RELIABILITY OF SOLDER JOINTS FOR LED APPLICATIONS
BART VANDEVELDE
R&D PROJECT LEADER
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

Support in electronic design - guidelines - design-f-X - manufacturability - failure analysis - etc.
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.

![Photo of one electronic module](image)

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

## Failure Mechanisms

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### PCB Failure Mechanisms

- **Soldarable Finish**
  - Lead-free HASL
    - Solderability
    - Surface Insulation Resistance and corrosion

- **Component Body Related**
  - Excessive heating during reflow soldering
    - Active components
    - Passive components

- **Solder Joint Reliability**
  - Thermal fatigue/low-cycle fatigue
    - Component side
  - Intermetallics failure
    - PCB side

- **Solder Interface Failures**
  - Lead finish, lead substrates, SBA substrate, soldering conditions, storage temperature, operational temperature

### Laminate Related

- **Via cracking during soldering**
  - Electroless Ni Immersion Au (ENIG)

- **Degradation of laminate during soldering**
  - Solderability, voiding

### Moisture-Related Component Issues

- **Immerison Sn**

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**PBA Failure Check**

[Image of PBA failure check process]

[Logo: imec]
**BATHTUB CURVE**

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

\[ h(t) = \frac{f(t)}{R(t)}: \text{hazard or instantaneous failure rate.} \]

Probability of failure \((f(t))\) at time \(t\) when no failure \((R(t))\) took place prior to \(t\).
Electronics: Today and the Future
Electronics: 1960s, 1970s, 1980s

Failure Rate vs Time

Wearout!
No wearout!
WARRANTY RETURNS FOR LAPTOPS

Laptop 3 year Failure Rates

- Total Failure Rate
- Malfunction Rate
- Accident Rate

% of Laptops Failing

Months since Item Purchase

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

Reduce Costs by Improving Reliability Upfront

- Cost of Unreliability 2x More

1000 x

100 x

10 x

1 x

CONCEPT
DESIGN
VALIDATION
PRODUCTION

- Ideas/Sketches
- Engineering/Design
- Specs/Drawings

- Lost Market Share
- Verification/Testing
- Lost Production

- Warranty/Recall
- Prototype Parts

Ref: DfR Solutions
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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.
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 DEFORMATION INDUCED BY TEMPERATURE VARIATIONS

$T = 20^\circ C$

Si: CTE = 2.6 ppm/°C
PCB: CTE = 15 ppm/°C

$T = 125^\circ C$

Si
PCB

$T = -55^\circ C$

Si
PCB
MECHANICAL FATIGUE MECHANISM

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

\[ \Delta y = C \frac{L_D}{h_s} \Delta \alpha \Delta T \]

\[ \Delta W \approx \Delta y \cdot \tau \quad \rightarrow \quad N_f = (0.0015 w_{acc})^{-1} \]

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

imec
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.
Empirical model defines how much the crack propagates in each temperature cycle.
PREDICTION OF THE LIFE TIME OF LED ASSEMBLIES
FINITE ELEMENT MODELLING VS. ENGELEMAIER

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

**Tilting Angle [°]**

**Thermal Cycles to Failure**

0,0  0,5  1,0  1,5

0  500  1000  1500  2000  2500  3000

Heat Sinks

LED

Al
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 Prediction of the wear-out life is feasible using finite element modelling.
- A tilted assembly does not reduce the life time of the assembly.