As strong as the weakest link:

Reliability from the LED system perspective

Rudi Hechfellner, Dir. Of Applications, Philips Lumileds
Mark Hodapp, Senior Application Engineer, Philips Lumileds

INTERTECH pira

Design for reliability

Agenda

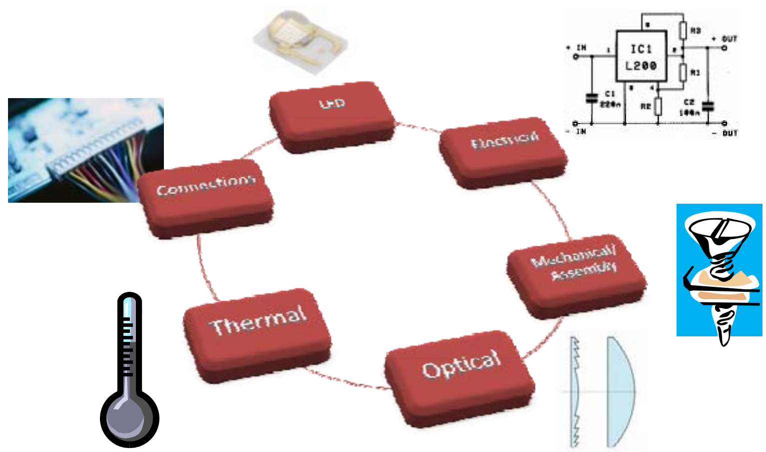
- Long term LED reliability (from a LED manufacturers point of view)
  - lumen maintenance, wear-out failure probability and long term color stability
- Methods of scaling single LED behavior to a system with multiple LEDs
- The impact of LED behavior on a luminaires light output performance
- Best known practices for designing reliable lighting sub-systems

Notice

LEDs from different manufacturers will have different reliability profiles

- Different material systems
- Different manufacturing methods etc.

System Reliability ≠ LED Reliability



$$R_{system} = R_{electrical} * R_{connections} * R_{LEDs} * R_{optical} * R_{thermal} * R_{mechanical}$$

Reliability – Influencing Factors

LED design
- Electrical parameters
- Heat transport
- ESD layout
- Package

Customer application
- Heat transport
- PCB layout and material
- ESD protection
- Electrical circuit

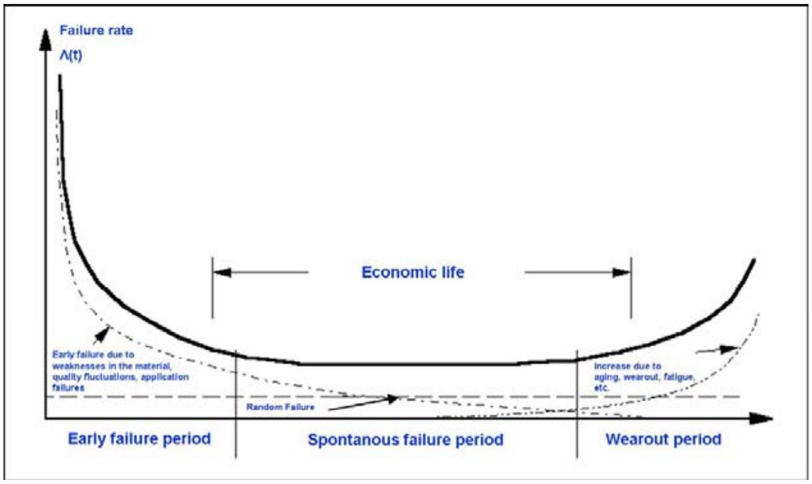
System Reliability

Assembly
- Storage condition
- Soldering process
- Handling (pick & place; ESD)

Environment
- Ambient temperature
- Temperature cycles
- Humidity
- Pollution
- Light radiation

Source: OSRAM OS Application Note Reliability and Lifetime July '08

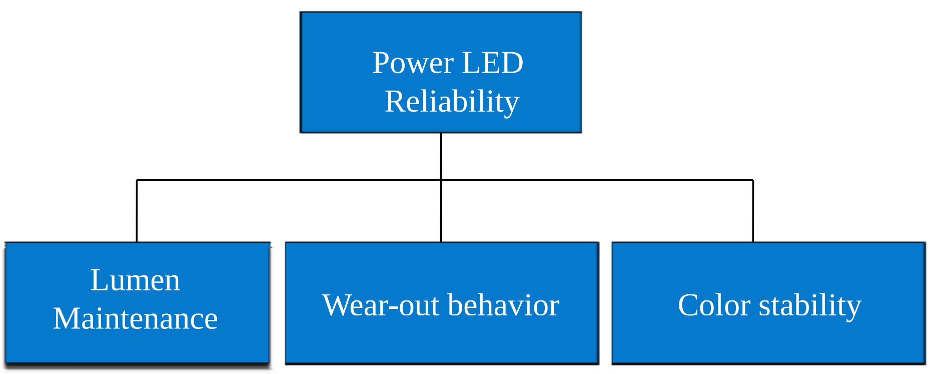
Chronological progression of system failure rate



Source: OSRAM OS Application Note Reliability and Lifetime July '08

Design for Reliability Workshop, October 25, 2010

LED Reliability



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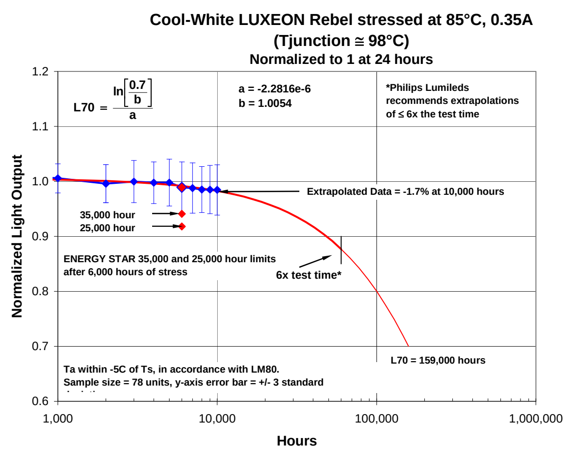
Lumen Maintenance

Not all LEDs behave the same way!

Data collection following IESNA LM-80
Data projection following IESNA TM21

For LUXEON Rebel

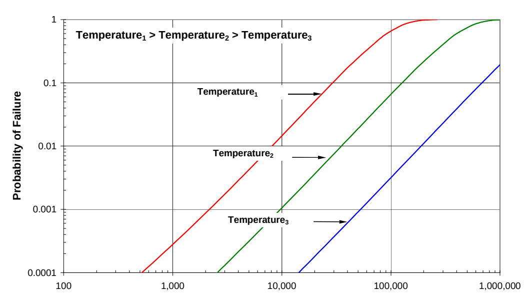
- Drive current and Junction Temperature **affect** lumen maintenance.
- Ambient Temperature T_A has no confirmed impact on lumen maintenance.



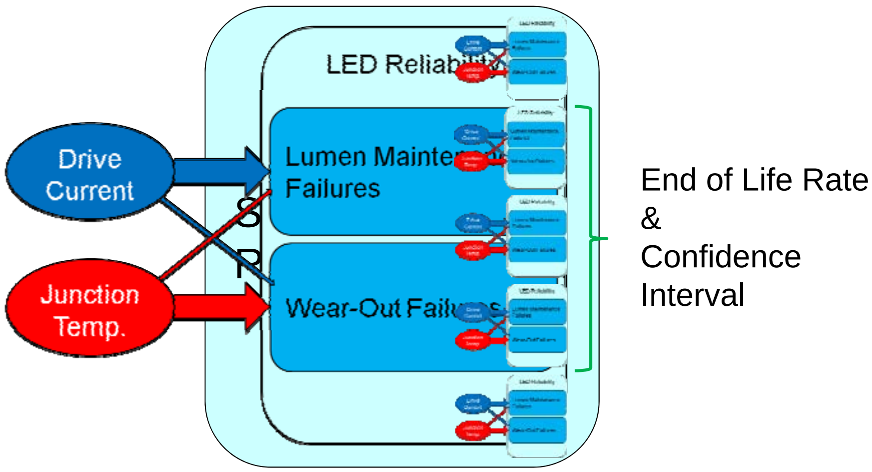
End of Life Failure Analysis

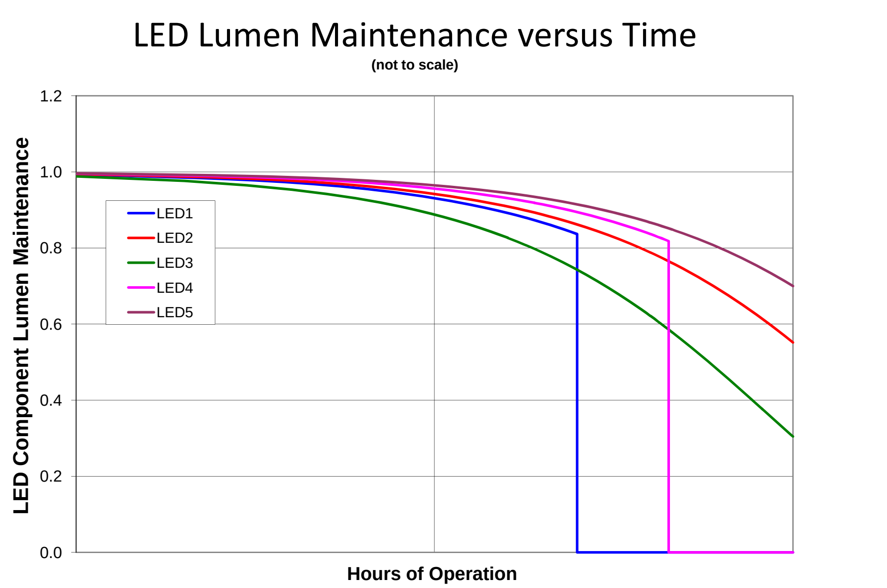
- LED End of Life failure rates can be modeled using the same general principles as silicon-based semiconductors.
  - Failure rate versus operating time can be determined for several different stress conditions [i.e. different combinations of T_J and I_F].
- By design, white **LUXEON Rebel LEDs fail short.**

End of life behavior

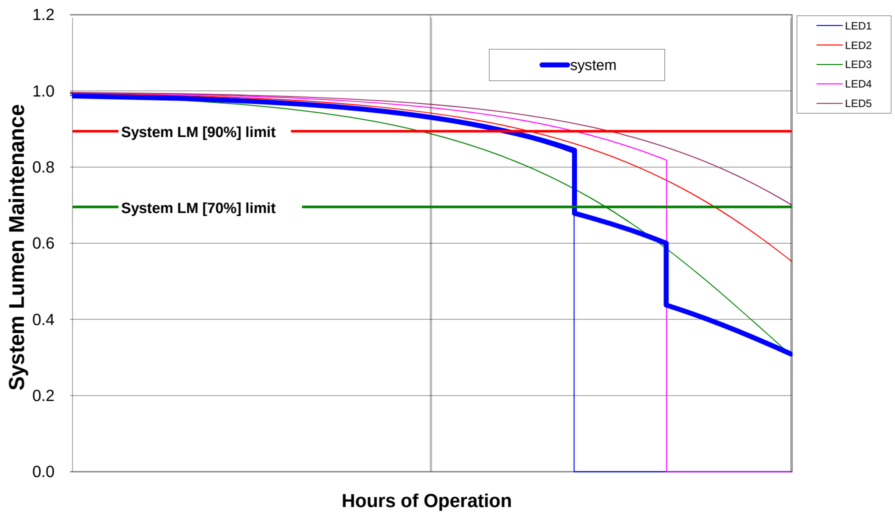


Curves are 90% LCL worst case. Curve shifts to the left at higher temperatures.

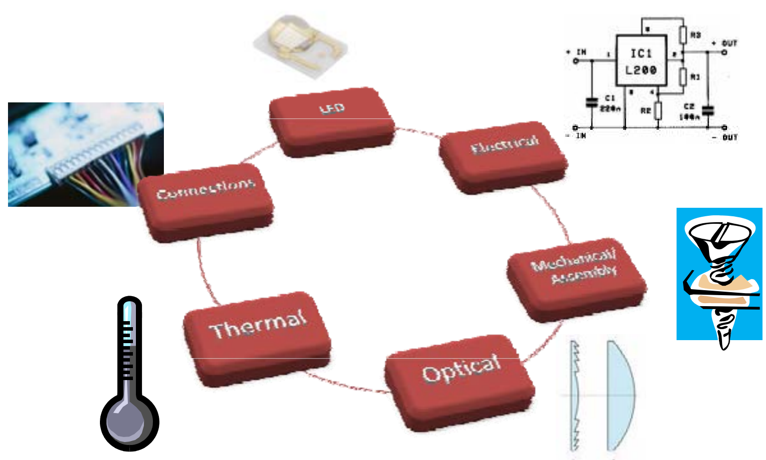

Drive Current
Junction Temp.
LED Reliab
Lumen Mainte
Failures
Wear-Out Fail
End of Life Rate
&
Confidence
Interval


LED Lumen Maintenance versus Time
(not to scale)
LED Component Lumen Maintenance
Hours of Operation
1.2
1.0
0.8
0.6
0.4
0.2
0.0
LED1
LED2
LED3
LED4
LED5

LED Sub-System Lumen Maintenance versus Time



System Reliability ≠ LED Reliability



$$R_{system} = R_{electrical} * R_{connections} * R_{LEDs} * R_{optical} * R_{thermal} * R_{mechanical}$$

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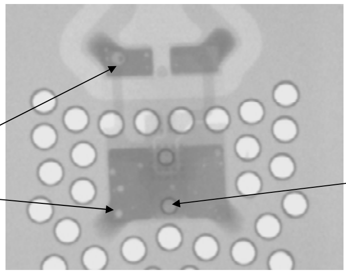
How to build a reliable system

- Best practices base on our experience
  - Real world examples to make your system more reliable and more robust

Solder joint voiding criteria

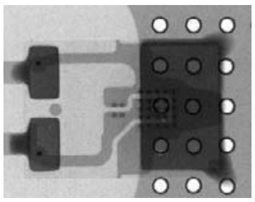


X ray image Rebel on FR4

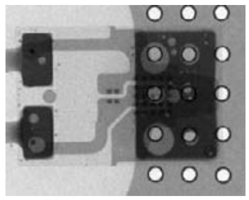
- IPC A-610d:
  - 8.2.14 Components with Bottom Thermal Plane Terminations
- Philips Lumileds recommendation : 25% voids max

LUXEON Rebel solder voids

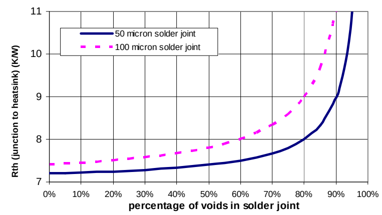
- Influence of voids on thermal resistance
- LUXEON Rebel examples
  - Voids % has no impact on thermal resistance



Voids : 0%



Voids: ~20%



Measured Rth values shows no significant difference versus voiding %

Process steps with risk of mechanical stress

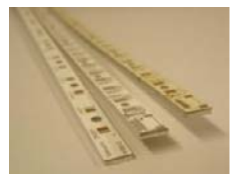
- Reflow
  - Warping during heat cycles (material)
- Separating the PCB from the panel
  - V-cut
  - Breaking
- Final assembly
  - Mounting warped PCB
  - Uneven force distribution for fixing PCB
    - Positioning of screws

Reflow soldering

- A PCB is a layered stack-up of different materials having different Coefficient of Thermal Expansion (CTE).
- Temperature cycling can lead to elastic deformation of the PCB (as with a “bi-metal”)
- In the reflow oven, at max temperature the board is bent the most.
- With cooling down, the PCB will flatten and further stresses components.
- Note
  - Maximum curvature will depend on board material and geometry.
  - The amount of relaxation depends on the material combination.

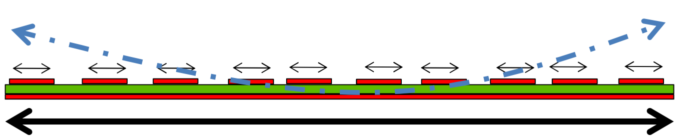

Reflow oven

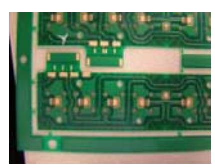

Bent boards in the reflow oven

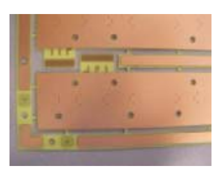

Relaxation of the board will differ per material choices.

Board design

- The PCB layout influences warping
- Different copper surface area (top vs. bottom layer) will bend during reflow

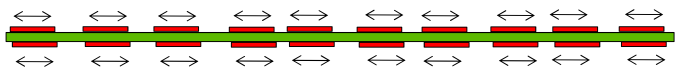


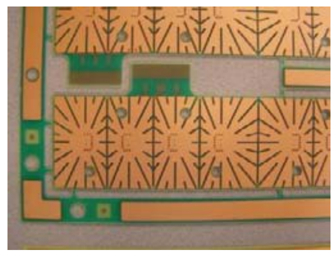

Top side of PCB with traces


Bottom side - one large continuous copper area

Board design

- Equal copper areas on top and bottom side balance forces
  - Board won't bend





Back side copper islands

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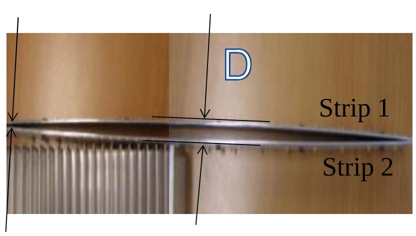
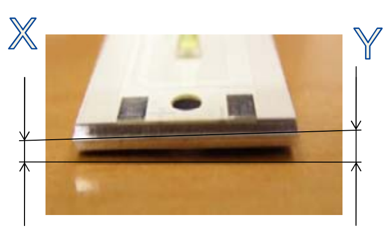
Separation of boards

- Separation of the board from the panel has to be done with care



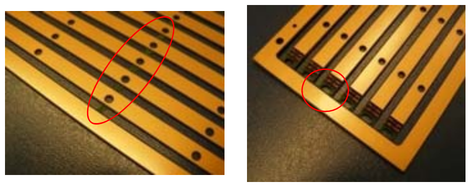
- Bending in long direction of the PCB



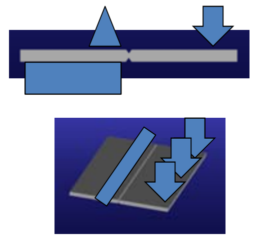
- Twisted in short direction of the PCB

De-panelling

Routing of Bridges



V-cut

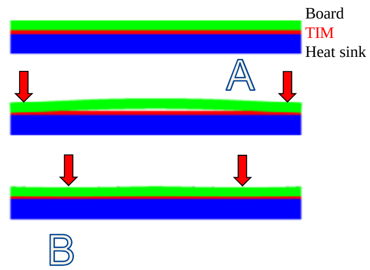


Mounting the PCB

- Mounting a bent PCB increases risk of component cracks.
  - This is not limited to LEDs (also applies to resistors, capacitors etc.)

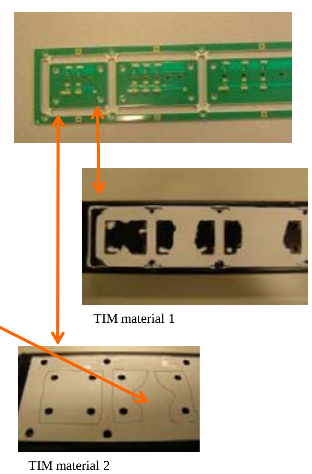
Screw positions for board assembly

- Thermal Interface Material (TIM) is often used between board and heat sink (for defined thermal contact)
  - If the holes are positioned on the edges of the board the TIM will be pressed together and the board will bend, especially for thick, soft TIM (A).
  - If the holes are positioned more to the center the forces will be distributed more equally and the bending of the board is less (B). See also next slide.



PCB screw positions experiment

- PCB test boards with different screw positions.
- After assembly and removal of the PCB the contact areas of the TIM are visible.
- For larger distances between the holes the center area did not make contact, the PCB is bent and doesn’t have solid thermal contact.



Secondary optics materials

Transparent materials evaluated

- **PMMA (Polymethyl methacrylate)**
- **PMMI (Polymethylmethacrylimide)**
- **PC (Polycarbonate)**
- **PA (Polyamide)**
- **COP (Cyclic Olefin Polymers)**
- **COC (Cyclic Olefin Copolymer)**

PMMA / Lucite

PC / DSM

PMMI / Evonik

PA / EMS

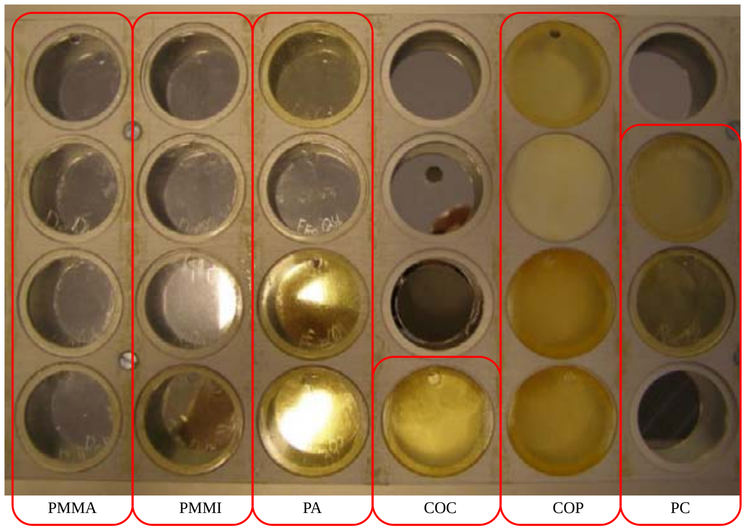
COP / ZEON

COC / Topas

Important material parameters

- For transparent materials the most important parameters are:
  - Maximum operating temperature
    - Can this material be used in this application?
  - Brittleness
    - Important for screw holes or click fingers
  - Optical transmission (over time)
    - Can have influence on the Lumen Maintenance of the application
  - Refractive Index
    - key optical design parameter
  - Material cost
  - Moldability
    - Quality, process time, accuracy

Sample overview transparent materials



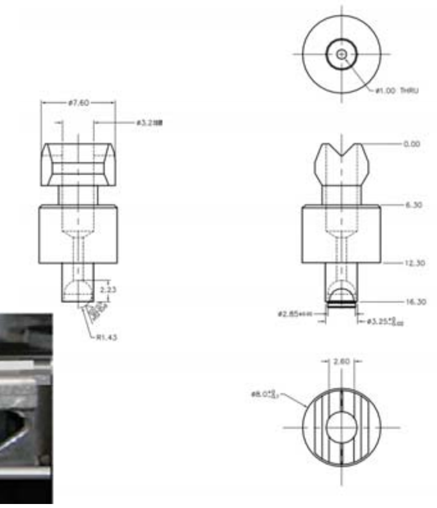
Best choices for secondary optics materials

- PMMA gives the best overall performance for use in outdoor application where the maximum operating temperature is below 85°C.
  - Based on lens quality (molding process), UV resistance, cost, and molder selection.

- PMMI gives the best overall performance where the maximum operating temperature is above 85°C.

Board Assembly - Pick and Place

- Nozzle Choice
- Special Feeders



Conclusion

- Simulations around the LED Sub-system are useful to determine system reliability
  - One step further than relying simply on an LM-80 test report
- LED Sub-system integration is important
  - Mounting, assembly and component placement etc.
- Understanding this can have a significant impact on the sustainability of the business