Measurements of thermal resistance of power LEDs

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A short history

- 1962 – first LED emitting red light
- 1968 – first LED emitting green light
- 1981 - first LED emitting blue light
- 1994 - first power LED emitting white light
- Nowadays
  - the dynamic development of solid-state light sources
  - legal regulations supporting to spreading the LED lighting

Why the great interest of power LEDs is observed?

- 20-30% of the electrical energy produced in the world is used up on lighting
- Power LEDs attain high values of the luminous efficiency (above 200 lm/W) – the electrical energy saving
- LEDs do not contain mercury
- High outlays in EU, U.S.A. and Australia on the development of the power LED technology

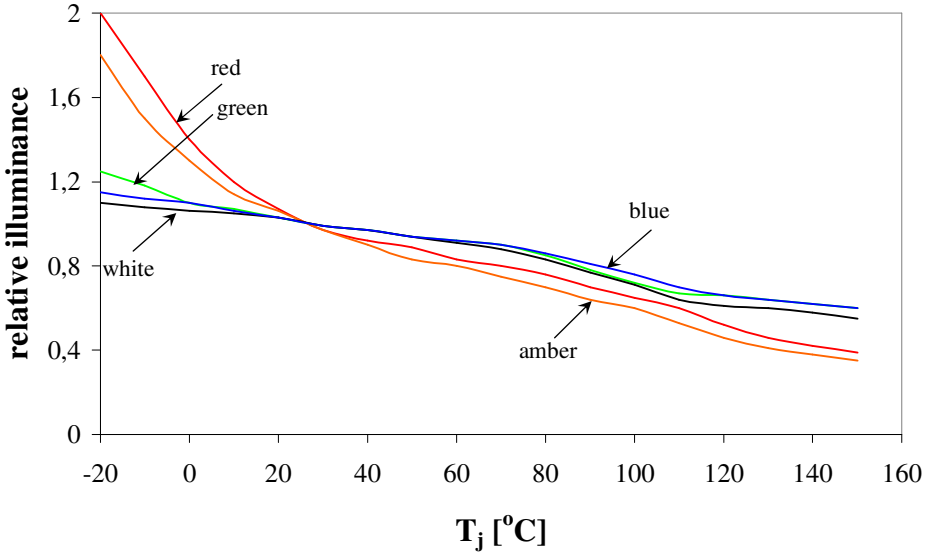
Advantages of LED lighting

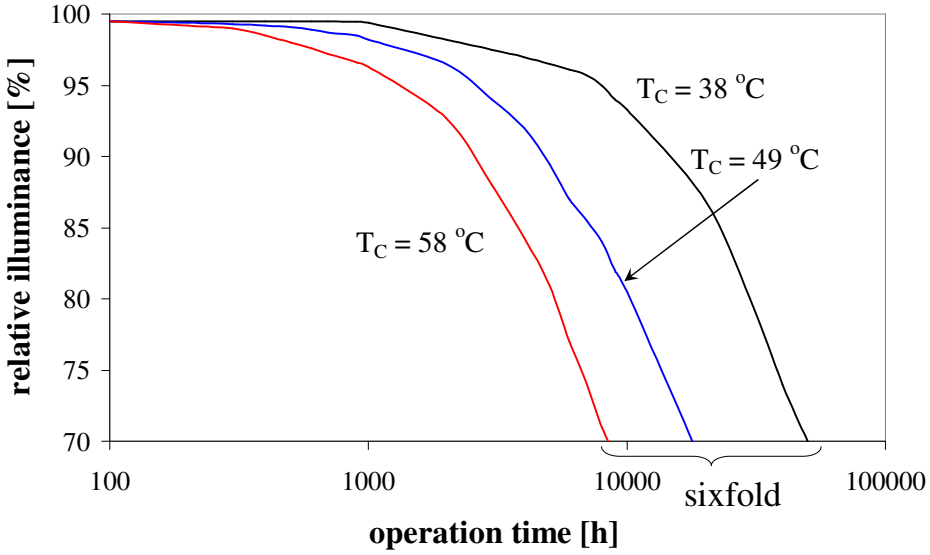
- Spectrum of emitted light similar to solar spectrum,
- Easy selection of the colour temperature of emitted light,
- The low (safe) supply voltage,
- The high resistance on mechanical shocks,
- The high watt-hour efficiency (35 – 50%),
- The long life time (up to 50 000 h),
- Small dimensions,
- Easy control of the brightness of emitted light.

Disadvantages of LED lighting

- Low value of the luminous flux emitted by the single LED,
- The necessity of the use of the dedicated power supply,
- Strong influence of temperature on characteristics and parameters of LEDs,
- A decrease in the value of emitted luminous flux in the function of time,
- The unfavourable influence of LED lamps on the quality of the electrical energy in the line,
- The small angle of the emission – the necessity of the use of dispersing lenses,
- Low value the admissible reverse voltage,
- Necessity of using the cooling system

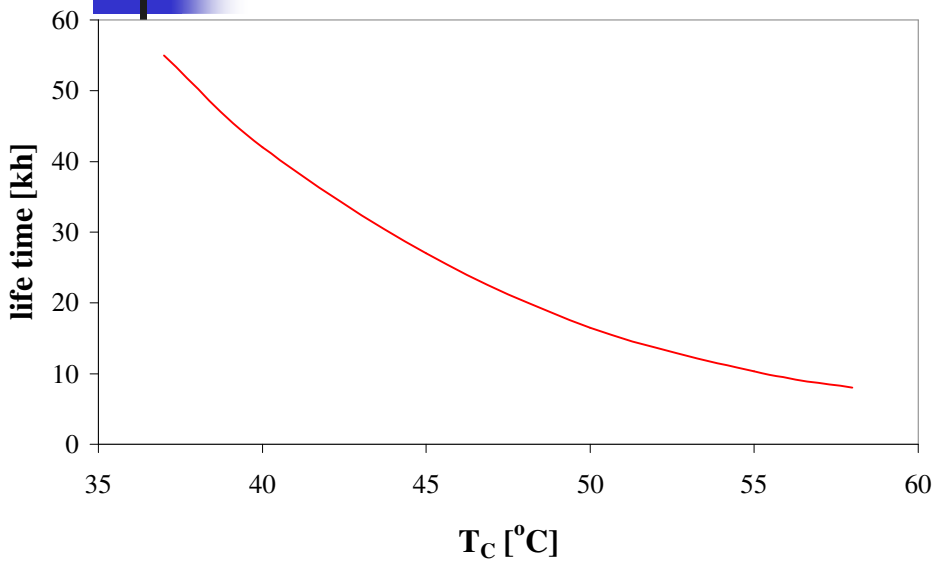
Influence of temperature on characteristics of power LEDs

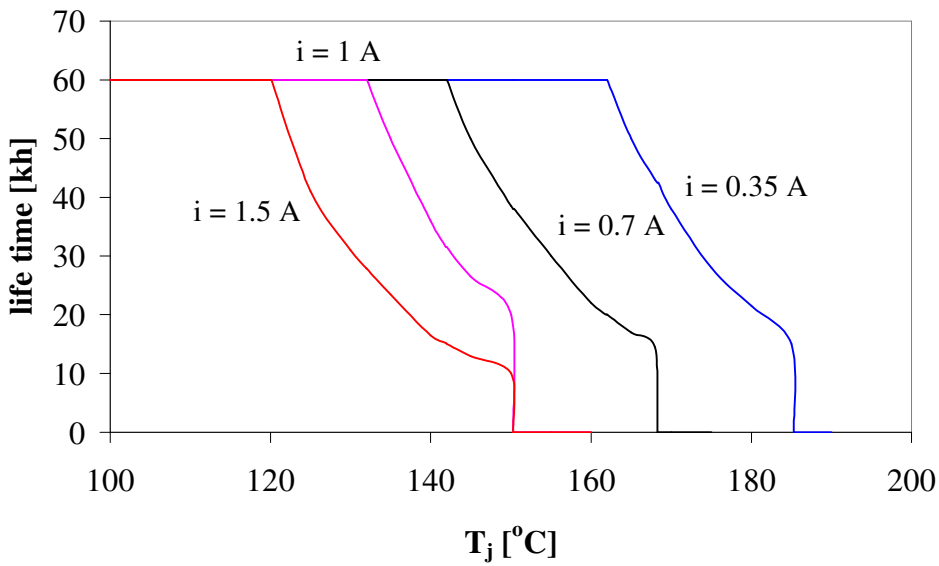




- Illuminance is a decreasing function of temperature
- Illuminance decreases up to 70% of the nominal value after tens thousands hours of the operation

Influence of temperature on characteristics of LEDs





- An decrease of the LED temperature equal to 20°C causes sixfold increase of the life time
- The life-time strongly depends on the forward current and the internal device temperature

Influence of temperature on characteristics of LEDs

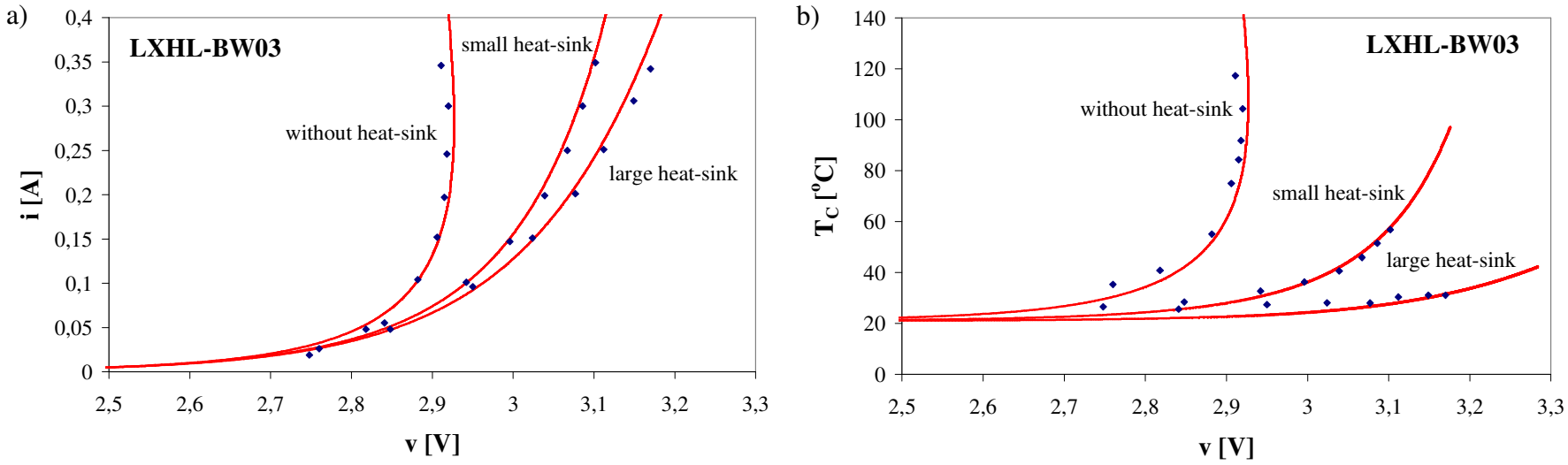
- An increase in the internal device temperature causes:
  - A change of the forward voltage of the LED,
  - A decrease in the value of the emitted luminous flux,
  - A decrease of life time,
  - A possibility of the change of colour of emitted light,
- Therefore, the essential problem is effective cooling of power LEDs

Self-heating phenomenon

- Reasons
  - The transformation of the electrical energy dissipated in the electronic device into heat
  - Non-ideal cooling conditions of the device
- Results
  - An increase in value of the internal temperature of the device
  - The change of the device characteristics
  - The change of the parameters values of the device

Self-heating phenomenon(1)

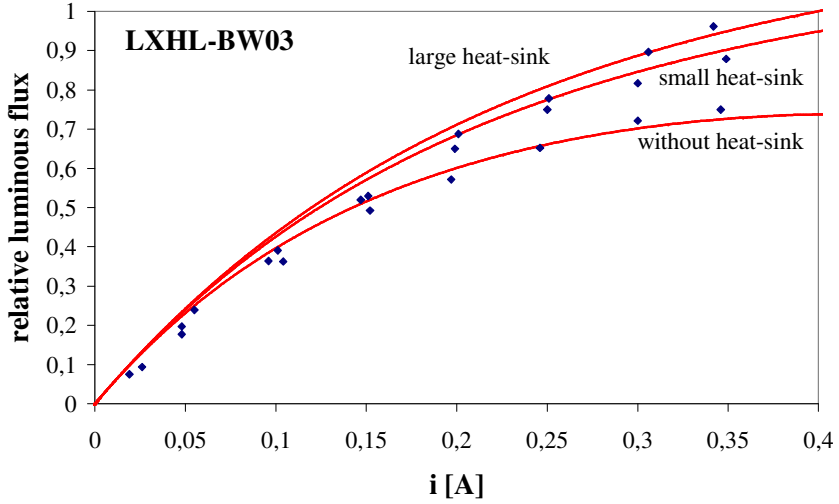
- The influence of self-heating on selected LEDs characteristics



- As a result of selfheating, the current-voltage characteristics move to the left.
- This displacement is greater for worse cooling conditions of the diode.
- It is easy to observe that for the diode operating without any heat-sink the dependence i(v) has a negative slope in the range of high currents.
- In this range the case temperature of the diode reaches 120°C.

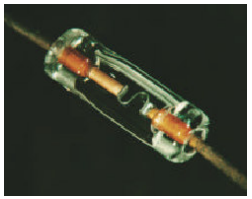
Self-heating phenomenon (2)

- Influence of self-heating on selected LED characteristics

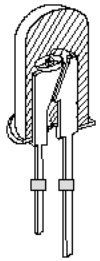


- The value of the luminous flux decreases at the worse cooling conditions.
- Modification of the cooling conditions of the investigated diode, which corresponds to the changes in the internal temperature of this device higher than 100°C, causes a change of the emitted luminous flux not exceeding 30%.

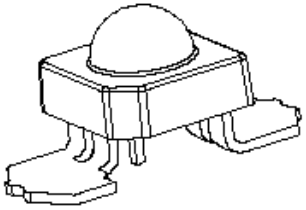
Cooling power LEDs (1)



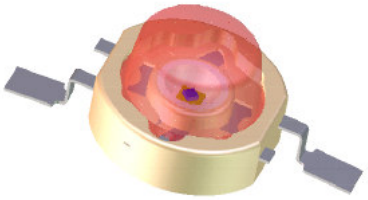
The first LED (1962)



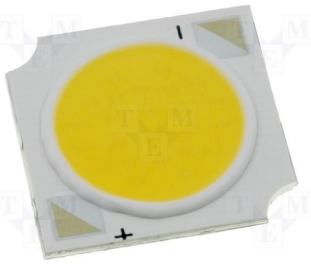
Signal LED (1970)
R_{th} = 200 K/W
P_{max} = 0.1 W



The first power LED (1994)
R_{th} = 50 K/W
P_{max} = 0.4 W



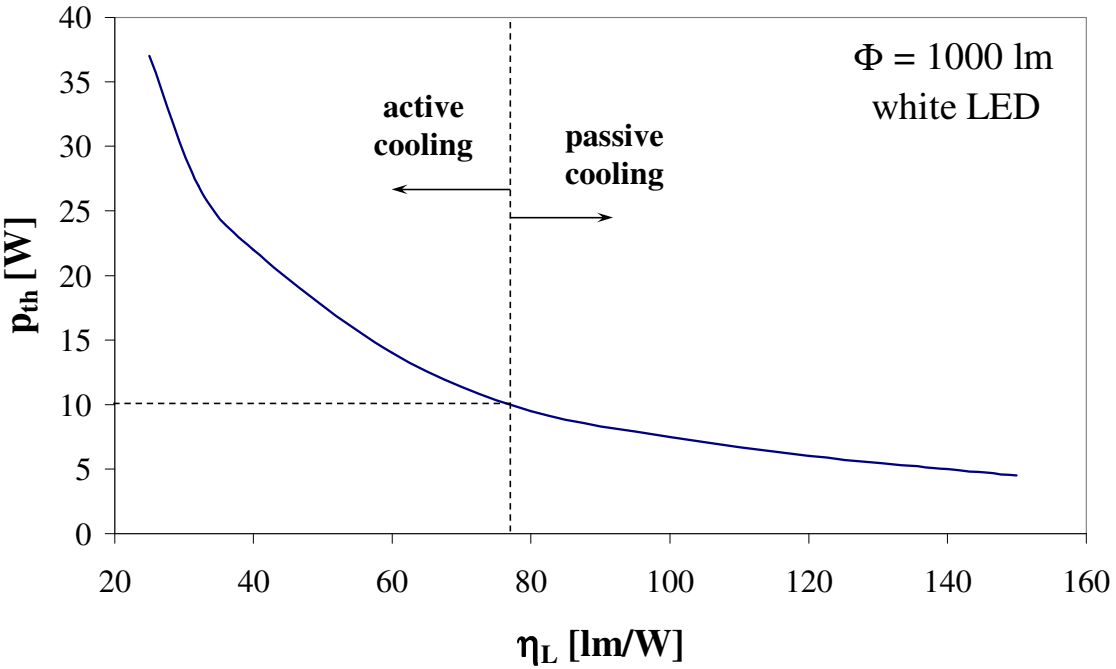
Power LED EMITER (1998)
R_{th} = 14 K/W
P_{max} = 4 W



Power LED COB (2009)
R_{th} = 2.1 K/W
P_{max} = 22 W

- Cases of present power LEDs:
  - Small value of the thermal resistance
  - The heat-sink with the good thermal contact
  - The optical lens of small losses – the high optical efficiency (above 95%)

Cooling the power LEDs (2)



Cooling the power LEDs (3)

- LED chips do not emit the infrared radiation
- All the dissipated heat is transferred to the case in the way of the conduction
- Special constructions making effective cooling:
  - The use of PCB with the aluminium core
  - Special heat-sinks,
  - Cases of LEDs optimized to efficient heat removing.

Thermal parameters

- Transient thermal impedance $Z_{th}(t)$

$$Z_{th}(t) = \frac{T_j(t) - T_a}{P_{th}}$$

- Thermal resistance R_{th}

$$R_{th} = \frac{T_j - T_a}{P_{th}}$$

T_j – the internal device temperature

T_a – the ambient temperature

P_{th} – the thermal power (Heaviside function)

To obtain R_{th} - indispensable measurements of T_j and P_{th}

Methods of the measure of the internal device temperature

- Optical methods – the detection of the infrared radiation and the use of the Stephan-Boltzmann equation
  - The possibility of the delimitation of the spatial distribution of the temperature
  - The problem of the emissivity of the surface of the device
  - The surface of the die cannot be blanket off by the case – only for devices without the case

Methods of the measure of the internal device temperature (2)

- Electrical methods – the measurement of the electrical parameter on the well-known and one-for-one dependence on the temperature
  - One value of averaged internal temperature of the device is measured
  - The not destructive method
  - Often used voltage on forward biased p-n junction
  - It is necessary to calibrate the thermometric characterization
  - The problem to obtain of the high sensitivity of the measurement

Measurement of the thermal power

- In other semiconductor devices than LEDs – the thermal power equal the total power dissipated in this device
- In LEDs – the part of the electrical energy is transformed into light, and the part into heat

$$P_{th} = P - P_L$$

- The omission of the light-radiation in the energy balance causes the understating of the value of the thermal parameters
- The participation of the light in the energy balance increases with the development of the LED technology and with an increase of obtained values of the luminous efficiency

Measurement of the thermal power (1)

- The total power – the product of the current and the voltage
- The lighting power
  - The measurement of the power of the optical radiation in the photometric sphere
  - The measurement of the spectral characteristics and the emission angle and the integration of the spectral characteristic
  - The measurement of the lighting power demands the special instrumentation

Conception of the measurement method

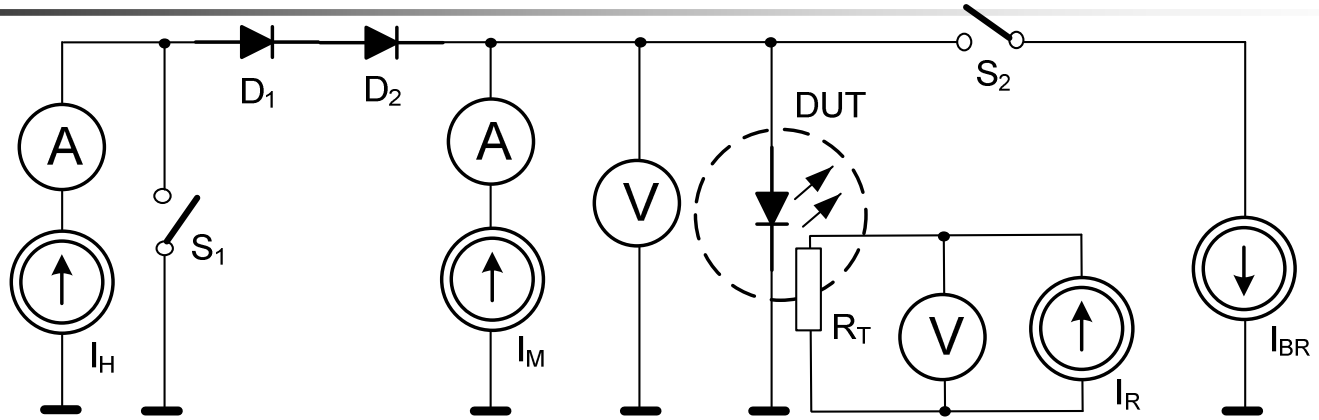
- The new method belongs to the group of electrical methods
- The temperature-sensitive parameter is the voltage on the forward biased LED at small value of the forward current
- The thermal power is estimated by comparison of the device case temperature during operation in forward mode and in reverse breakdown region
- The difference between total power dissipated in the LED in both the modes of its operation at the same value of the case temperature is equal to the optical power

Conception of the measurement method (1)

- 4 steps of the method realisation
  - Calibration of the thermometric characteristics
    - Measurement of the forward voltage u_A at ambient temperature T_a and the slope F
  - In the forward biased LED the power of the form of the rectangular pulses train is dissipated to reach the steady state
    - the frequency of this signal is low and the duty is near 1
    - at steady state the case temperature T_{CF} and the forward voltage u_L are measured
  - In the reverse breakdown range the voltage u_{BR} and the current I_{BR} at the case temperature $T_{CB} = T_{CF}$ are measured
  - Calculation of the R_{th} using formula

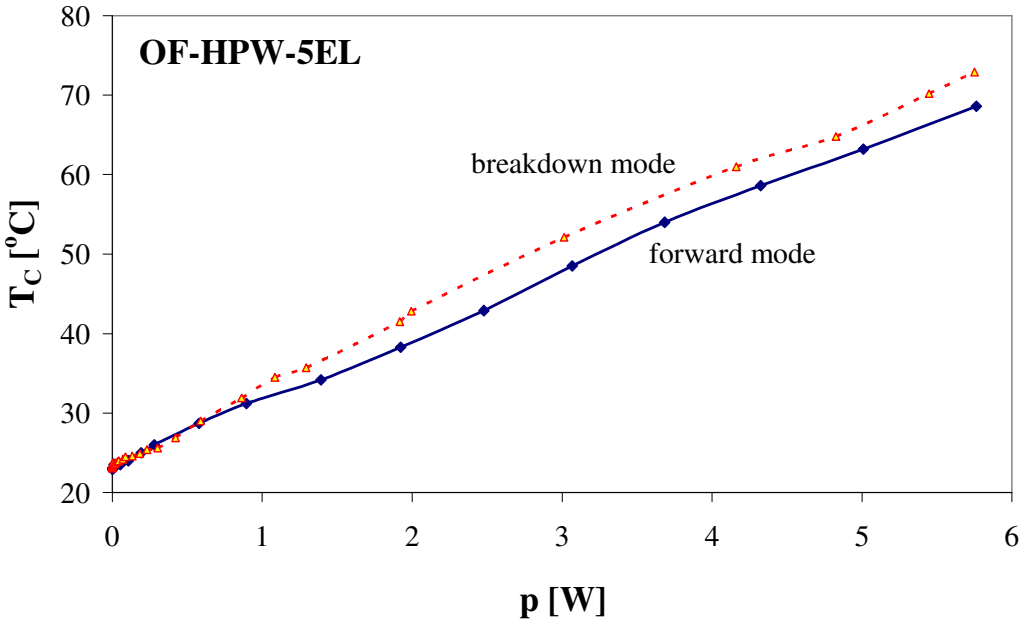
$$R_{th} = \frac{u_L - u_A}{F \cdot (I_{BR} \cdot u_{BR})}$$

Measurement set



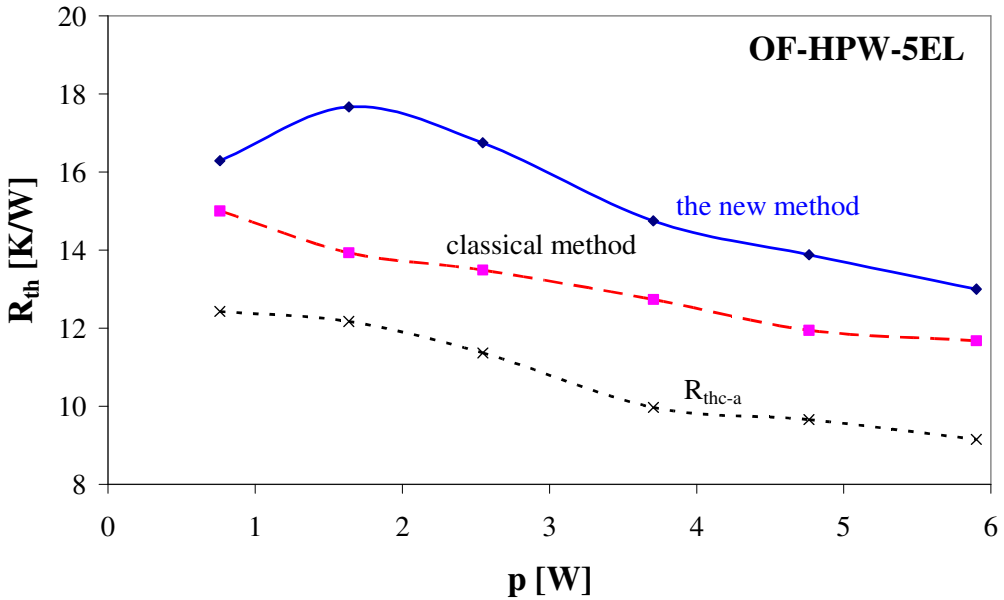
- thermoresistor R_T is situated in the case of the investigated LED (DUT) and is used to the measure of the case temperature.
- The current source I_M extorts the LED current during the calibration and at the low the current during the second step of the measurement.
- The high current in the second step of the measurement determines the current source I_H.
- the current source I_{BR} determines the LED current in the third step of the measurement.
- The switch S_1 is opened during the first and the third step of the measurement, whereas in the second step of the measurement, it is periodically closed in time indispensible for measuring the voltage on the investigated LED at the current I_M.
- Diodes D_1 and D_2 protect the current source I_M against the short-circuit with the switch S_1.
- The switch S_2 is opened in first and in the second step of the measurements and closed - in the third step of the measurements.

Results of measurements



- At the same value of the power dissipated in the diode the higher values of the case temperature of the device operating in the breakdown range are obtained.
- Analyzing the obtained course $T_C(p)$ it can show that the identical value of the case temperature of the investigated diode operating in the breakdown mode and in the forward mode are obtained when the dissipated power in the diode operating in the forward mode is about 0.5 W higher than the power dissipated in the breakdown range.
- The difference between the considered courses $T_C(p)$ is the highest when the power is smaller than 3 W.

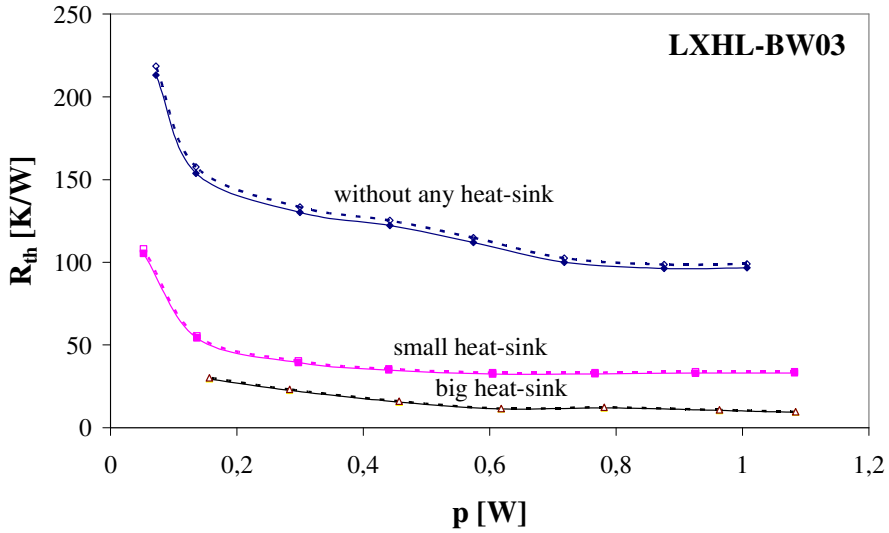
Results of measurements (2)



- The thermal resistance is a decreasing function of the power.
- The omission of the exchange of the part of the electrical energy into light results in understating the value of the thermal resistance even by about 20%.
- The thermal resistance between the case and the surrounding R_{thc-a} is even about 30% smaller than the thermal resistance junction-to-ambient R_{thj-a}.

Results of measurements (3)

- LXHL-BW03 – η_L = 16.7 lm/W



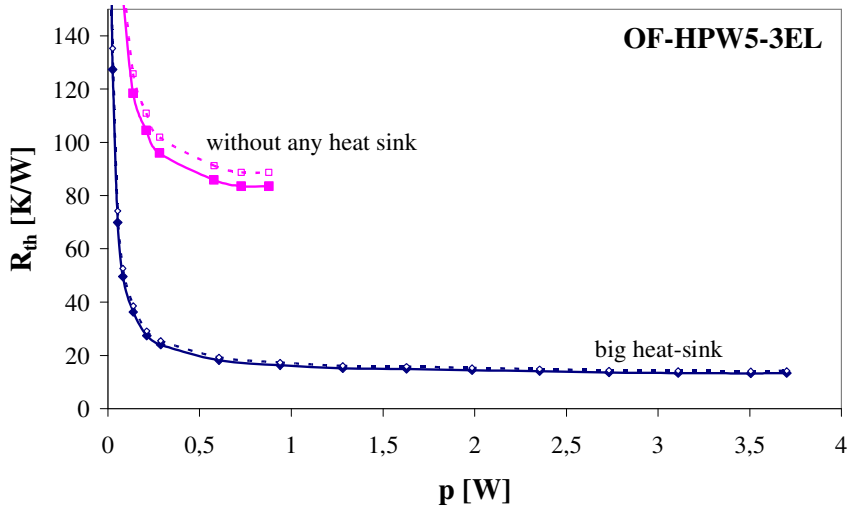
——— - results of the measurements obtained by omitting the power of the emitted light

– – – – – – results obtained while taking into account the power of the emitted light

- for all the considered cooling conditions the monotonically decreasing dependence $R_{th}(p)$ was obtained.
- Taking into account the power P_L causes an increase in the value of the thermal resistance. This increase is not large and does not exceed 3%.

Results of measurements (4)

- OF-HPW5-3EL – η_L = 40 lm/W

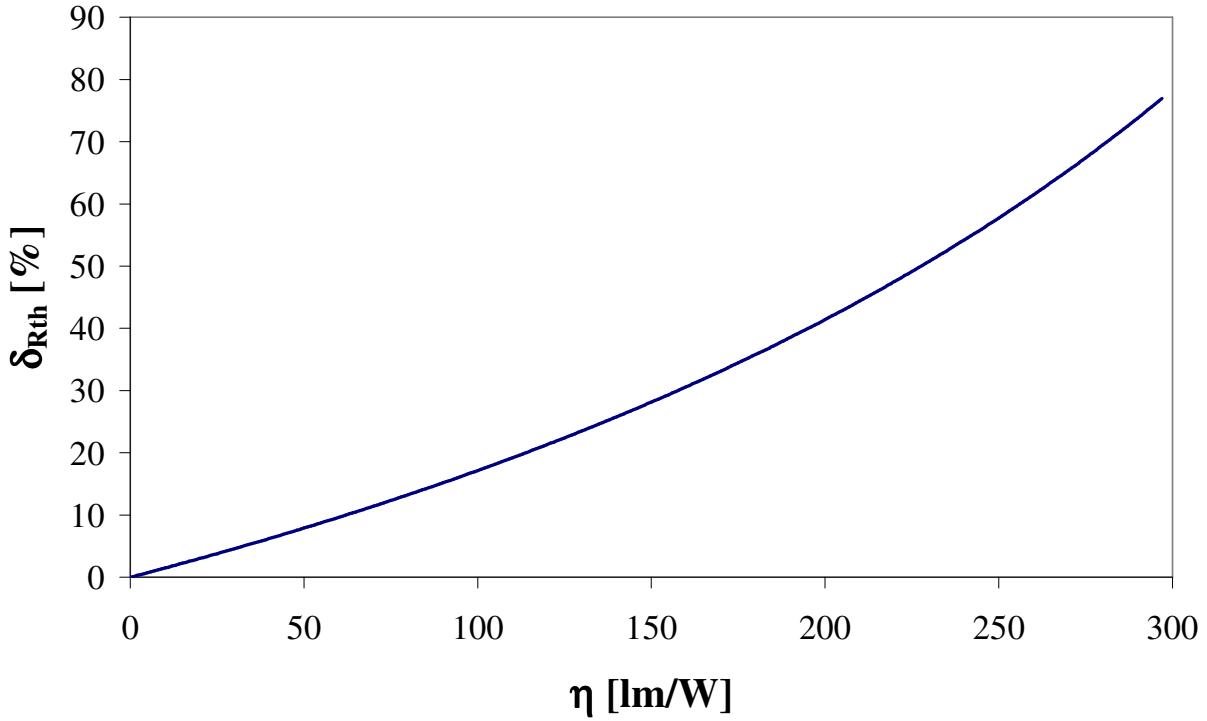


——— - results of the measurements obtained by omitting the power of the emitted light

– – – – – – results obtained while taking into account the power of the emitted light

- an increase of the dissipated power causes a decrease of the thermal resistance resulting from an increase of the efficiency of the heat removing by convection and radiation.
- For the considered diode, taking into account the power of the emitted light causes an increase in the value of the thermal resistance even by about 6%.

The error of R_{th} measurement resulting from the omission of the light emission



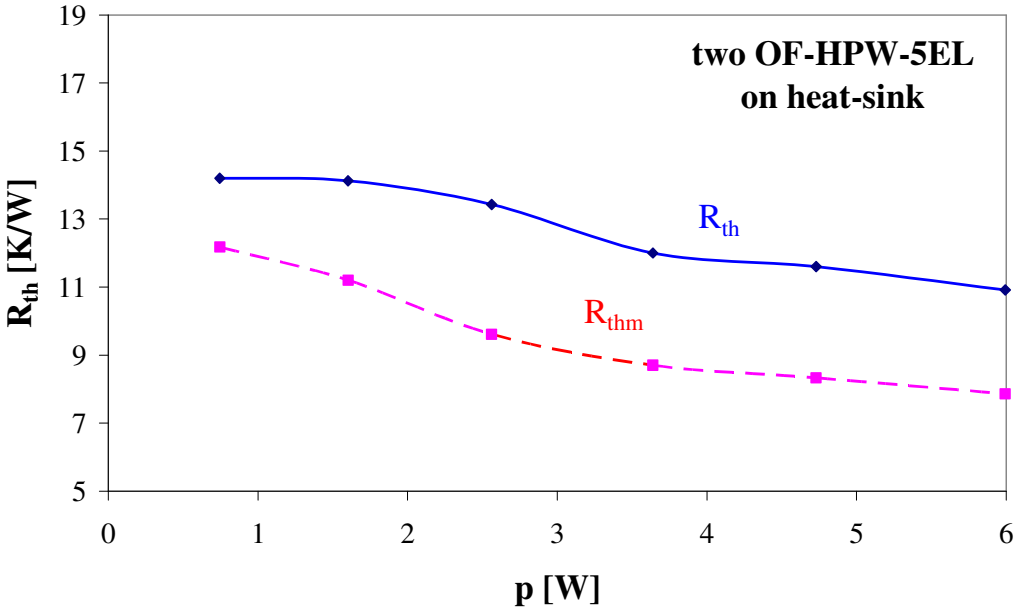
- for old types of power LEDs η < 30 lm/W – measuring error < 5%
- for modern power LEDs η > 200 lm/W – measuring error > 40%

The measurement of mutual thermal resistance between LEDs

- Between semiconductor devices situated on the common heat-sink or common PCB mutual thermal interactions are observed
- Results of these interactions is additional increase of the device junction temperature
- These interactions are characterised by mutual thermal resistance
- To measure the mutual thermal resistance it is indispensable to dissipate thermal power in one device and to measure the change of internal temperature of the thermally coupled device (using electrical method)

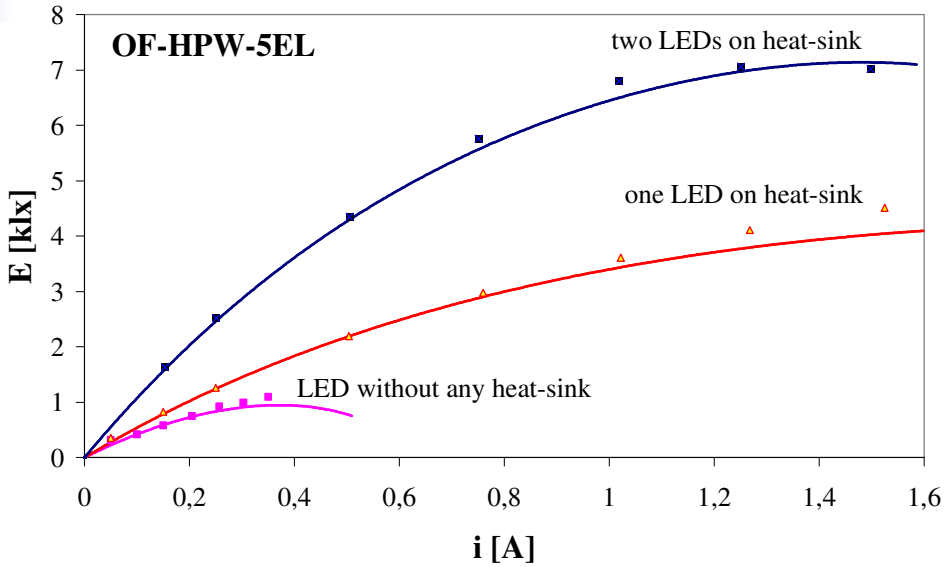
Results of measurements (5)

- Two OF-HPW5-3EL on the heat sink 2x100x75 mm



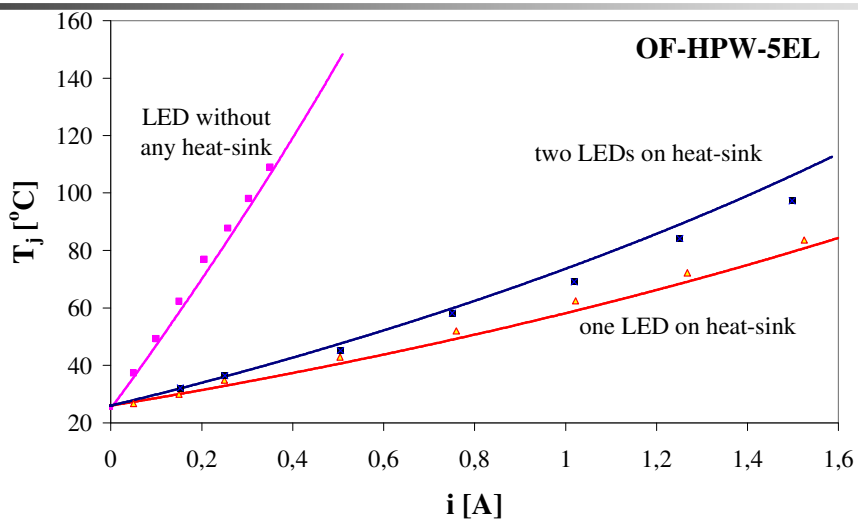
- The mutual thermal resistance is smaller than the device thermal resistance
- The difference between R_{th} and R_{thm} is near 4 K/W, which corresponds to the thermal resistance junction-to-case

Influence of the mutual thermal interactions on LED characteristics



- The diode operating without the heat-sink has the smaller value of the illuminance, even by about 30%, than the diode situated on the heat-sink.
- For currents smaller than 1A the value of the illuminance being descended from the two diodes is practically equal to the doubled value of this illuminance being descended from one diode.
- Due to the thermal phenomena, an increase of the current causes the slower and slower increment of the value E, and even its fall at the diode current crossing 1 A.

Influence of the mutual thermal interactions on LED characteristics (2)



- For the diode operating without any heat-sink the junction temperature attains even 110°C at the forward current equal to 23% of the admissible catalogue value.
- For the diode on the heat-sink the considerable depreciation of the junction temperature is observed. At the current equal to 1.5 A the junction temperature attains only just 85°C.
- The location of the second diode on the heat-sink causes additional increase of the junction temperature of the tested diode due to the mutual thermal coupling. This increase is a increasing function of the second diode current and it can amount even 20°C.

Conclusions

- In the paper the new method of measuring the thermal resistance of power LEDs is proposed.
- This method is based on the electric impulse-method and additionally it takes into account the fact of the exchange of the part of the electrical energy into light.
- The obtained results of measurements confirm that the use of the classical method of the thermal resistance measurement of the diode for power LEDs can result in understating the value of the thermal resistance even by about 15%.
- The accuracy of the described method depends on the measuring error of the voltage on the forward biased diode and the measuring error of the case temperature of the diode operating in the forward mode and in the breakdown range.

Conclusions (2)

- It results from the obtained dependence that for the old-style power LEDs, characterized by the low value of luminous efficiency, the omission of the power of the emitted light causes not a large measuring error.
- Together with the development of technology of power LEDs appearing with an increase of luminous efficiency, the problem of the calculating the power of the emitted light at the measurements of the thermal resistance, are the more and more significant.
- The proposed manner of measuring the thermal resistance of LED is also useful while measuring the mutual thermal resistance between the diodes situated on the common heat-sink.