Reliability & Lifetime calculations using Power Tester & FloTHERM

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May 2019

Realize innovation.

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Importance of Thermals

The Importance of Thermal design in electronics

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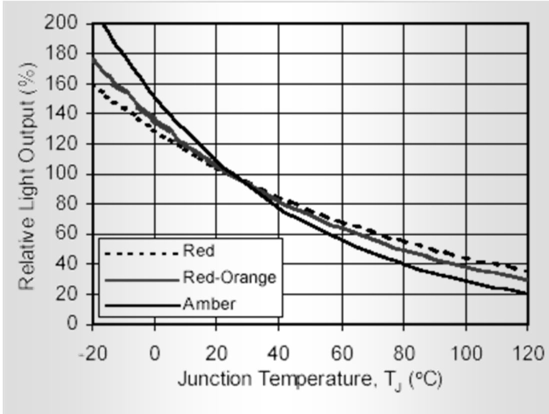
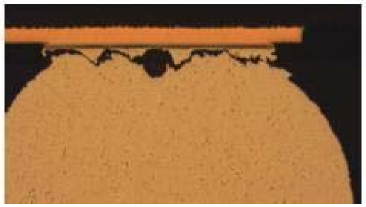
In any semiconductor IC package, we are concerned with the Junction Temperature
Temperature effects are linked to:

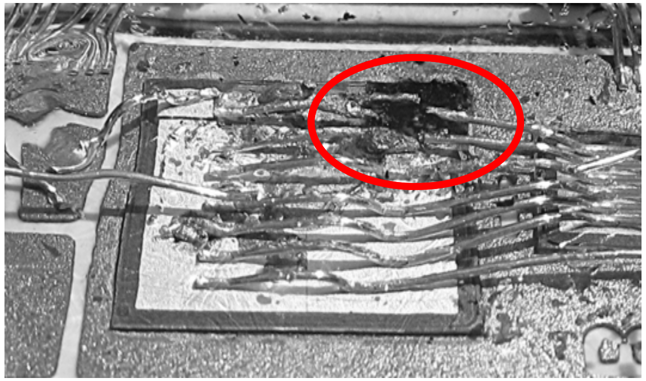


Source: Lumileds

Functional performance

- Timing errors in digital ICs
- Performance of analog circuits
- LED colour and brightness





Reliability

- Solder joint cracking
- PCB trace delamination
- PCB FR4 melt
- Fusing
- Broken bond wires

How Thermal Simulations can help ?

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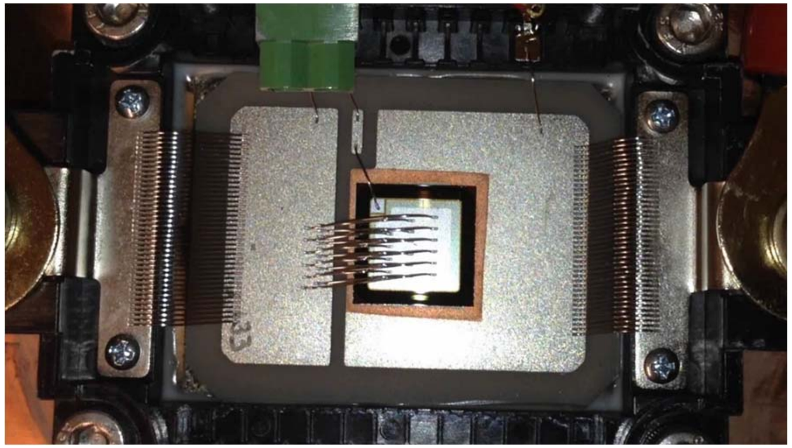
Minimise the risk of 1st physical prototype failure

By observing performance of simulated 'virtual prototypes' throughout the design process

Can also be used to help predict life time and reliability of products



Power Electronics - IGBT technology trend: Power densities are increasing

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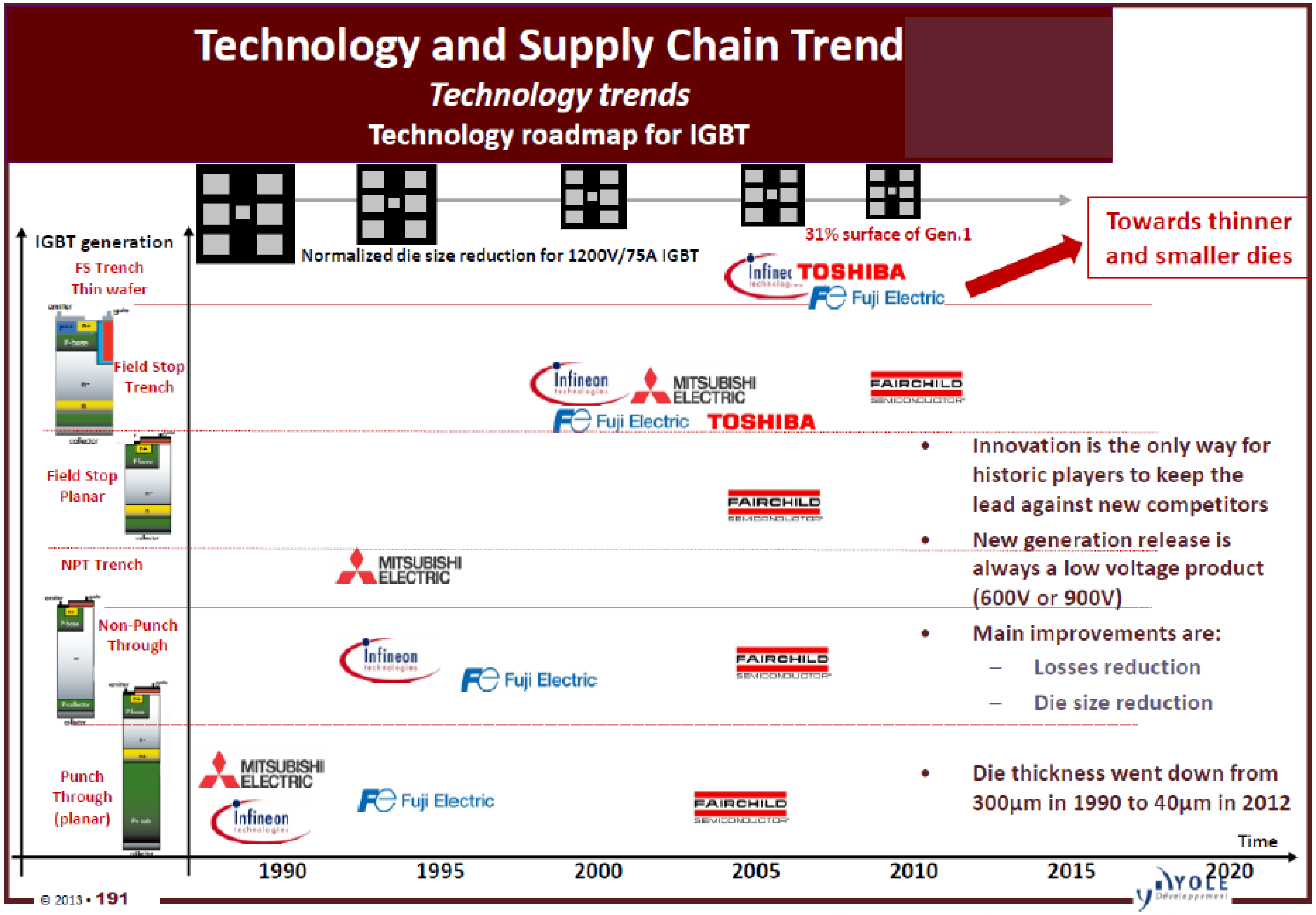

Insulated Gate Bipolar Transistors (IGBT) / Power Electronics Applications

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Motor drives
- Commercial motor drives
- Motor drives discrete
- Motor drives modules
- Motor drives IPM

UPS
- UPS discrete
- UPS modules

PhotoVoltaic inverters
- Commercial PV
- Residential PV
- Solar farms

Electric Vehicles/Hybrids
- PHEV/EV
- Full HEV
- Mild HEV
- Micro HEV
- EV/HEV charging stations

Railway traction
- Rail traction inverters
- Rail auxiliary inverters

Wind turbines
- Wind turbine >1MW
- Residential/commercial wind turbines

Industrial applications
- Welding
- Other industrial

Consumer applications
- Induction heating
- DSC–DSLR camera flash
- Air conditioner
- Washing machine
- Microwave oven
- Flat panel (LCD/PDP)
- Lighting supplies
- Other home appliances

Others
- Other power supplies (SMPS)
- Automotive ignition
- Marine propulsion
- Medical applications
- Defibrillators
- Avionics converters
- Heavy duty vehicles
- Grid –T&D

Classification by Yole Développement

IGBT Market Forecast by Segment

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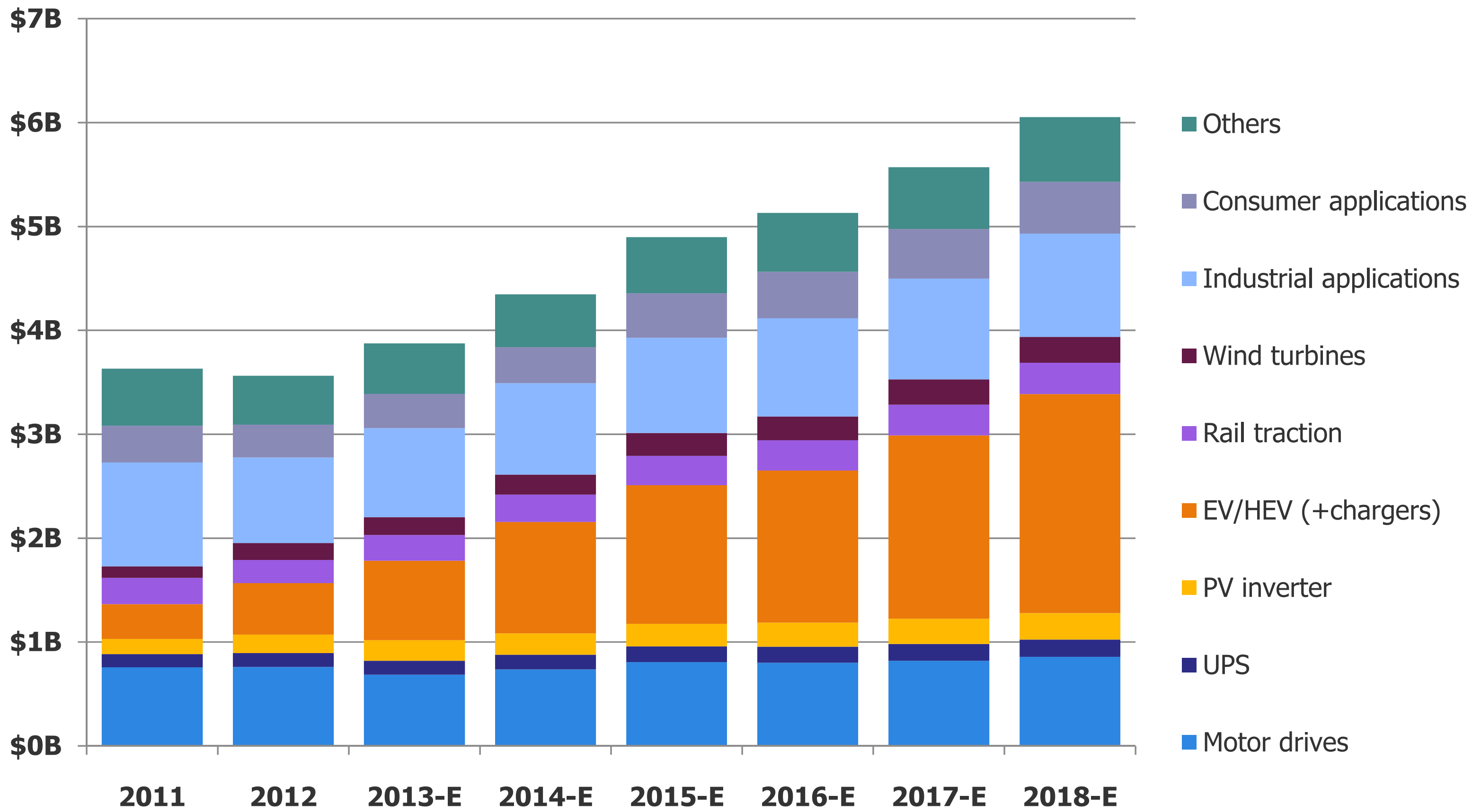

Source: Yole Developpement - IGBT Markets & Application Trends, 2013

Test Methodologies

Commonly used test methods

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IGBT testing includes some major branches, like

- Module electrical characterization tests (QM and QC)
- Environmental tests (QE)
- Lifetime tests (QL)
- etc. (mechanical tolerances, chemical resistance, …)

Siemens expertise covers an important range
of these testing branches,

especially those which are related to powering solutions and
thermal effects

Environmental testing (QE) for automotive industry

The environmental tests serve to verify the suitability of power electronics modules for use in motor vehicles.

Some commonly used environmental test solutions

- **Temperature shock tests (TST)**
- Contactability (CO)
- Vibration (V)
- Mechanical shock (MS)

We focus only on those which induce mechanical damage in the heat conduction path of the power module

- Combined with structure function evaluation it is a good test method
- **Power Cycling Tests**

Vulnerable areas of a typical power device

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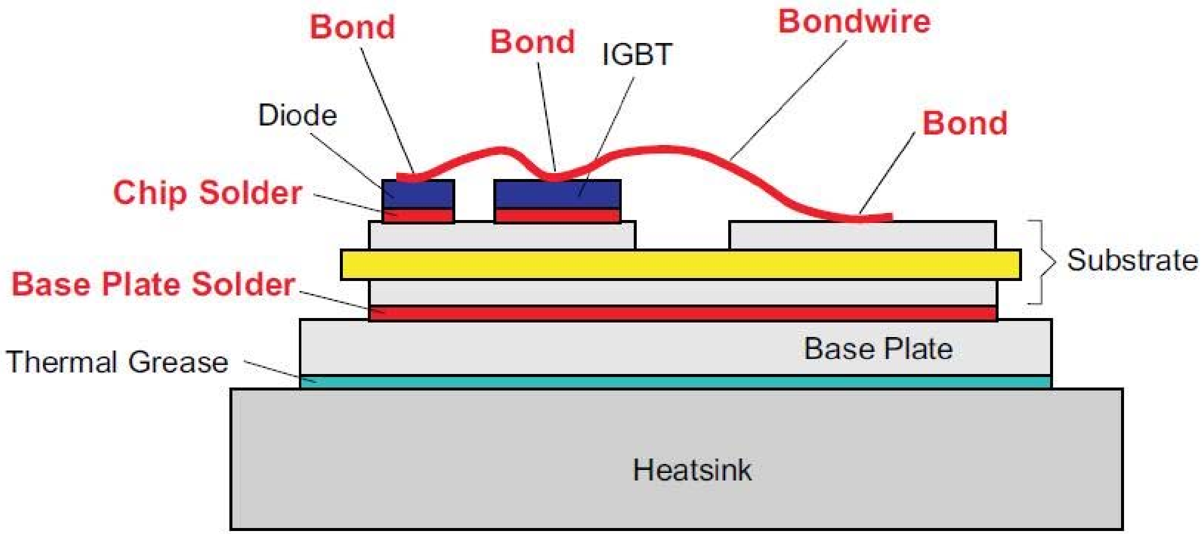
The thermo-mechanical stress is the largest when the temperature difference between layers is high and the contact surface is large



Vulnerable areas of a typical power device

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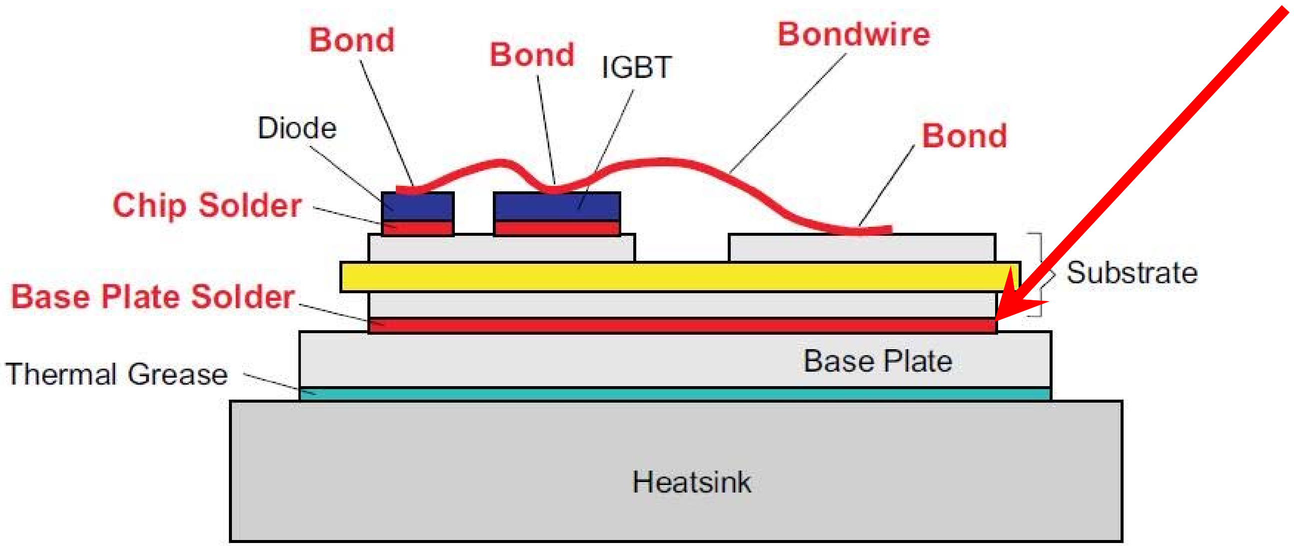
The thermo-mechanical stress is the largest when the temperature difference between layers is high and the contact surface is large

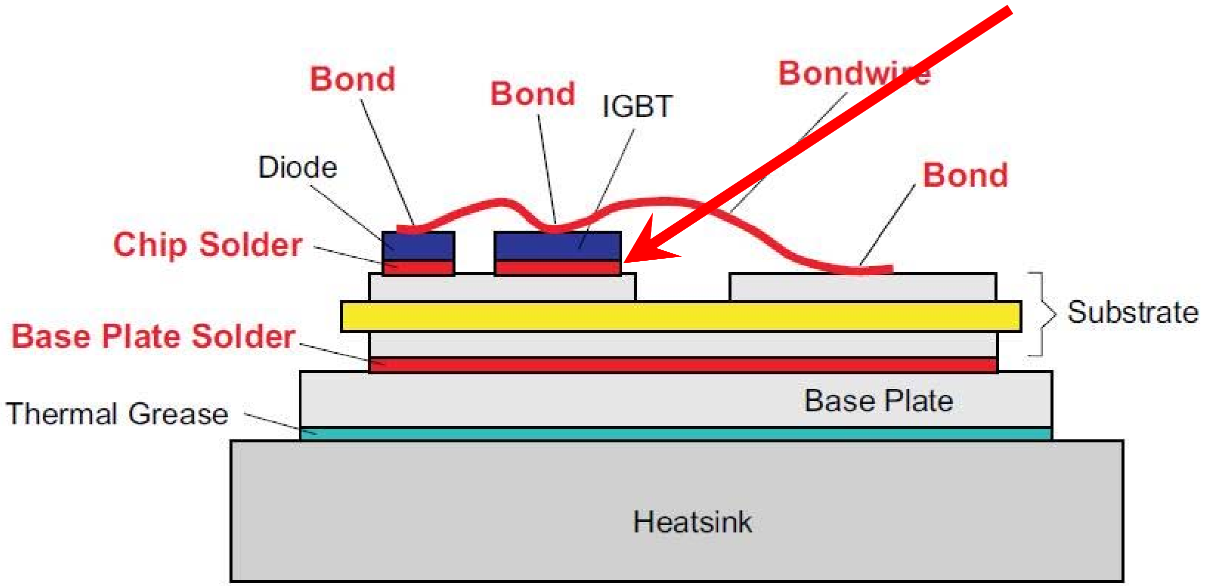
Solder joint between the base plate and the back-side metallization of the substrate



Vulnerable areas of a typical power device

The thermo-mechanical stress is the largest when the temperature difference between layers is high and the contact surface is large

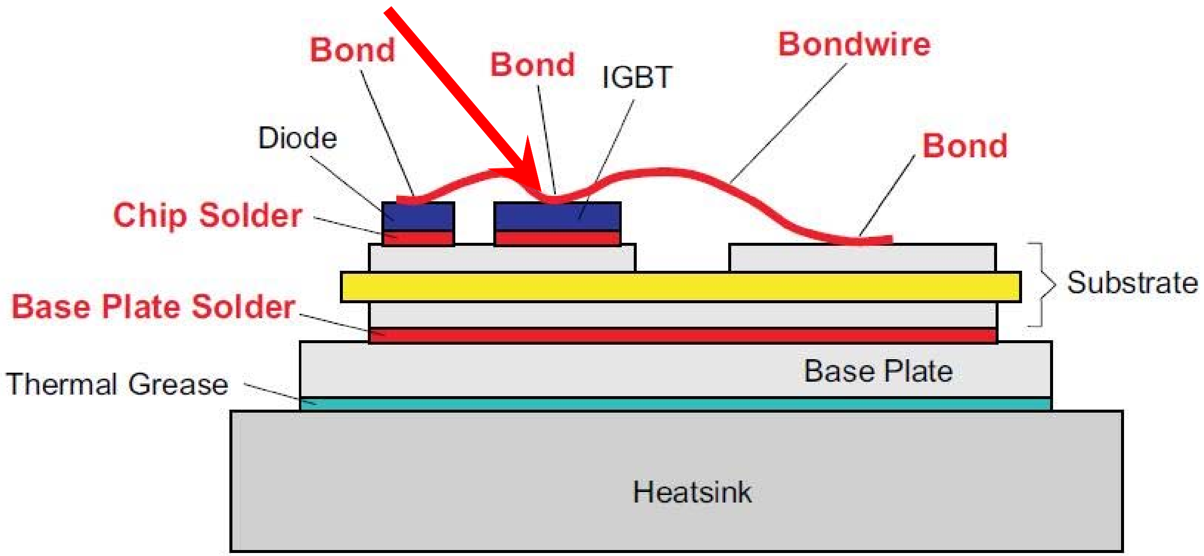
Die attach – There was extensive research in this field towards better materials and processes



Vulnerable areas of a typical power device

The thermo-mechanical stress is the largest when the temperature difference between layers is high and the contact surface is large

Bond wires - Small area but high temperature swing and CTE mismatch make it vulnerable



The ageing process (cycling) has to be simulation based

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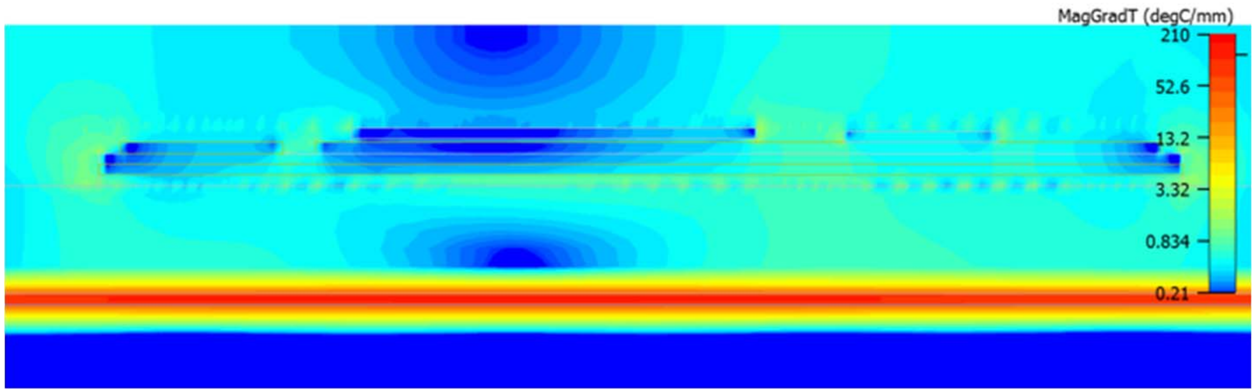
Temperature gradient development during power cycling



Mission Profile Based Lifetime Testing

Power Cycling Tests – Our Solution: Power Tester

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Uses T3Ster technology

- Structure Functions

High Power applications

- 600A, 1500A, 1800A, 2400A, 3600A

Automated Power Testing and Power Cycling tests

For MOSFETs, IGBTs & generic two-pole devices

Example: Electric traction in a car

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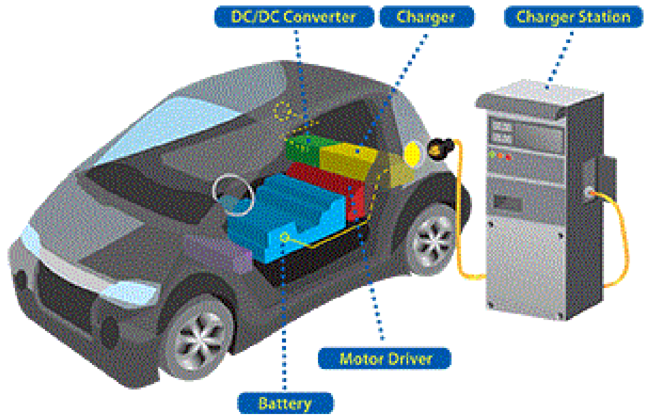
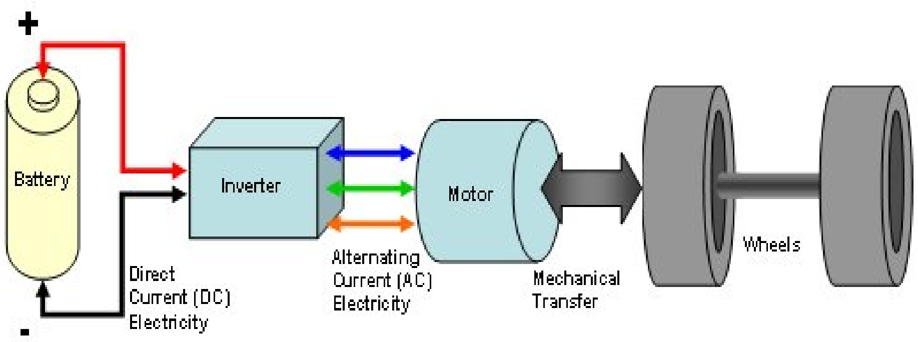
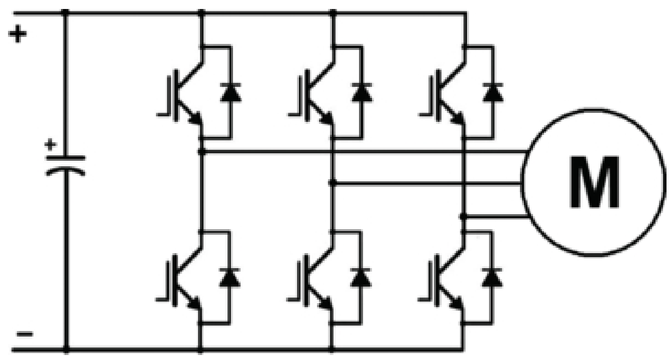
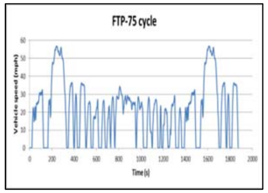






Heating and cooling is determined by the motion of the wheel

Definition of the application – The driving profile



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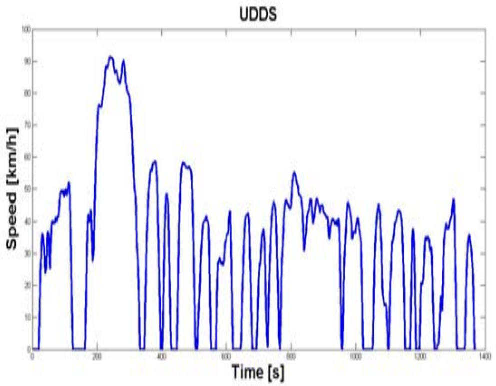

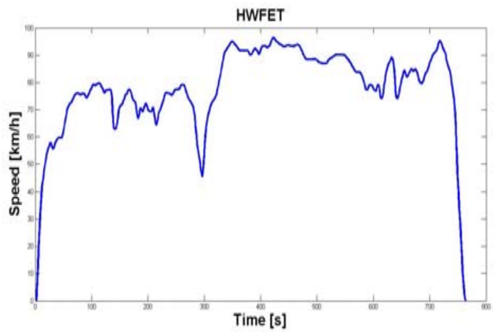

For the design of the power module the exact definition of the task is necessary

Possible input data:

- Electrical data: V, I
- Velocity vs. time functions

Driving profile examples

Test standards defined by the US EPA

- **FTP-75** for the general city driving
- UDDS: Inside the city for light vehicles
- US06: Aggressive driver
- HWFET: Highway, standard driver

1. Lifetime calculation workflow

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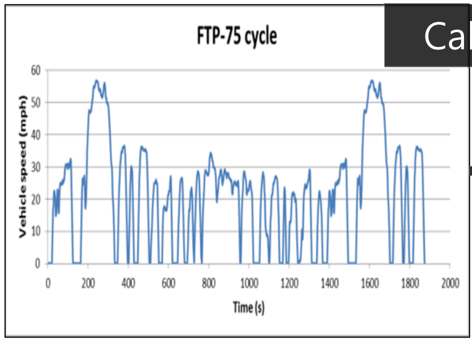
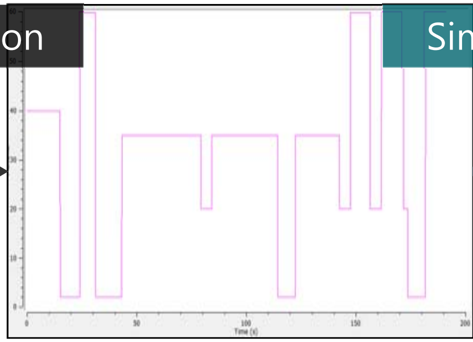
1. Driving Profile



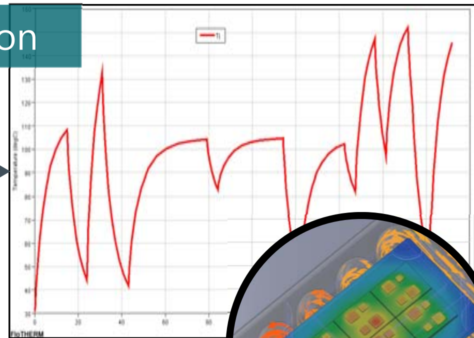
Calculation

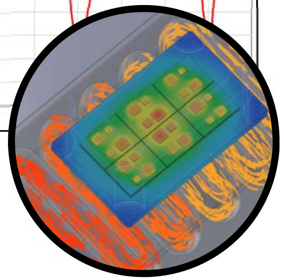
2. Power Profile



Simulation

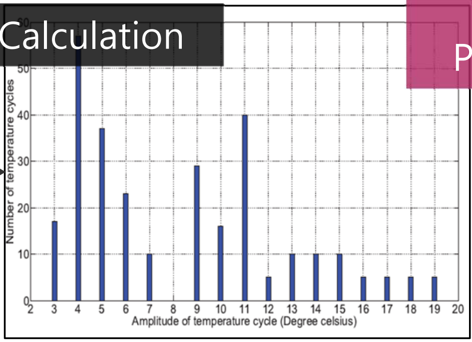
3. Temperature Profile





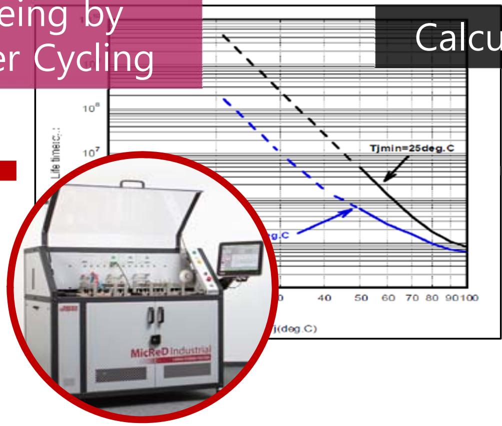
4. Distribution of Temperature Changes

Calculation



5. Lifetime Curves

Ageing by Power Cycling



Calculation

6. Lifetime calculations

Expected Lifetime (e.g 12 yrs)

2. Power profile based on mission profile

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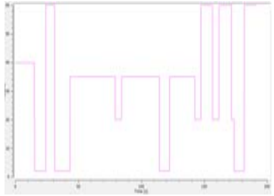


Forces used for modeling the movement of a car

- Rolling resistance: $F_g = \mu_g mg$
- Air resistance: $F_{air} = \frac{1}{2}\rho A C_d v^2$
- Acceleration resistance: $F_{acc} = ma$
- Elevating resistance: $F_{elev} = mgsin(\varphi)$ *(neglected)*

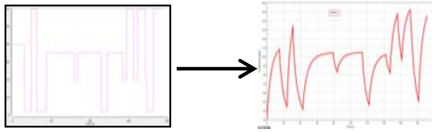
Engine power: $P_{engine}(t) = \Sigma F v(t)$

Total required power: $P_{total}(t) = \frac{P_m(t)}{\eta}$ *(η – efficiency)*

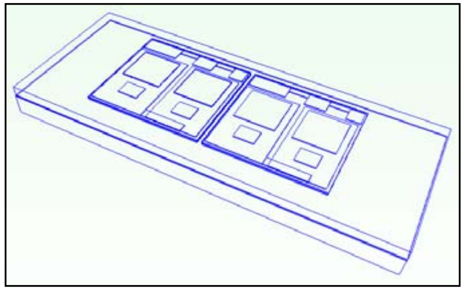
Power loss: $P_v(t) = P_{total}(t) - P_{engine}(t)$

- $P_v(t)$ is partially the conduction and switching loss of the IGBT

3. Temperature profile simulation



Step 1.



3D model

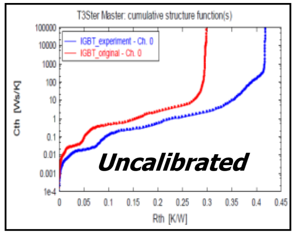
FloTHERM/FloTHERM XT detailed model of a single IGBT module.

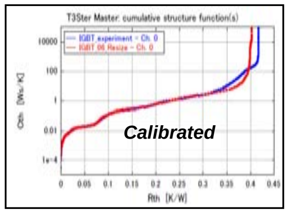
- Same environmental conditions as PwT tests.
- Same power dissipations of the dies.

Step 2

Use Auto-Calibration to calibrate the simulation model. Gives us:

- Accurate transient behavior
- Confidence with simulation model



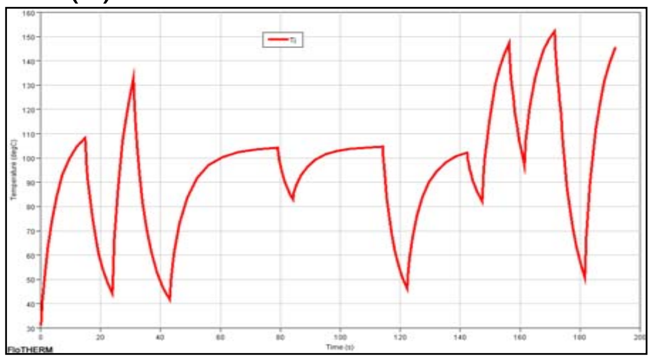


Step 3

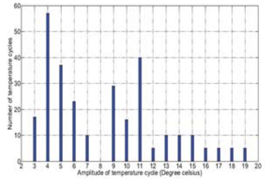
With a calibrated IGBT module in FT, we can now create a system level of the inverter (> 1 IGBTs + coldplate)

Simulate with driving cycle

We obtain the resulting temperature vs. time profile for the die(s)



4. Temperature histogram calculation



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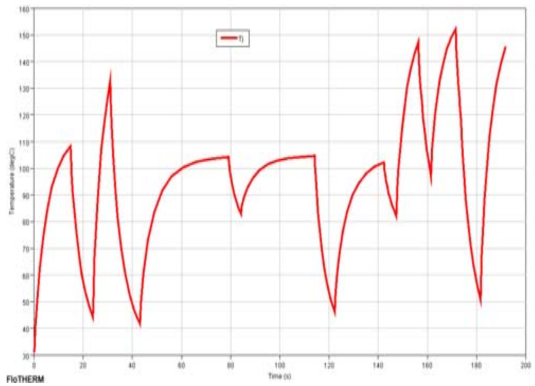
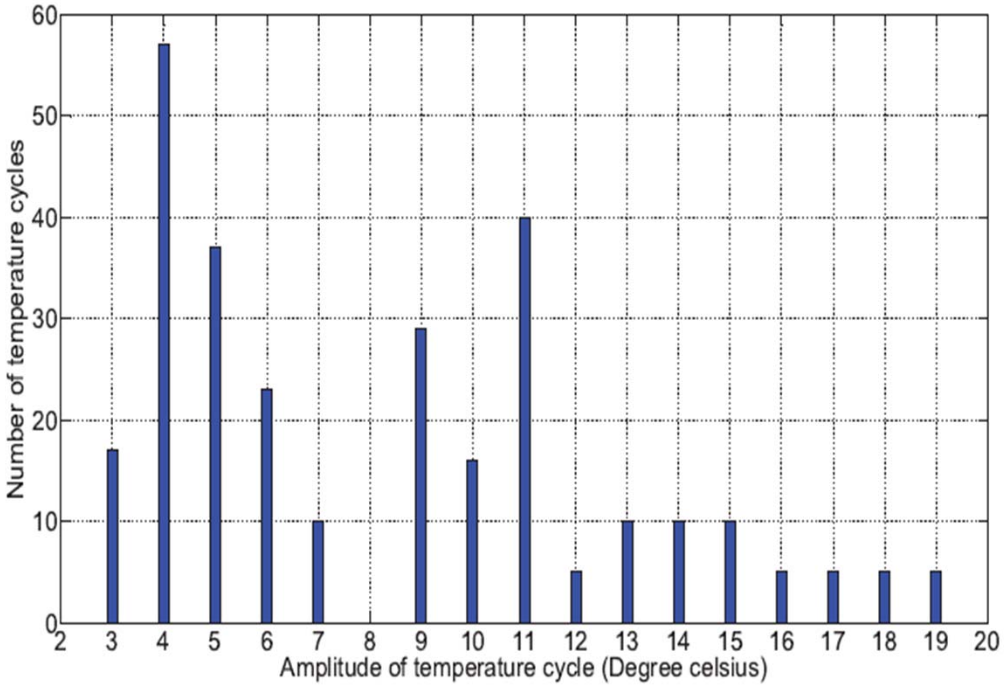
Count the individual temperature gradient components in the temperature profile – future weighting factor in cycling





5. Power cycling

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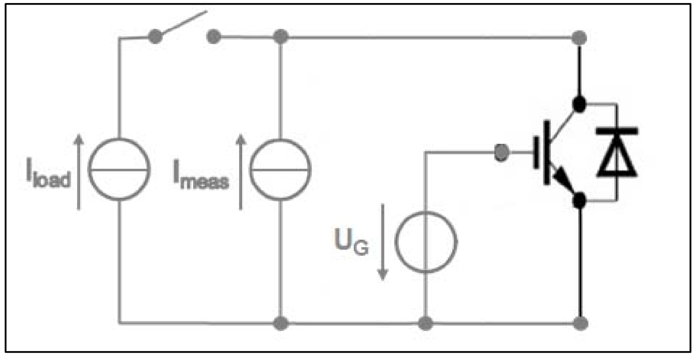
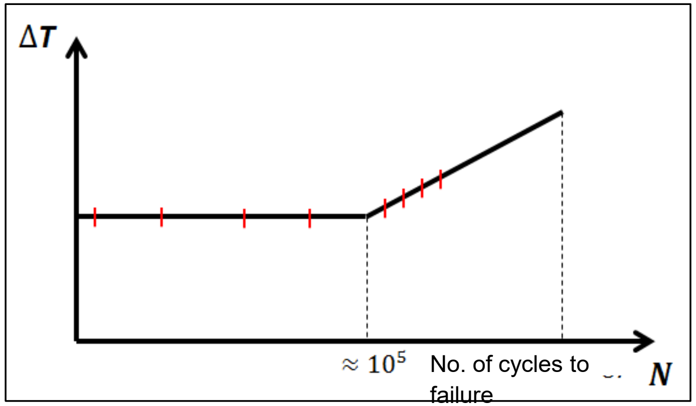
▶ Reliability/ lifetime test



Switching the power between two defined states

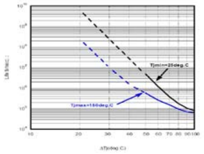
- Induces mechanical stress
- Leading to failure



Monitoring the phenomenon with optical/thermal tests

Checking the maximum temperature change of the sample in each cycle

6. Measure points of the lifetime curves and estimate lifetime



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Arrhenius model: $N_f = e^{\left(\frac{E_a}{k_b \cdot T}\right)}$ Cycles to failure

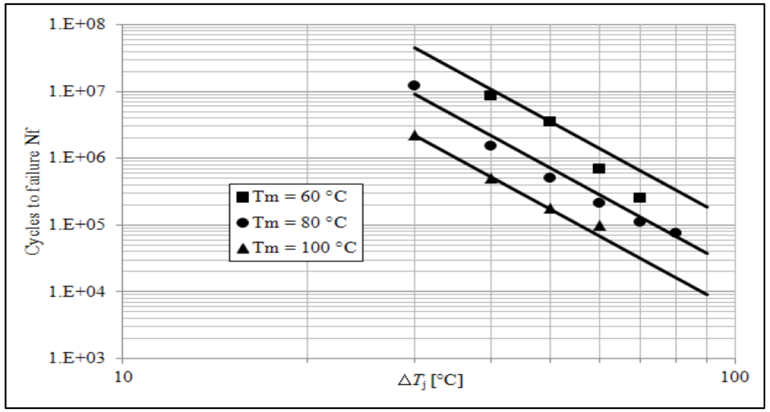
Extended Arrhenius models:

- $N_f(\Delta T) = A \cdot (\Delta T_j)^{\alpha} \cdot e^{\left(\frac{E_a}{k_b \cdot T}\right)}$ (used by: F* Company)
- $N_f(\Delta T) = A \cdot f^{\beta} \cdot (\Delta T_j)^{\alpha} \cdot e^{\left(\frac{E_a}{k_b \cdot T}\right)}$ (used by: I* Company)

Lifetime estimation

$$N_{f\_sum} = \frac{1}{\sum_{k=1}^{n} \frac{w_i}{N_{f\_i}}}$$

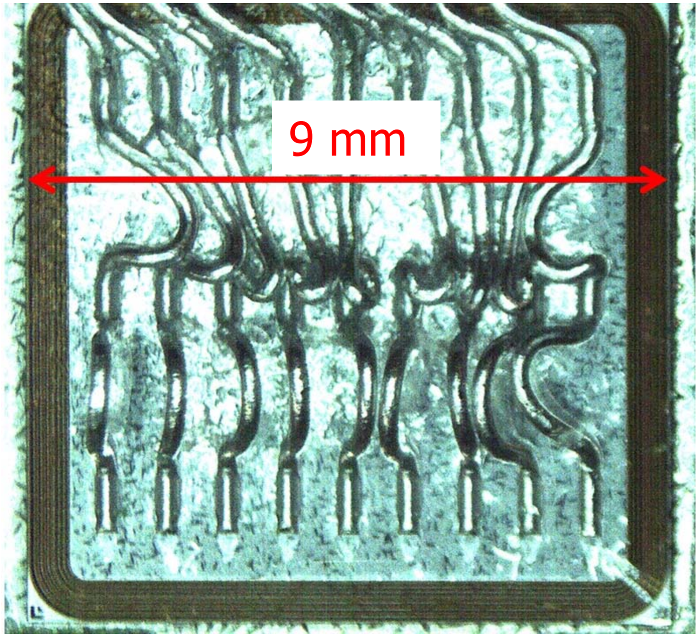
$$t_{operation} = N_{f\_sum} \cdot t_{cycle}$$

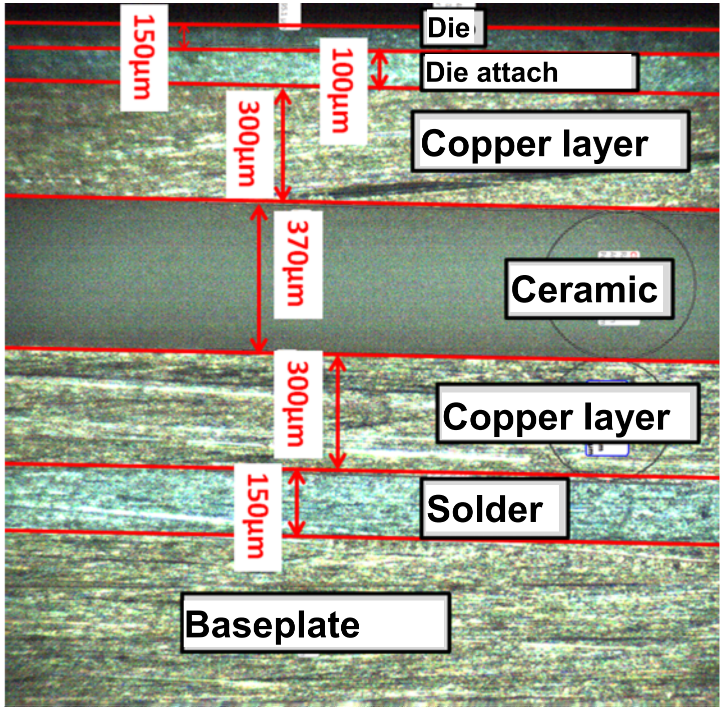


Case Study

IGBT Sample

We opened up and measured the sample's geometry





IGBT Detailed simulation model

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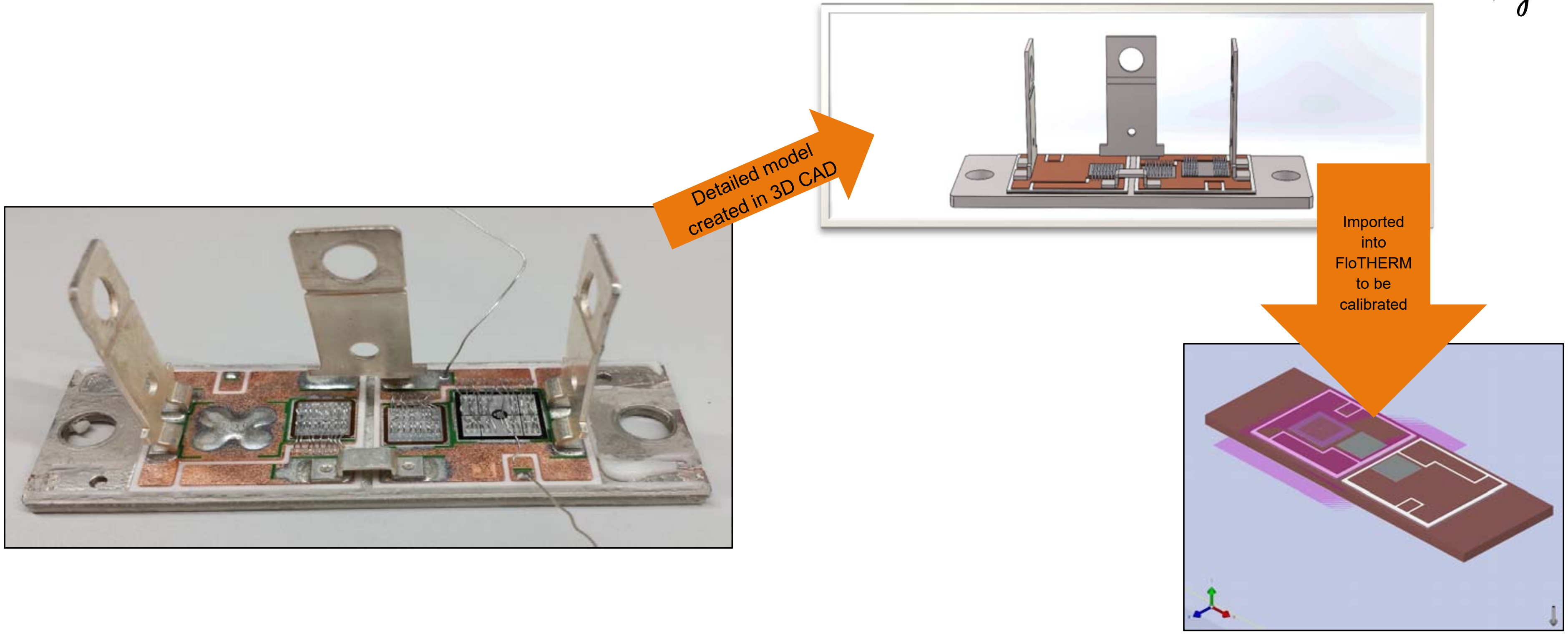

Material Properties assigned to the different layers in FloTHERM

Model calibration

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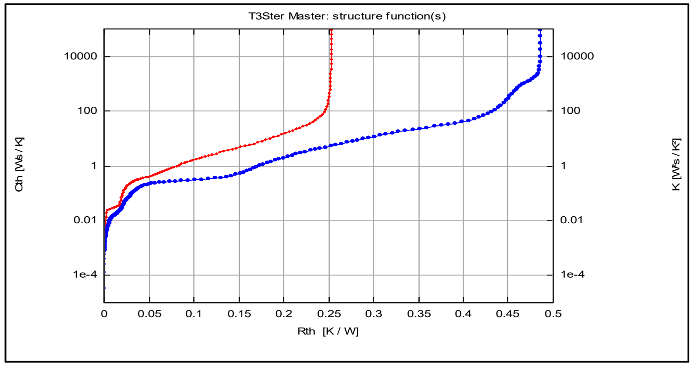
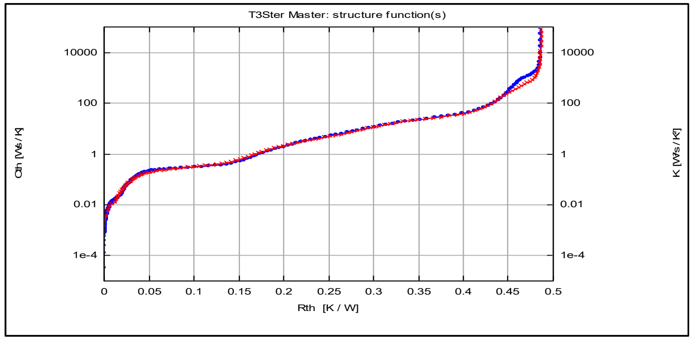
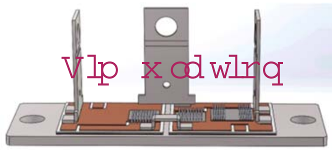
- Adjustment of material properties until a perfect match is achieved between structure functions

Layers	Original			Modified		
	Density [kg/m^3]	Specific heat [J/kgK]	Thermal conductivity [W/mK]	Density [kg/m^3]	Specific heat [J/kgK]	Thermal conductivity [W/mK]
Chip	2330	700	**117,5**	2330	700	**100**
DA	**14520**	**151**	**59**	**14000**	**1000**	**67**
Copper	8930	385	385	8930	385	385
Ceramics	3300	725	170	3300	725	170
Solder	1	1	57	1	1	57
Copper base	8930	385	385	8930	385	385







Simulation of the IGBT's temperature profile

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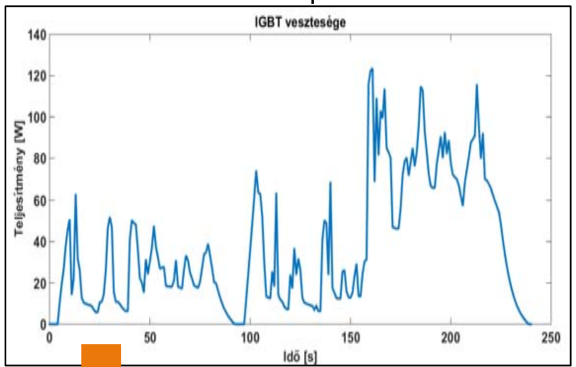
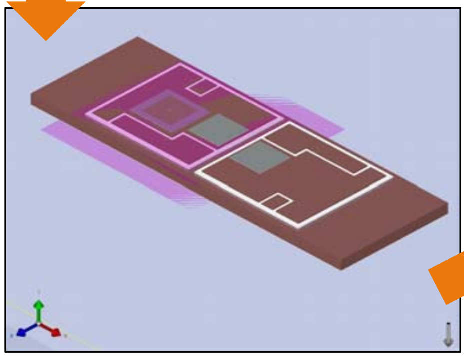
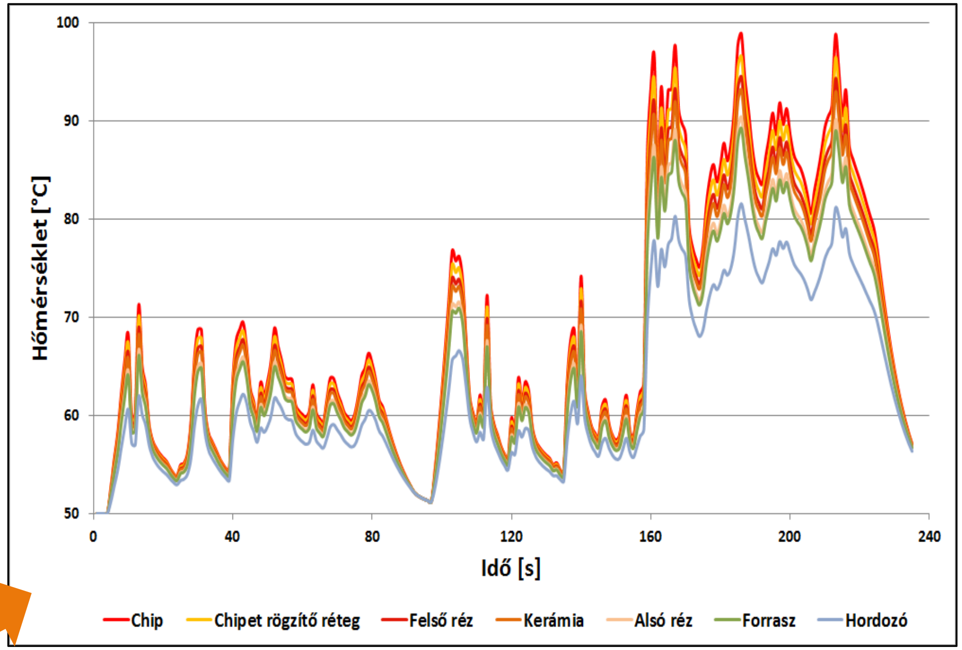
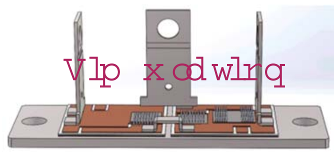
Transient Power profile for IGBT







Temperature profiles of the different layers in the IGBT



ΔT Histogram

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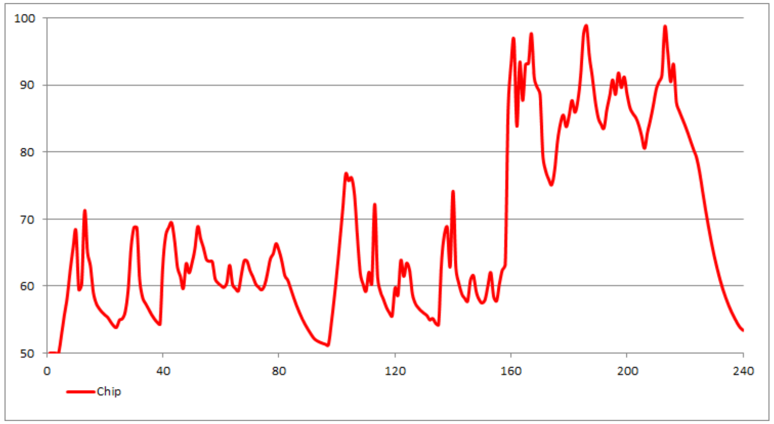
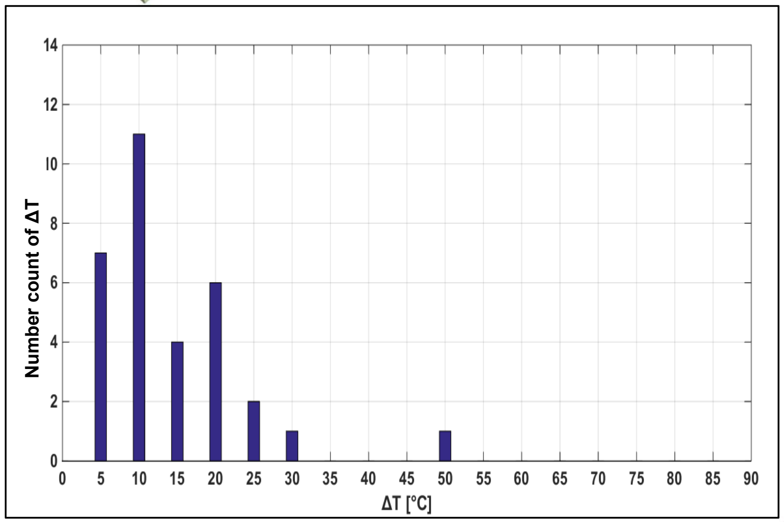
Rainflow Algorithm to determine the distribution of ΔT from temperature results



Rainflow Algorithm

https://en.wikipedia.org/wiki/Rainflow-counting_algorithm



Accelerated lifetime tests

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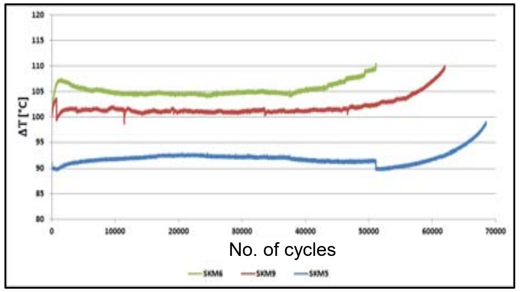

	Average ΔT [°C]	Cycle number to failure [-]
SKM6	105	51104
SKM9	101	61969
SKM5	92	68465

Samples were tested at 3 different environmental temperatures: 110°C, 100°C, 90°C.

Lifetime curve

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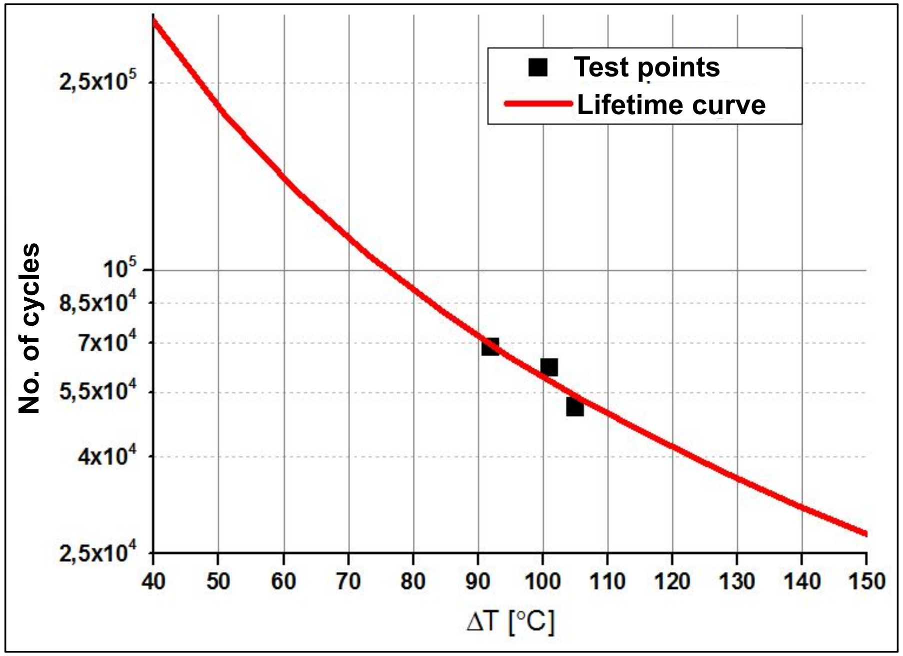
Curve fitting following the Coffin-Manson model

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



A	α
$3{,}69448 \cdot 10^{8}$	-1,89743

Lifetime prediction

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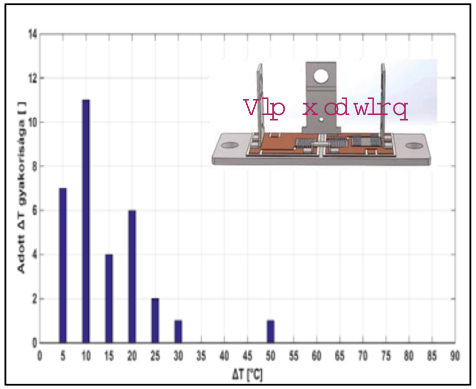
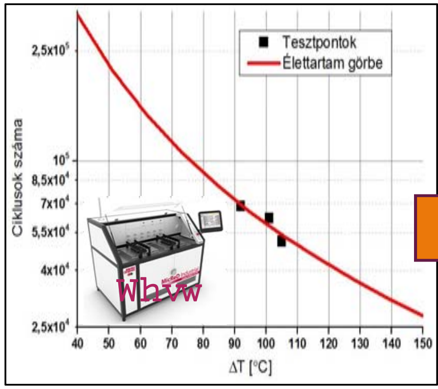
Ingenuity for life





ΔT [°C]	Count (w_i)	Cycle number (N_i)
5	7	17430372
10	11	4678680
15	4	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**

Questions ?

Thank you.

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