### **RELIABILITY OF SOLDER JOINTS FOR LED APPLICATIONS**

### **BART VANDEVELDE R&D PROJECT LEADER**



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# **CEDM WITHIN THE IMEC COMMUNITY**





### IN THE NEWSYESTERDAY ...



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.





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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

### 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



## **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.







### 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





### FUNDAMENTAL INNOVATION IN ELECTRONICS PRODUCT DEVELOPMENT





### WHY DFR: EARLIER IS CHEAPER







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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





# 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)  

$$\Delta \alpha = \text{CTE difference}$$

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

### • Shortcomings of this model:

- No warpage of components included
- No stiffness of PCB included
- Independent on solder land size

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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



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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



- $\circ$  Testing under real life condition are not possible  $\rightarrow$  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.









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### **IMPACT OF TILTED LED ASSEMBLIES ON LIFE TIME** SIMULATION OF THE TWO EXTREME CASES

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### **IMPACT OF TILTED LED ASSEMBLIES ON LIFE TIME** INTRODUCING CRACK PROPAGATION MODELLING



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### **IMPACT OF TILTED LED ASSEMBLIES ON LIFE TIME** PREDICTED LIFE TIME





# **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







