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WÜRTH ELEKTRONIK

LEDs – an introduction

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Wurth Elektronik Benelux

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The Würth Group – A strong family

WÜRTH ELEKTRONIK

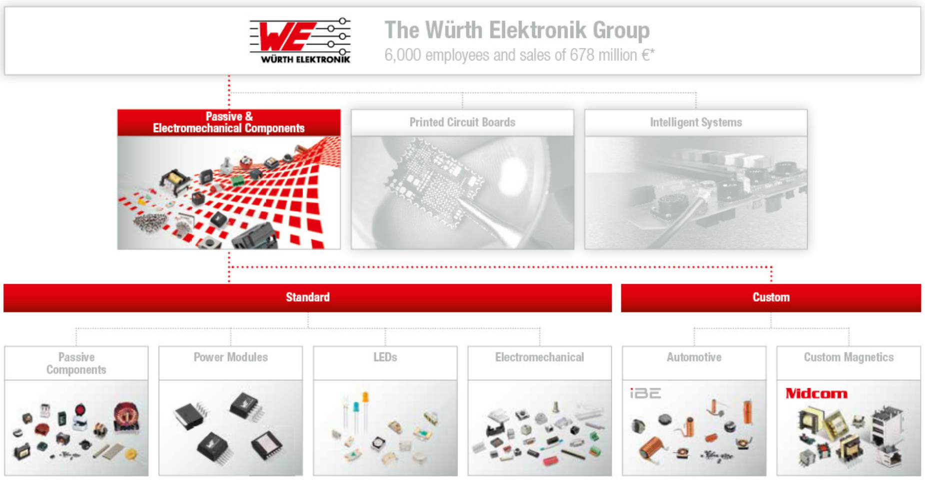
The Würth Group

- Over 65,000 employees*
- 9.98 billion € sales*
- 400 companies*
- in 80 countries*
- Rating A outlook stable (Standard & Poor's and Fitch)*
- Privately owned

WÜRTH GROUP

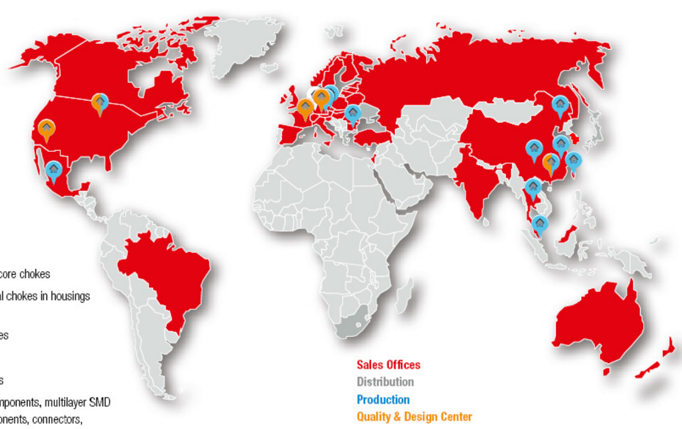
* Preliminary figures 2012

The Würth Elektronik Group



* 2012

Globally available. Locally present.



- **Germany:** Snap ferrites, power elements and rod core chokes
- **Czech Republic:** Toroidal chokes in housings and rod core chokes
- **Bulgaria:** Rod core chokes
- **USA:** Transformers
- **Mexico:** THT components
- **China:** THT and SMD components, multilayer SMD components, LTCC components, connectors, transformers, rotary, tact & dip switches
- **Taiwan:** TVS diodes, varistors, multilayer components, varistors, Power Modules, connectors and switches
- **Malaysia:** Power Modules
- **Thailand:** Inductors

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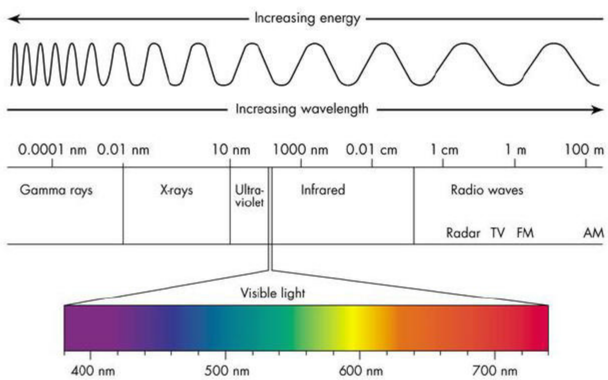
LED Introduction

- **LED – Light-Emitting Diode**
- **Light – electromagnetic radiation**
  - **Wavelength (frequency)**
  - **Energy**
  - **Visible spectrum**
  - **Non visible – UV, IR**
  - **Radiofrequency**
  - **Radiation – Gamma and X-Ray**

Electromagnetic Spectrum



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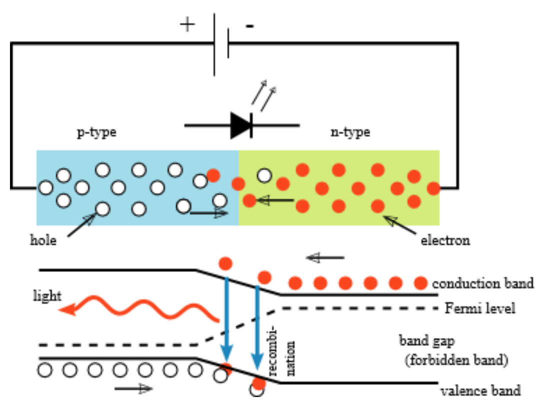
LED Introduction

- **LED – Light-Emitting Diode**
- **Diode**
  - **P-N junction**
  - **Recombination energy - wavelength**
  - **Recombination of carrier in the Active region**
  - **Active region – Quantum Wells structure**
  - **Active devices – current driven**

Diode Scheme



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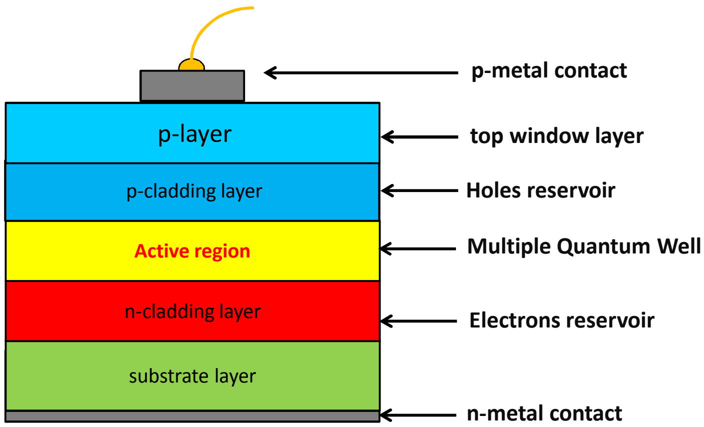
LED – The diode

- Electrical device that converts electricity to light



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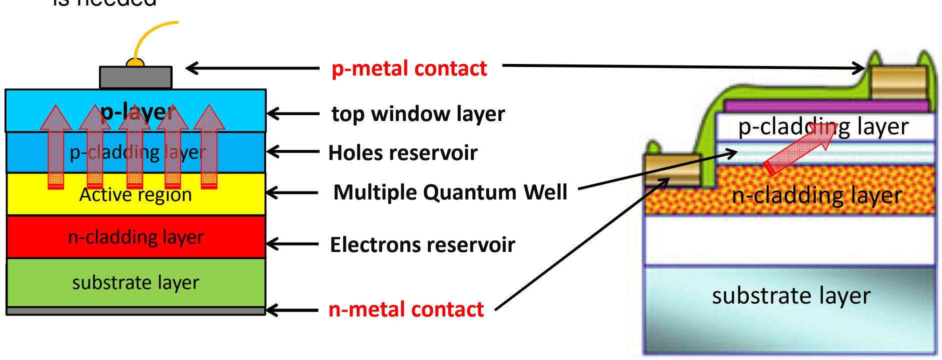
LED Chip designs

Vertical Design
- Better current distribution
- Better light output
- Harder to produce – good substrate layer is needed

Horizontal Design
- Easier to produce
- Low thermal conductivity – due to substrate
- Substrate from standard material



Material – Color – Turn on Voltage

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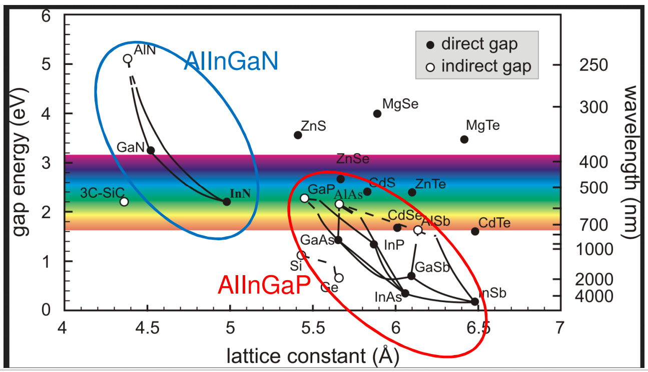
- **AlInGaN – from Deep UV to 530nm**
  - **Green (530nm), Blue, Deep Blue, UV** **- Turn on voltage ~ 3.2V**
- **AlInGaP – from 550 to mid IR range (1100nm)**
  - **True Green (550nm), Yellow, Amber, Red, IR** **- Turn on voltage ~ 2.0V**



Optical : Wavelength and spectrum

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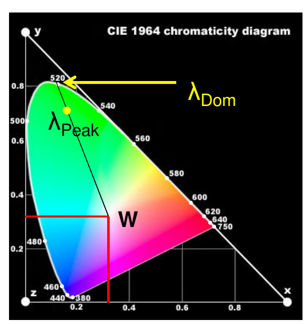
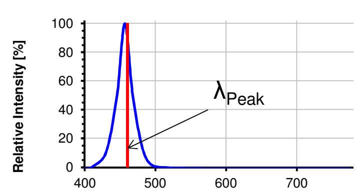
- **LED spectrum spans over a few wavelengths**
- **Specifications:**
  - λ_{Peak} – wavelength with maximum intensity
  - $\lambda_{Dominant}$ – wavelength of the eye perception, equal to a monochromatic light (single wavelength)
- **How to find $\lambda_{Dominant}$**
  - The monochromtatic perception of the eye on the border of the CIE diagram
  - Cross point of the W- λ_{Peak} line
  - W is the white point with coordinates W(1/3,1/3)





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Optical : Light intensity

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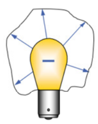
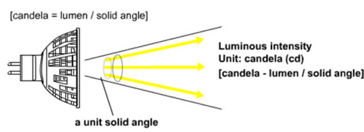
- **Total flux –** lumen **(lm)**
  - **CIE 127:2007 – measured in an Integrating sphere**
- **Intensity -** candela **(cd)** = lumen / solid angle **[lm/sr]**
  - **According to CIE 127:2007 – I_{LEDB} standard**
- **Illuminance –** lux **(lx)** = lumen / square meter **[lm/m2]**
  - Not an LED parameter – used for General lighting standards

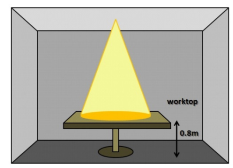
Lumen [lm]



Candela [cd]



Lux [lx]



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Efficacy of LEDs

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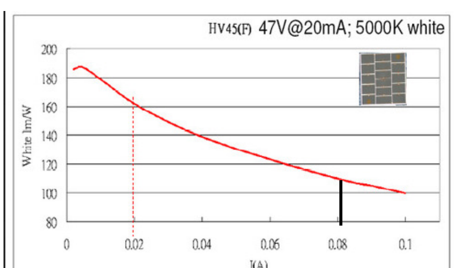
- **Efficacy of led – Conversion of electrical power into light**

$$\text{Efficacy: } \frac{P_{out}}{P_{in}} = \frac{Optical\ output}{V*I}$$

- Optical output power – How much light come out from the LED
- Total input power – Electrical power W = V·I

- Typical Efficacy curve
  - Peak at low current
  - Decrease up to 100% with current Increase
  - **Typical values**



Record breaking 162 lm/W 5000K is achieved by 45mil blue HV-LED

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Optical: White light

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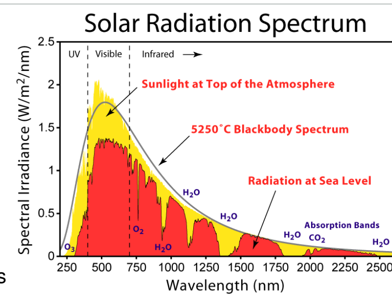
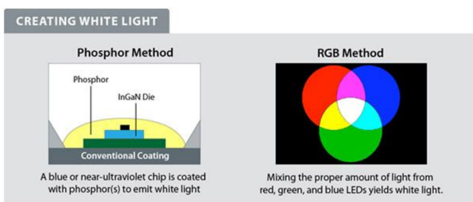
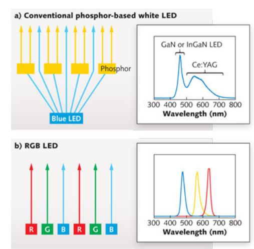
- **Mixture of different wavelengths**
- **Example spectrum of the sun**
- **How to create this with LEDs**
  - **RGB mixing**
    - Better mixing
    - Need a mix distance – due to separation of sources
  - **Blue LED and wavelength convertor**
    - Lower efficiency, cheap and easy to produce







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Optical : White light parameters

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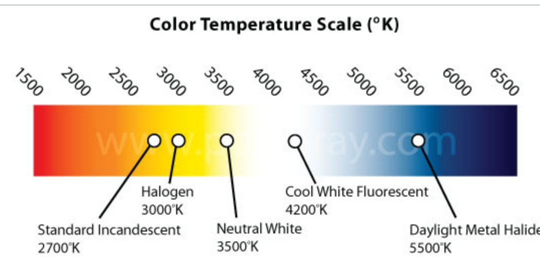
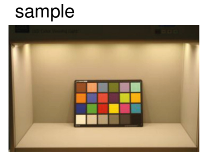
- **Correlated Color Temperature**
  - Perception effects achieved by using different color temperatures
  - Sunlight ~ 5500K
  - Moonlight ~ 4000K
  - Incandescent light bulbs ~ 3000K

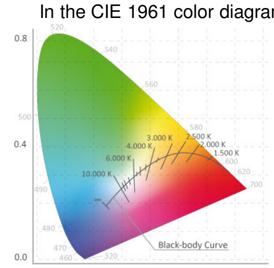


- **Color Rendering Index**
  - Ability of light to show the real colors of a illuminated object
  - Comparison of emission light to a black body radiation
  - Test compared to the illumination of a 8 color sample defined by CIE(2004)
  - Typical LEDs CRI > 80

CRI Test colors sample



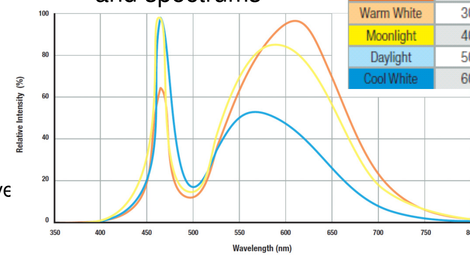
Black body radiation curve
In the CIE 1961 color diagram



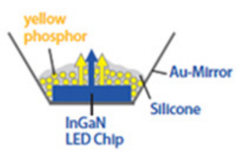
Wurth Electronic white LEDs

- **Phosphor conversion –**
  - Warm white - $Ca_2Si_5N_8:Eu^{2+}$ (SNEu)
  - Cold white - $Y_3Al_5O_{12}:Ce$ (YAG:Ce)
  - Mixture of both for different CCT
- **Two designs**
  - PLCC – low power LED, silicon resin with phosphor
  - Ceramic – high power LED, phosphor thin laye on top of led

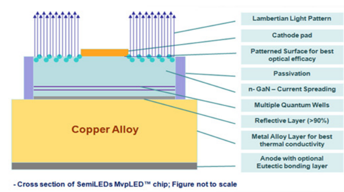
Würth CCT selection and spectrums



Emitting color	CCT (K)
Sunrise	2700
Warm White	3000
Moonlight	4000
Daylight	5000
Cool White	6000



Silicone resin model



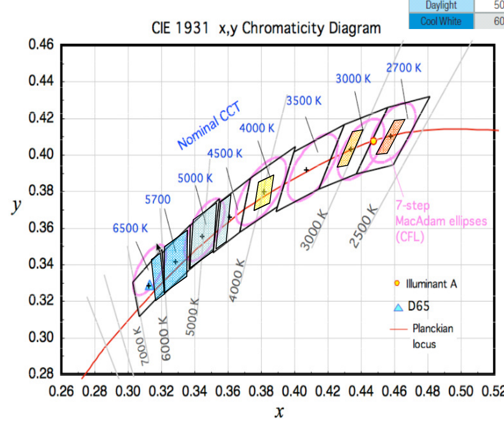
Phosphor thin layer on surface

CRI index of Wurth LEDs
>80 / typ. 85

Binning definitions

- **Standard binning defined by ANSI C78.377A and compliant with Energy Star**
  - Black lines – standard CCT color bins
  - MacAdams ellipses correspond to Energy star Fluorescent lamps binning
  - **MacAdams ellipses – regions with color undistinguishable for human eye**
- **WE bins for every CCT**
  - Ceramic bins –WE offers more accurate bins compared to others
  - PLCC bins – comparable to standard CCT color bins

Emitting color	CCT (K)
Sunrise	2700
Warm White	3000
Moonlight	4000
Daylight	5000
Cool White	6000



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Binning definitions

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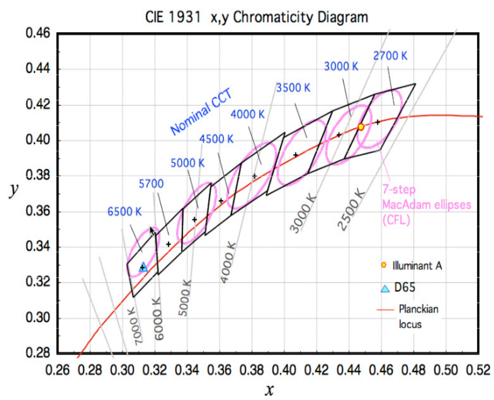

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MacAdam ellipses - Definition

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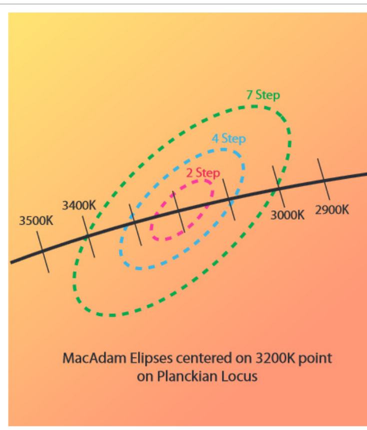
- **MacAdam - step ellipses**
  - **“Step” = standard deviation**
- ANSI recommends - Lamp manufacturers to stay in the 4-step MacAdam ellipses
- WE needs to compare to ANSI C78.377A 4-step MacAdam ellipses if the binning lies within standard borders
  - Ceramic are comparable to 4-step(only warm colors) and 7-step)(cold colors)
  - PLCC are comparable to 7-step



MacAdam ellipses - Definition

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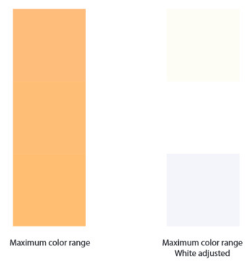
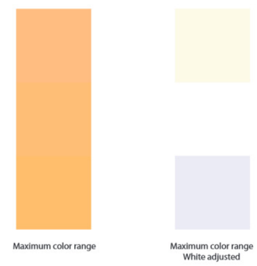
MacAdam - step ellipses deviation
"Step" = standard deviation



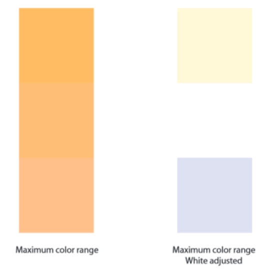
2 Step MacAdam Ellipse Color Variation

Figure 6 – White color variation at 3200K: 2-step



4 Step MacAdam Ellipse Color Variation

Figure 5 – White color variation at 3200 K: 4-step



7 Step MacAdam Ellipse Color Variation

Figure 4 – White color variation at 3200 K: 7-step

WE chromaticity performance

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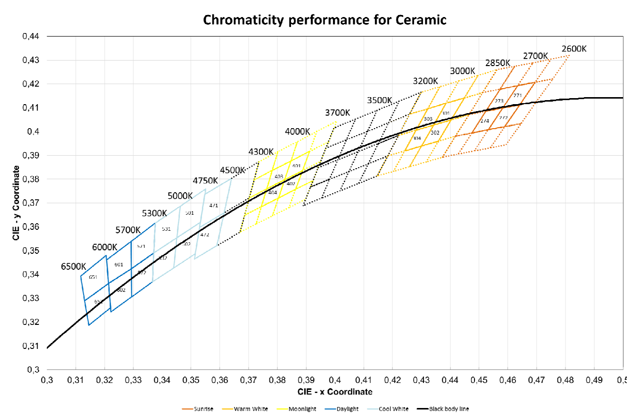
WE bins for available CCT

Ceramic bins –WE offers smaller bins compared to other competitor (solid lines)

PLCC bins – comparable to standard CCT color bins(dashed lines)

Emitting color	CCT (K)
Sunrise	2700
Warm White	3000
Moonlight	4000
Daylight	5000
Cool White	6000



Power output and thermal management

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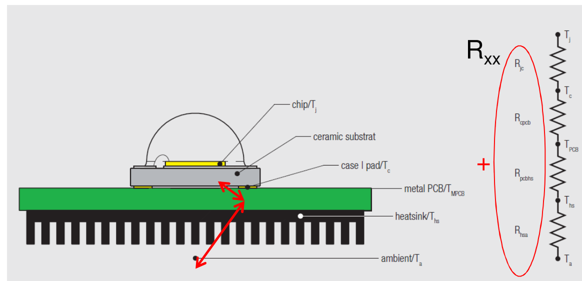
- **Thermal resistivity – defines how temperature generated in the chip is released in the ambient**
- **Higher resistivity – warmer chip**

- Low power LEDs < 0.5W
  - Low thermal specifications
  - Low luminescence output
- High power LEDs > 1W
  - High thermal flows
  - Sensitive to thermal design
  - High luminescence output



$$T_j = T_a + R_{ja} * P_{Diss}$$

T_j – junction temperature
T_a – ambient temperature
$R_{j\text{-}s}$ – thermal resistivity between junction and pad
$R_{s\text{-}a}$ – thermal resistivity between pad and ambient
$R_{j\text{-}a} = R_{j\text{-}s} + R_{s\text{-}a}$ – thermal resistivity of the whole package

Derating curve and thermal management

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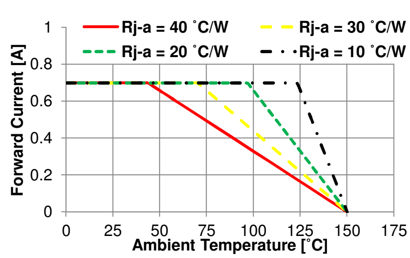
- Understanding the Derating curve
  - **Link between maximum forward current and maximum ambient temperature**

$$T_j = T_a + R_{ja} * P_{Diss}$$
$$P_{Diss} = V_F * I_F$$
$$I_F = \frac{T_j - T_a}{R_{ja} * V_F}$$



Constant parameters:
$R_{j\text{-}s}$ = 8-10 K/W
V_F – depends on material
T_j – maximum allowed junction temepráture

Maximum driving current depends on $R_{j\text{-}a}$ - good thermal conductivity design of the structure is needed

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Thermal management

- **Link between junction temperature and ambient temperature**

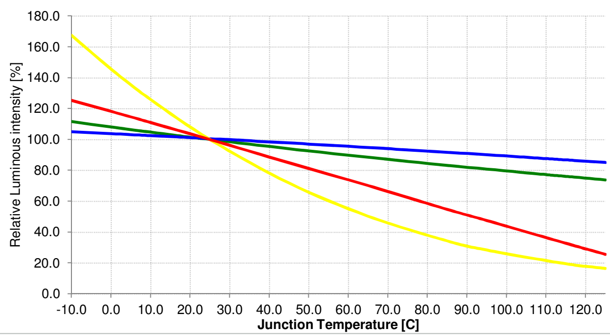
$T_j = T_a + R_{ja} * P_{Diss}$

- **Luminous intensity, Wavelength and Forward voltage depend on T_j**
  – Efficiency losses up to 80%
- **Low junction temperature is important for efficient LED work**

Thermal design for predefined operation conditions:

- Constant operating current
- Constant operating voltage
- Constant ambient temperature

- **Good thermal conductivity design is important to support higher efficiency output.**



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