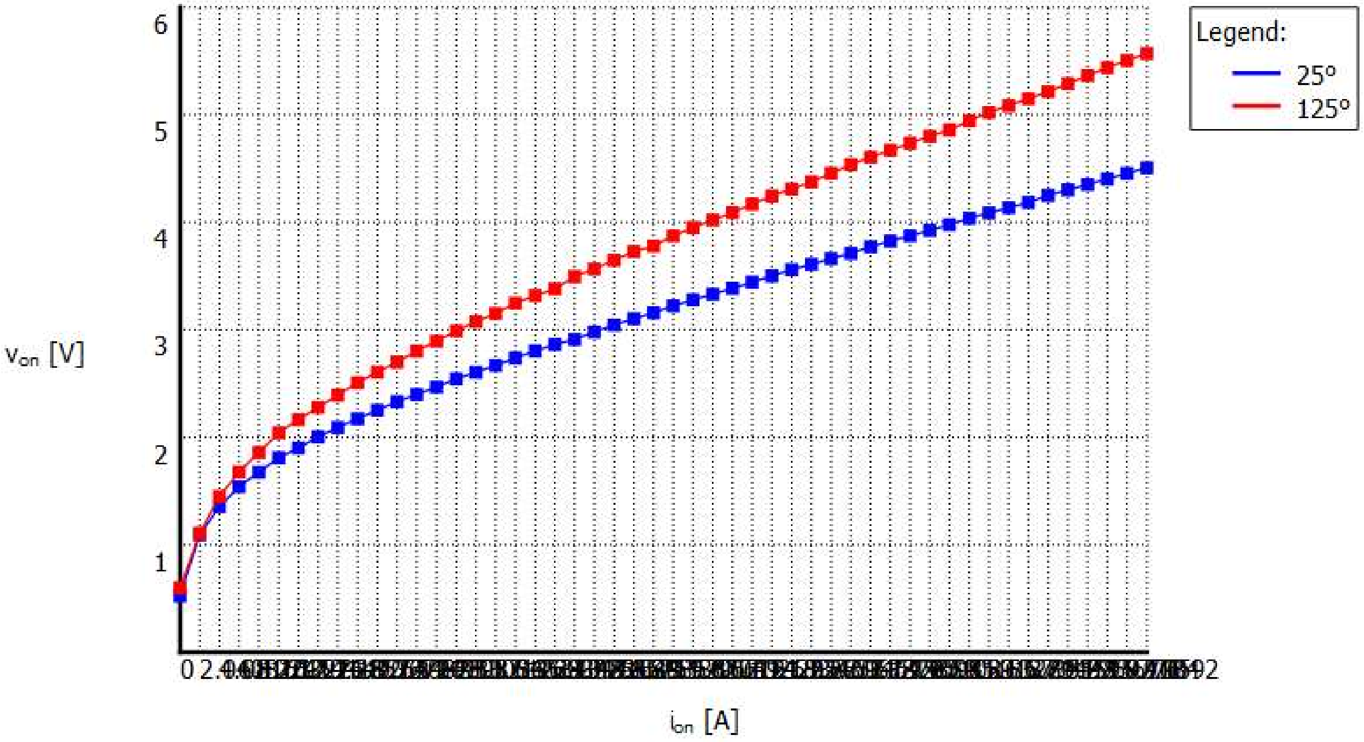
N_f

	Function	Input	Output	Model can be used	Required information	Where to get these information
Reliability	Loss profile calculation	Device current	▪ Conduction loss	▪ Look up table	▪ Conduction voltage drop under different temperature and device current	▪ Device datasheet
			▪ Switching loss		▪ Switching losses under different temperature and device current	
	Thermal profile calculation	Power losses	▪ Junction temperature, ▪ Junction temperature fluctuation	▪ Causer structure model, ▪ Foster structure model(preferred)	▪ Thermal resistance, ▪ Thermal time constant or thermal capacitance, for each layer	▪ Device datasheet, ▪ Or experimental power cycling tests.
	Lifetime calculation	▪ Junction temperature ▪ Junction temperature fluctuation	▪ Remain useful lifetime	▪ Coffin-Manson model, ▪ Norris-Landzberg model, ▪ Bayerer model	▪ The coefficients used in each model	▪ Experimental power cycling tests

IGBT Lifetime Prediction

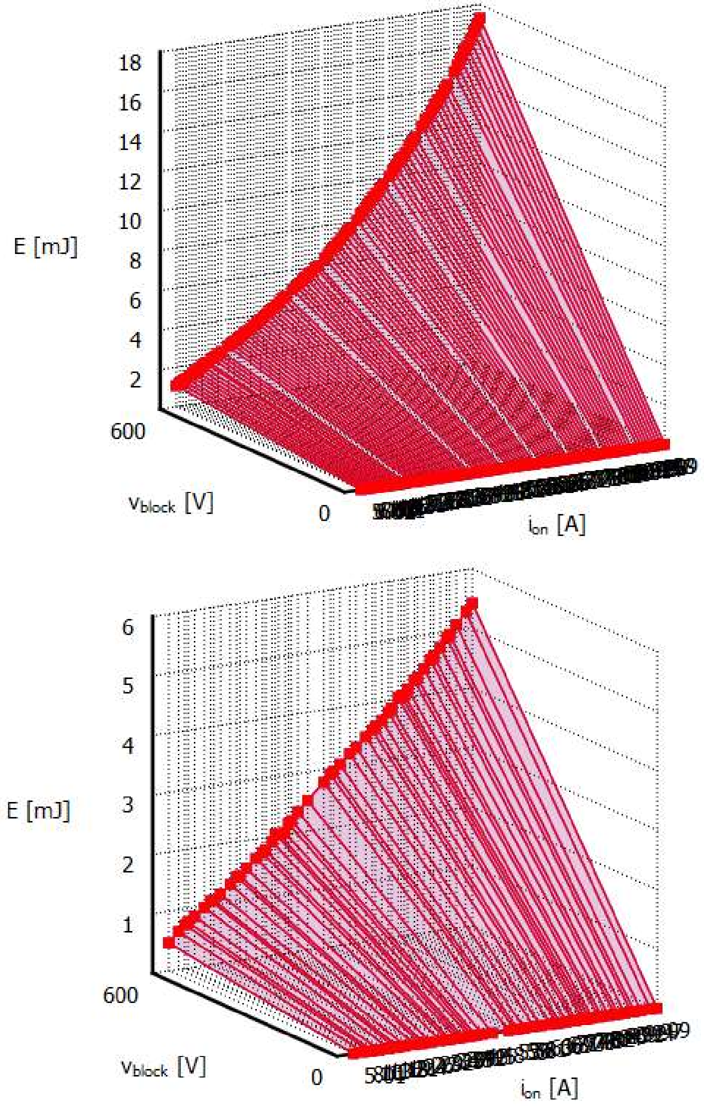
Step 1: power loss and temperature calculation

Power loss



Conduction loss

Datasheet: Infineon-F4_50R12KS4-DS

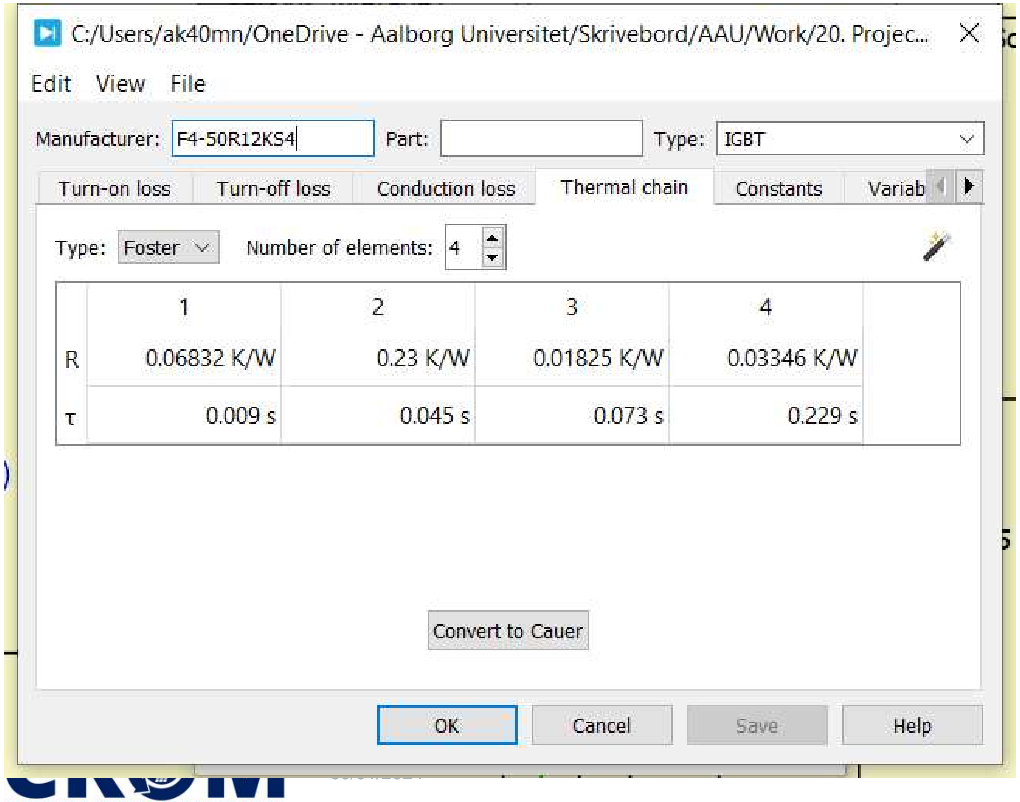


Turn on/off loss

IGBT Lifetime Prediction

Step 1: power loss and temperature calculation

Temperature calculation



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Manufacturer: F4-50R12KS4

Part:

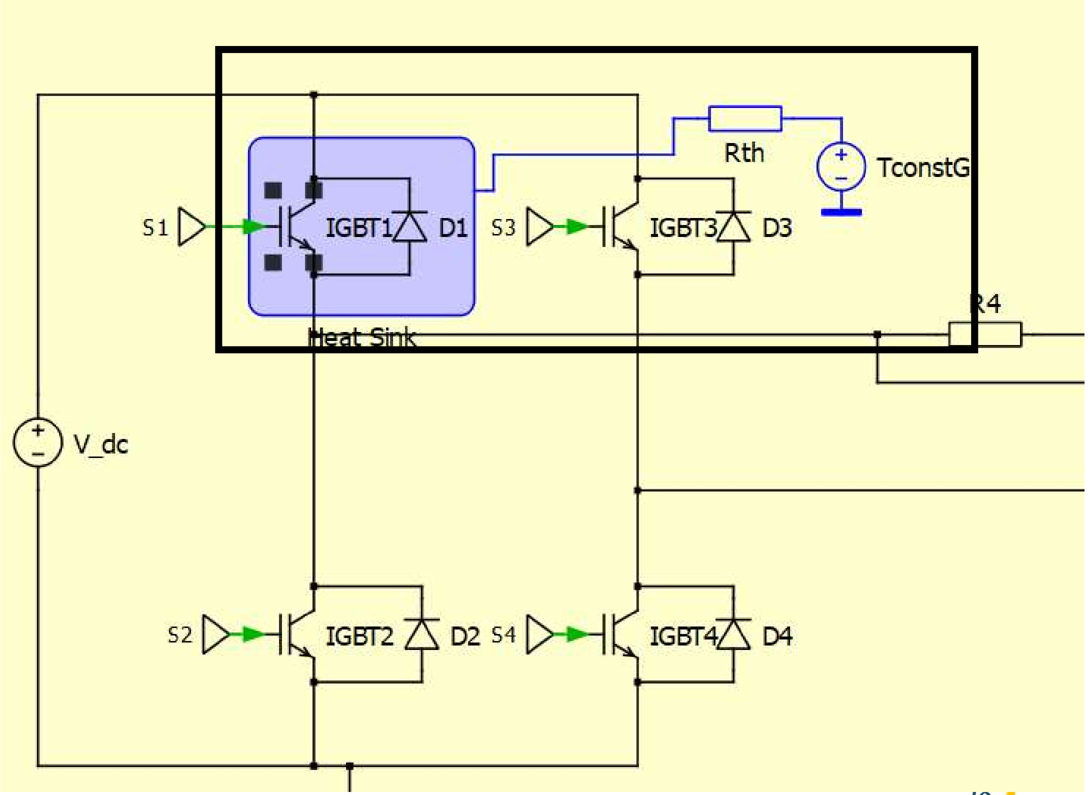
Type: IGBT

Type: Foster

Number of elements: 4

	1	2	3	4
R	0.06832 K/W	0.23 K/W	0.01825 K/W	0.03346 K/W
τ	0.009 s	0.045 s	0.073 s	0.229 s

Junction to case thermal model



Case to sink thermal model

IGBT Lifetime Prediction

Step 2: life time calculation

Coffin-Manson model

$$N_f = \alpha(\Delta T_j)^{-n}$$

Improved Coffin-Manson model

$$N_f = a(\Delta T_j)^{-n} e^{E\alpha/(kTm)}$$

Norris-Landzberg model

$$N_f = Af^{-n_2}(\Delta T_j)^{-n} e^{E\alpha/(kTm)}$$

Bayerer model

$$N_f = A(\Delta T_j)^{-\beta_1} e^{-\beta_2/(T_{jmax}+274K)} t_{ton}^{-\beta_3} \cdot I^{-\beta_4} \cdot V^{-\beta_5} \cdot D^{-\beta_6}$$

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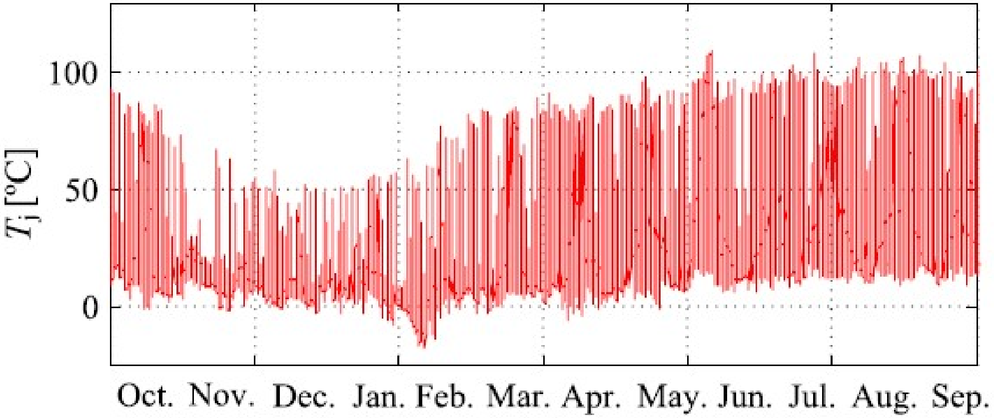
IGBT Lifetime Prediction

Step 2: life time calculation



$$Damage = \sum_i \frac{1}{N_i}$$

$$L = \frac{T_{on}}{Damage}$$

Thank you !

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