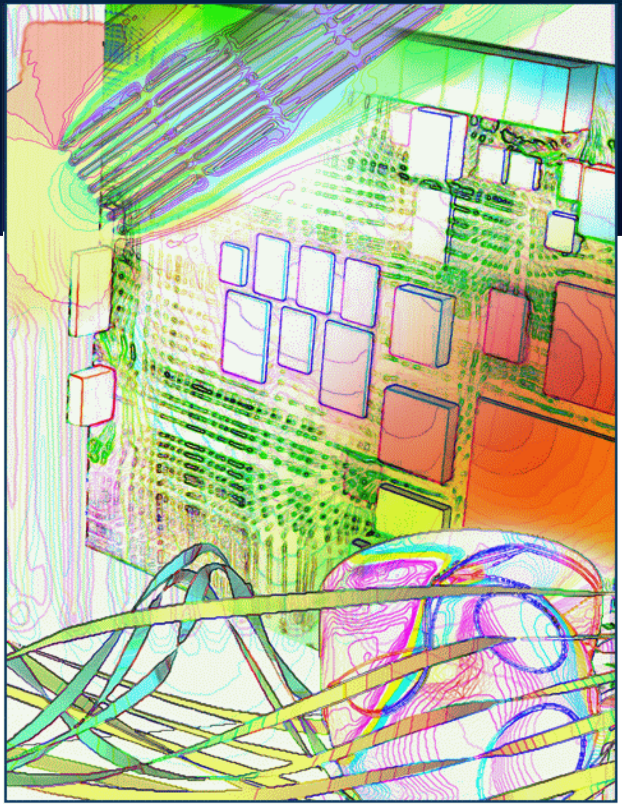

Thermal testing of LEDs: emerging standards

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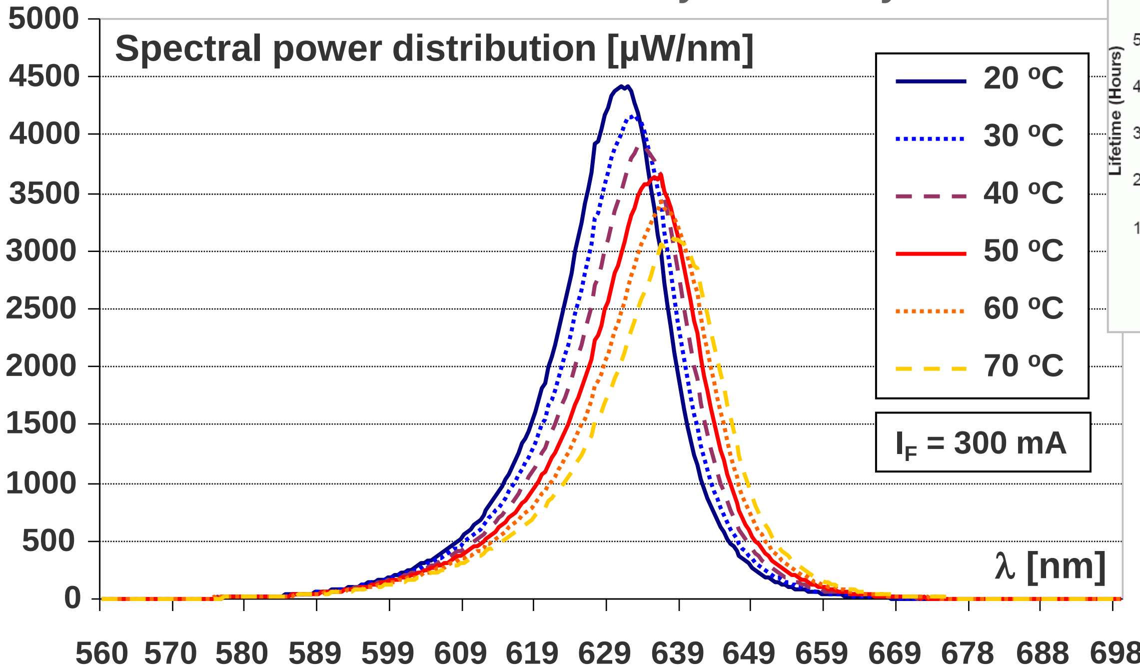
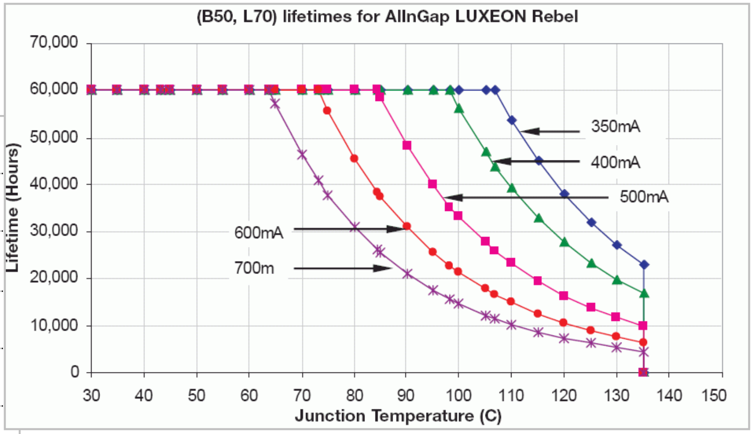
Budapest, Hungary

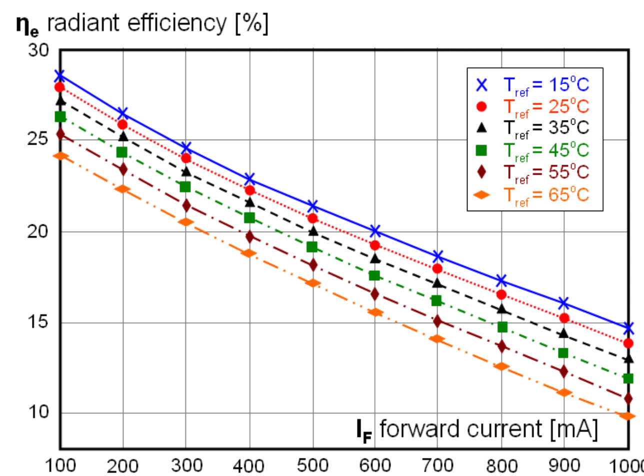
Mentor Graphics®

Why to deal with thermal issues in case of LEDs?

- Reliability is connected to thermal issues
  - life time (failure mechanisms are thermally assisted)
  - mechanical stress
- Optical properties strongly depend on temperature
  - spectra
  - emitted flux / efficiency / efficacy







No doubt that **reliable thermal data** is a must for power LEDs: widely accepted **standards are needed**

Standardization status at CIE (from Y. Ohno)

LED chips/ packages

(low power)
- CIE 127:2007
- CIE TC2-46

(high power)
- IES LM-80 Lumen maintenance
- IES TM-21
- IESNA new project
- CIE TC2-63, 64

SSL products (Integrated LED lamps & LED luminaires)
- IES LM-79 Photometric meas.
- ANSI C78.377 Chromaticity
- CIE TC1-69 Color rendering

TC2-63	Optical measurement of High-Power LEDs (Y. Zong, USA)
TC2-64	High speed testing methods for LEDs (G. Heidel, Germany)

clusters and arrays

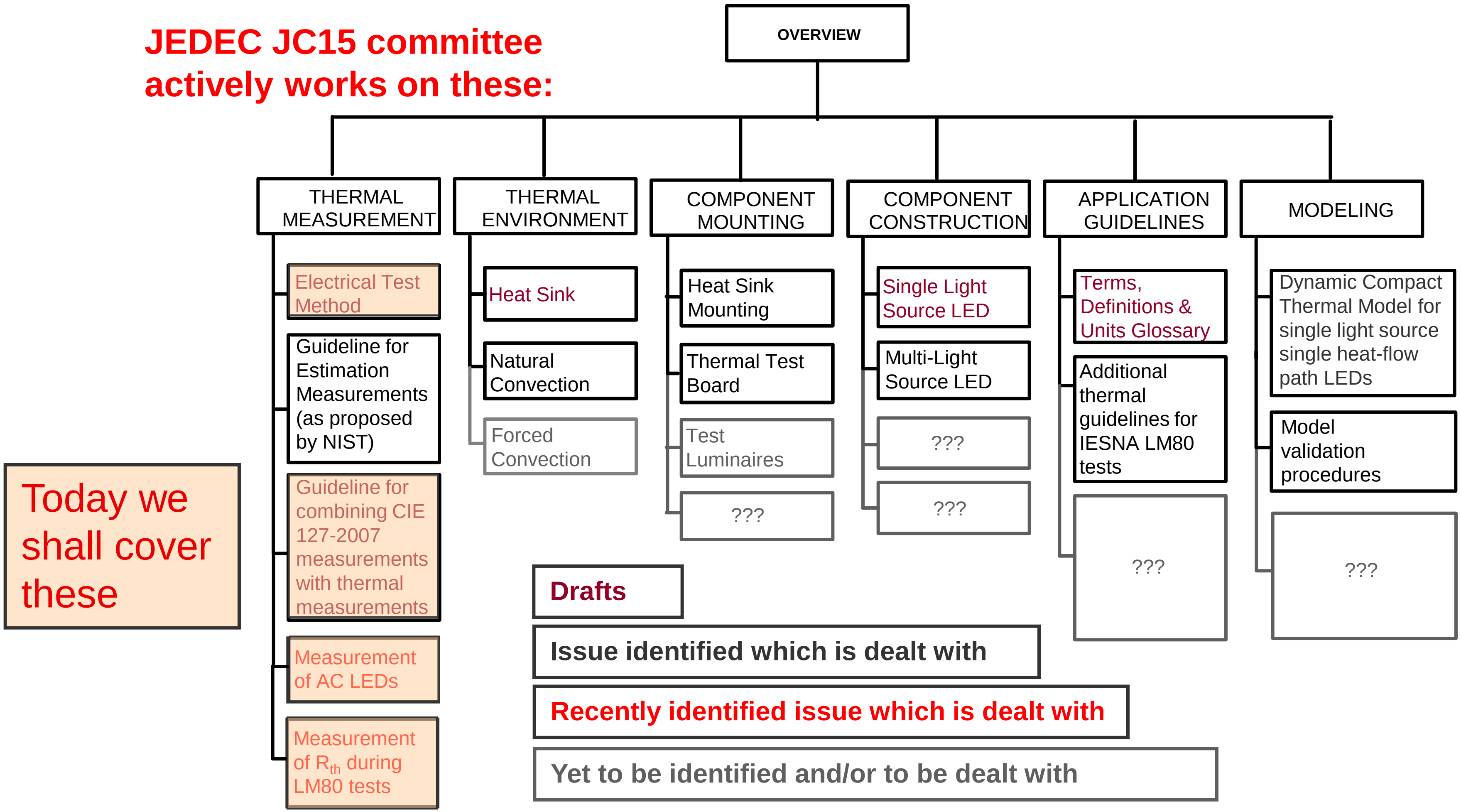
Safety UL 8750
- CIE TC2-58 radiance/luminance
- Several projects in IEC TC34A

LED light engines
- (ASSIST Recommends ..)
- IESNA new project

Definitions (terminology)
- IES RP-16 addendum a
- IEC TS 62504

Approach of the JEDEC JC15 committee

- Overview document (not yet accepted)



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

A few words about thermal resistance of LEDs

- Original definition in the JEDEC JESD51-1 document

EIA/JEDEC Standard No. 51-1
Page 3

2. MEASUREMENT BASICS

The thermal resistance of a semiconductor device is generally defined as:

$$R_{JX} = \frac{T_J - T_X}{P_H}$$

where $R_{\theta JX}$ = thermal resistance from device junction to the specific environment (alternative symbol is θ_{JX}) [°C/W]
T_J = device junction temperature in the steady state test condition [°C]
T_X = reference temperature for the specific environment [°C]
P_H = power dissipated in the device [W]

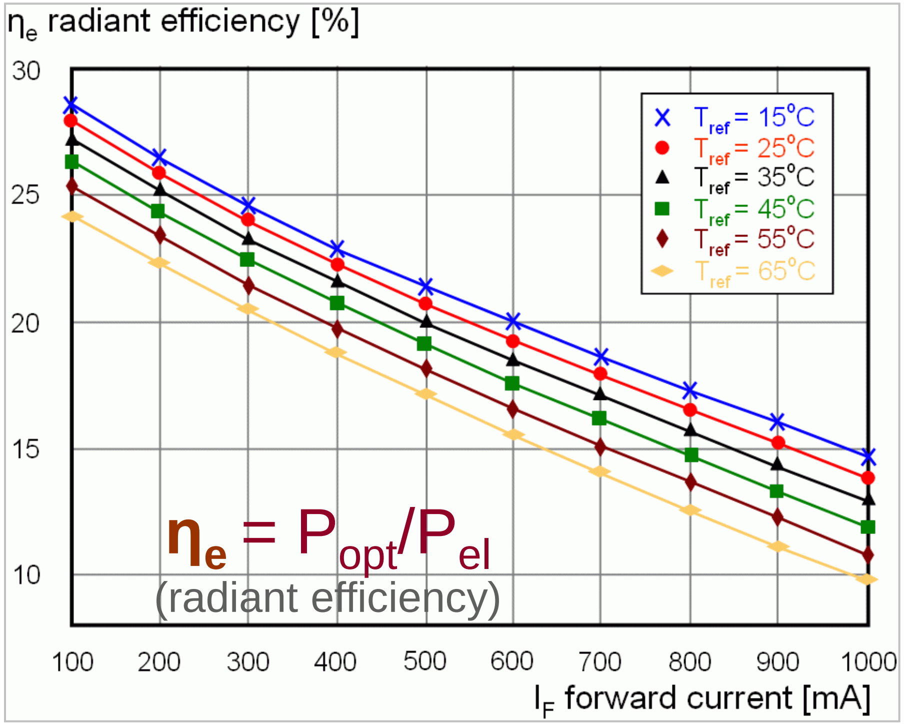
- Classically, for Si semiconductor diodes: $R_{th\text{-}el} = \Delta T_J / (I_F \times V_F)$
  Accurate; the questions are:
  - what is the dissipated power of an LED? *Subtract radiant flux*
  - what is the T_X reference temperature *Use cold plate!*
- For LEDs, consider the radiant flux: $R_{th\text{-}r} = \Delta T_J / (I_F \times V_F - P_{opt})$
- Both $R_{th\text{-}el}$ and $R_{th\text{-}r}$ are correct, if proper power is used to calculate T_J

Importance of the definition of R_{th} for LEDs

- Traditionally: $R_{th\text{-}el} = \Delta T_J / P_{el} = \Delta T_J / (I_F \times V_F)$
- Due to high efficiency, radiant flux must be considered:

$$R_{th\text{-}r} = \Delta T_J / (P_{el} - P_{opt})$$
$$= \Delta T_J / (I_F \times V_F - P_{opt})$$

By neglecting P_{opt} vendors report much nicer data than reality



EXAMPLE:

- Let us assume two η_e -s

  $\Delta T = 50^oC$, $P_{el} = 10W$

  — η_e =0% (electrical only)

  ➔ "$R_{th\text{-}el}$" = $\Delta T / P_{el}$ = 50/10 = **5 K/W**

  — η_e = 25%

  ➔ $R_{th\text{-}r} = \Delta T / (P_{el} - P_{opt}) = \Delta T / [P_{el} \cdot (1-\eta_e)]$ =
  = 50/(10·0.75) = **6.67 K/W**

  — η_e = 50%

  ➔ $R_{th\text{-}r} = \Delta T / (P_{el} - P_{opt}) = \Delta T / [P_{el} \cdot 1-\eta_e)]$ =
  = 50/(10·0.5) = **10 K/W**

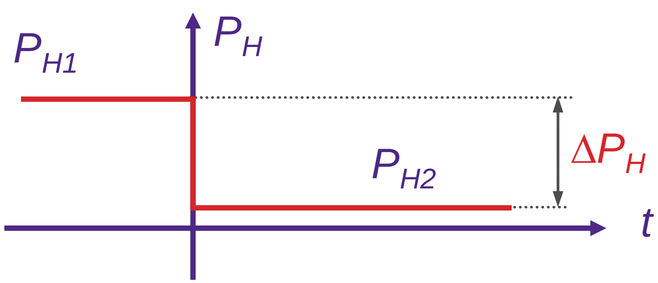
Junction temperature — performance indicator

- Calculation: $T_J = R_{thJ\text{-}X} \cdot P_H + T_X$
  - — $R_{thJ\text{-}X}$ *junction-to-reference_X* *thermal resistance* supplied by the LED vendor
  - — P_H *heating power* measured/calculated by the LED user
    - – How?
  - — T_X *reference temperature* (un)specified by the LED user
- Used in the design process to decide if the foreseen cooling is sufficient or not...
  - — Not enough: in case of LEDs, prediction of "hot lumens" is also required

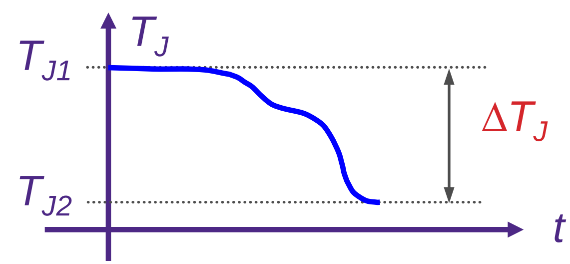
Differential formulation of the thermal resistance

$$R_{thJ-X} = \frac{T_J - T_X}{P_H} = \frac{[\Delta T_J]_X}{P_H}$$

Instead of spatial difference (temperature values at junction and reference point) temporal difference of the junction temperature can be used

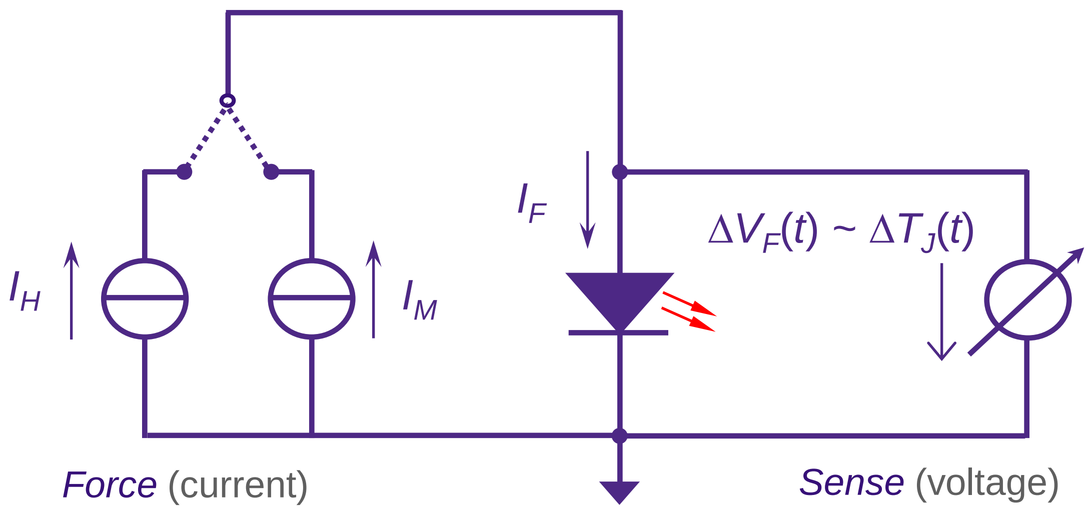


$$R_{thJ-X} = \frac{\Delta T_J(\infty)}{\Delta P_H}$$



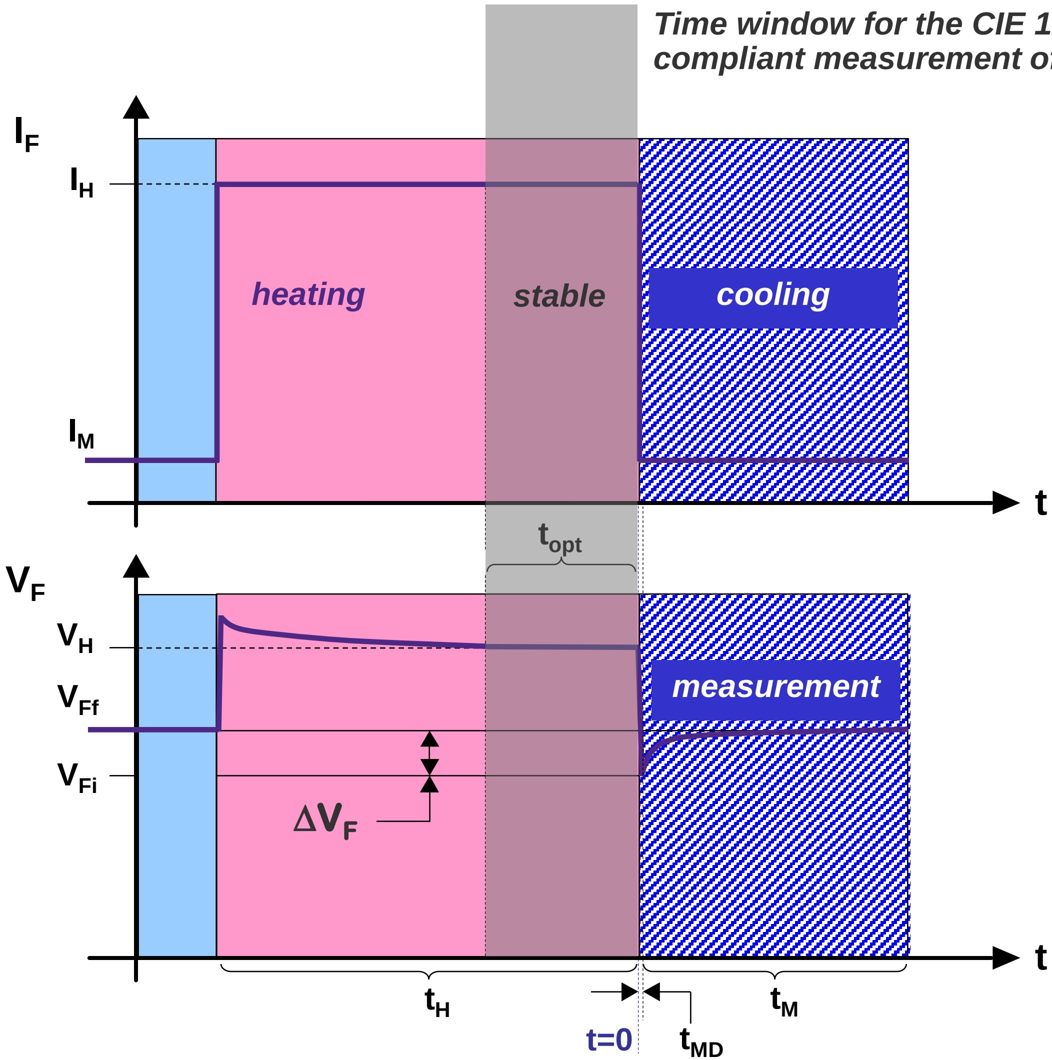
How do we know $\Delta T_J(t)$?

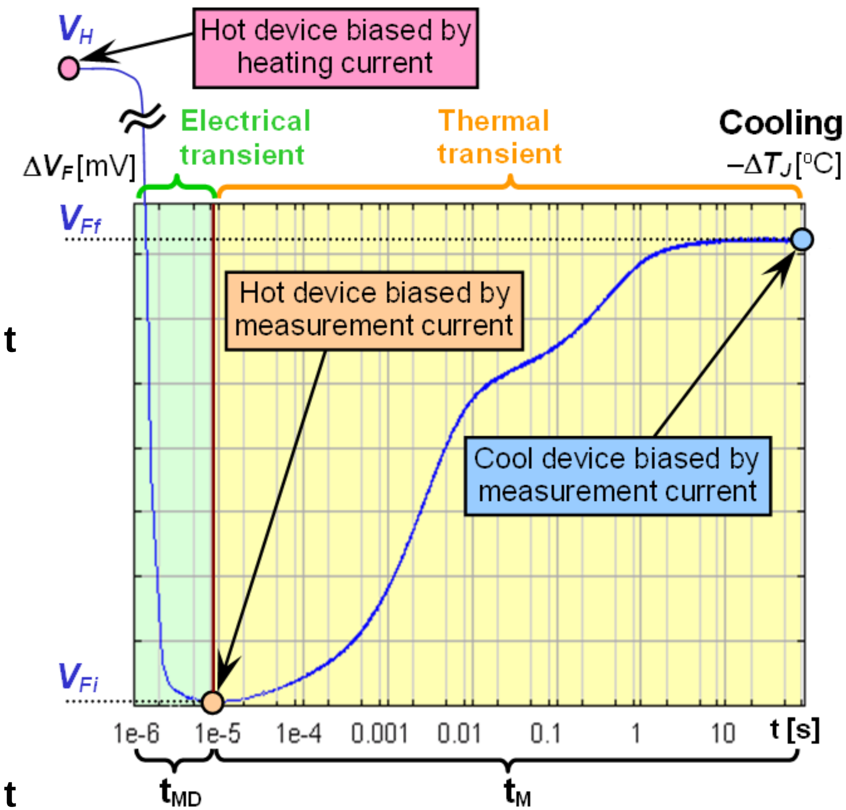
- The LEDs′ forward voltage under forced current condition can be used as a very accurate thermometer
- The change of the forward voltage (TSP – temperature sensitive parameter) should be carefully calibrated against the change of the temperature (see JEDEC JESD51-1 and MIL-STD-750D)
  - In the calibration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



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

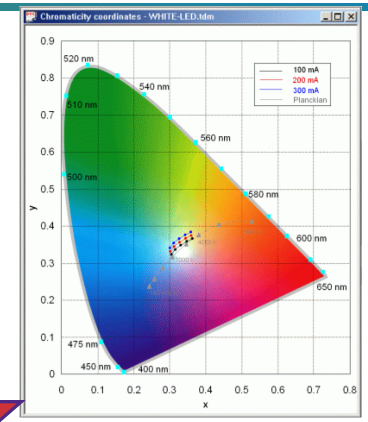
The measurement waveforms

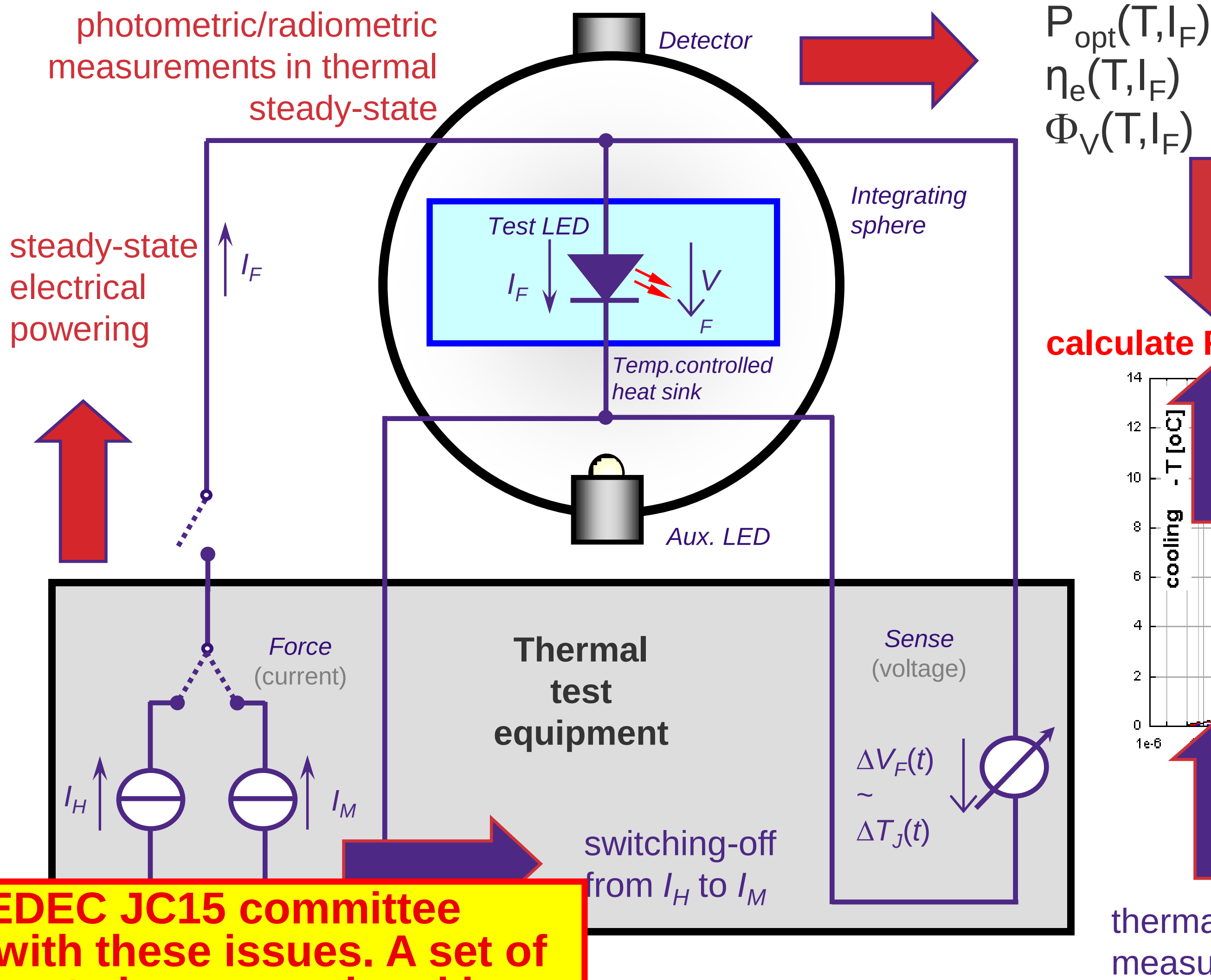


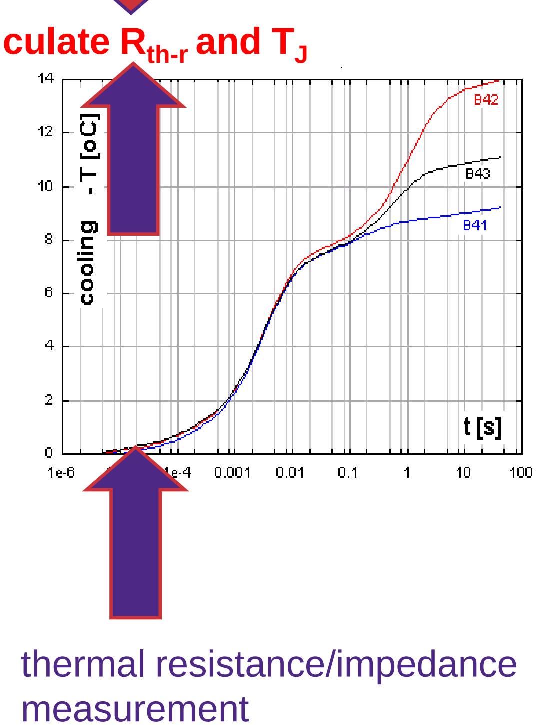


Comprehensive LED testing solution:

CIE 127-2007 compliant photometric & radiometric measurement system





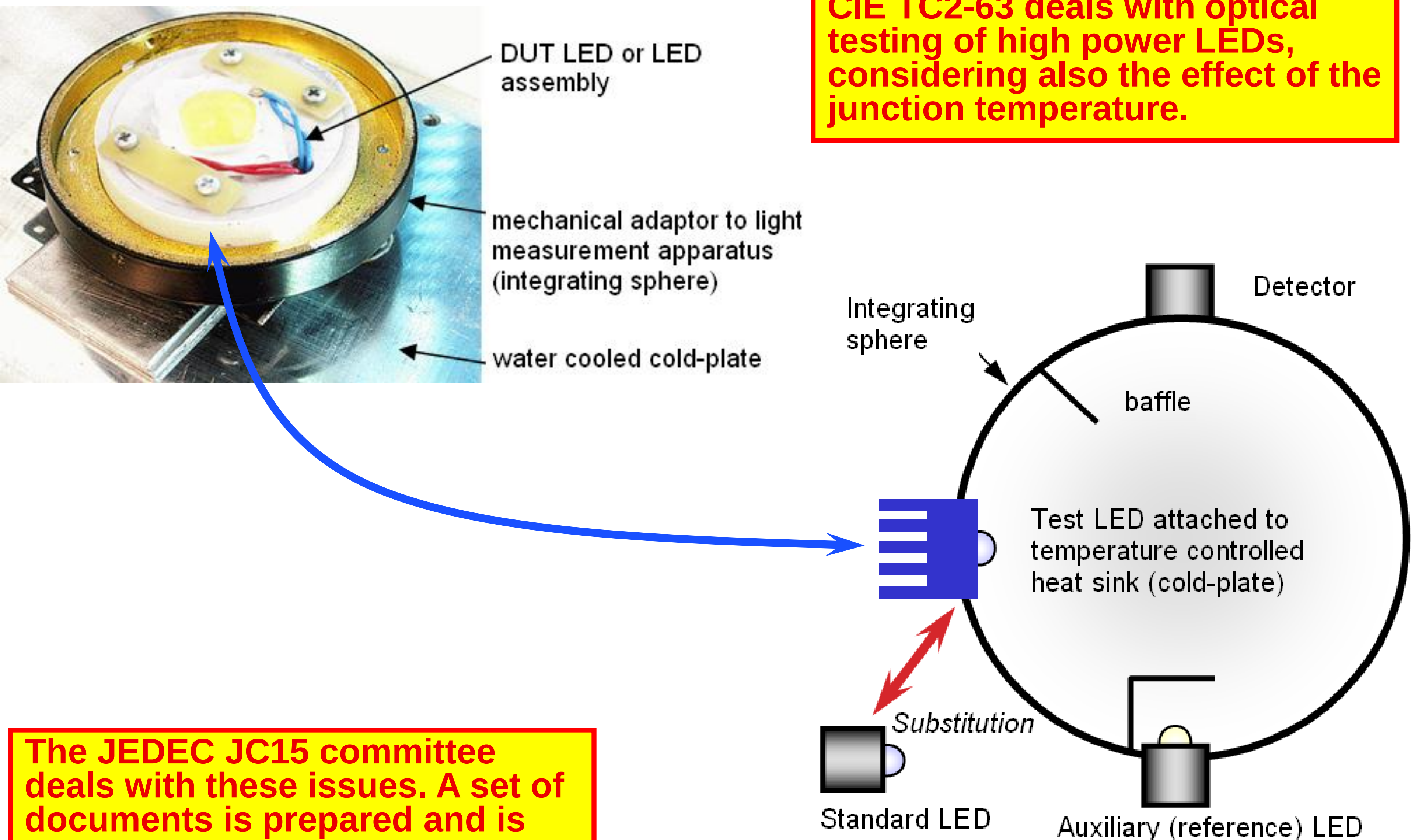


The JEDEC JC15 committee deals with these issues. A set of documents is prepared and is being discussed (how to apply JESD51-1 & CIE 127-2007)

...mpliant thermal measurement system

Some details of the test environment

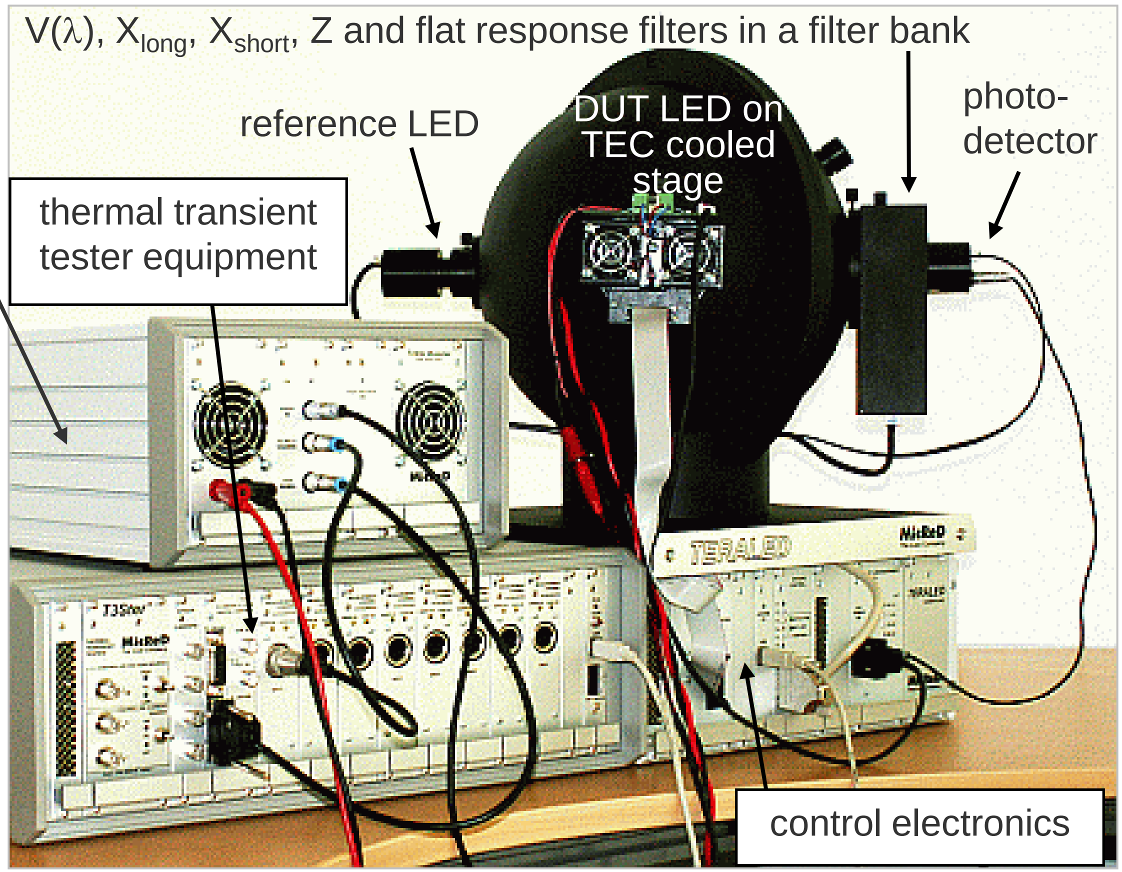
CIE TC2-63 deals with optical testing of high power LEDs, considering also the effect of the junction temperature.



The JEDEC JC15 committee deals with these issues. A set of documents is prepared and is being discussed (how to apply JESD51-1 & CIE 127-2007).

The Mentor Graphics MicReD implementation:

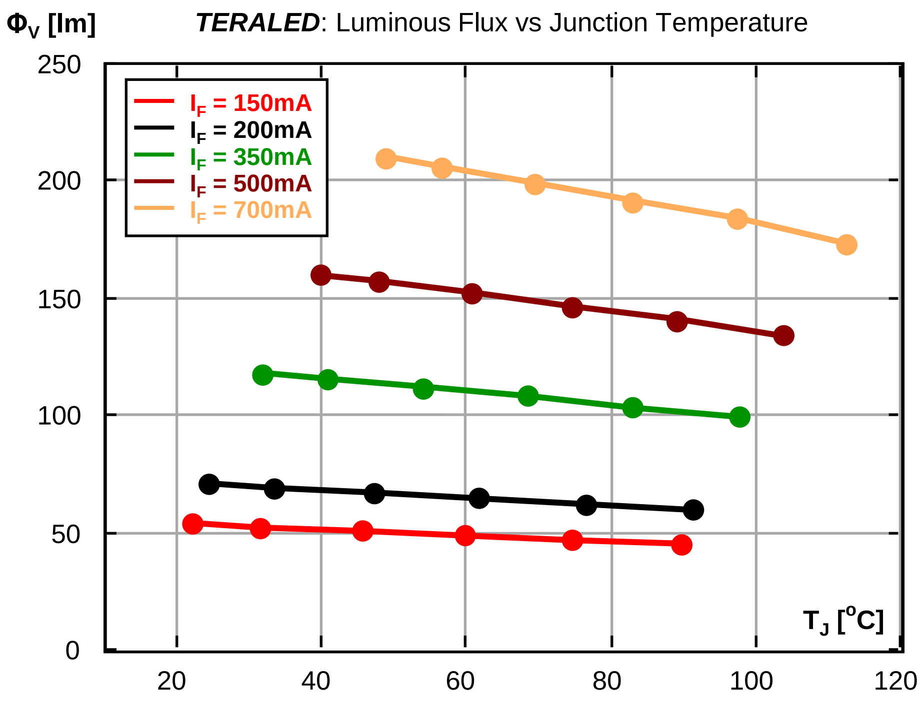
Special LED booster: allows high voltage across a LED line (overall forward voltage can reach 280V – needed for AC mains driven LEDs).



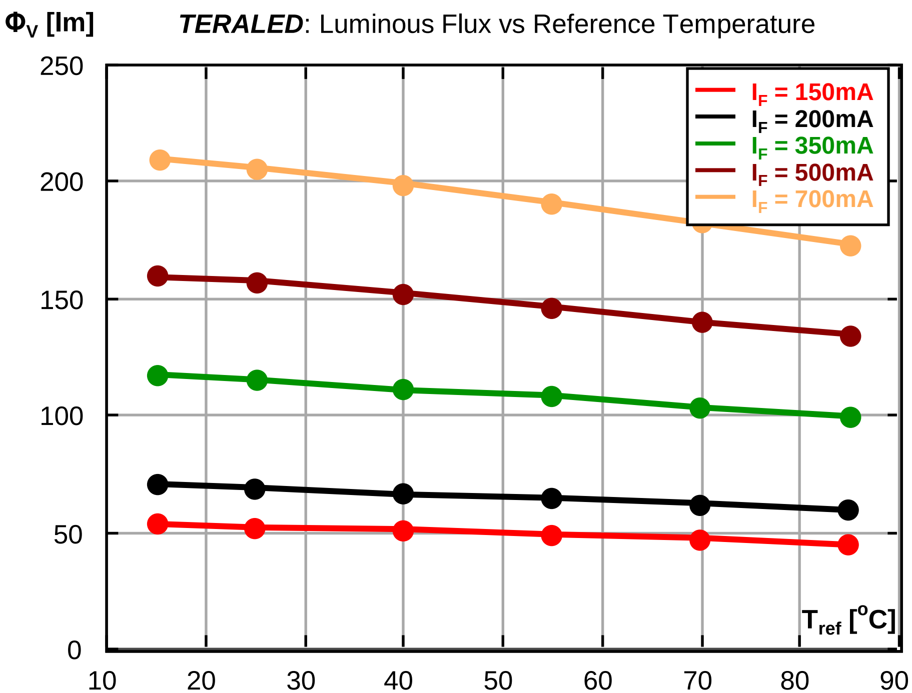
It can be added to the system in a plug&play manner if the voltage of the base tester is not sufficient.

What temperature to report?

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



The JEDEC JC15 committee deals with these issues. A set of documents is prepared and is being discussed (how to apply JESD51-1 & CIE 127-2007)

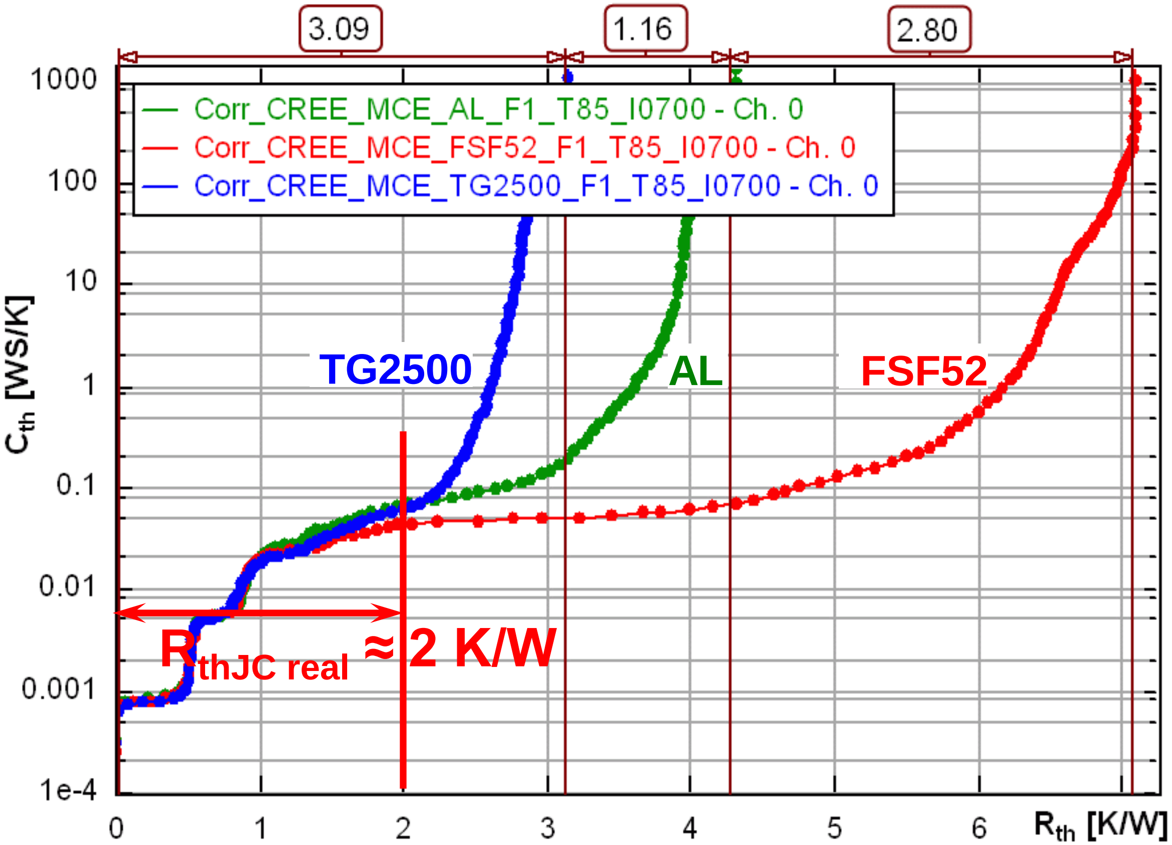


The junction temperature is the one which determines the light output, this is the relevant quantity.

Case study:
10W white LEDs with their thermal properties and light output characteristics as function of forward current and junction temperature

Results for 10W white LEDs

- Measured at 700 mA and 85 ^{o}C
  - Structure functions of 3 samples, power corrected with P_{opt}

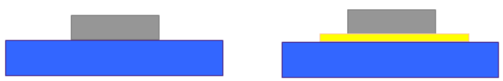


  - R_{thJC} is identified in a way similar to the *transient double interface method*, a new standard: JEDEC JESD51-14

The transient dual interface method for R_{thJC}

- Original idea from 2005, **standard JESD51-14 published in November 2010**
- Change of thermal interface quality at the 'case' surface
- Divergence point in measured structure functions: 'case' surface

package

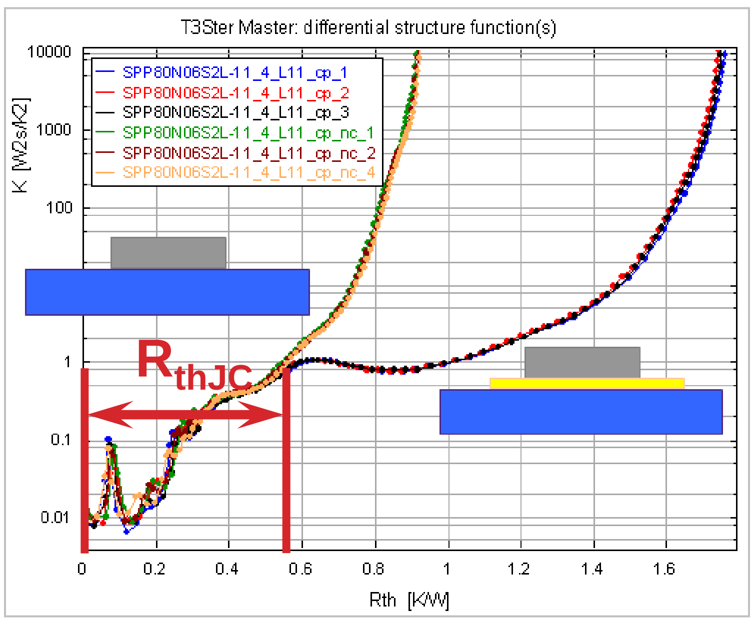


cold-plate

Change at the case: insulator inserted

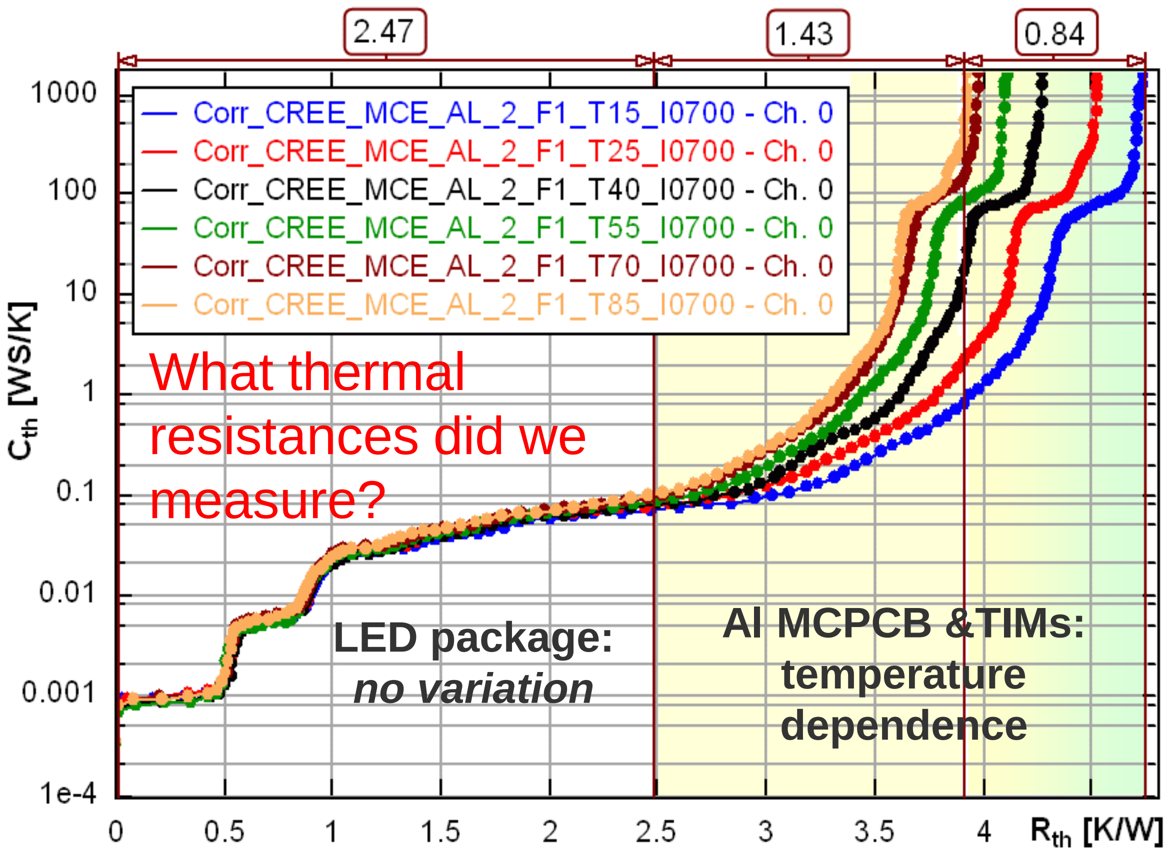
Measurement of 2 setups (2x3 min), ***structure functions***

Dirk Schweitzer - Harvey Rosten Award (24 March 2011)



Results for 10W white LEDs

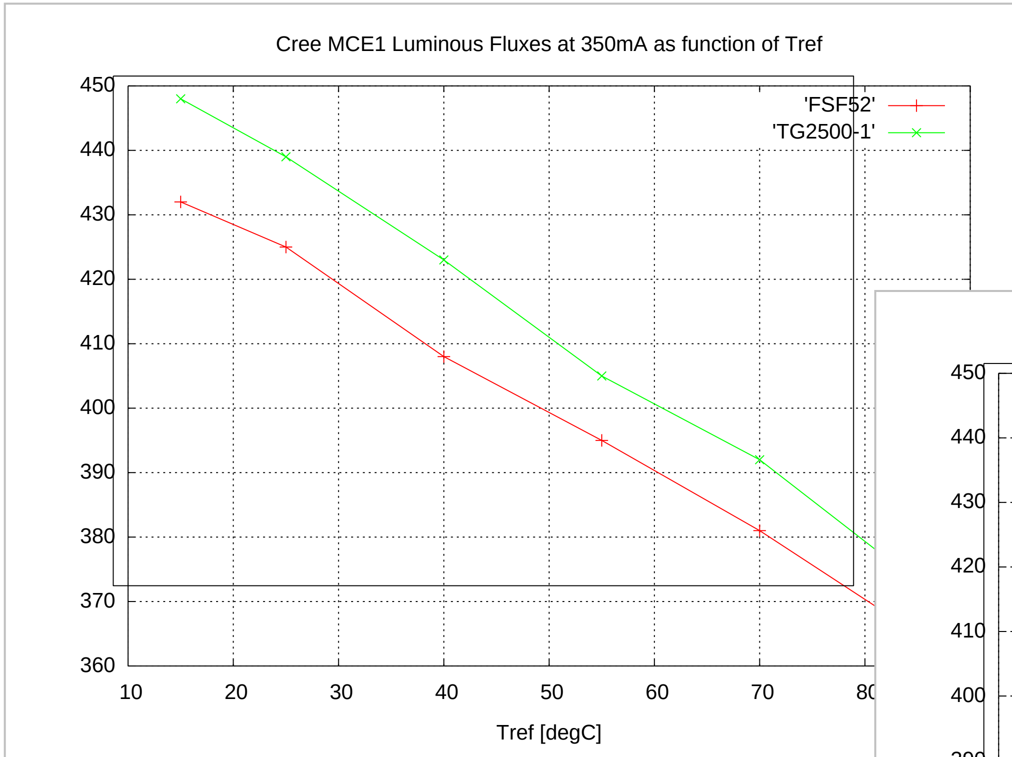
- Measured at 350/700 mA & between 15 ^oC and 85 ^oC
  - Structure functions of sample AL-2, power corrected with P_{opt}



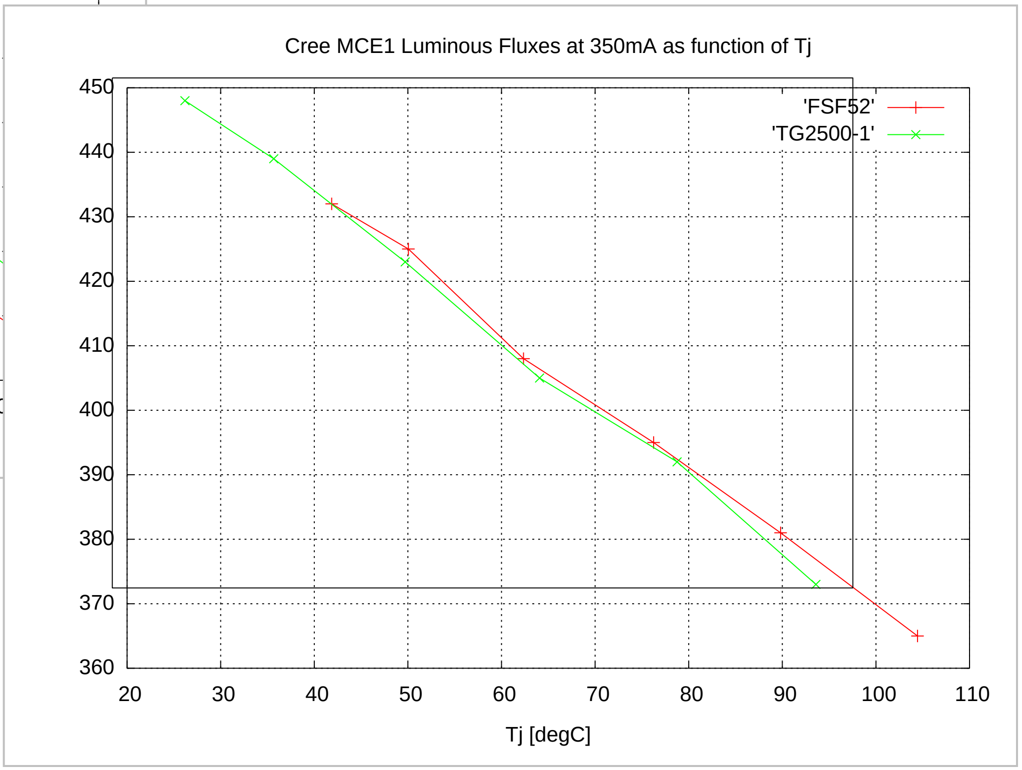
$R_{thJC\text{-}package} + R_{th\text{-}MCPCB} + R_{th\text{-}grease}$ ➔ for "**hot lumen**" estimates

Changes in TIM quality contribute to light output variations

$\Phi_V(T_{ref})$ plots for two cases (I_F=350mA)



$$T_J = T_{ref} + R_{th\text{-}r} \times (I_F \times V_F - P_{opt})$$



Variation of R_{th} means, the device characteristics scaled in reference temperature will be different

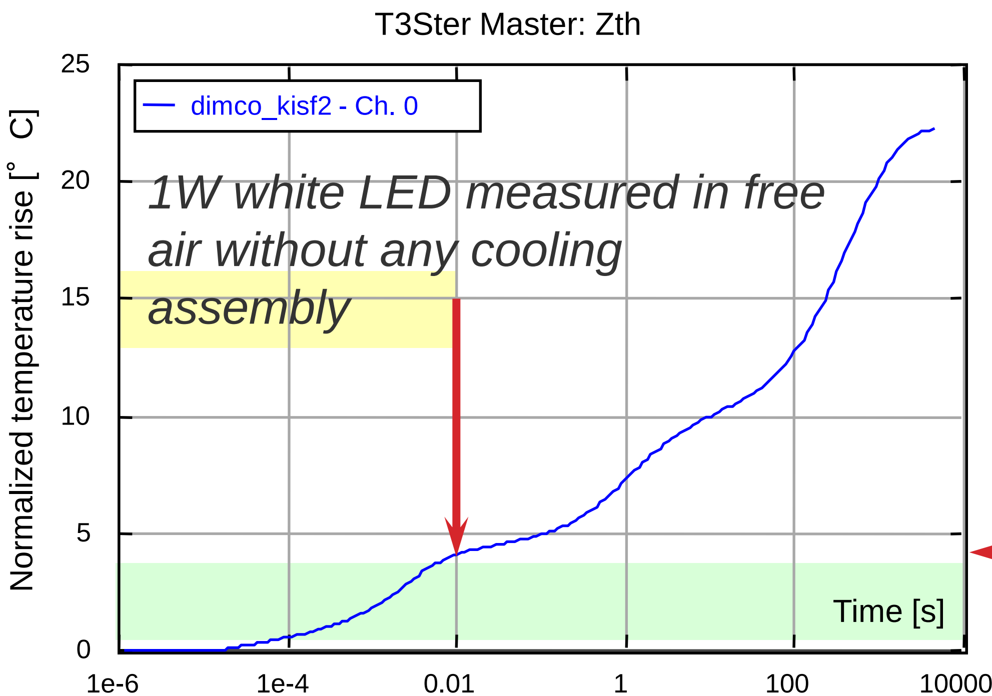
No need for a sophisticated control of the TEC in the integrated sphere

Re-scaling for junction temperature eliminates the effect of the different thermal resistance values

Further problems:
Thermal issues in short-pulse testing
and in LM80 tests,
AC LEDs

Short pulse measurements

- During in-line testing photometric/colorimetric properties are measured with a short pulse
  - $T_J = T_{ref}$ = constant is assumed, ***THIS IS NOT TRUE:***
    In 10 ms significant junction temperature change may take place

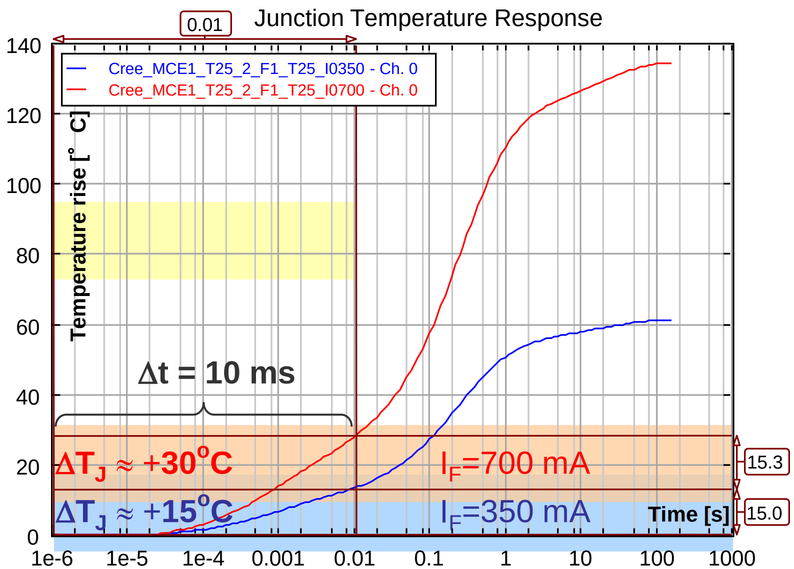


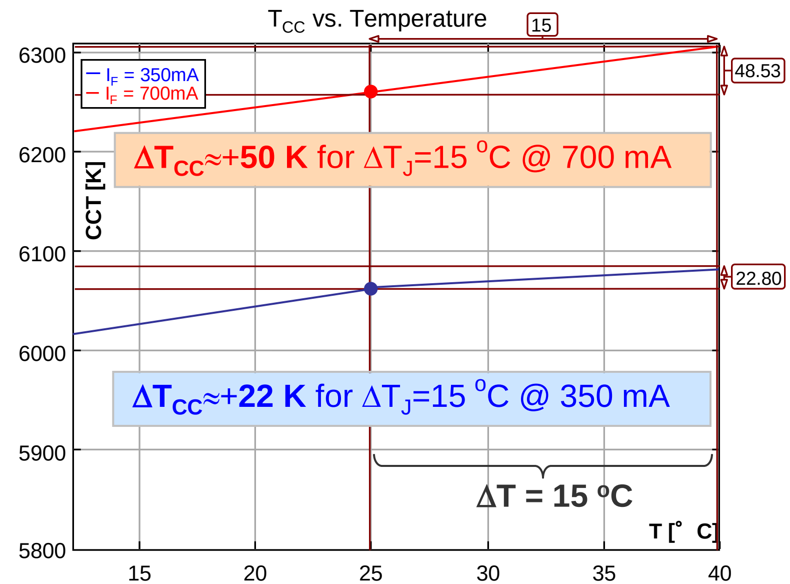
Question is if this causes big problems or not…

During 10 ms T_J changes almost by 5 °C

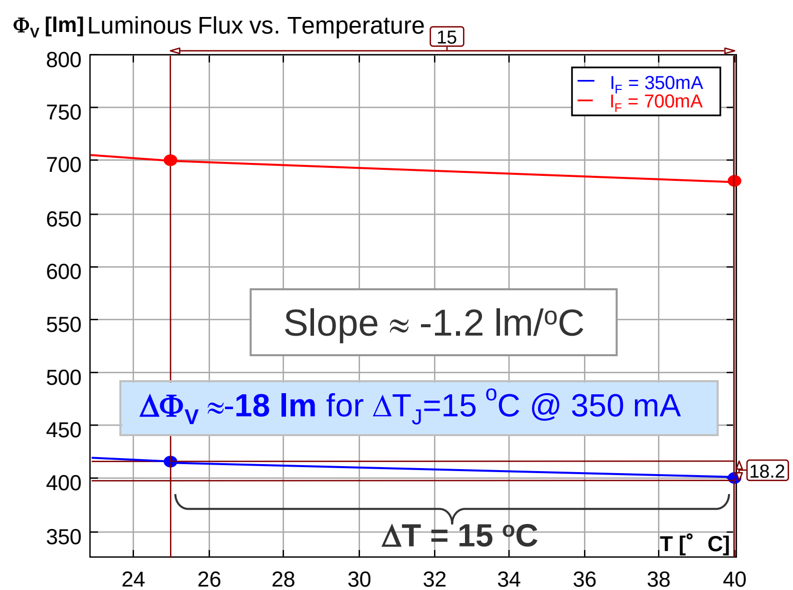
Addressed by CIE TC 2-64

Example: 10W white LED





$P_{heat} \approx$ 3W @ 350mA
$R_{th\text{-}r} \approx$ 20K/W



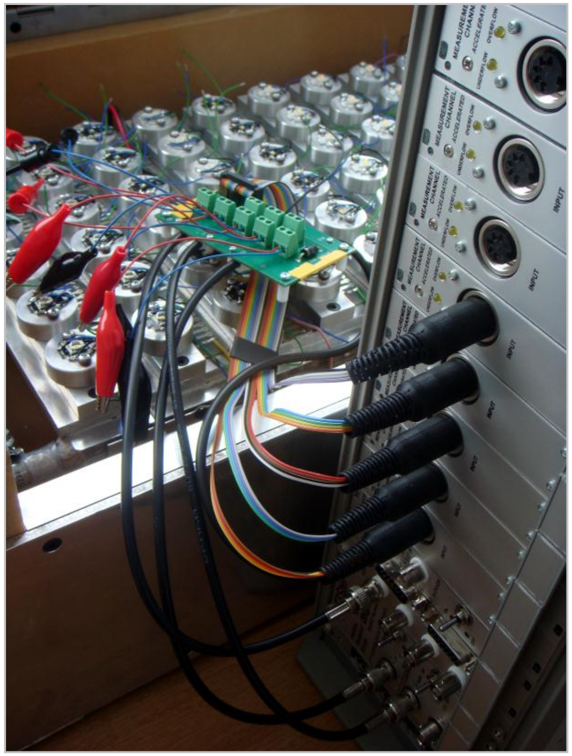
Addressed by CIE TC 2-64

In-situ thermal measurements during LM80 tests

LM80 test chamber with all the LEDs assembled

All measurements are done in-situ to eliminate any R_{th} change which is NOT due to ageing

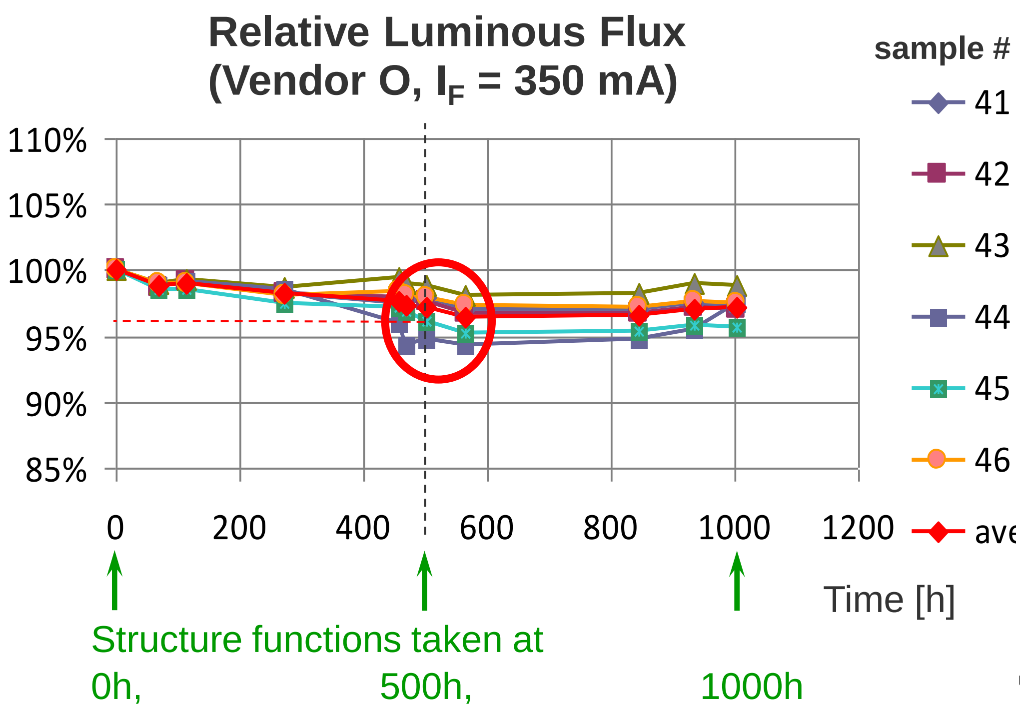
In-situ light output measurement



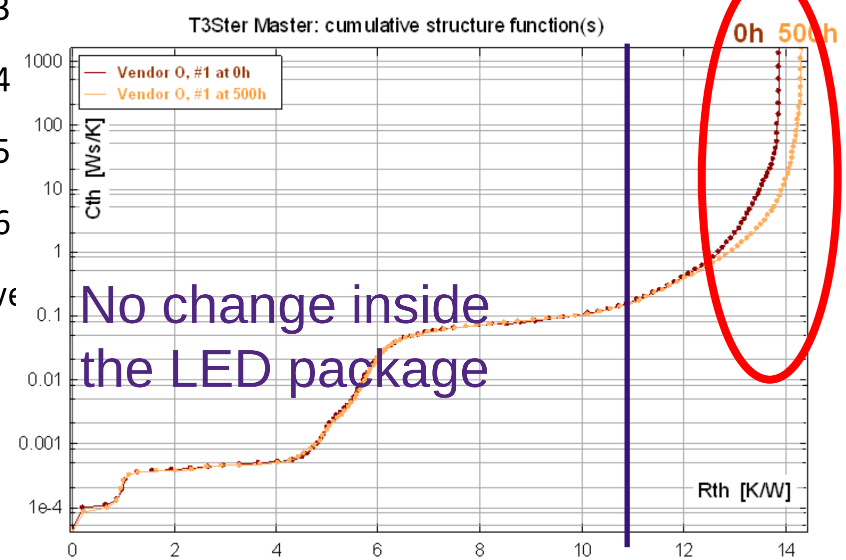
In-situ thermal transient measurement

Recent results from LM80 test of different LEDs

- In cooperation with University of Pannonia, Veszprém (Hungary), prof. J. Schanda's group within the KöZLED project of the Hungarian Goverment



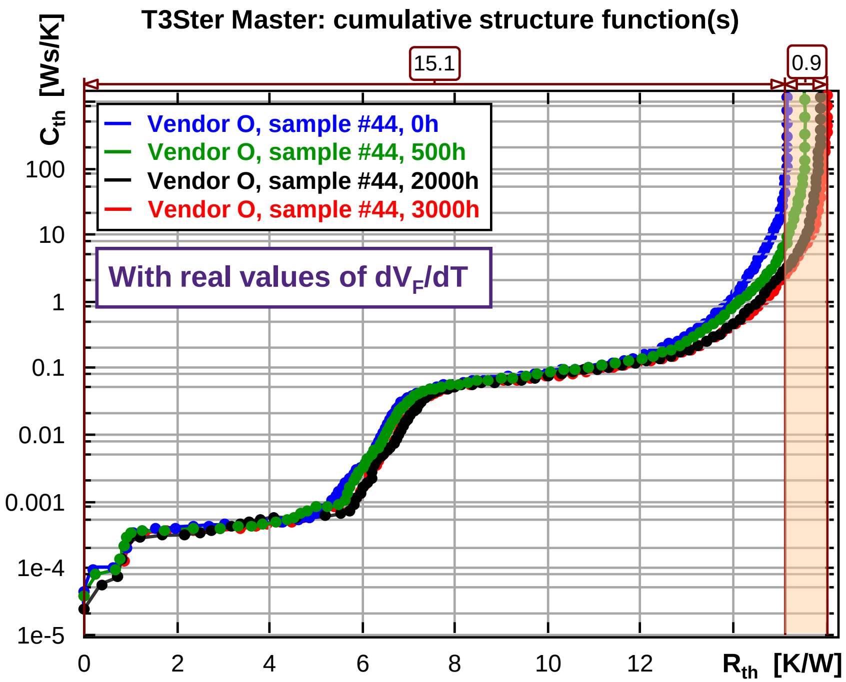
Ligh output drop likely due to increased R_{th} caused by TIM degradation, not by LED degradation



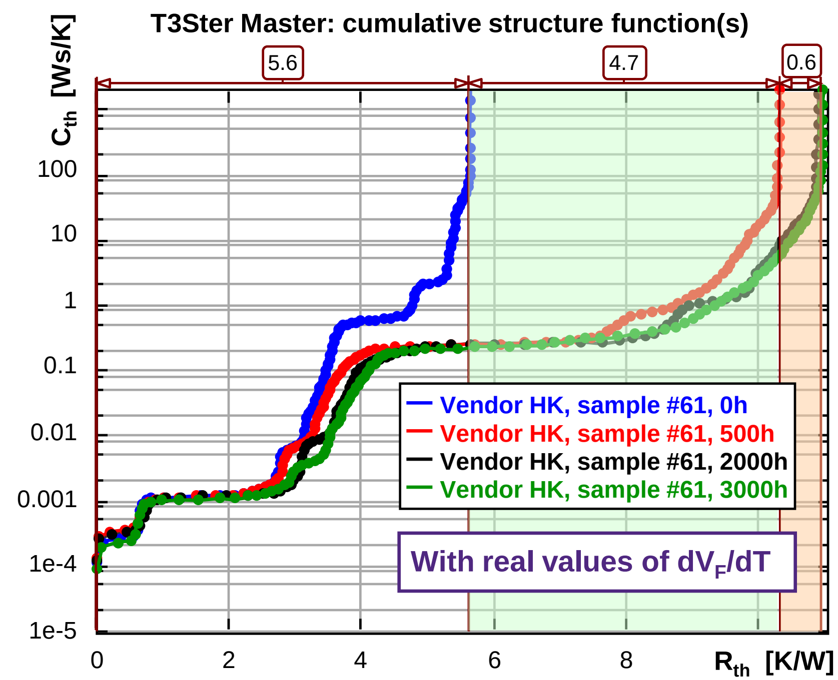
- 8 different kinds of LEDs from 4 vendors, so far 6500h burning time, processing measurement data in progress

Recent results from LM80 test of different LEDs

- Results after 3000h:



TIM ageing: external to the LED – LM80 measurement results must be compensated for this

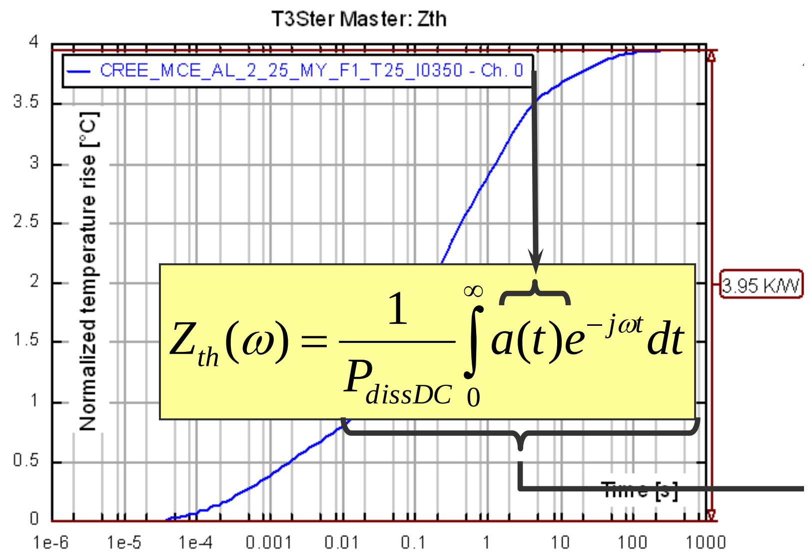


- All HK LEDs have already died

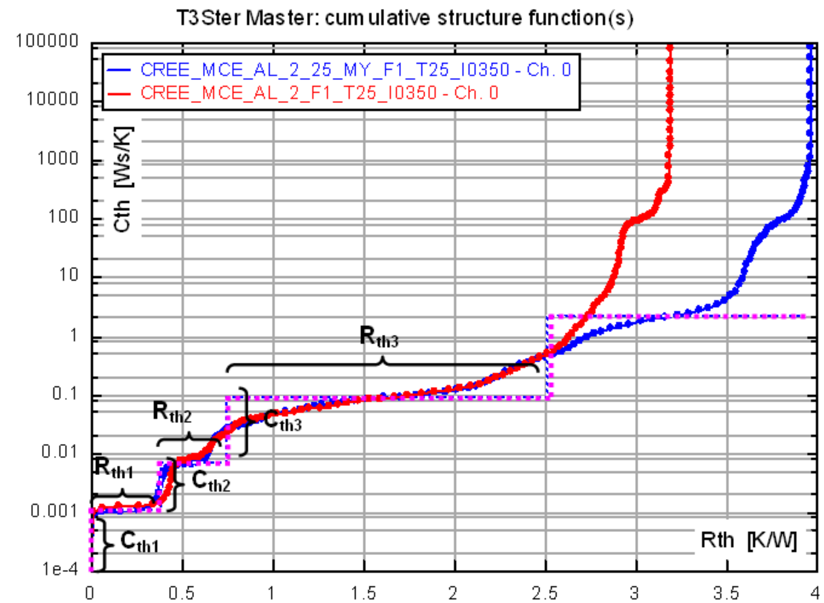
Delemination from the MCPCB: a failure inside the LED assembly, its contribution to light output degradation is part of the LM80 test result

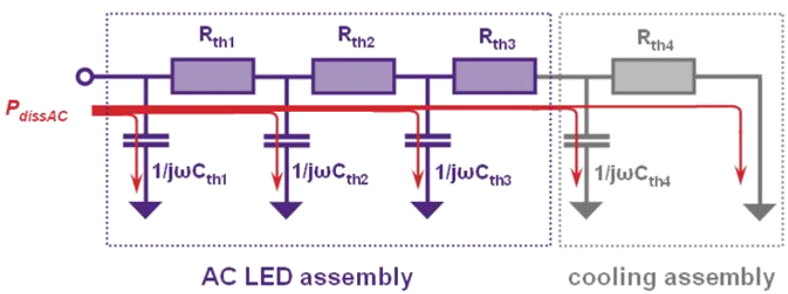
Problems of testing AC LEDs: what "Z_{th}" to use?

- For AC LEDs instead of the classical time-domain representation of Z_{th} we need its frequency domain representation



$$Z_{th}(\omega) = \frac{1}{P_{dissDC}} \int_0^{\infty} a(t) e^{-j\omega t} dt$$





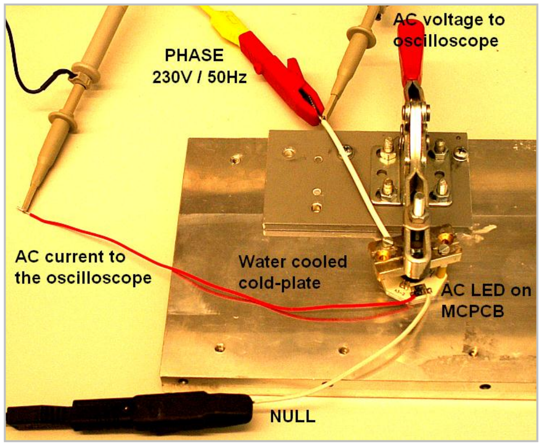
$$Z_{th}(\omega) = \frac{1}{j\omega C_{th1}} \times \left\{ R_{th1} + \frac{1}{j\omega C_{th2}} \times \left(R_{th2} + \left[\frac{1}{j\omega C_{th3}} \times \left(R_{th3} + Z_{th-cooling\_ass} \right) \right] \right) \right\}$$

Problems of testing AC LEDs: dissipation, Z_{thAC}

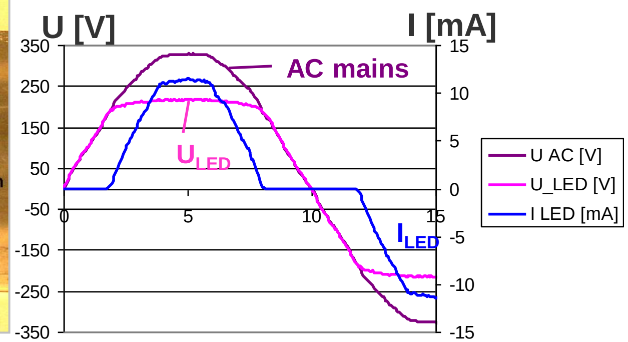
- The AC dissipation for voltage generator driven LED:

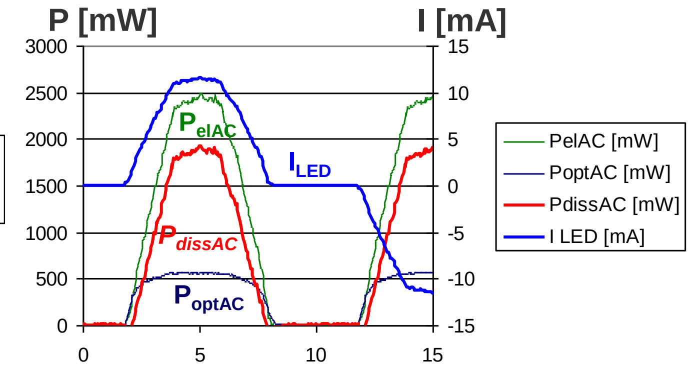
$$P_{dissAC}(\omega) = U_{MAX}^2 \cdot \frac{I_0}{mU_T} \cdot \frac{1}{1!} \sin^2(\omega t) + U_{MAX}^3 \cdot \frac{I_0}{(mU_T)^2} \cdot \frac{1}{2!} \sin^3(\omega t) + U_{MAX}^4 \cdot \frac{I_0}{(mU_T)^3} \cdot \frac{1}{3!} \sin^4(\omega t) + \ldots$$

Multiple frequencies

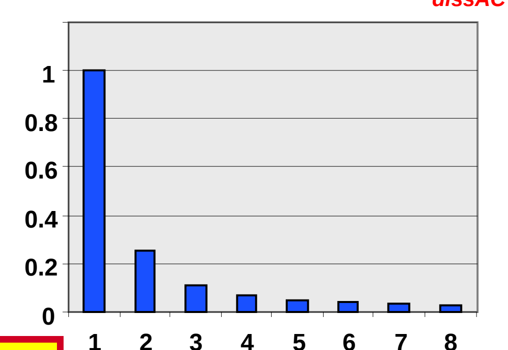


SSC Archie driven by 50Hz mains

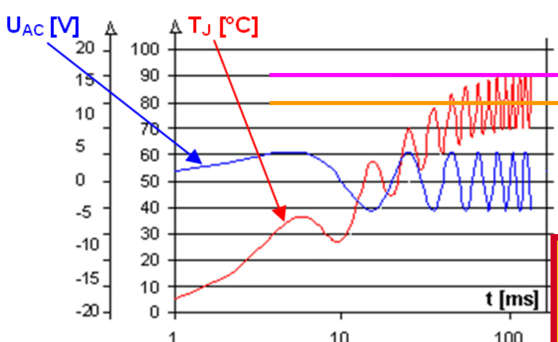




The first 8 harmonics of P_{dissAC}



- How to define a single number thermal metric?



$Z_{thAC\text{-}max} = T_{JAC\text{-}max} / P_{dissAC\text{-}mean}$

$Z_{thAC\text{-}mean} = T_{JAC\text{-}mean} / P_{dissAC\text{-}mean}$

See details in our paper in the LED session of SEMI-THERM

Conclusions

- Brief overview of standardization needs and recent activities was given
- Measurement setup for consistent measurement of thermal and light output metrics of power LEDs was shown
  - Based on existing standards (JEDEC JESD51-1, CIE 127-2007)
  - Therefore with some new measurement guidelines it is easily implemented
    - Such guidelines are being developed by the JEDEC JC15 Committee on Thermal Standards of Packaged Semiconductor Devices
- Merits of such a combined thermal/radiometric LED testing station were shown by a case study
  - Importance of changing properties of thermal interface materials and their effect on light output was shown
- Combined thermal transient and photometric measurements suggest that the constant junction temperature assumption in short pulse in-line testing is not valid
- To eliminate effect of variations (ageing) of TIM during LM80 tests, *in-situ* measurements are suggested, combined with thermal transient measurements
- Problems related to the “AC thermal impedance” as a single number thermal metric for AC mains driven LEDs were raised