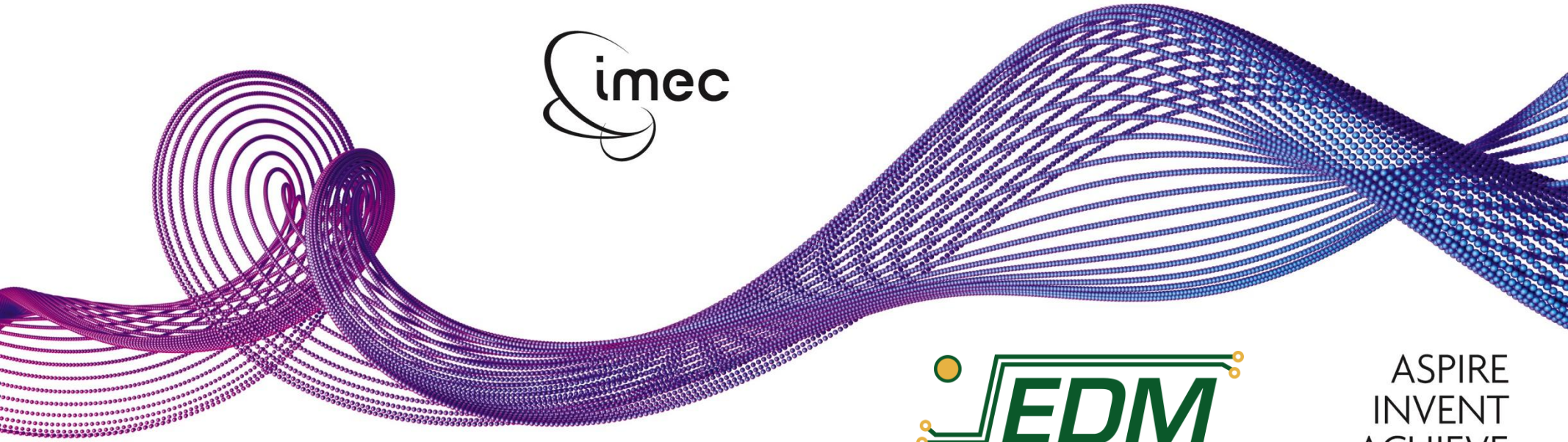
RELIABILITY OF SOLDER JOINTS FOR LED APPLICATIONS

BART VANDEVELDE

R&D PROJECT LEADER



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EDM
Electronics Design & Manufacturing

ASPIRE
INVENT
ACHIEVE

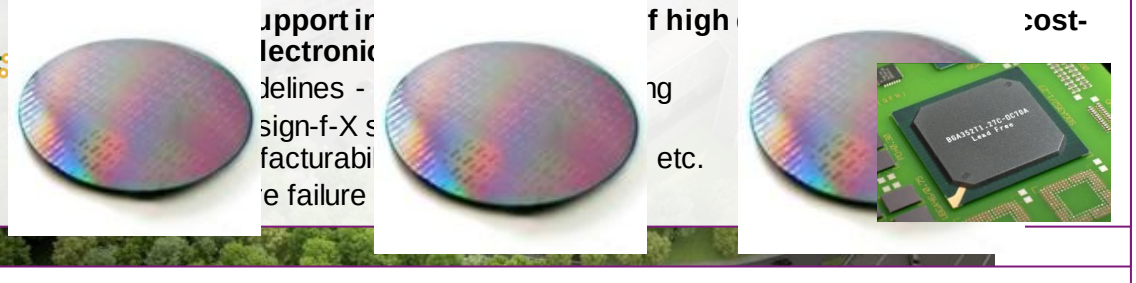
CEDM WITHIN THE IMEC COMMUNITY

World-leading research in nano-electronics

- Founded in 1984; HQ: Leuven, Belgium
- > 2200 employees

Value chain aggregator (VCA): support companies, universities and research institutes to layout, prototype, fabricate, test and qualify their electronic products

- Design and manufacturing services (IC, package, board)
- Access to foundries (TSMC, UMC, ...) for various IC technologies
- Prototyping to low-volume



IN THE NEWS YESTERDAY ...

Flightglobal
AVIATION CONNECTED

NEWS | PRODUCTS AND SERVICES | ABOUT

NEWS > AIRLINES > OPS & SAFETY > CIRCUIT-BOARD SOLDER CRACK CITED IN INDONESIA AIRASIA CRASH PROBE

Circuit-board solder crack cited in Indonesia AirAsia crash probe

01 DECEMBER, 2015 | BY: ELLIS TAYLOR | SINGAPORE

Investigators have concluded that cracked solder joints on a circuit board were the main contributor to the fatal crash of Indonesia AirAsia flight QZ8501 on 28 December 2014.

The channel A and channel B boards were visually examined under magnification at BEA.

The presence of cracks on solders was confirmed on the surface of both channels (Figure 35).

The summary of the examination found the electronic cards shows the evidence of cracking of soldering of both channel A and channel B. Those cracks could generate loss of electrical continuity and lead to a TLU failure.

Thermal cycles associated to powered/not-powered conditions and ground/flight conditions, generate fatigue phenomenon of the soldering, and may result in soldering cracking. Soldering cracking could induce a disconnection of components from the circuit. The disconnections could create a loss of the affected RTLU channel.

The electronic module pictures are shown below.

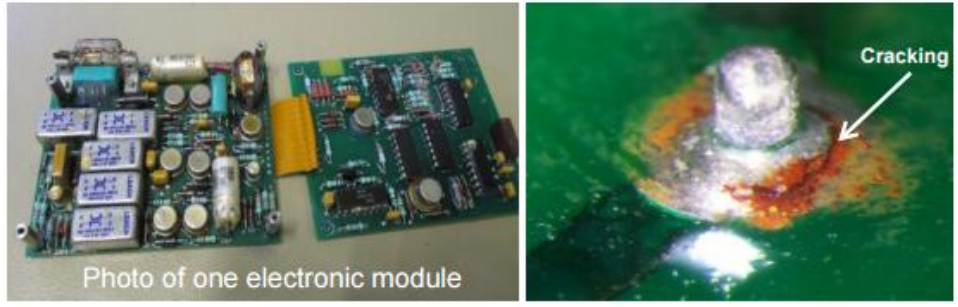


Figure 35: Electronic Module of RTLU

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OUTLINE

- Printed Board Assembly reliability
- High-end LED assemblies
- Solder joint fatigue: a general failure mode in Printed Board Assemblies
- Prediction of the life time of LED assemblies:
- Impact of tilted LED assemblies on life time

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DEFINITIONS: RELIABILITY & QUALITY

Definition of reliability

Probability that a product will perform its required **function** under stated conditions for a specific period of time

"cEDM definition of reliability"

Probability of the product to

... maintain its **Quality**

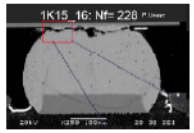
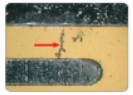
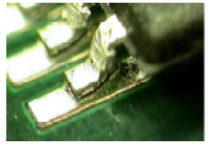
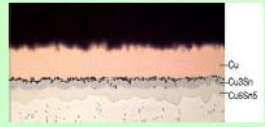
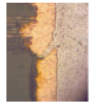
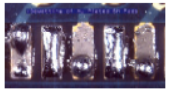
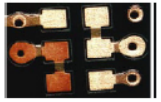
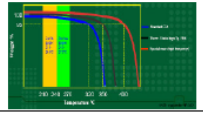
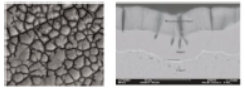
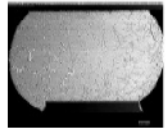
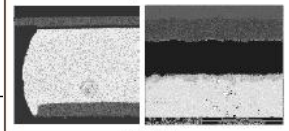
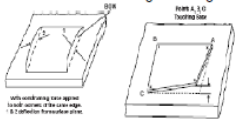
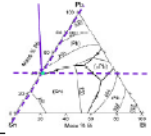
... under stated conditions

... for a specific period of time

Quality definition

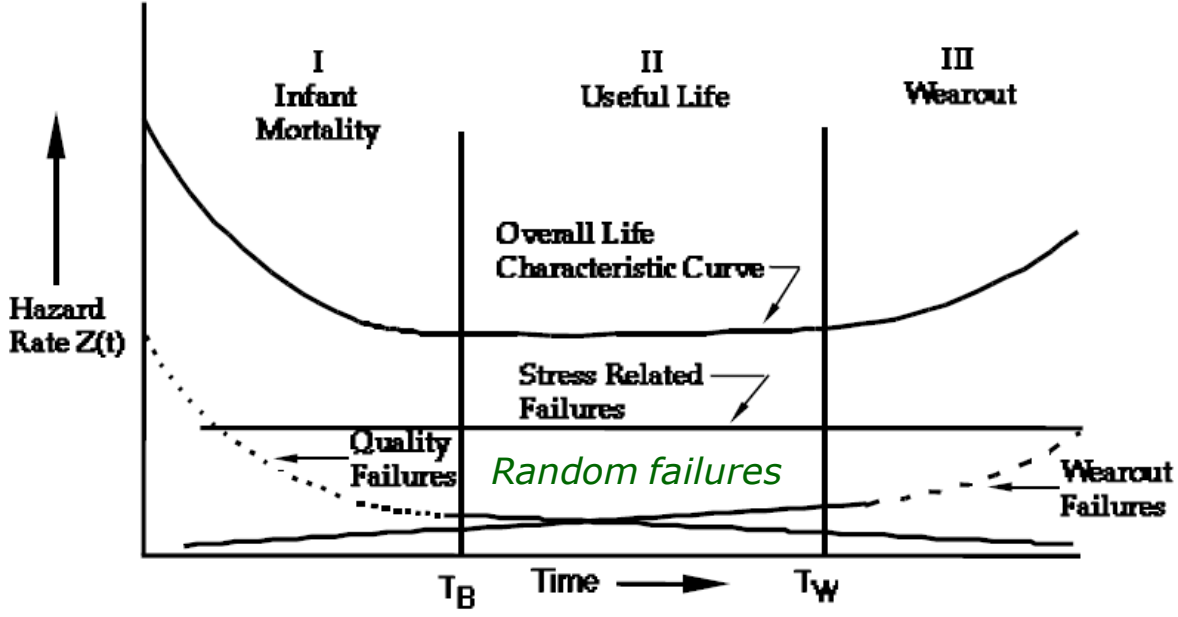
- The properties of the product – whatever they may be – agree to or exceed specifications or expectations.
- A non-quality issue is any property of the product that does not satisfy specifications or expectations.

A FLAVOUR OF PBA RELIABILITY FAILURES

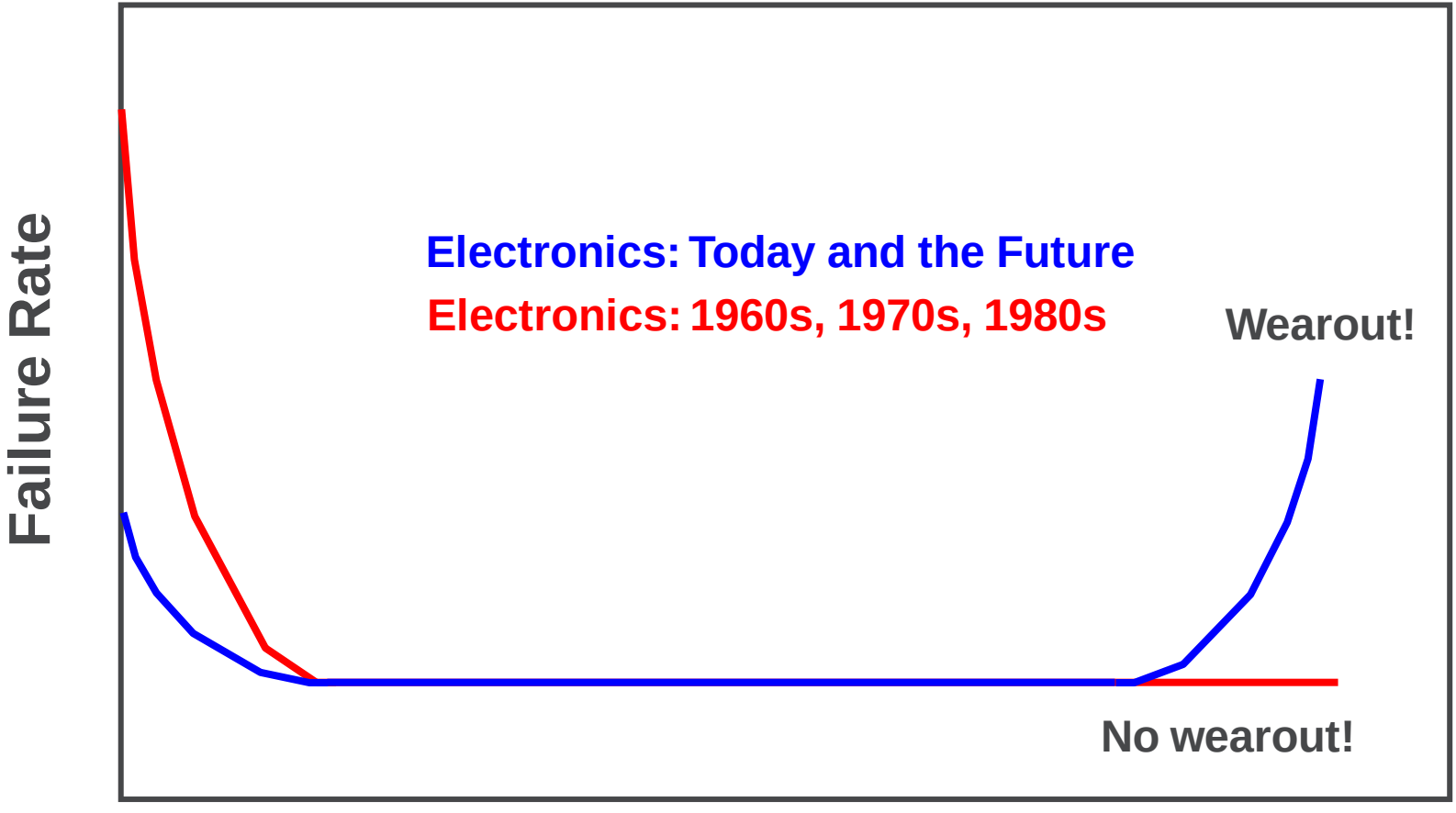
Failure mechanisms	Critical elements	Where to address?					Standards
		Design Actions		Qualification/Validation	Production		
		Design requirements (to be specified)	Design test (to be performed)	Qualification/Validation actions	Production test	Early failure screening	
PCB failure mechanisms	**Solderable finish**	**Component body related**		**Solder joint reliability**	**Solder interface failures**		
General quality issues 	**Lead-free HASL**	**Excessive heating during reflow soldering** 		**Solder joint reliability: intrinsic**	**Intermetallics failure**		
	Solderability			Thermal fatigue/low-cycle fatigue 	Component side	Lead finish, lead substrate, BGA substrate, soldering conditions, storage temperature, operational temperature	
	Surface Insulation Resistance and corrosion 	Active components			PCB side 	PCB finish, intermetallics type: Cu, Ni,.., soldering conditions, storage temperature, operational temperature	
Laminate related	**Electroless Ni Immersion Au (ENIG)**	Passive components		Vibration/high-cycle fatigue 	**Kirkendall voiding** 	Process not fully understood. Large differences between apparantly similar material combinations.	
Via cracking during soldering 	Solderability 	**Excessive heating during wave soldering**					
		Active components			Component side	Finish, storage temperature, operational temperature	
Delamination during soldering 	Solderability: skip plating 	Passive components		Shock resistance			
		SMD component heat stress failure 		**Solder joint reliability: contamination**	PCB side	Finish, storage temperature, operational temperature	
Degradation of laminate during soldering 	Solderability: black pad 	**Moisture-related component issues**		Pb in lead-free: weak spots 	**Weak solder-Ni interface**	NiAu finishes esp. ENIG	
		Pop-corning 			Component side 	NiAu finish type, high P concentration in Ni, mechanical load: shock, bending, strong vibrations	
Bow and Twist during soldering 	Surface Insulation Resistance and corrosion			Bi in SnPb: weak spots 	PCB side 	NiAu finish type, high P concentration in Ni, mechanical load: shock, bending, strong vibrations	
Conductive Anodic Filament 	**Immersion Sn**			Au-embrittlement			

BATHTUB CURVE

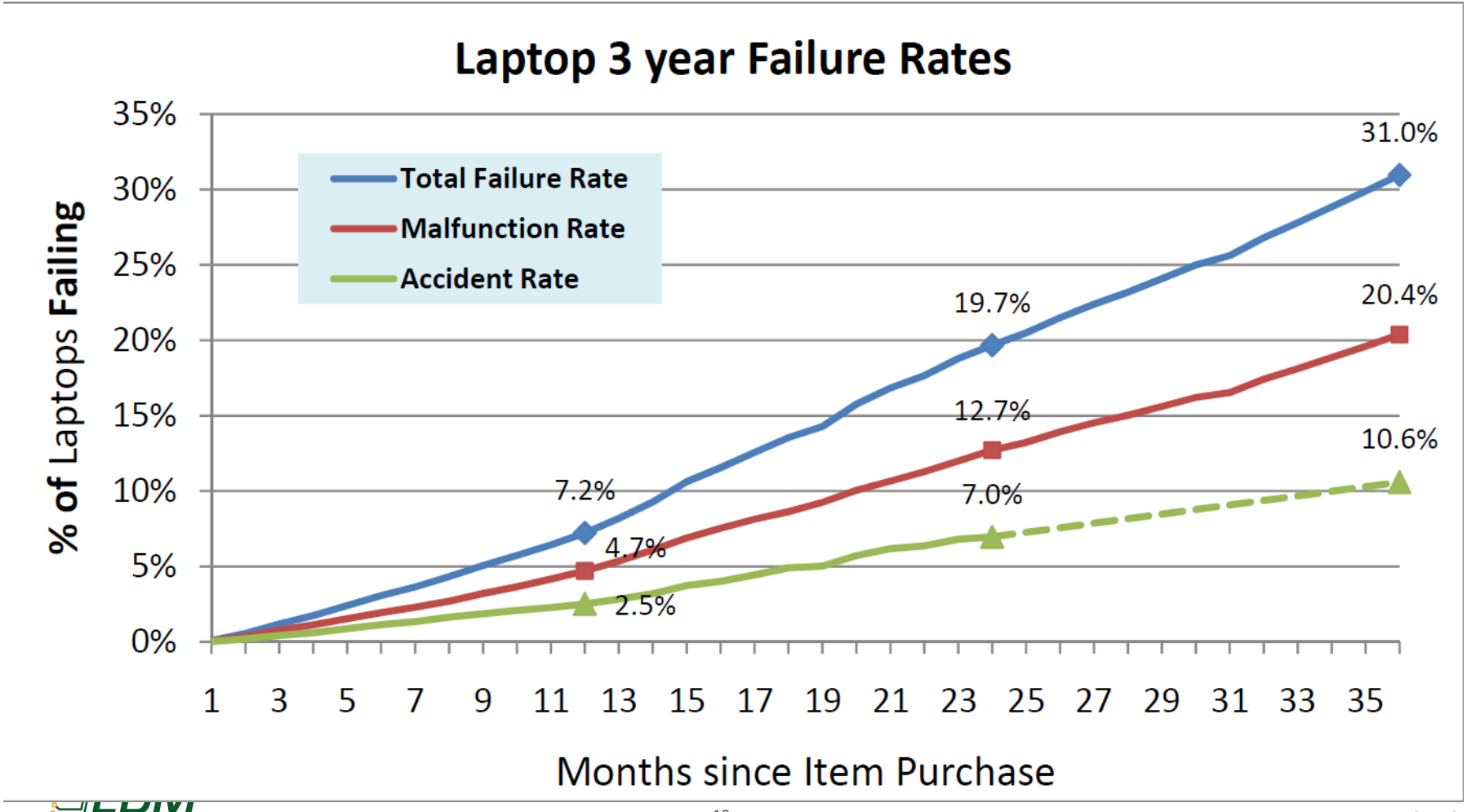
- Number of failures as a function of time or number of cycles:
- The Bathtub Curve (Ref: MIL-HDBK-338B)



h(t)=f(t)/R(t): hazard or instantaneous failure rate.
Probability of failure (f(t)) at time t when no failure (R(t)) took place prior to t.


Failure Rate
Electronics: Today and the Future
Electronics: 1960s, 1970s, 1980s
Wearout!
No wearout!
Time

WARRANTY RETURNS FOR LAPTOPS

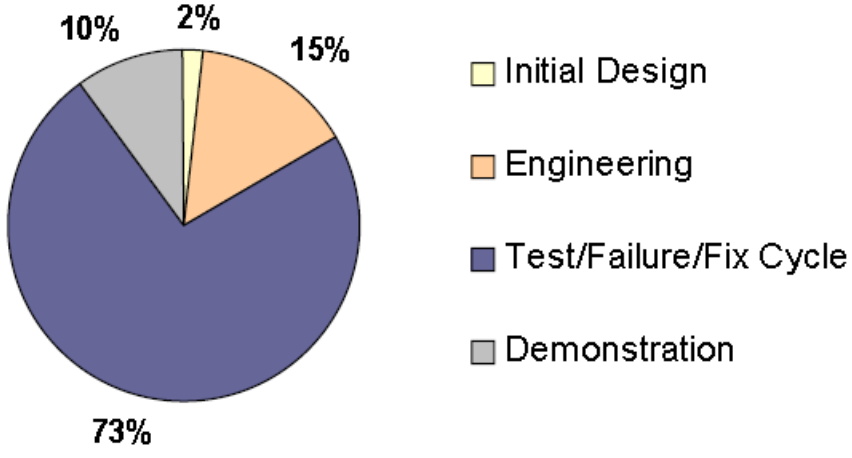


Ref: DfR Solutions

WHY DESIGN FOR RELIABILITY (DFR)

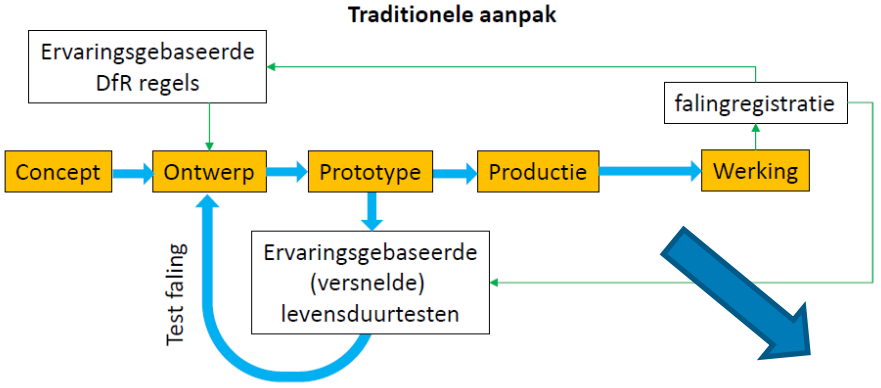
- Traditional OEMs spend almost 75% of product development costs on test-fail-fix

- Electronic OEMs that use design analysis tools
  - Hit development costs 82% more frequently
  - Average 66% fewer re-spins
  - Save up to $26,000 in re-spins



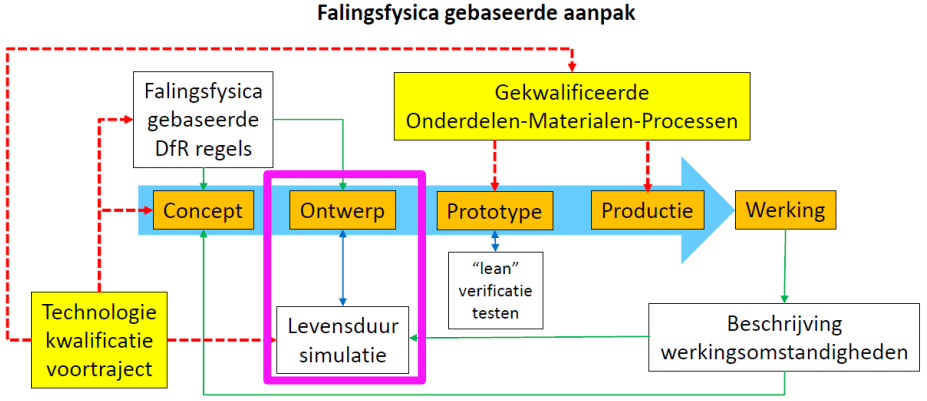
Ref: DfR Solutions

FUNDAMENTAL INNOVATION IN ELECTRONICS PRODUCT DEVELOPMENT

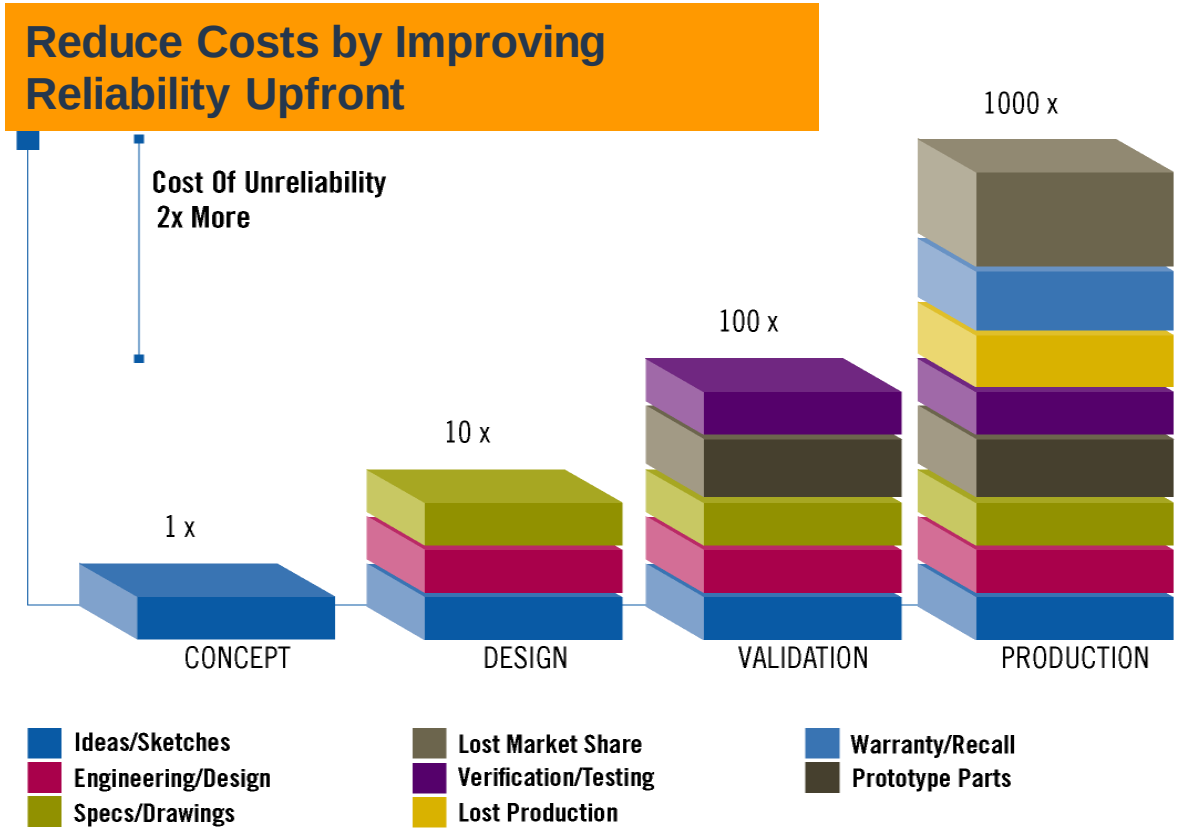


- PoF know-how
- Models
- Methods
- Guidelines
- Tools

- Design
- Qualification
- Supply chain control



WHY DFR: EARLIER IS CHEAPER



Ref: DfR Solutions

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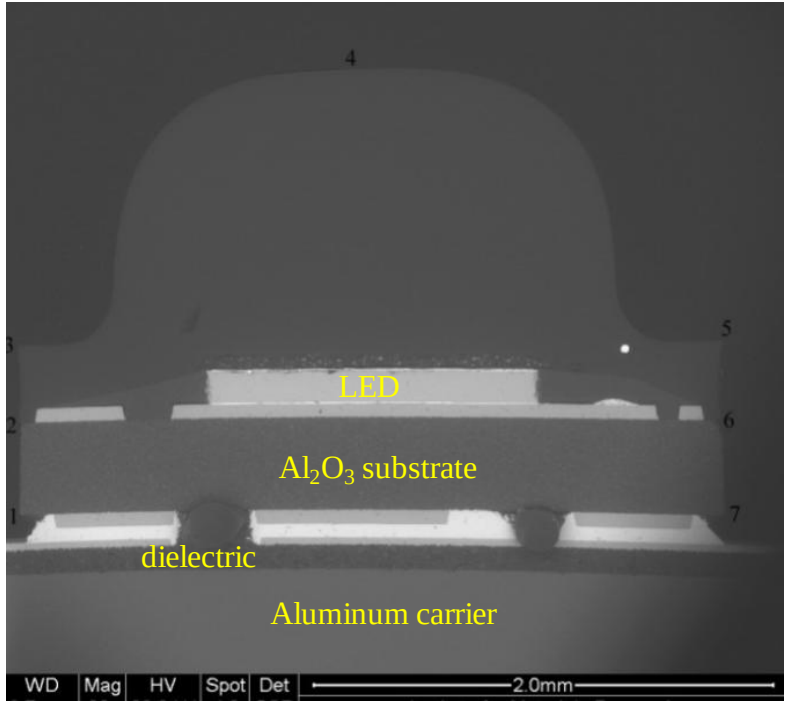
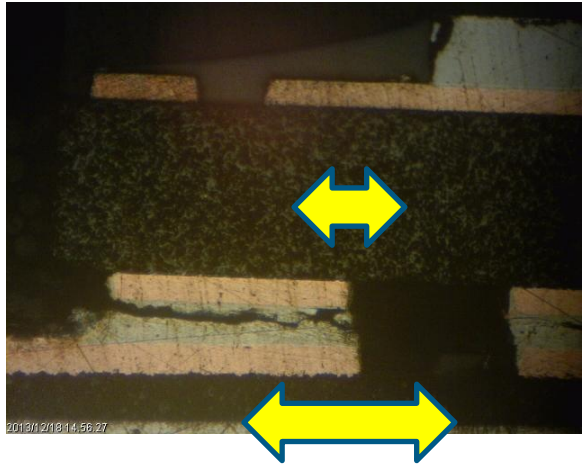
HIGH POWER LED ASSEMBLIES FOR HIGH-END APPLICATIONS

- High-power (2-3 W) LEDs with ceramic substrate are soldered on Insulated Metal Substrates (IMS).
- The solder connection provides a good heat removal pathway from the LED to the substrate.



HIGH POWER LED ASSEMBLIES FOR HIGH-END APPLICATIONS (2)

CTE mismatch between LED package and PCB leads to stress in the solder interconnection which translates into inelastic deformation, causes mechanical fatigue fracturing.



Switching on and off the LED results in a temperature cycle of the component and therefore stresses the solder joint each time and solder fracture is therefore a major potential cause of failure.

High-end LED assemblies require a minimum lifetime which reflects into a minimum number of temperature cycles.

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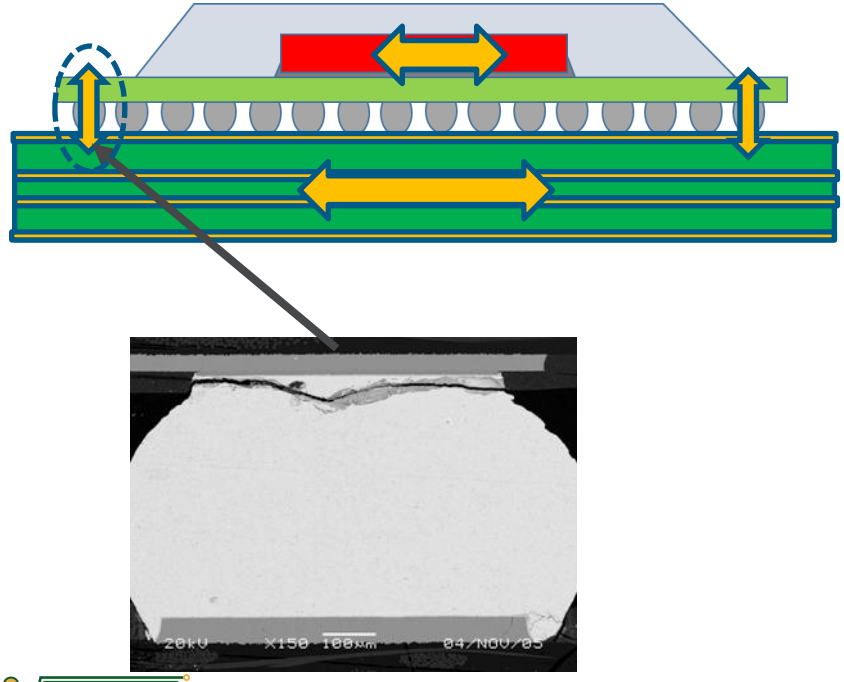
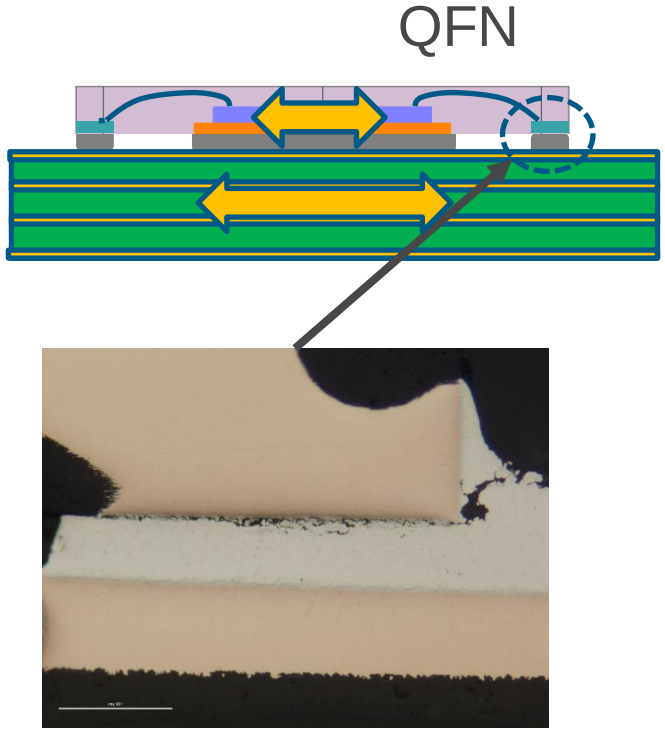
SOLDER JOINT FATIGUE KNOWN FAILURE MODE IN PRINTED BOARD ASSEMBLIES

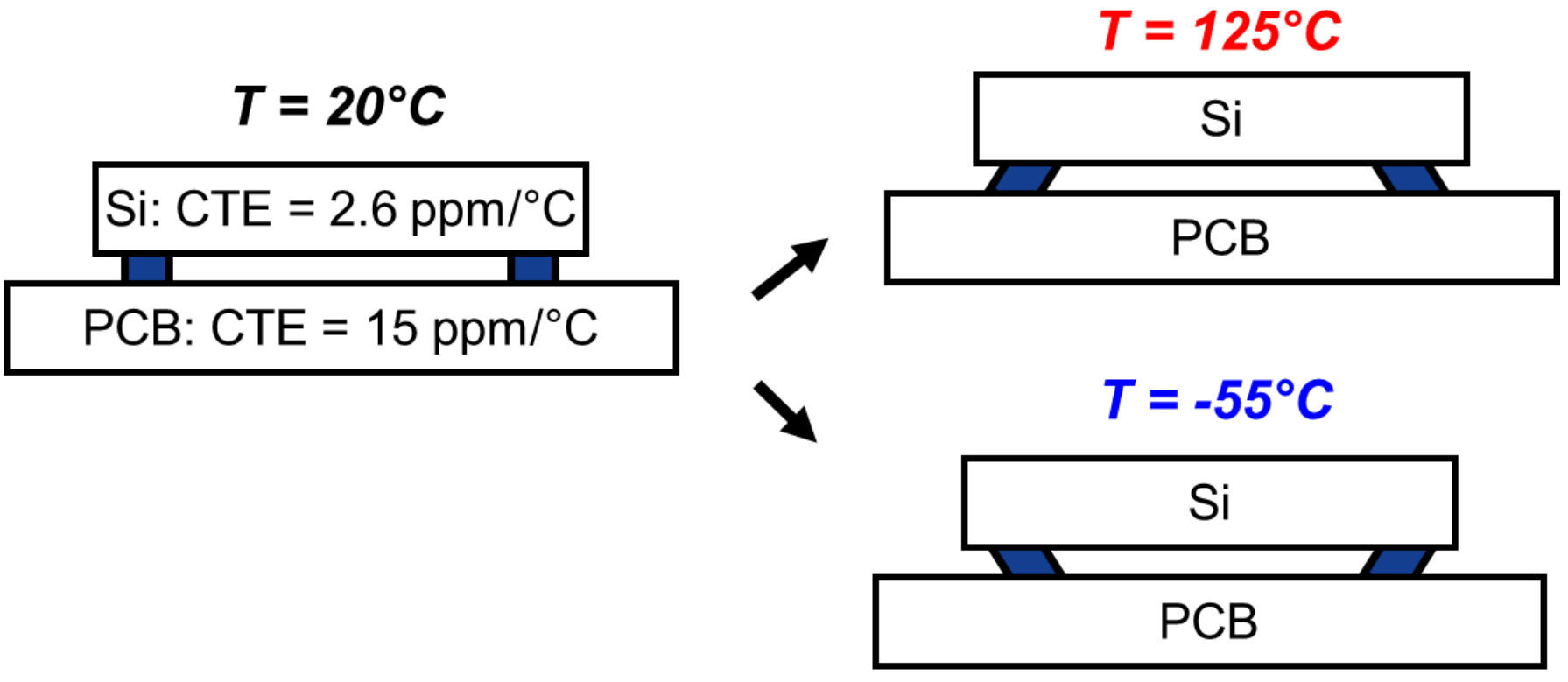
In-plane and out-of-plane mismatch between component and board finally leads to solder fatigue fractures



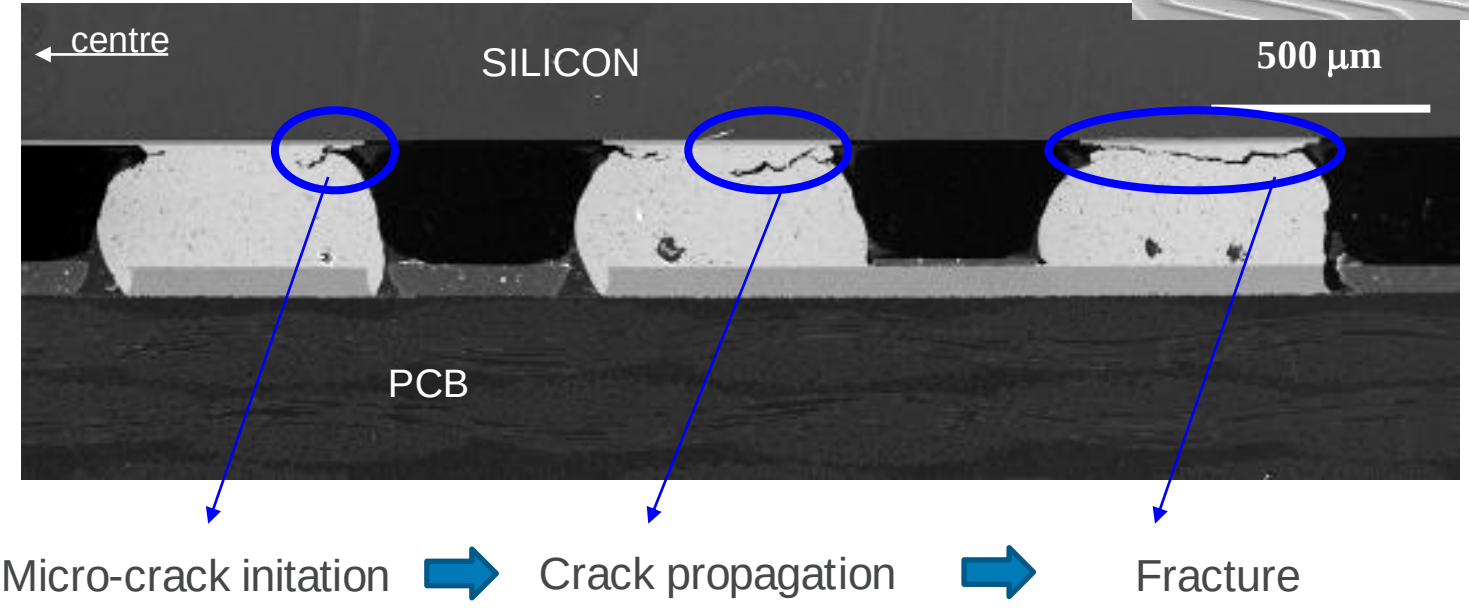
QFN



SOLDER JOINT DEFROMATION INDUCED BY TEMPERATURE VARIATIONS



MECHANICAL FATIGUE MECHANISM



Remark: Cracks can already start quite early in the reliability test (10% of MTTF). It still takes many temperature cycles till comlete fracture.

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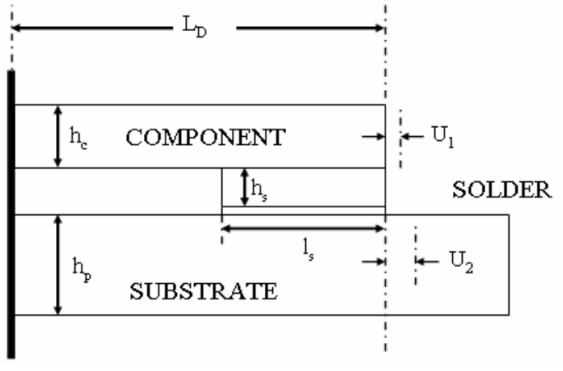
PREDICTION OF THE LIFE TIME OF LED ASSEMBLIES
SIMPLIFIED METHODS

- Engelmaier Model for Leadless Ceramic Chip Devices with Pb-free Solder



$$\Delta\gamma = C\frac{L_D}{h_s}\Delta\alpha\Delta T$$

With C = 0.5 (empirical number)
$\Delta\alpha$ = CTE difference

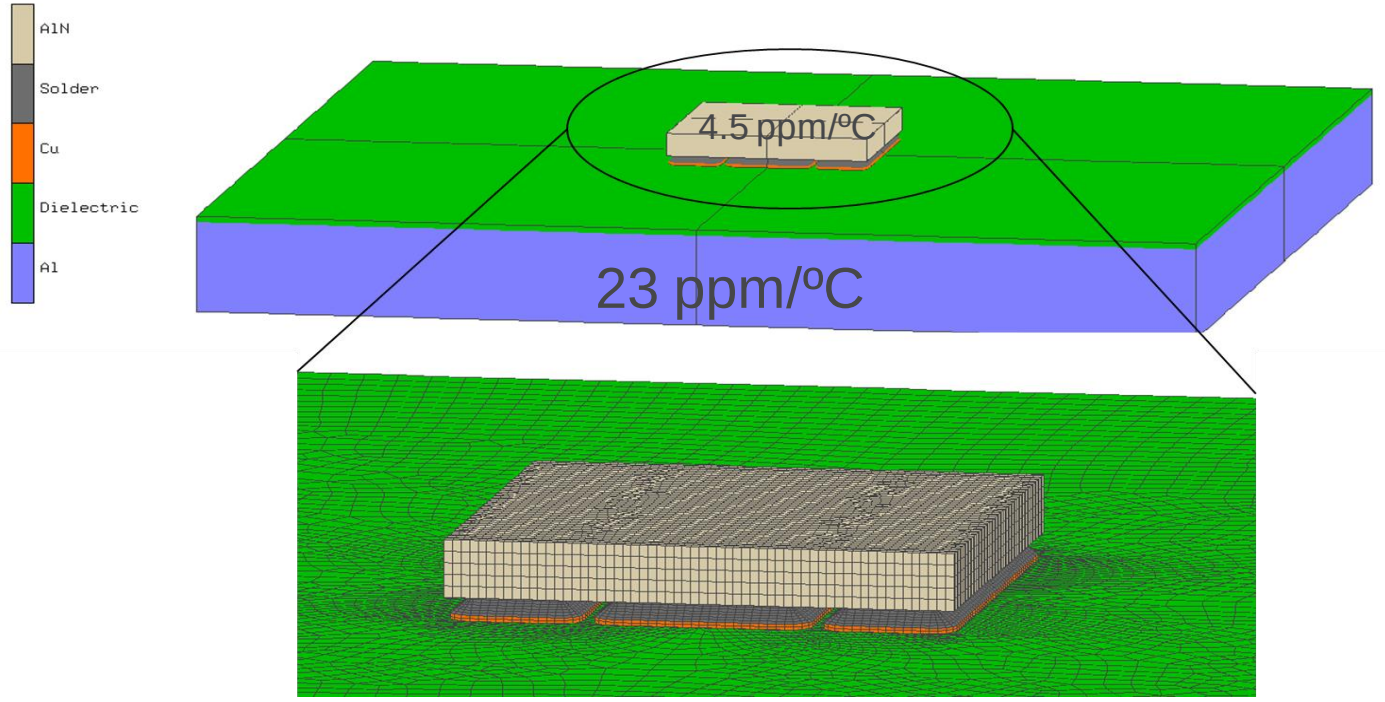
$$\Delta W \cong \Delta\gamma \cdot \tau \Rightarrow N_f = \left(0.0015 w_{acc}\right)^{-1}$$

- **Shortcomings of this model:**
  - No warpage of components included
  - No stiffness of PCB included
  - Independent on solder land size

cEDM is working on an improved analytical model for solder interconnect life time

PREDICTION OF THE LIFE TIME OF LED ASSEMBLIES

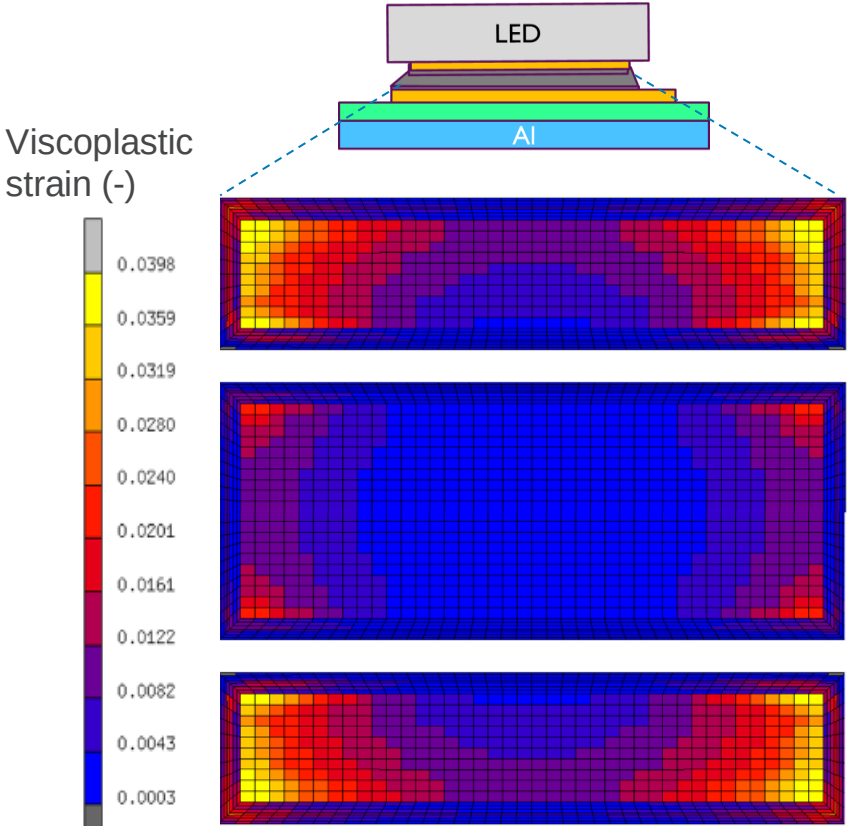
FINITE ELEMENT MODELLING SIMULATIONS



Finite Element model simulates the impact of the temperature cycling on the solder joints

PREDICTION OF THE LIFE TIME OF LED ASSEMBLIES

FINITE ELEMENT MODELLING SIMULATIONS: OUTPUT



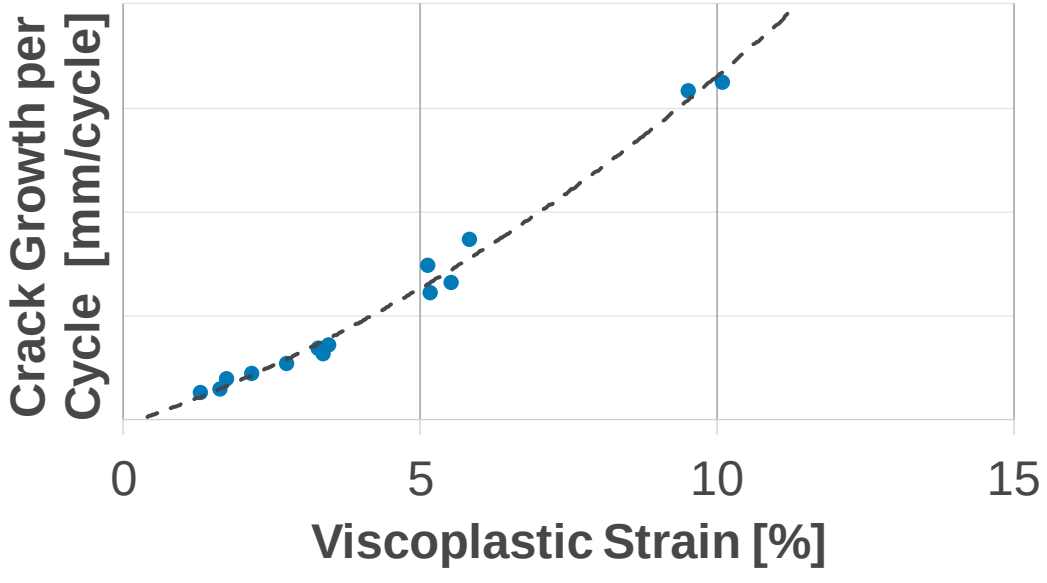
Strain concentrations in the four corners.

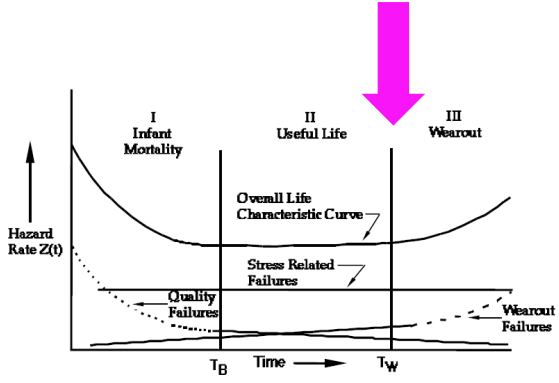
Cracks are expected to initiate in these corners

PREDICTION OF THE LIFE TIME OF LED ASSEMBLIES

FINITE ELEMENT MODELLING SIMULATIONS: LIFE TIME PREDICTION

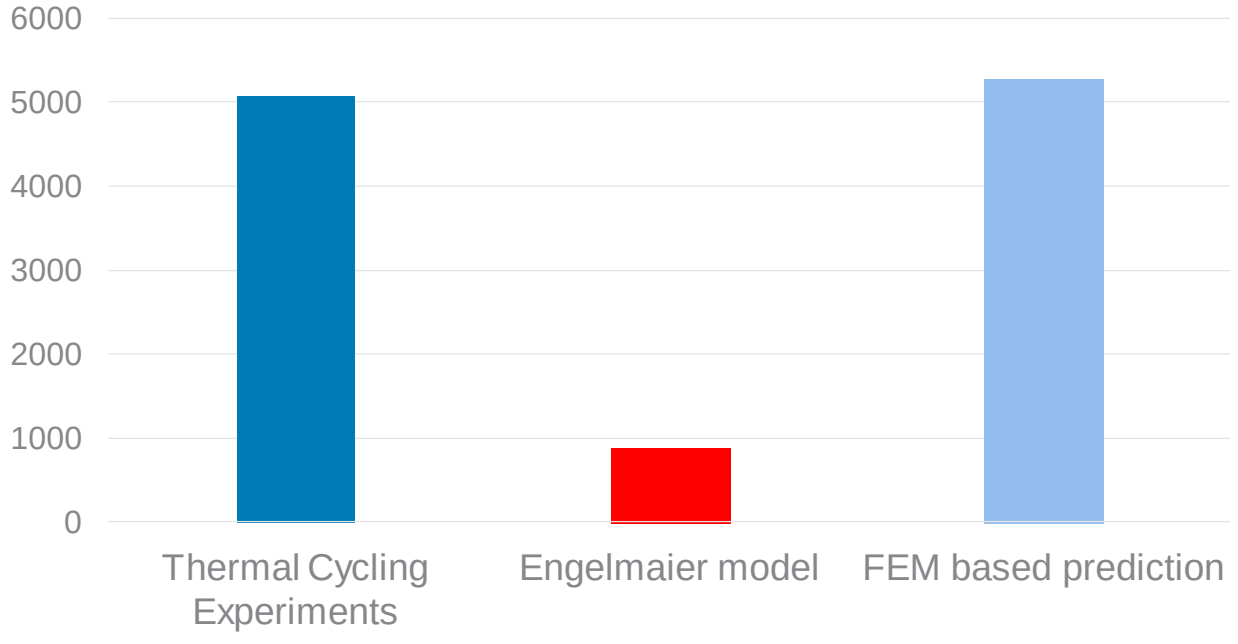
- Empirical model defines how much the crack propagates in each temperature cycle





PREDICTION OF THE LIFE TIME OF LED ASSEMBLIES

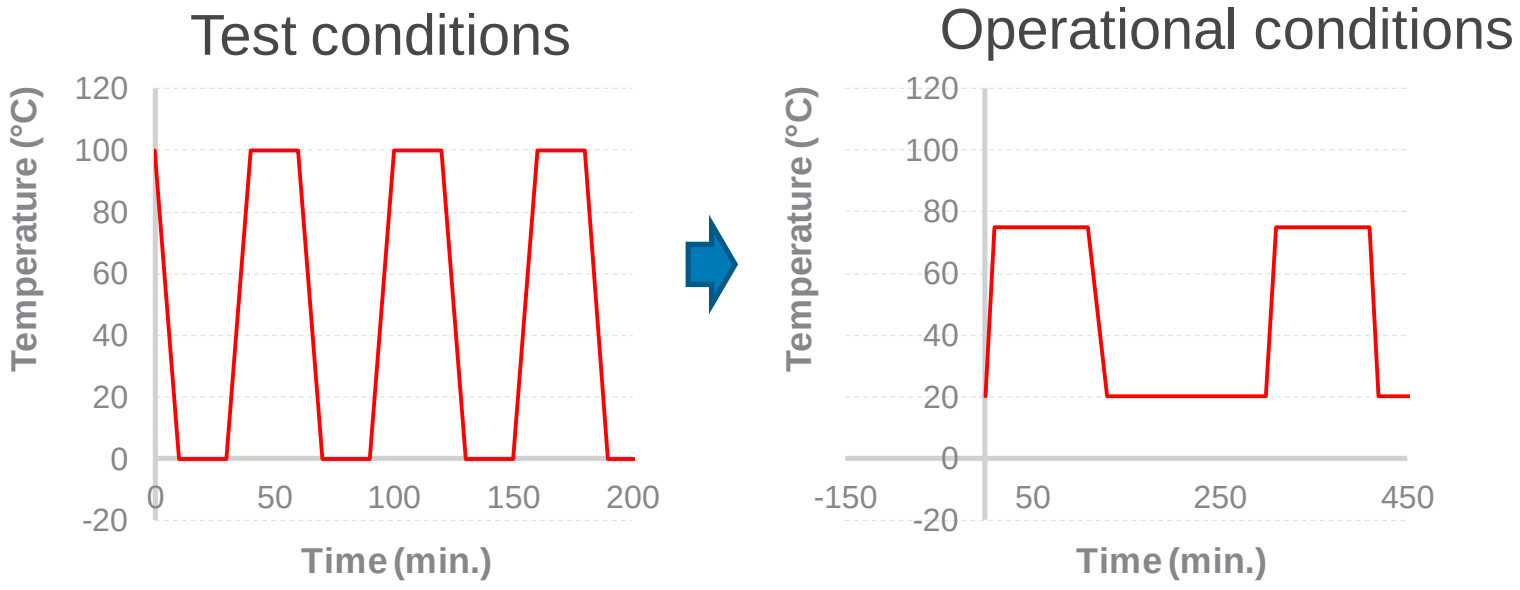
FINITE ELEMENT MODELLING VS. ENGELMAIER



Engelmaier is an underestimation of wear out
FEM predictions are more accurate (typically ±25%)

PREDICTION OF THE LIFE TIME OF LED ASSEMBLIES

EXTRAPOLATION TO OPERATIONAL CONDITIONS



- Testing under real life condition are not possible → accelerated testing needed
- Simulations allow to predict the life time for real life conditions

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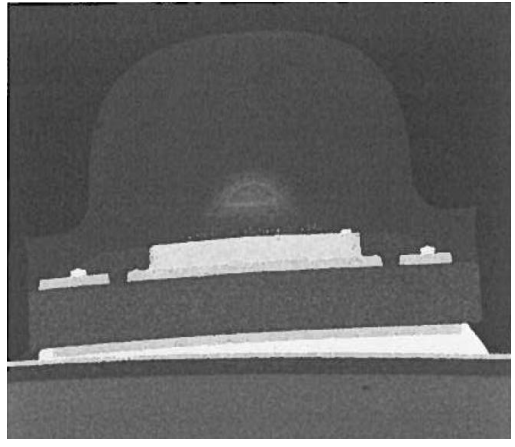
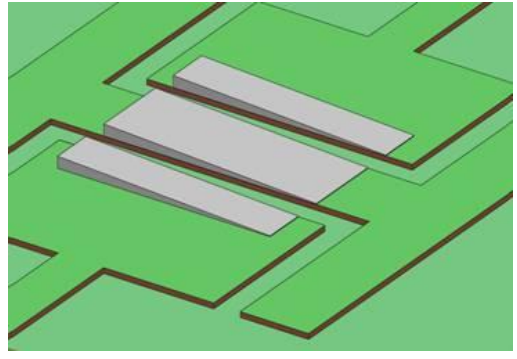
IMPACT OF TILTED LED ASSEMBLIES ON LIFE TIME

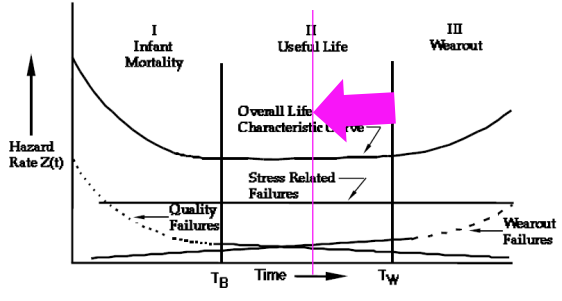
DESCRIPTION

- Ideal situation: uniform stand-off height all over the solder pad.
- However, the LED can tilt resulting in a lower stand-off height at one side and a higher stand-off at the other side because of some unbalances during soldering phase enforced by the surface tension effects of the solder.





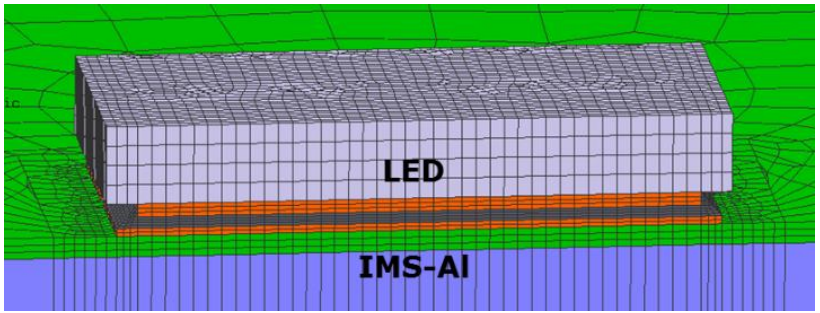
Will this reduce the life time?

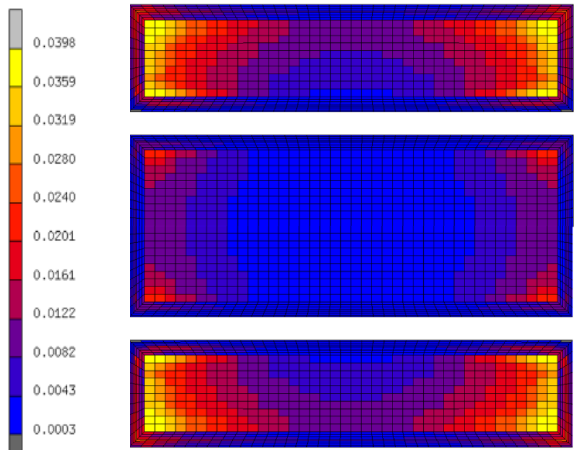


IMPACT OF TILTED LED ASSEMBLIES ON LIFE TIME

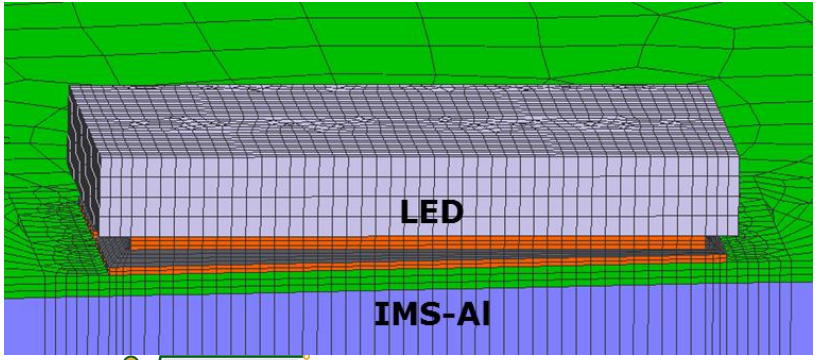
SIMULATION OF THE TWO EXTREME CASES

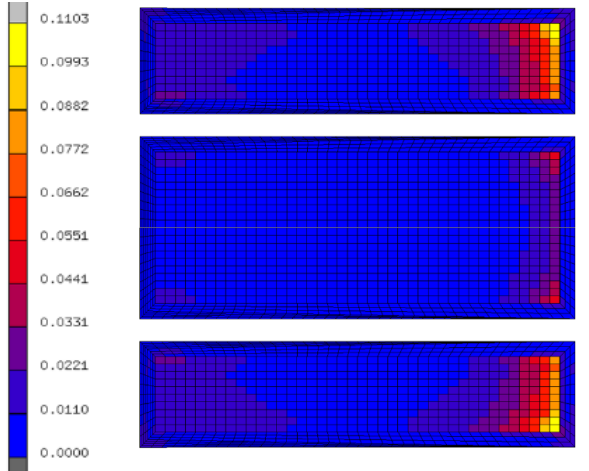
Perfect assembly (no tilt)





Assembly with maximum tilt



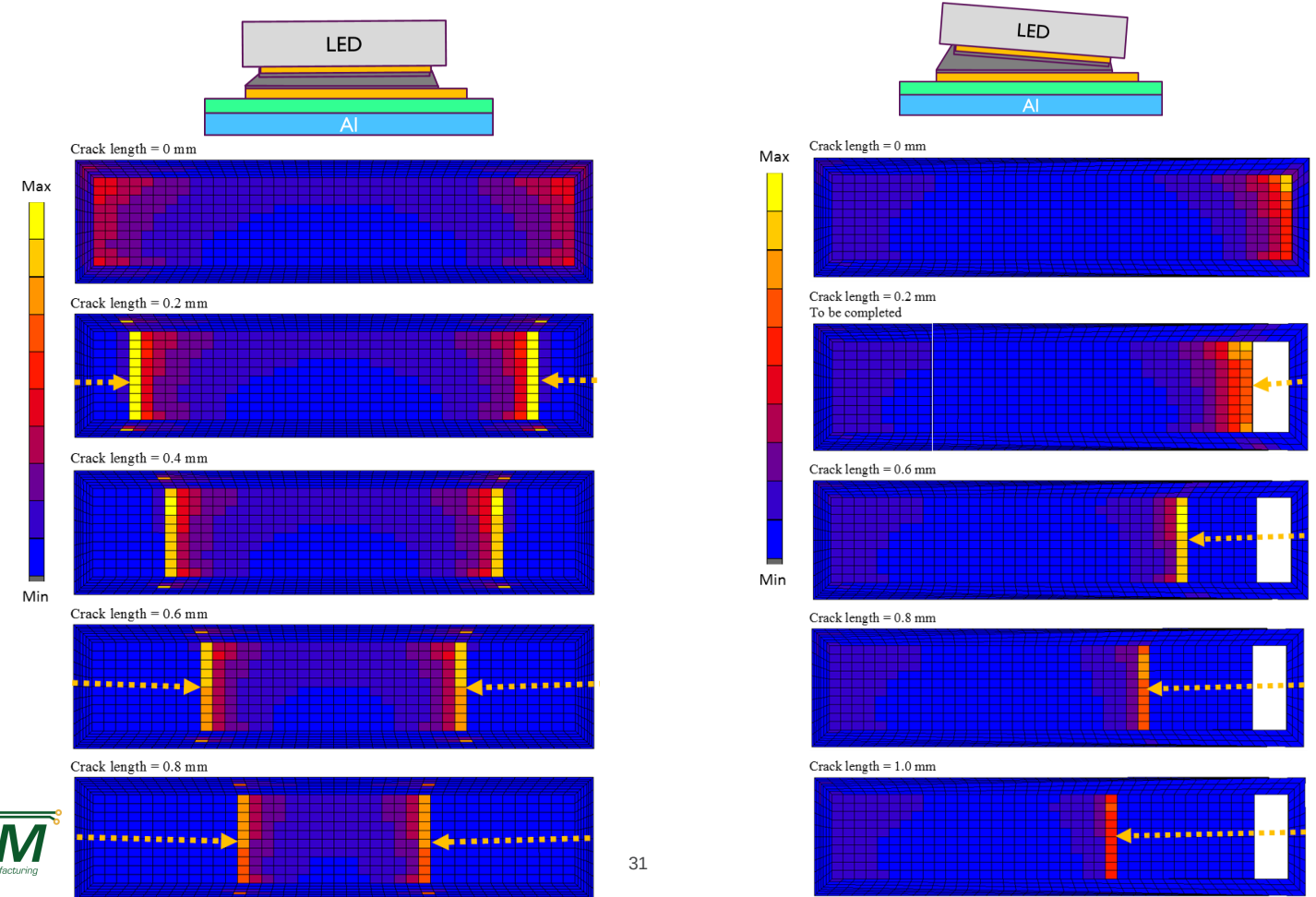


Creep strain over damage area

2.5 x higher

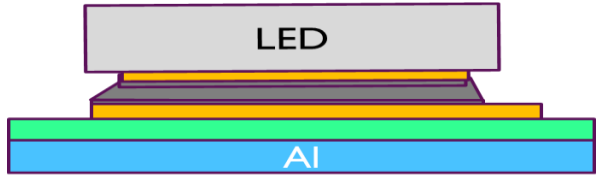
IMPACT OF TILTED LED ASSEMBLIES ON LIFE TIME

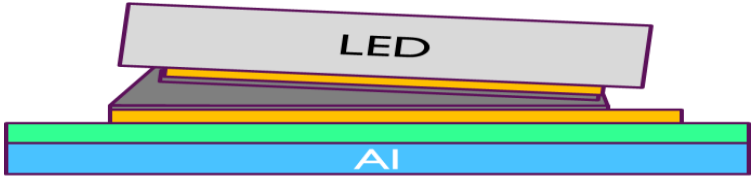
INTRODUCING CRACK PROPAGATION MODELLING



IMPACT OF TILTED LED ASSEMBLIES ON LIFE TIME

PREDICTED LIFE TIME

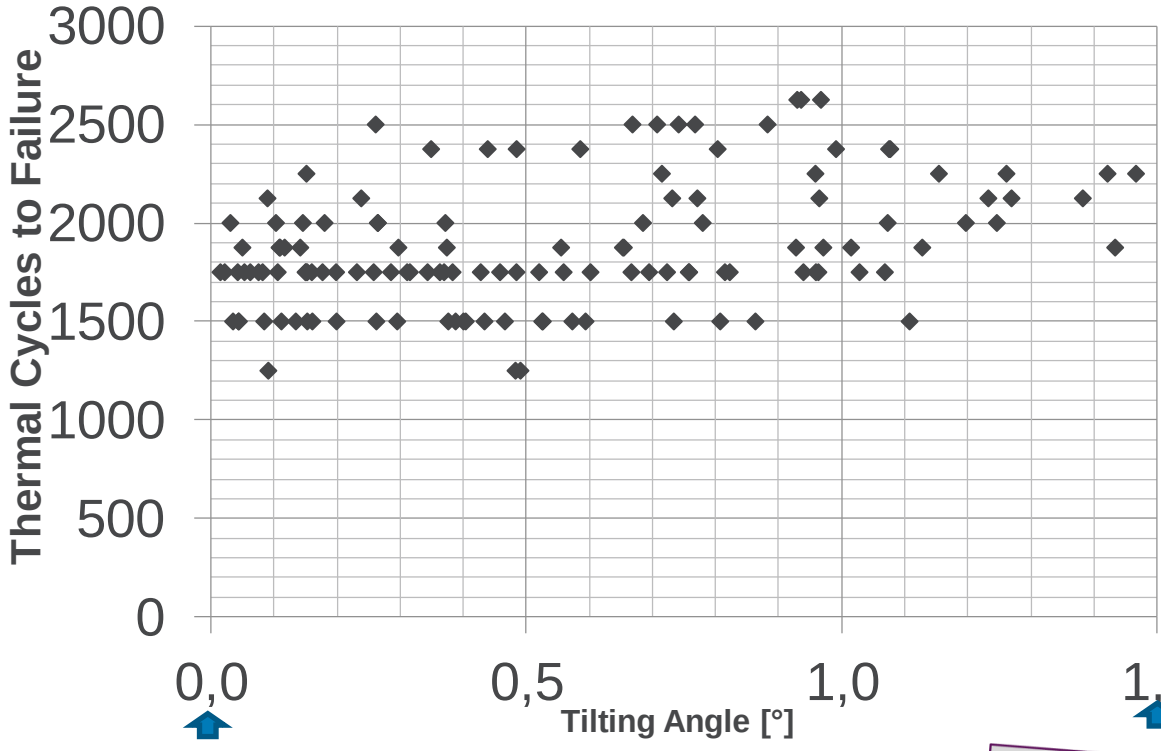




Equal life time is predicted

IMPACT OF TILTED LED ASSEMBLIES ON LIFE TIME

EXPERIMENTS CONFIRMS THE SIMULATION RESULTS



CONCLUSIONS

- PBA reliability issues are one of the major causes for hardware failures
- For high-end LEDs, solder joint failure is limiting the life time of the component assembly
- FEM based Predcition of the wear-out life is feasible using finite element modelling
- A tilted assembly does not reduce the life time of the assembly

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