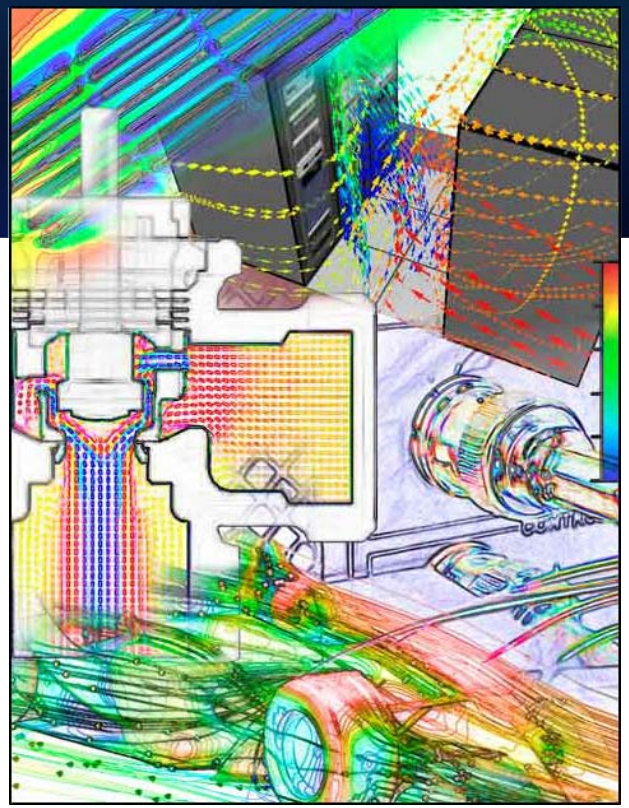
New JEDEC thermal testing standards for high power LEDs



András Poppe, PhD
Mentor Graphics
Mechanical Analysis Division MicReD team

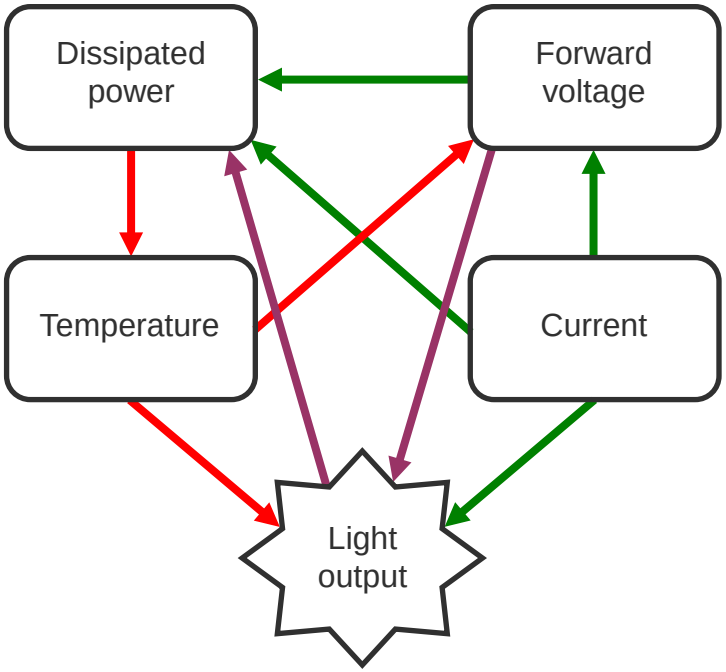
also with

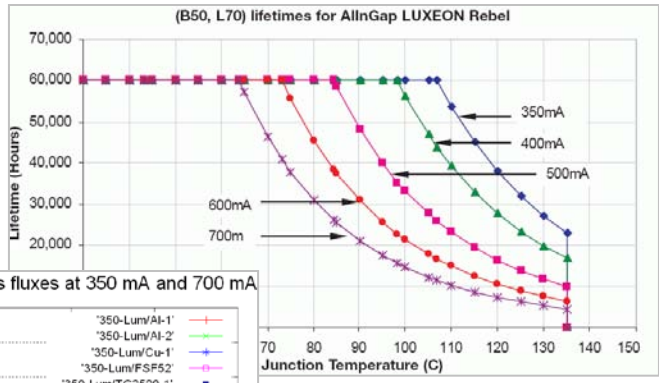
Budapest University of Technology & Economics
Department of Electron Devices

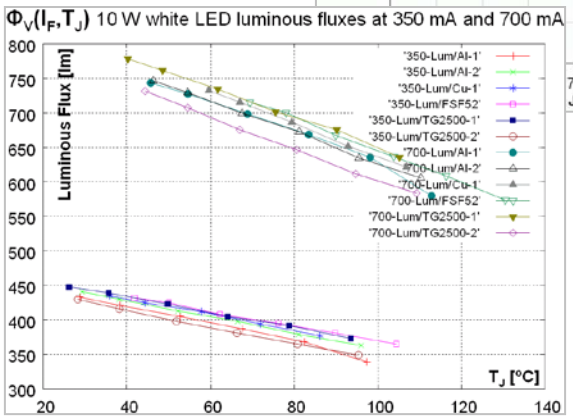
Budapest, Hungary

Download starting from next week from: www.eet.bme.hu/~poppe/corm2012

Thermal issues in LEDs affect everything...





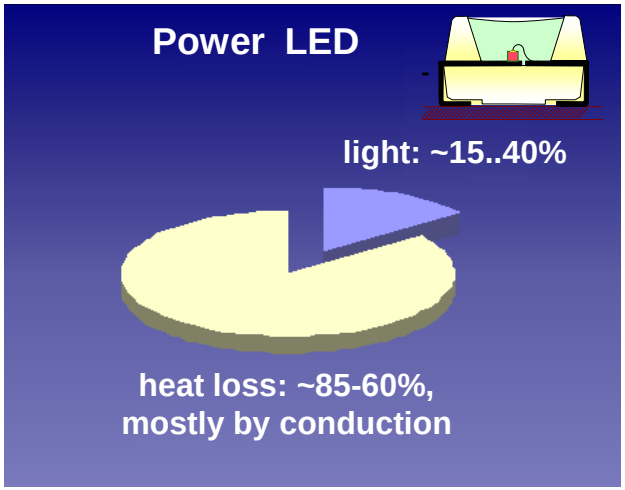


- Light output is the ultimate design objective, but ...
  it depends on "everything"
  - Three coupled domains
- Thermal properties need to be considered even at photometry (see for example CIE TC2-63, TC2-64)

- Cool LEDs live longer …
- … and provide more luminous flux
  - Be aware of importance of the heat-conduction path
  - Make sure there is proper heat-removal at the end of the heat-flow path (apply good heat-sink)

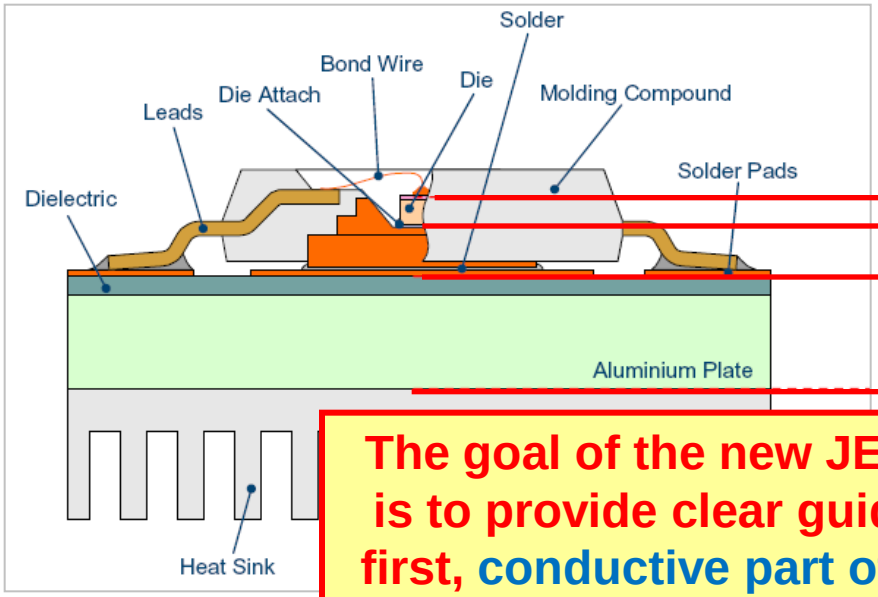
On LED component level: heat conduction only

- In case of LED components, heat loss is mainly by conduction



- Maintain compatibility
  - Use of existing luminaries
    - heat transfer to the ambient starts with **conduction in the LED component,**
    - via different thermal interfaces
  - Ultimate heat transfer to the ambient: natural convection

- Different thermal interfaces: major role in the heat conduction path



active layer to submount
classical die attach (TIM1)
solder/glue to MCPCB
classical TIM to heat-sink (TIM2)

The goal of the new JEDEC LED thermal testing standards is to provide clear guidelines for R_{th} measurements of the first, conductive part of LEDs' heat transfer to the ambient.

The new JEDEC standards for thermal testing of LEDs

- Aimed at **component level testing**
  - Single LEDs or LED arrays in a single package
  - Packaged LEDs / LED arrays mounted on to a substrate forming a single assembly
  - Equipped with a cooling surface through which the LED package or LED assembly is to be **heat-sunk during normal operation**
- **Recommended thermal metric**: junction to case thermal resistance
- **Recommended test environment**: temperature controlled cold plate
- **Recommended test procedures**:
  - **Rely on existing ones**:
    - JESD51-1 (electrical test method for Rth measurement of semiconductor devices)
    - CIE 127-2007 (optical testing of LEDs)
  - Recommends **combined thermal and optical measurements**
  - **Subtract radiant flux** from supplied electrical power when calculating thermal resistance
- **Data reporting**: real R_{th}, real junction temperature, efficiency

The new JEDEC JESD51-5x series of standards for thermal testing of power LEDs

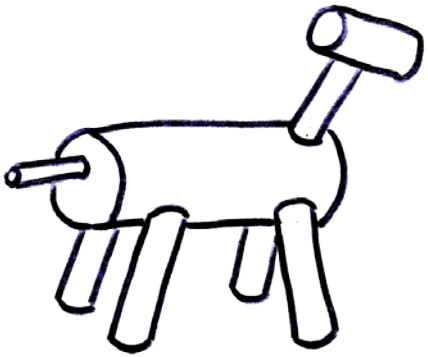
Standards make measurements reproducible

- Real life conditions must be simplified for standardized measurements
  - Good standards provide metrics which are close to real life conditions
  - Deviation from real-life conditions must be on the "safe" side
- Real life conditions must be simplified for standardized measurements

Real life horse

Too many individual, particular details
- color
- sex,
- muscles,
- teeth, etc

"Standard" horse



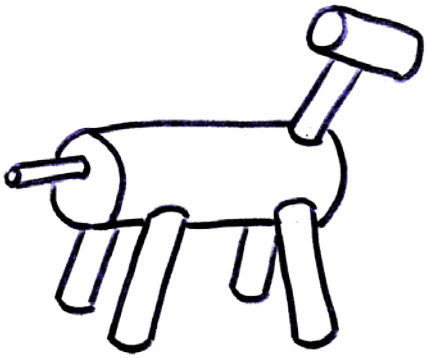
No individual details, but major characteristics of a real horse maintained
- has got four legs,
- has got a body, a neck, a head and a tail
- weight and form factor close to an average horse

Original standard horse example from Bruce Guenin, chairman of the JEDEC JC15 Committee on standardization of thermal characterization of packaged semiconductor devices.

Example from electronics cooling: power transistor

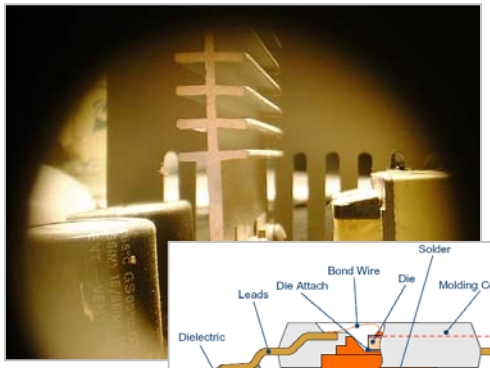
Real life horse

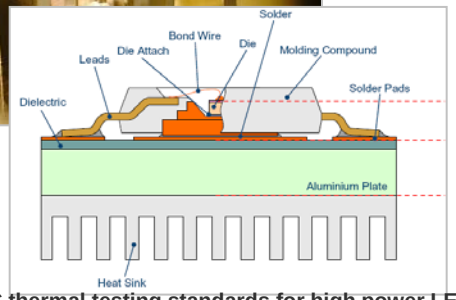
"Standard" horse



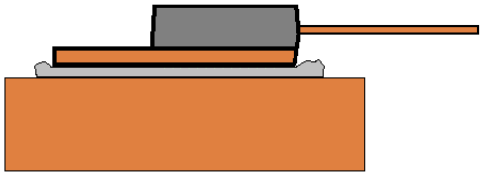
- How test conditions of transistors can be standardized?

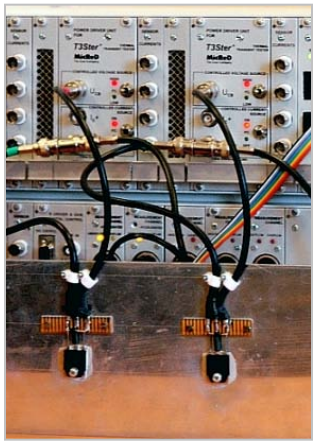
Real life application environment of **power transistors**: attached to a forced **air cooled heat-sink**





Standard test condition of **power transistors**: attached to a liquid cooled **cold plate**





Cold plate as thermal test environment is also recommended for LEDs

A. Poppe: New JEDEC thermal testing standards for high power LEDs

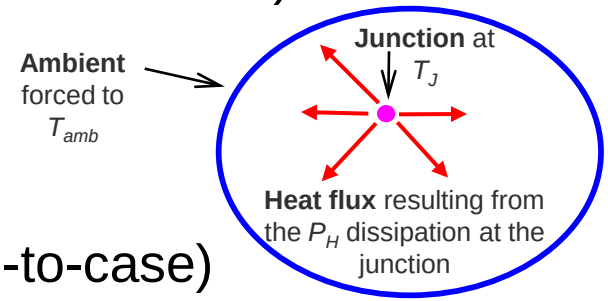
31 May 2012

Essential conditions for a correct thermal resistance

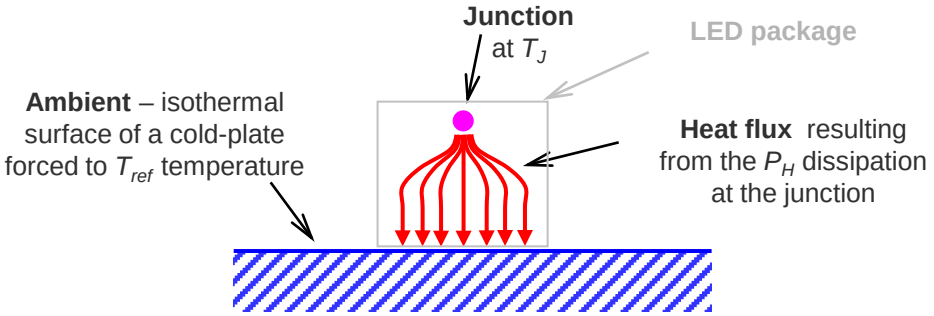
Required conditions to be able to define R_{th} between two points in space:

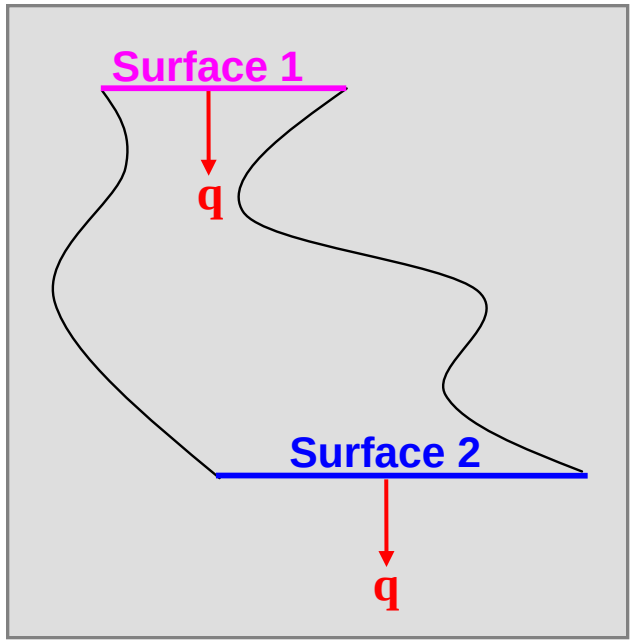
1. surfaces must be isothermal
2. the entire heat-flux **q** entering the heat-flow path at **Surface 1** must leave at **Surface 2**

- Real life situations: the above conditions are well met:
  - R_{thJA} (junction-to-ambient)



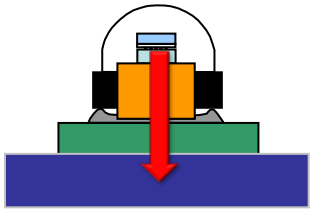
  - R_{thJC} (junction-to-case)

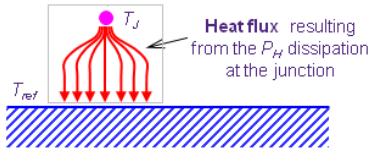




Test environments for LEDs and LED lamps

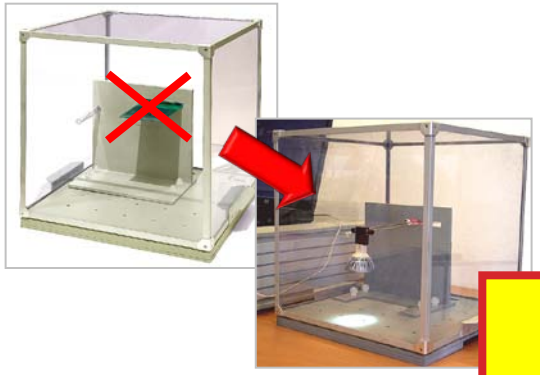
- For most of the un-mounted power LED packages or MCPCB assembled power LED packages **cold plates** provide an ideal test environment for **component level thermal testing**:



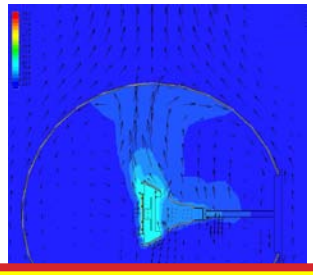


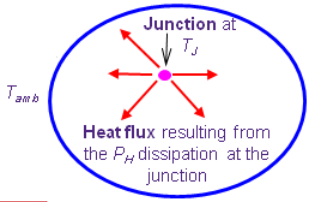
  - **Thermal metric** would be the **junction-to-case thermal resistance**

- For **complete LED assemblies** with a heat-sink / luminaire natural convection is the ultimate heat-removal mechanism, therefore a **still-air chamber** like test environment would be the right choice:



Integrating spheres used for light output measurement can replace a still-air chamber





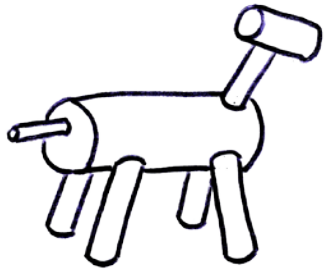
Out of the scope of this presentation; for AC driven LEDs: CIE TC 2-76

  - **Thermal metric** would be the **junction-to-ambient thermal *resistance*** (DC driven lamps) or **junction-to-ambient thermal *impedance*** (AC mains driven LED lamps)

JEDEC thermal characterization standards

- Classical standards: JESD51- series of documents

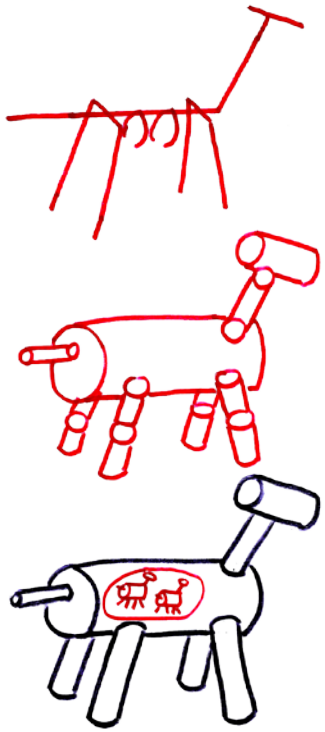
"JEDEC standard" horse



"JEDEC standard STATIC horse": JESD51-* series (1,2,3,4, etc) provide
- terms and definitions
- basic test methods (electrical test methods: **static** / dynamic)
- test environments (natural convection, forced air) and test boards
- data reporting guidelines

JESD51 – overview document

- JEDEC JC15 activities in the last few years resulted in new standards:



"JEDEC standard horse models": JESD15-* series for thermal compact modeling of packages
- compact modeling overview
- 2R and DELPHI models

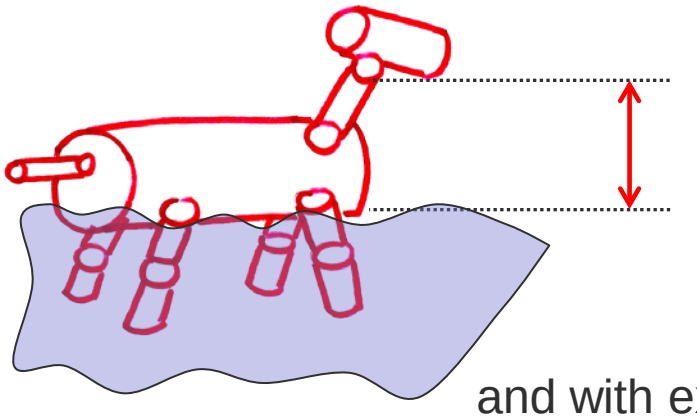
Work on standard model library file format in progress

"JEDEC standard DYNAMIC horse": JESD51-14 – the first thermal transient testing standard using structure functions
- new standard for **junction-to-case thermal resistance** measurement
- defines a **cold plate** as test environment
- defines thermal transient measurement and structure function analysis as test method

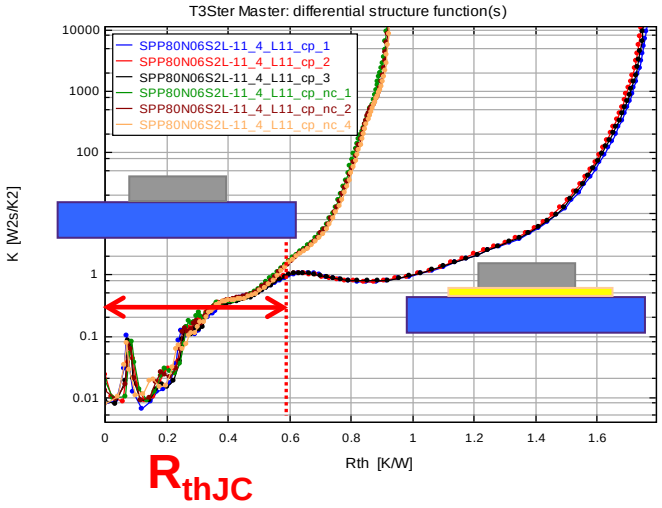
Extension of JESD51-* series standards to account for multi-chip packages
- JESD51-3x documents extending environmental conditions and test
- board definitions for multi-die packages

New standard "horses" – R_{thJC} with transient (2010)

- **JESD51-14**: R_{thJC} measurement with the dual thermal interface method
  - Measure twice: without

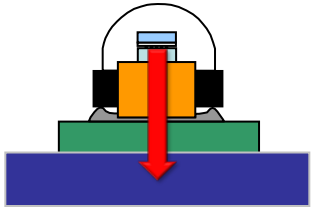


and with extra layer



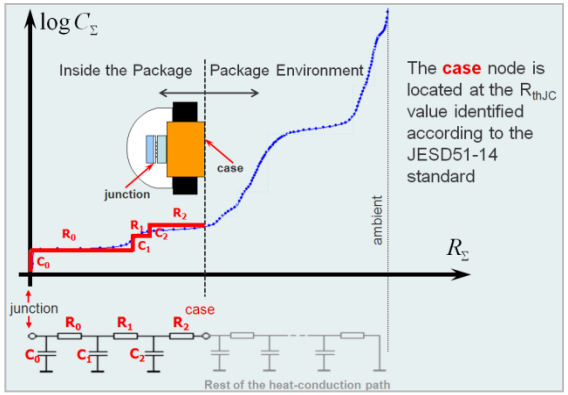
  - Location of deviation with respect to the junction defines R_{thJC}

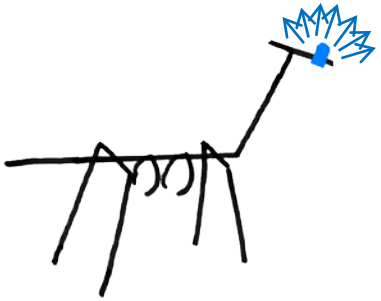
- Published in November 2010
- Applicable to power semiconductor device packages with an exposed cooling surface and a single heat-flow path
- **This condition is valid power LEDs as well, thus**
- **JESD51-14 is well applicable to LEDs provided that, the emitted optical power is properly accounted for.**

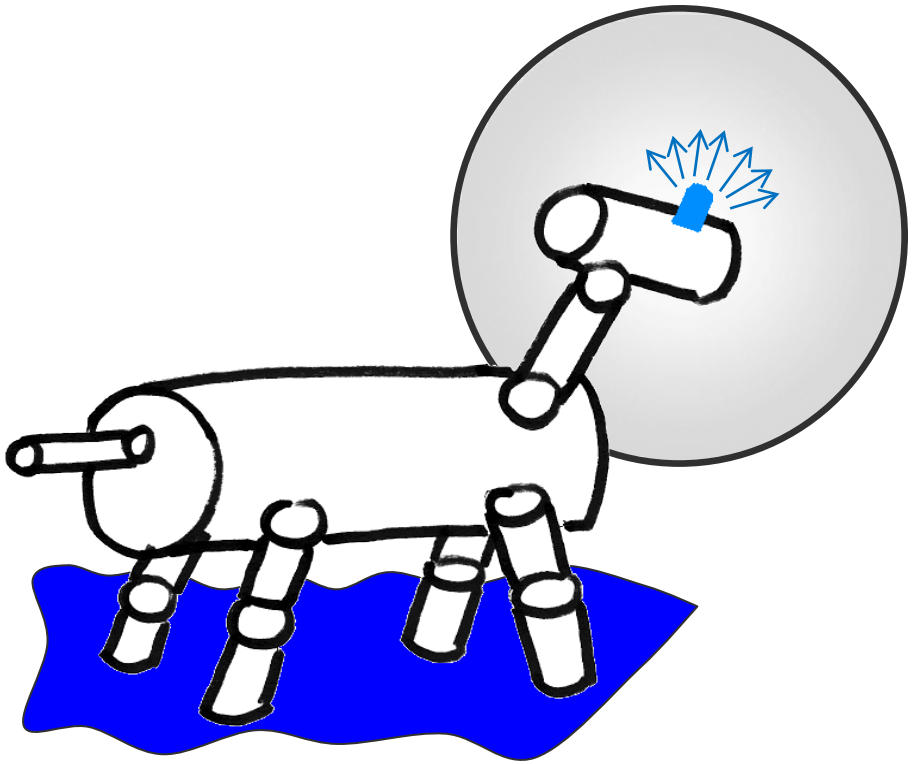


New standard "horses" – LED testing (April 2012)

- **JESD51-50, 51, 52, 53 series** LED thermal testing guidelines: published by JEDEC in **April/May 2012**





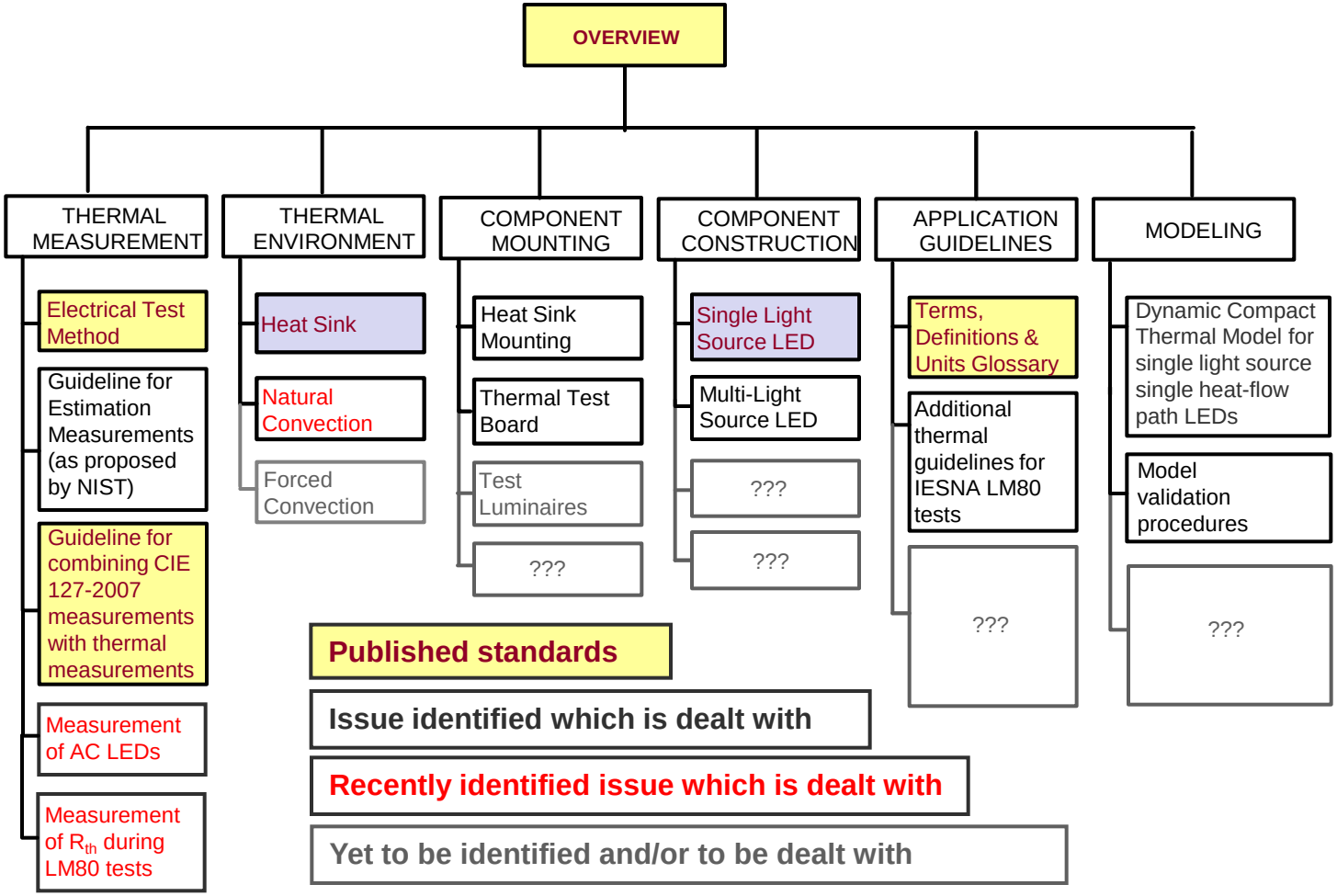


Measure the emitted light as well to account for the actual heating
Measure on cold-plate to assure thermal steady-state for light measurements

- This combined with a JESD51-14 compliant R_{thJC} measurement allows test based compact thermal modeling of power LED packages
  - Will not be discussed today…

Approach of the JEDEC JC15 committee

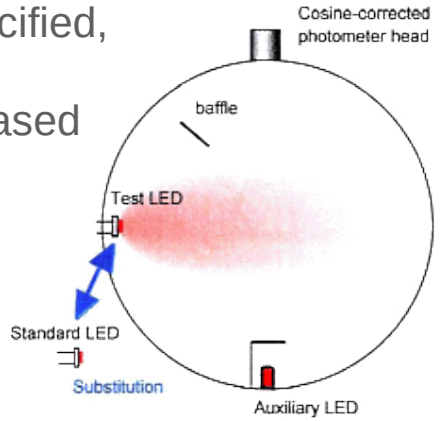
- **JESD51-50**: LED thermal testing overview document (April 2012)



- Each box represents recommendations for a particular problem.
  - New modules can be easily added

Compatibility with existing standards

- **Compatibility with JEDEC JESD51-1 / JESD51-14**
  - for DC driven LEDs
    - but the "power dissipated in the device" has to be calculated as P_{el}-P_{opt}
    - reference temperature needs to be well established and kept constant
    - for LEDs, the *static test method* must be used
  - **Additional new measurement guidelines**:
    - **measure P_{opt}** according to CIE 127-2007, use the **static test method**
    - ***measure on a cold plate***, $T_{ref} = T_{cold\ plate}$
    - calculate junction temperature as follows: $T_J = T_{ref} + R_{th} \cdot \Delta P_H$
- **Compatibility with CIE 127-2007**
  - for DC driven LEDs
    - thermal aspects of total flux measurement are precisely specified,
    - but scattered around in the document
    - *arrangement b of Figure 9* (2π geometry) allows e.g. TEC-based control of LED package temperature:
      attach DUT LED to a cold plate
  - **Additional measurement guidelines:**
    - ***4 wire connection to DUT LED*** to comply with JESD51-1, ***attach DUT LED to cold plate***
    - Identify and **report junction temperature**



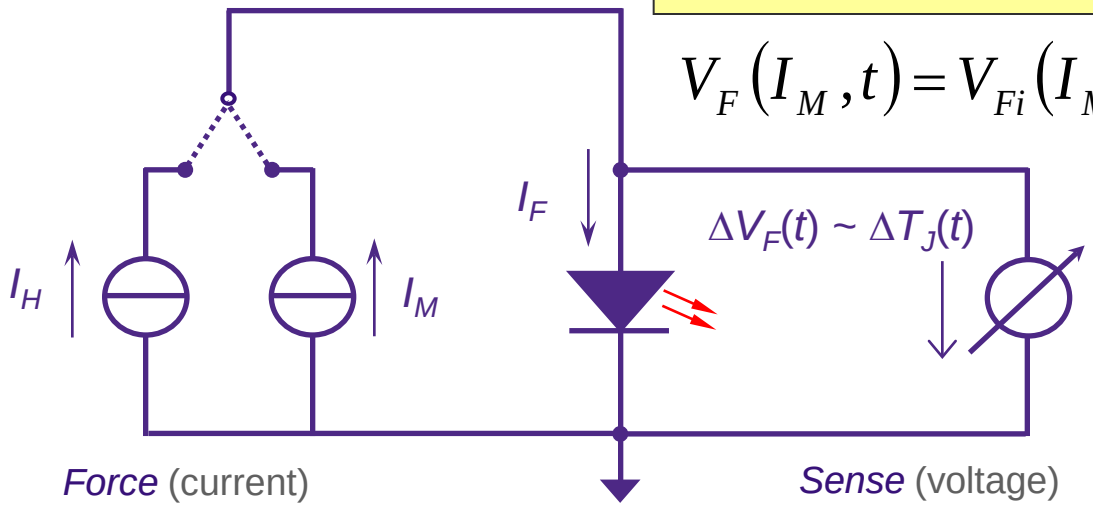
- The new JEDEC LED thermal testing standards are basically **recommendations how the above need to be implemented** for testing LEDs

JESD51-51: R_{th} measurement of LEDs: basic scheme

- The LEDs' forward voltage under forced current condition can be used as a very accurate thermometer
- The change of the forward voltage (TSP – temperature sensitive parameter) should be carefully calibrated against the change of the temperature (see JEDEC JESD51-1 and MIL-STD-750D)
  - In the calibration process the S_{VF} temperature sensitivity of the forward voltage is obtained

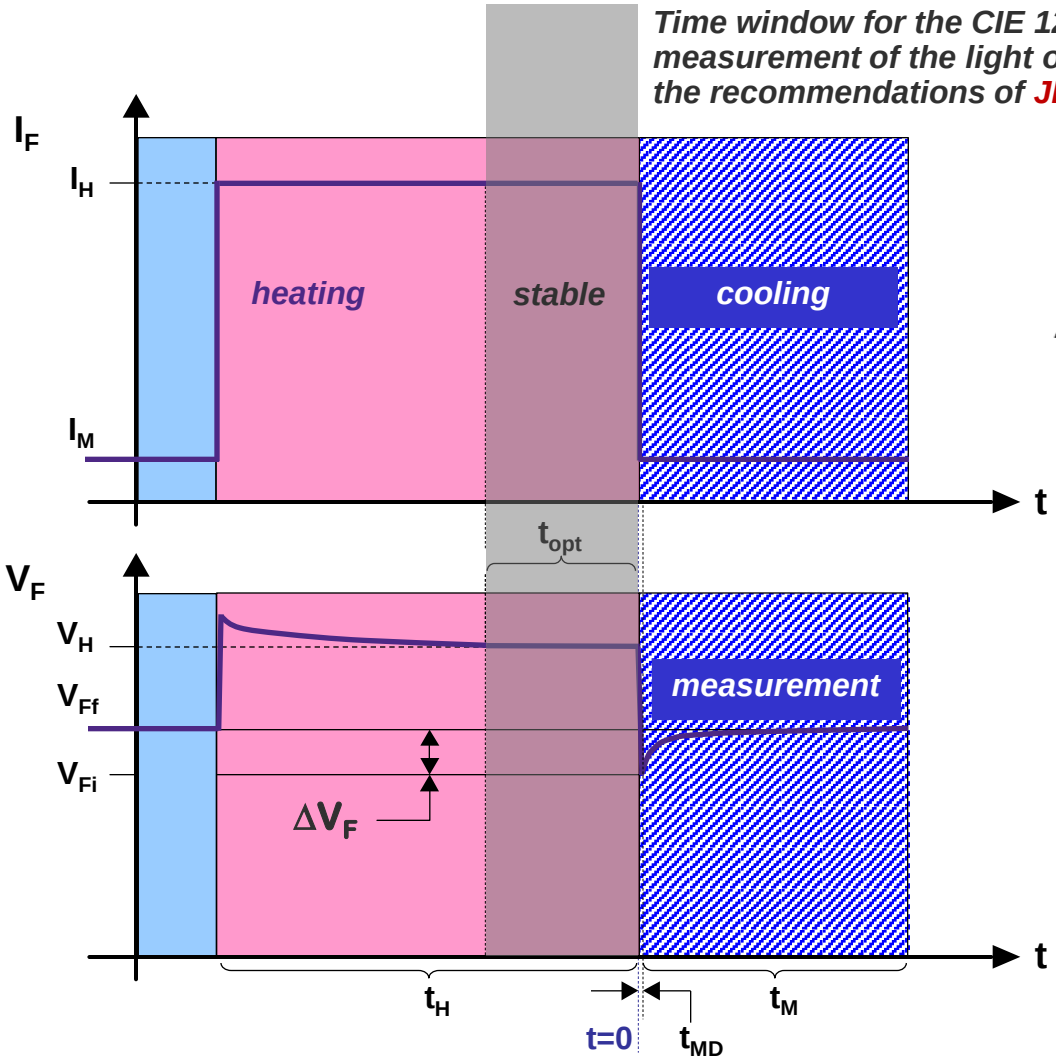
JEDEC JESD51-1 compliant test setup

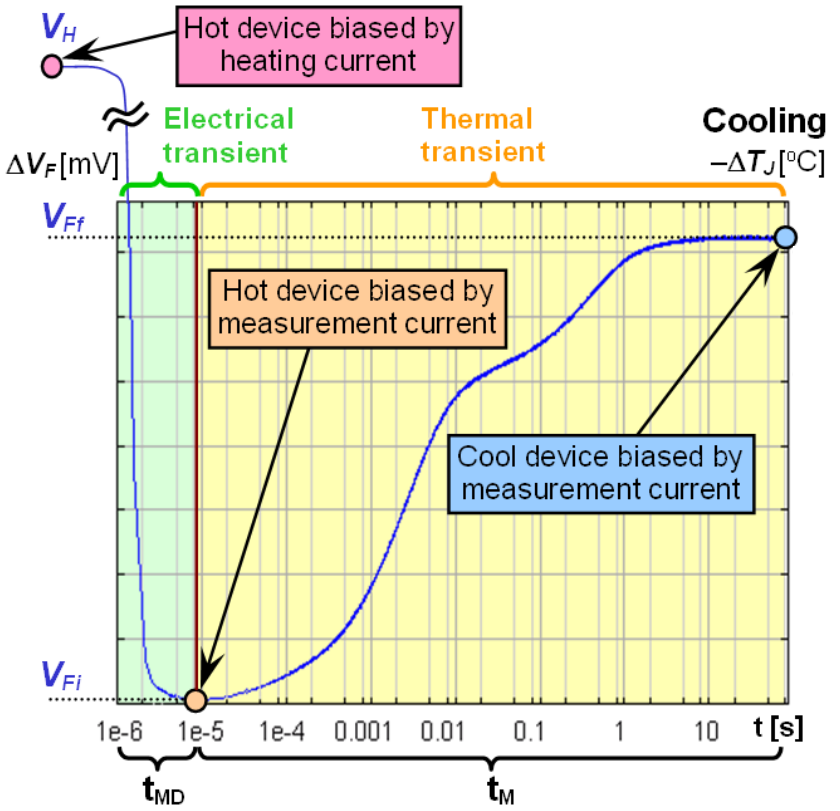
$$V_F(I_M, t) = V_{Fi}(I_M) + S_{VF} \cdot [T_J(t) - T_J(0)]$$



- Forward voltage change due to temperature change is measured using a 4 wire setup (Kelvin setup)

JESD51-51: The measurement waveforms

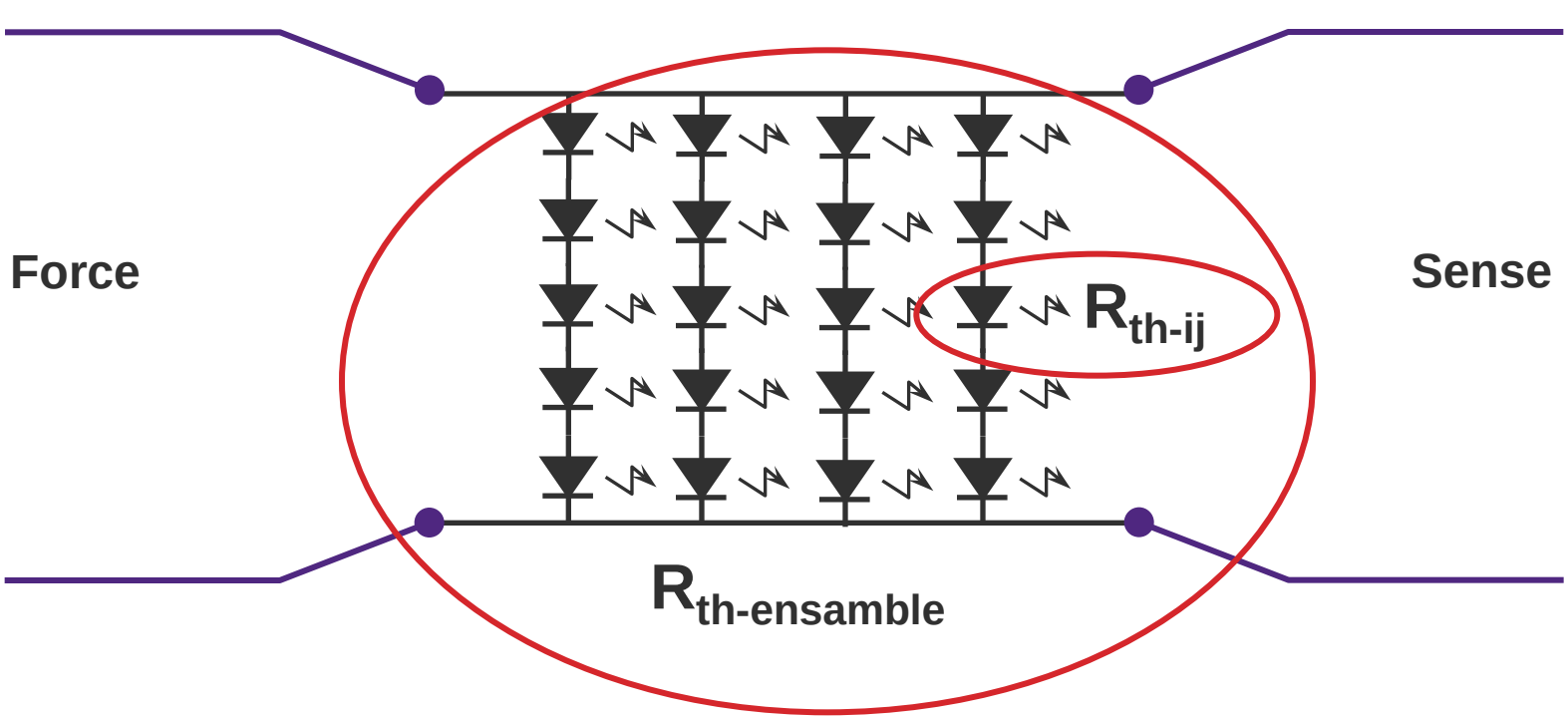




Images from the **JESD51-51** LED thermal testing standard

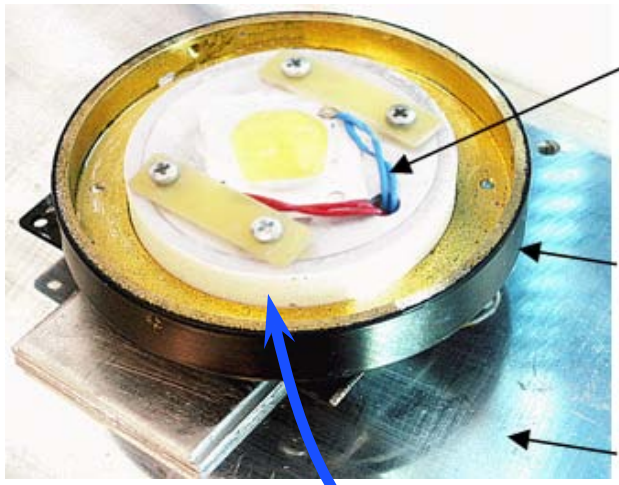
The problem of multiple LED dies in a single package

- 'Ensemble' R_{th} instead of individual R_{th} values of each die

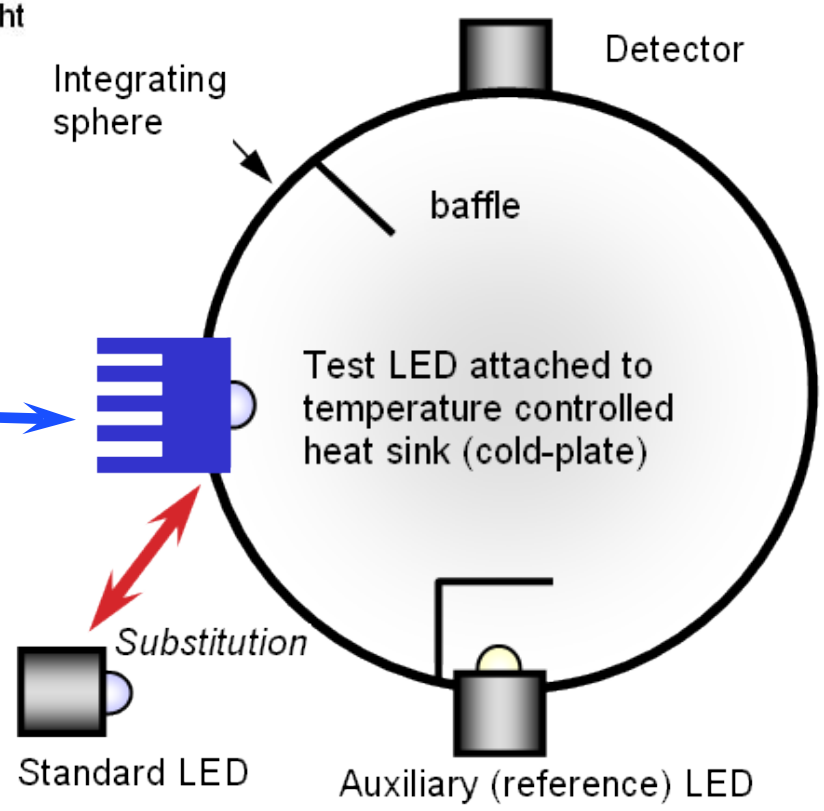


- Clear measurement guidelines are about this in JESD51-51
  - Typically 'ensamble R_{th}' is measured, since there is no individual access to every single PN-junction in the array
- No way to measure $R_{th\text{-}ji}$-s unless LED array is *designed for thermal testability*

JESD51-52: optical measurements for thermal tests



CIE TC2-63 deals with optical testing of high power LEDs, considering also the effect of the junction temperature.



Images from the **JESD51-52** standard

Ideally: the same test setup is used.

Recommendation: at least use the same test assembly of the DUT LED

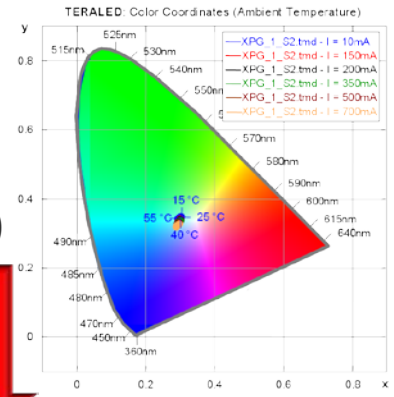
Comprehensive LED testing solution (suggested):

JESD51-52:

CIE 127-2007 compliant photometric & radiometric measurement system

photometric/radiometric measurements in thermal steady-state

$\Phi_e(I_F,T)$
$\eta_e(I_F,T)$
$\Phi_V(I_F,T)$



Detector

Integrating sphere

Test LED

I_F

V_F

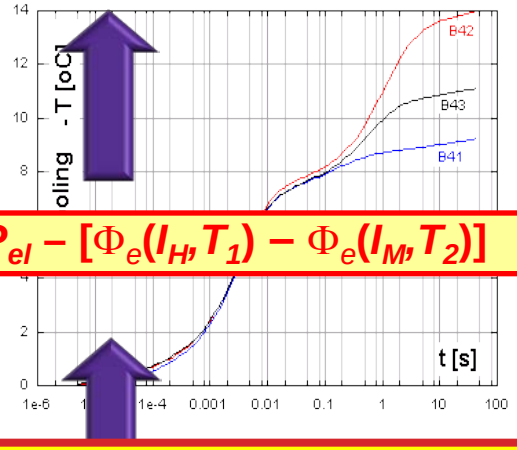
Temperature controlled heat-sink

Aux. LED

steady-state electrical powering

I_F

calculate real R_{th} and T_J



$\Delta P_H = \Delta P_{el} - [\Phi_e(I_H,T_1) - \Phi_e(I_M,T_2)]$

Thermal test equipment

Force (current)

Sense (voltage)

I_H

I_M

$\Delta V_F(t)$
~
$\Delta T_J(t)$

switching-off from I_H to I_M

From the **JESD51-52** standard: published April 2012

thermal resistance/impedance measurement

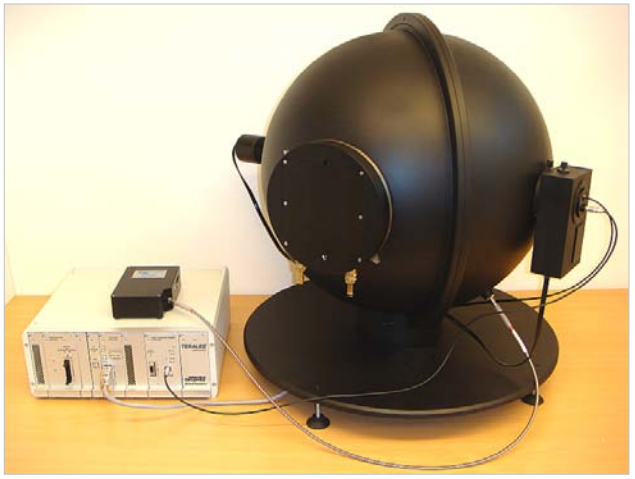
JESD51-51:

JEDEC JSD51-1 static test method compliant thermal measurement system

Our implementation:

- The sphere, cold plate and electrical powering sized according to the power of the LED to be tested
  - Avoid thermal coupling between the test LED and the detector head
  - Keep the luminance level at the detector port in a given range
  - Higher power LED (modules) are bigger – require bigger DUT LED port size; the ratio of the area of the openings and the total sphere surface must be kept small

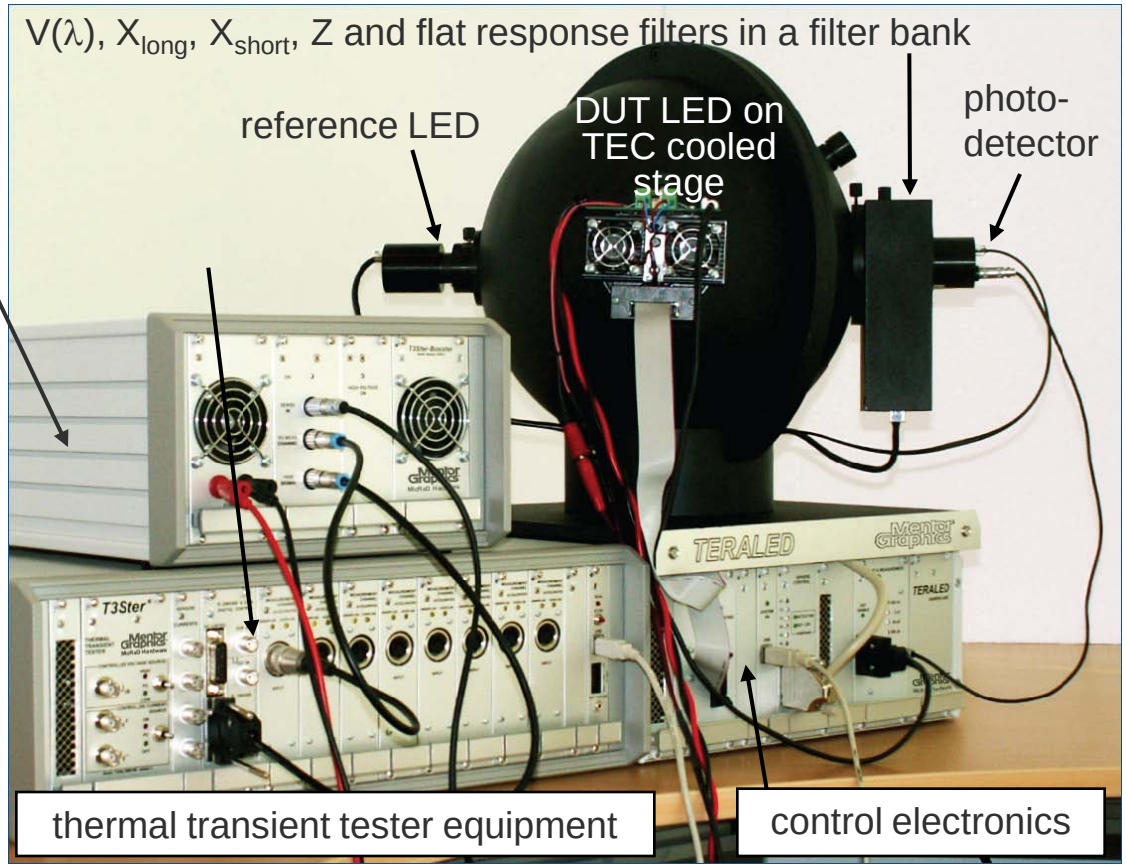
A ∅30cm sphere with a ∅60mm DUT LED port for LEDs up to 10W with a filter based detector system.



A ∅50cm sphere with a ∅150mm DUT LED port for LEDs up to 50W with a filter based detector system completed with a cheap array spectrometer.

Our implementation:

Special LED booster: allows high voltage across a LED line (overall forward voltage can reach 280V – needed for AC mains driven LEDs).



Data reporting

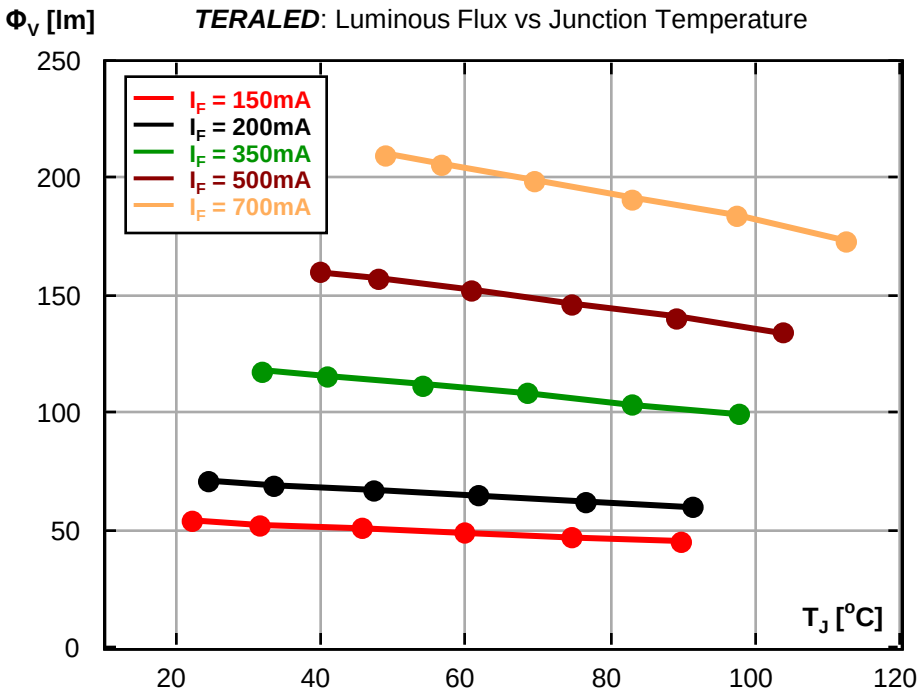
- According to JESD51-51:
  - The measured real thermal resistance is $R_{th\_real} = \Delta P_{H\text{-}corr} / \Delta T_J$
  - $T_{J\text{-}real}$ always to be calculated. Recommendation of JESD51-51:

$$T_{J\text{-}real} = T_{ref} + R_{th\_real} \cdot (P_{el} - \Phi_e)$$

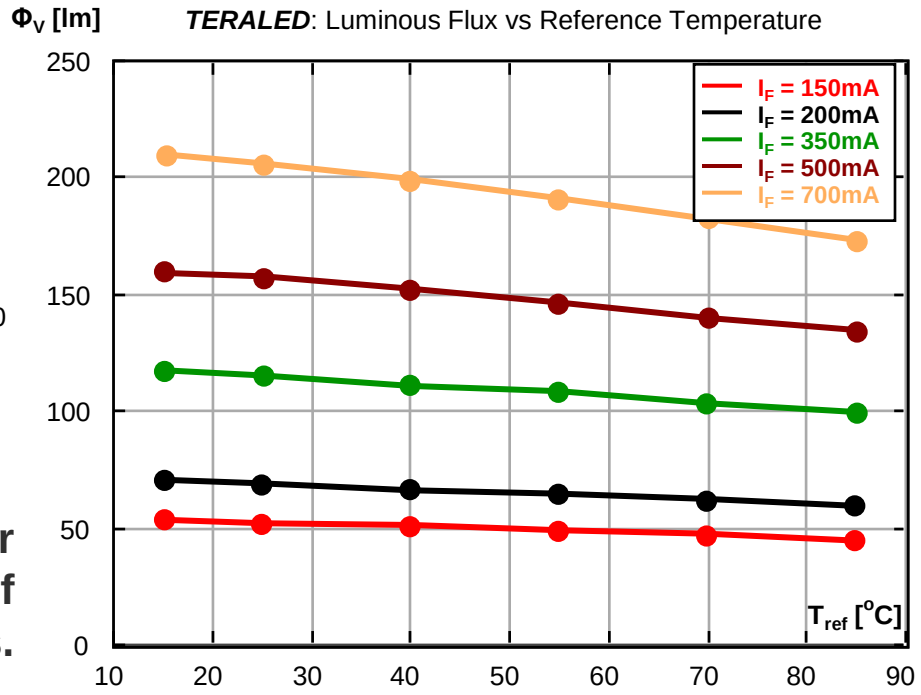
- According to JESD51-52:
  - "Light output metrics must be reported together with the applied forward current and the identified junction temperature."
  - "It is preferred that LEDs's data sheets always include typical data of $\Phi_e(I_F, T_J)$, *radiant flux values,* $\eta_e(I_F, T_J)$, *energy conversion efficiency values, and* $\Phi_V(I_F, T_J)$, *luminous flux values,* $\eta_V(I_F, T_J)$, *efficacy values,* preferably in the form of plotted diagrams and numerical tables."

What temperature to report?

- The same luminous flux measurement results shown as function of reference temperature and junction temperature

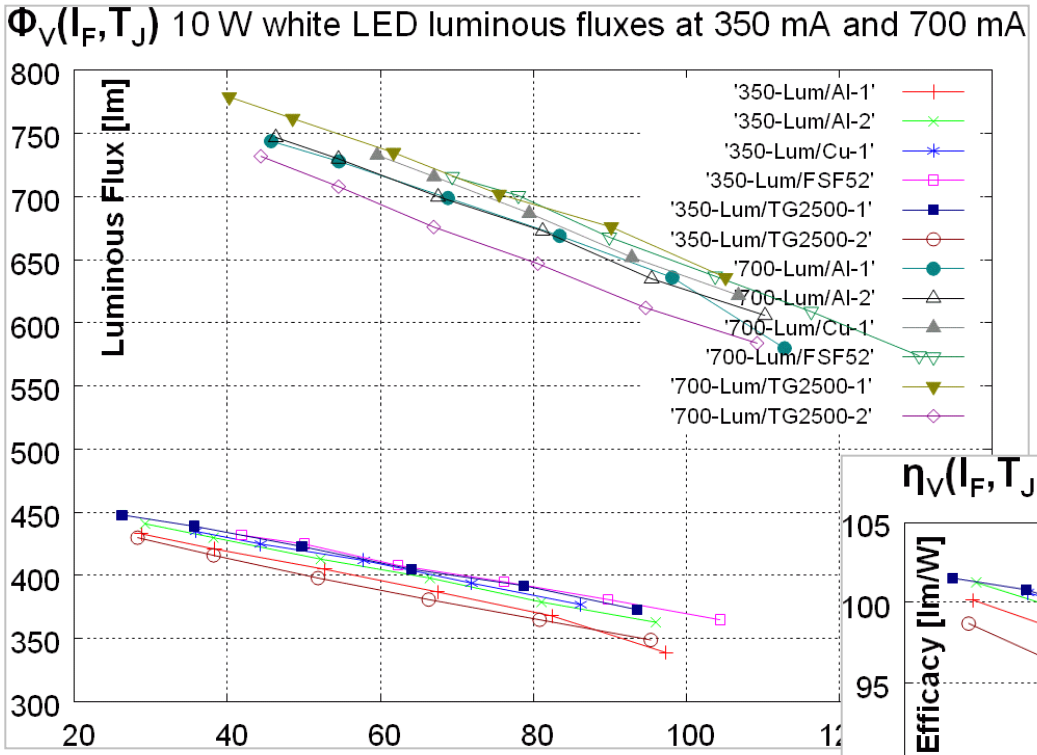


Data as function of *junction temperature* is to be used for physical, multi-domain modeling of LEDs as well as for "hot lumen" estimates.



***Ambient temperature* is relevant for thermal designers since this is one of the input parameters of their designs.**

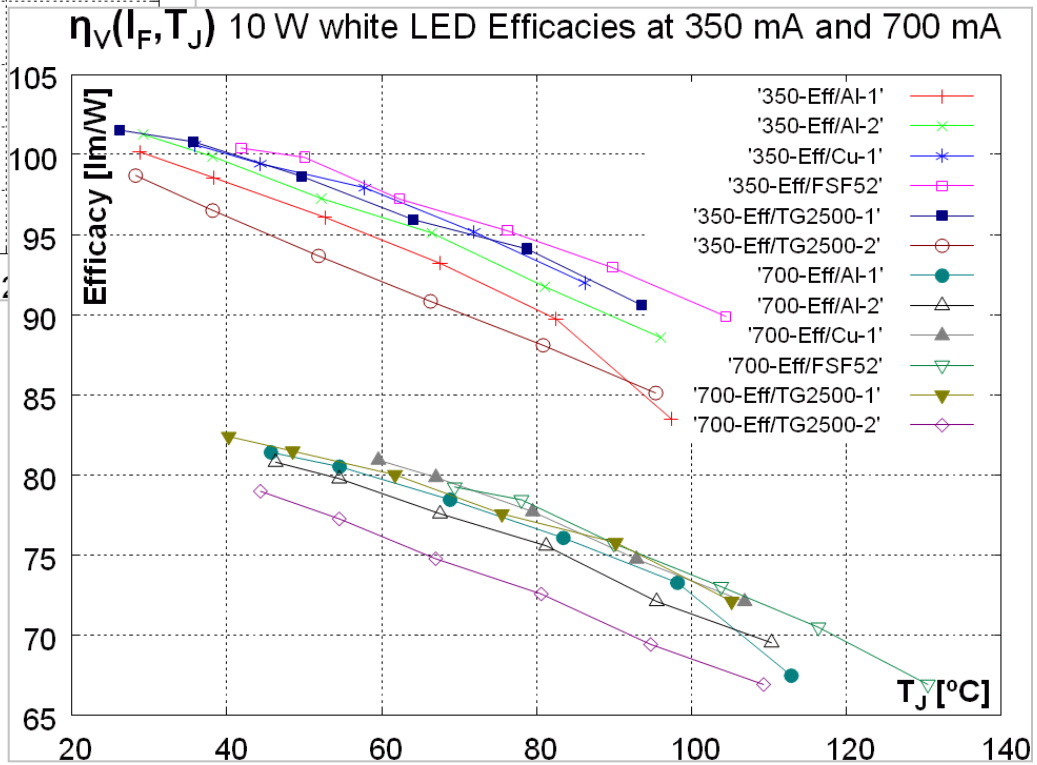
$\Phi_V(I_F,T_J)$ & $\eta_V(I_F,T_J)$ plots for 7 different samples



Luminous flux plots [lm]

Results for 10 W white LEDs

Efficacy plots [lm/W]

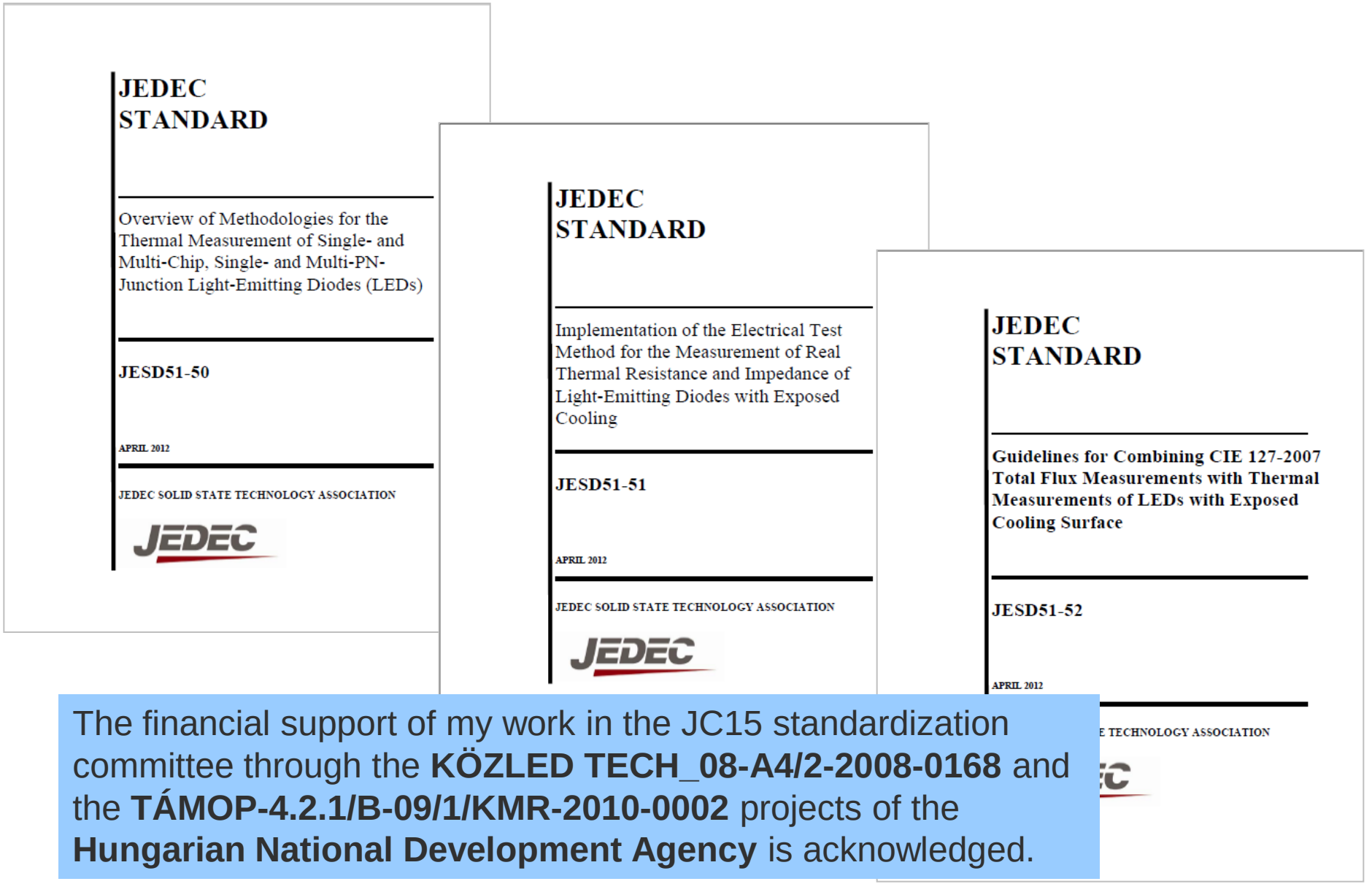


From the **JESD51-52** standard: published April 2012

Summary

- In April 2012 JEDEC published a new series of documents regarding thermal testing of power LEDs
- These documents follow the logic of all semiconductor thermal testing standards developed by the JEDEC JC15 committee
- **The four documents published recently**
  - **JESD-51-50: Overview of Methodologies for the Thermal Measurement of Single- and Multi-Chip, Single- and Multi-PN-Junction Light-Emitting Diodes (LEDs)**
  - **JESD-51-51: Implementation of the Electrical Test Method for the Measurement of the Real Thermal Resistance and Impedance of Light-emitting Diodes with Exposed Cooling Surface**
  - **JESD-51-52: Guidelines for Combining CIE 127-2007 Total Flux Measurements with Thermal Measurements of LEDs with Exposed Cooling Surface**
  - **JESD-51-53: Terms, Definitions and Units Glossary for LED Thermal Testing**
- **These documents restrict themselves to thermal testing and provide a good basis for the work in different CIE technical committees**

Summary



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