LED degradation - recent data and internationally discussed methods for LED life time calculation

Swissphotonics: From Daylight to Lighting 4.0

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Agenda

- **Methods for LED lifetime calculation**
- **Results**
  - **Forward voltage**
  - **Radiant flux**
  - **Color coordinates**
- **Acceleration**
- **Spectra**
- **Conclusion**

TM-21: possible functions

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IES TM-21-11

Table G1, Engineering-based models used in the analysis of model fitting for LED lumen decay life projection

Model	Decay Rate	Closed Form Solution	Comment
1	$\frac{dI_v}{dt} = k_1$	$I_v = I_v^0 + k_1 (t - t^0)$	
2	$\frac{dI_v}{dt} = k_2 I_v$	$I_v = I_v^0 \exp[k_2 (t - t^0)]$	
3	$\frac{dI_v}{dt} = k_1 I_v + k_2 I_v$	$I_v = \left(I_v^0 + \frac{k_1}{k_2}\right) \exp[k_2 (t - t^0)] - \frac{k_1}{k_2}$	Model 1 + Model 2
4	$\frac{dI_v}{dt} = \frac{k_3}{t}$	$I_v = I_v^0 + k_3 \ln\left(\frac{t}{t^0}\right)$	
5	$\frac{dI_v}{dt} = k_1 + \frac{k_3}{t}$	$I_v = I_v^0 + k_1 (t - t^0) + k_3 \ln\left(\frac{t}{t^0}\right)$	Model 1 + Model 4
6	$\frac{dI_v}{dt} = k_4 I_v^2$	$I_v = \frac{I_v^0}{1 + I_v^0 k_4 (t - t^0)}$	
7	$\frac{dI_v}{dt} = k_5 \frac{I_v}{t}$	$I_v = I_v^0 (t/t^0)^{k_5}$	
8	$\frac{dI_v}{dt} = k_2 I_v + \frac{k_5 I_v}{t}$	$I_v = I_v^0 \exp[k_2 (t - t^0)](t/t^0)^{k_5}$	Model 2 + Model 7
9		$I_v = I_v^0 \exp\left[-\left(\frac{(t - t^0)}{k_6}\right)^{k_7}\right]$	

$$\Phi(t) = A \cdot \exp(-\alpha t)$$

IEC 63013

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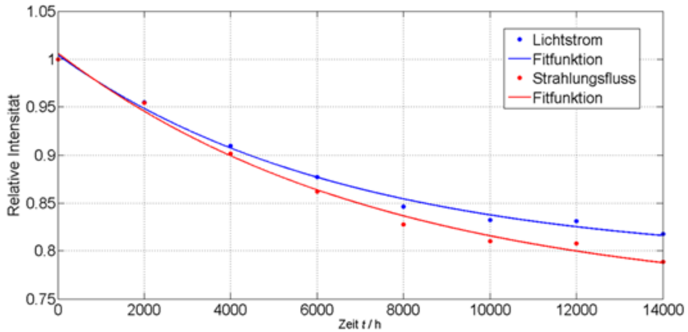
LED PACKAGES –
LONG-TERM LUMINOUS AND RADIANT FLUX MAINTENANCE PROJECTION

CONTENT

- Extrapolation of Lifetime for Luminous <u>and</u> Radiant Flux
- Use of the function from TM-21

- Exponential fit function (EFF)
- Border function (BF)
- Temperature data interpolation
- Temperature acceleration method (TA-A)



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Arrhenius

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Reaction rate as a function of the abs. temperature

$$\rho(T) = K \cdot \exp\left(-\frac{E_\mathrm{A}}{k_\mathrm{B} \cdot T}\right)$$

E_A activation energy

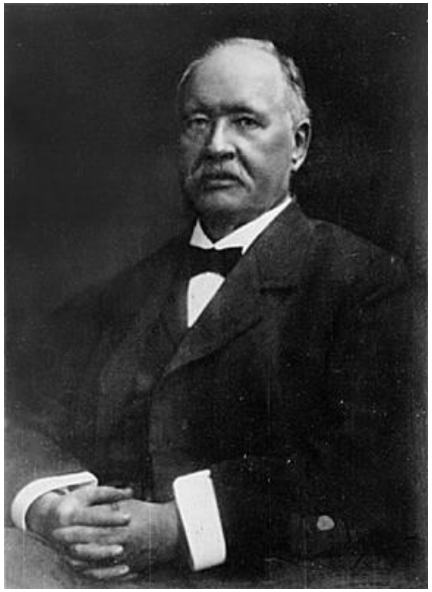
- Higher temperature -> higher reaction rate

Lifetime as a function of the abs. temperature

$$L(T) = C \cdot \exp\left(\frac{D}{T}\right)$$

Source: DIN EN 62506

- Higher temperature → shorter lifetime



Svante Arrhenius (1859-1927)
Nobel prize in chemistry 1903

Source: larousse.fr

LED aging test setup

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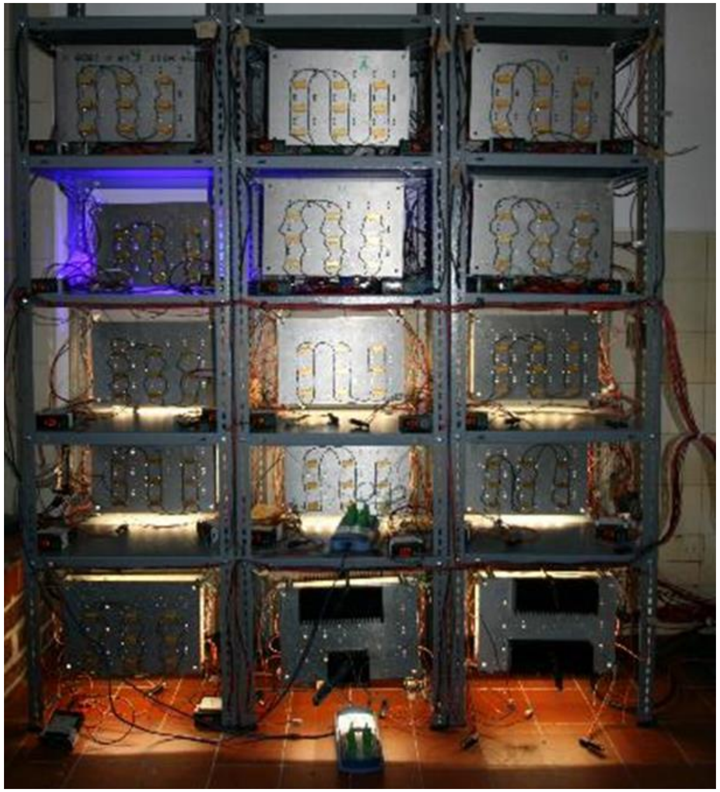
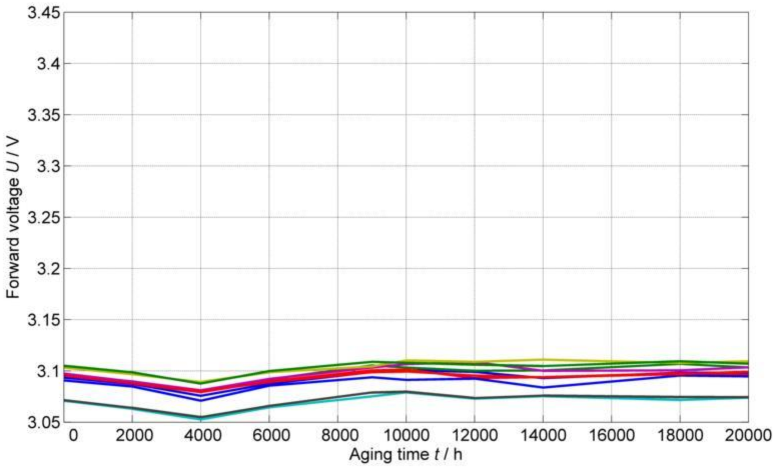
- **Aging conditions**
  - two types of High-Power LEDs
  - currents I_F= 350 mA; 700 mA;
  - 1000 mA;
  - temperatures T_S= 55 °C; 85 °C; 95 °C
  - 20/10 objects per aging condition



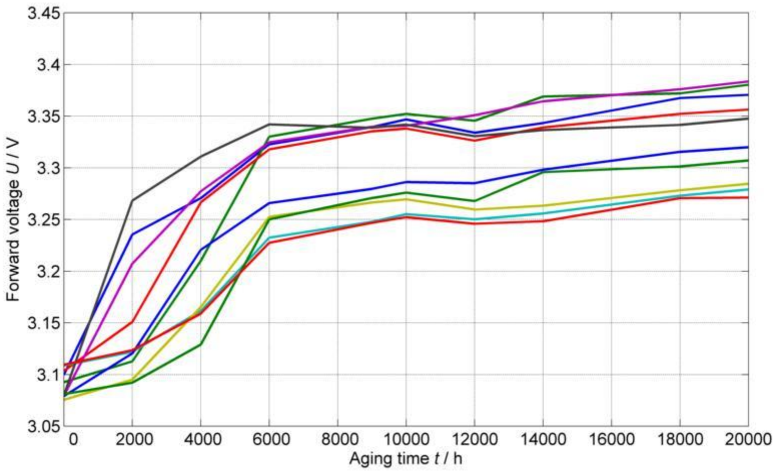
- **Measurement conditions**
  - temperature T_S = 25 °C
  - pulsed measurement
  - 30 cm Ulbricht sphere
  - spectroradiometer

Forward voltage

350 mA, 55 °C



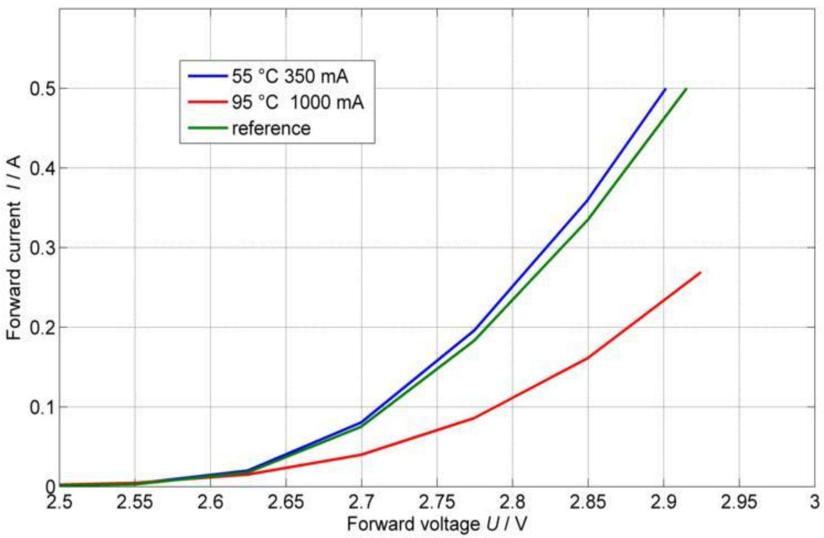
1000 mA, 95 °C

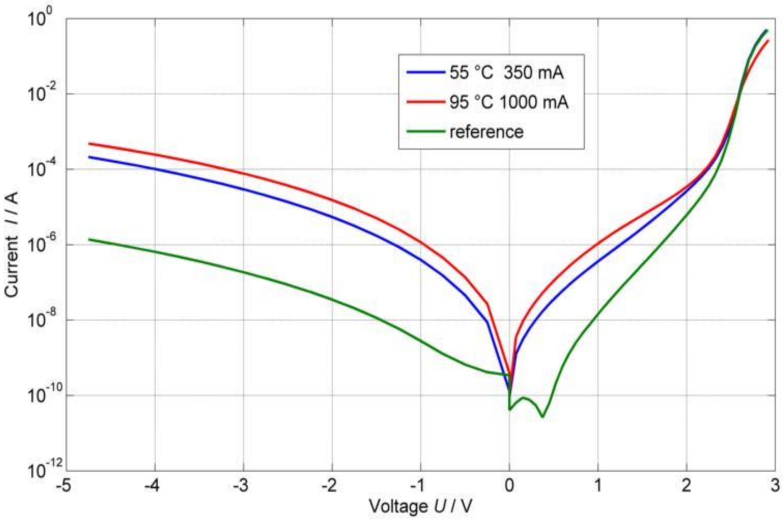


- No change of forward voltage

- Fast increase of voltage in the beginning
- General increase of the electrical resistance
- Two aging mechanism probable

I-*U*-curves





- Increase of the serial resistance
  - only at high temperature
- Remarkable from aging measurements (Forward voltage at higher current)

- Reduction of the parallel resistance
  - at high and low temperatures
  - stronger at higher temperature
  - occurance of parallel current paths
- <u>Not</u> remarkable from aging measurements (Forward voltage at higher current)

Radiant flux (1000 mA, 95 °C)

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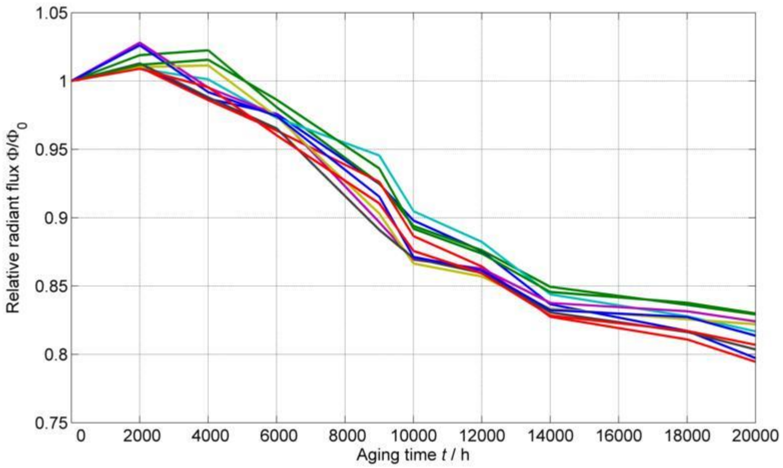
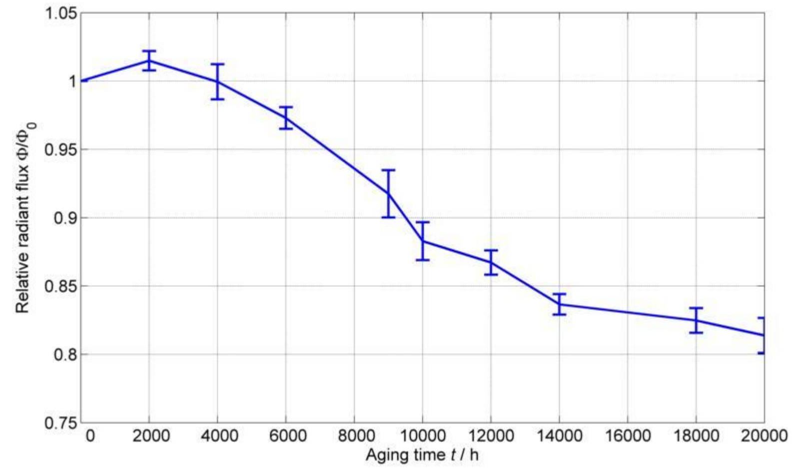
Single curves (10 LED-Packages)



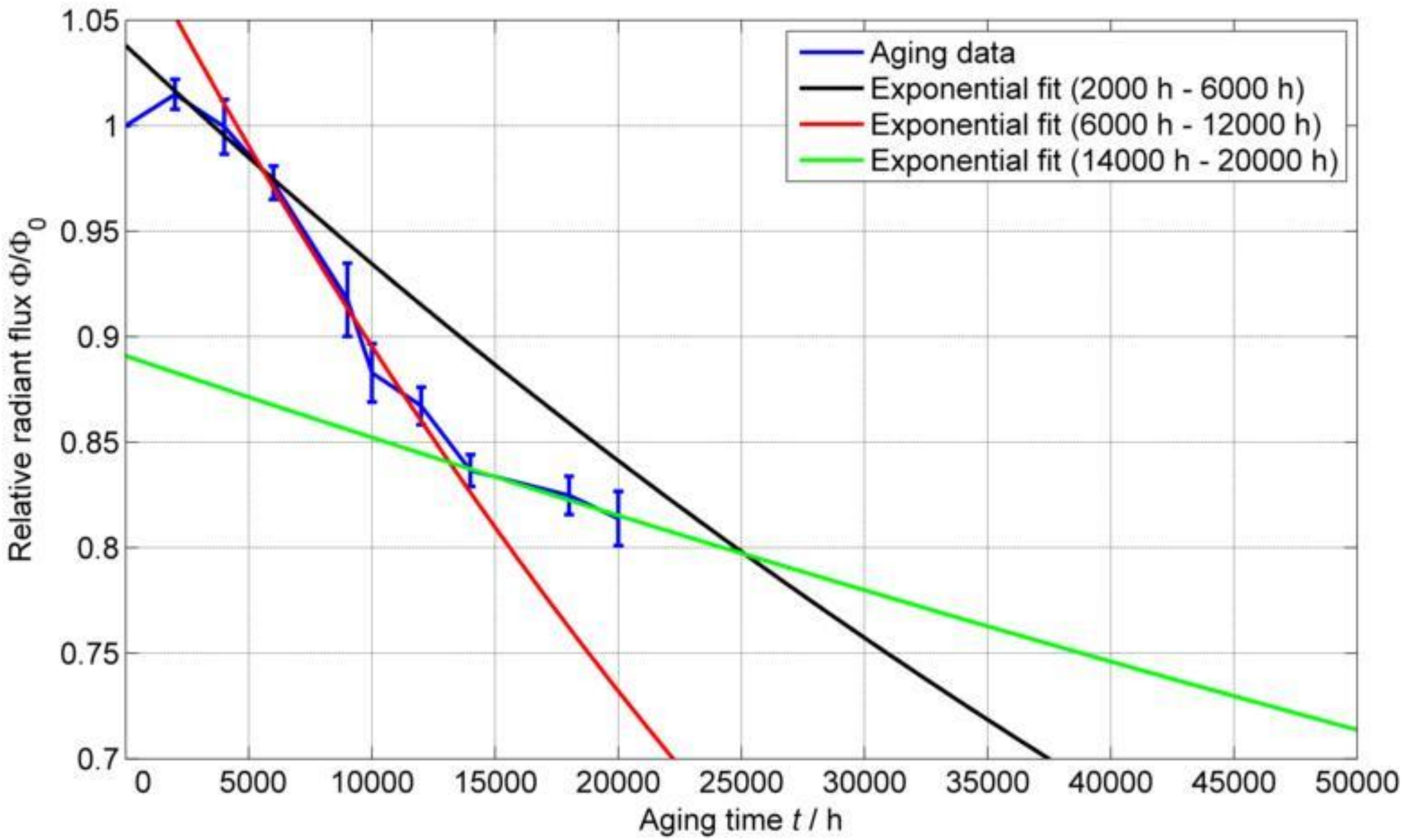
Mean values with standard deviation



- Single curves run in a narrow band
- More than one phase of aging

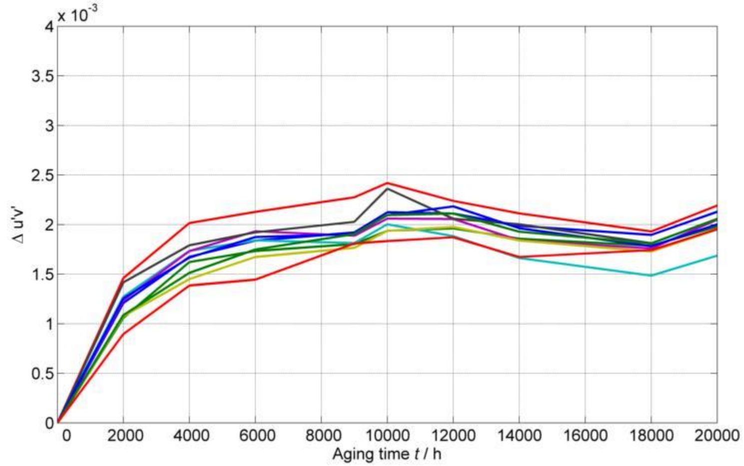
- Mean, relative radiant flux
- Increase based on the healing of the crystal
- More than one phase of aging

Extrapolation at different time periods

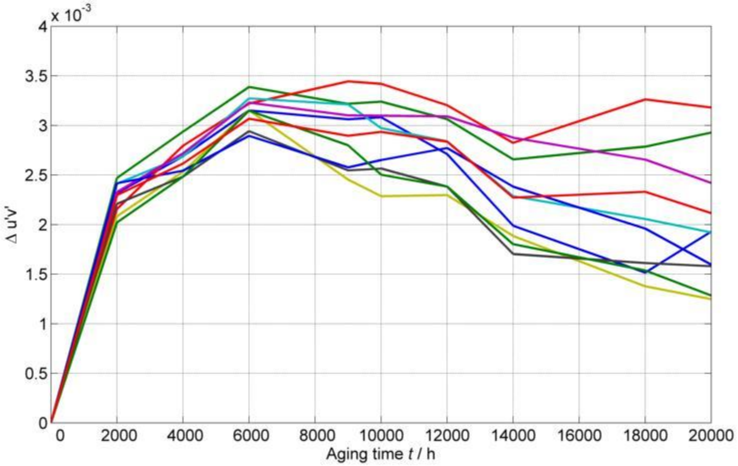


Change of the color distance

350 mA, 55 °C



1000 mA, 95 °C



- Increase up to 10,000 hours
- Second stable phase

- Increase up to 6,000 hours
- Second phase with divergent curves

Forward voltage and radiant flux

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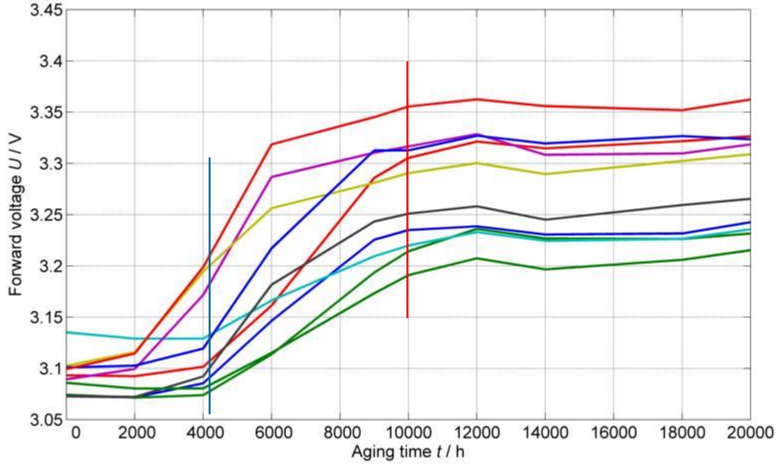
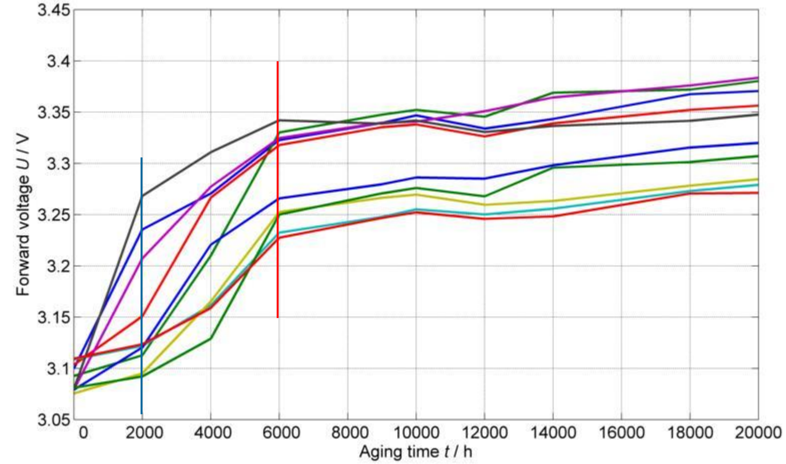
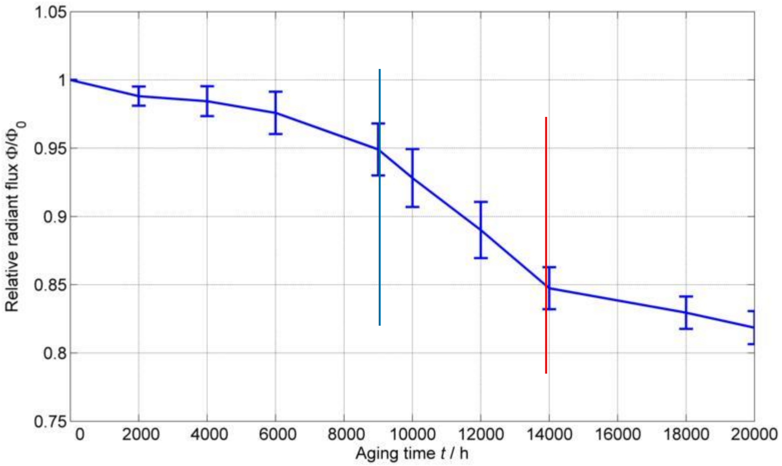
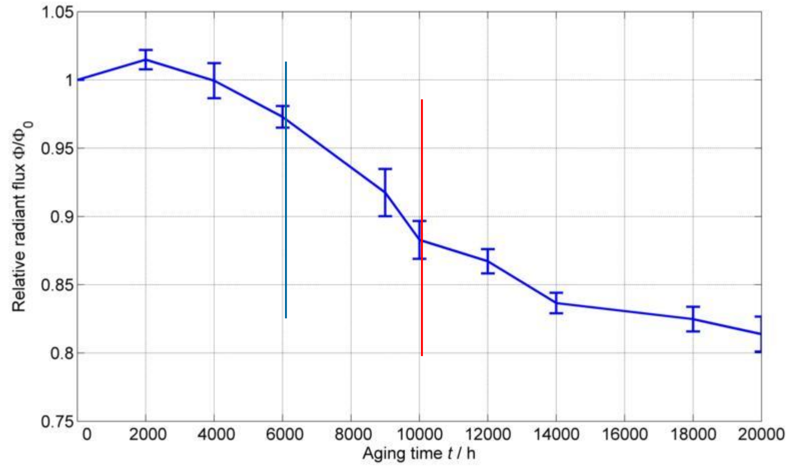




85 °C

95 °C





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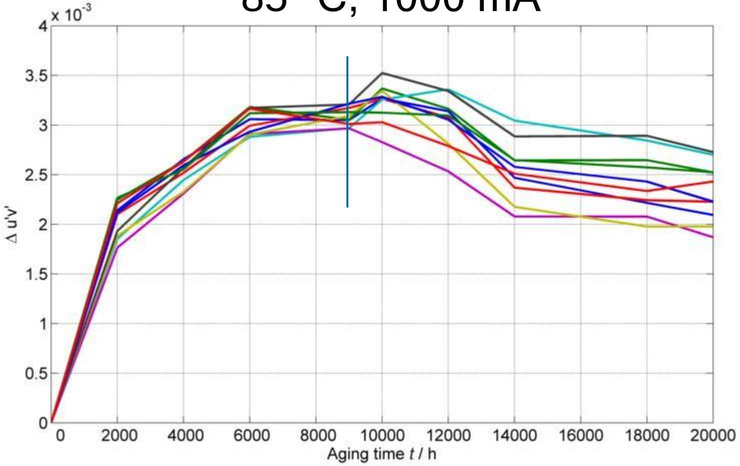
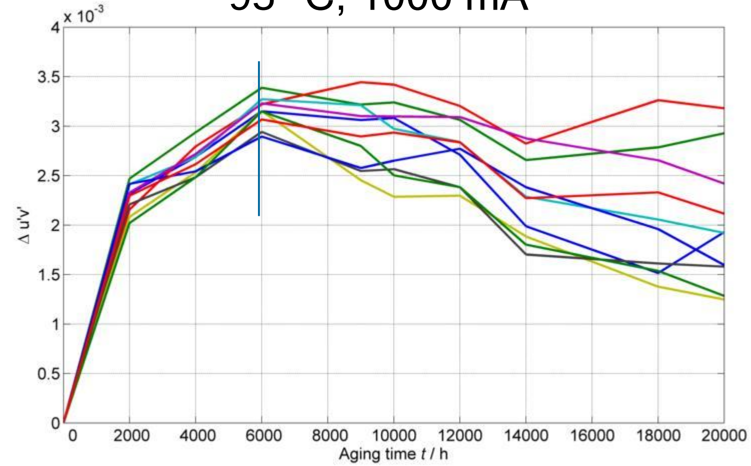
Reasons of the color shift

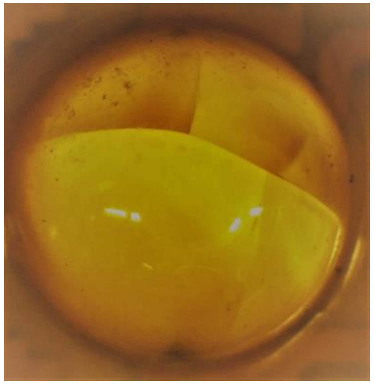
85 °C, 1000 mA



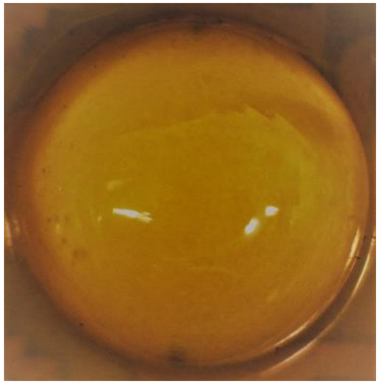
95 °C, 1000 mA



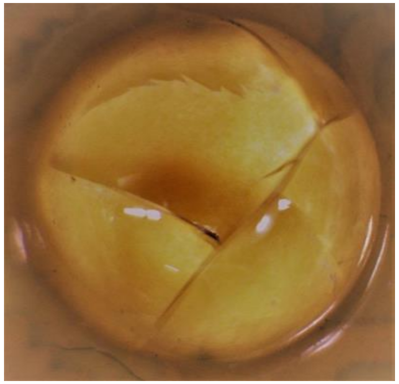
85 °C ,1000 mA



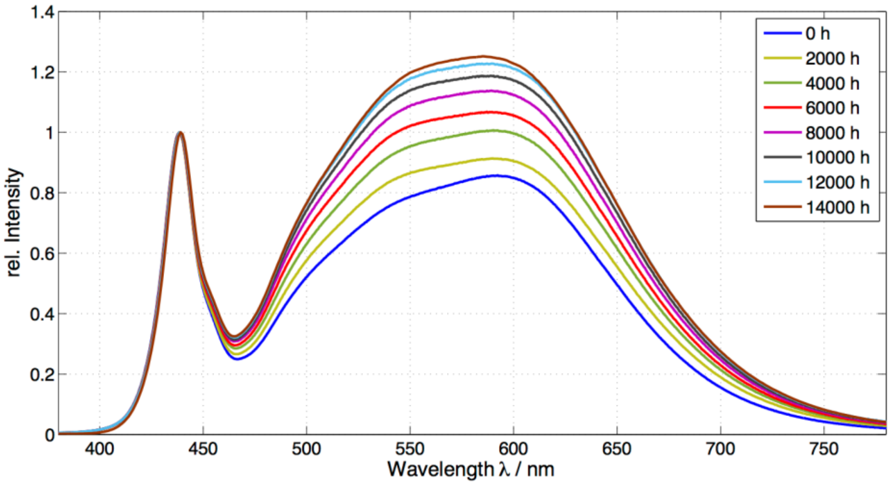
95 °C ,700 mA



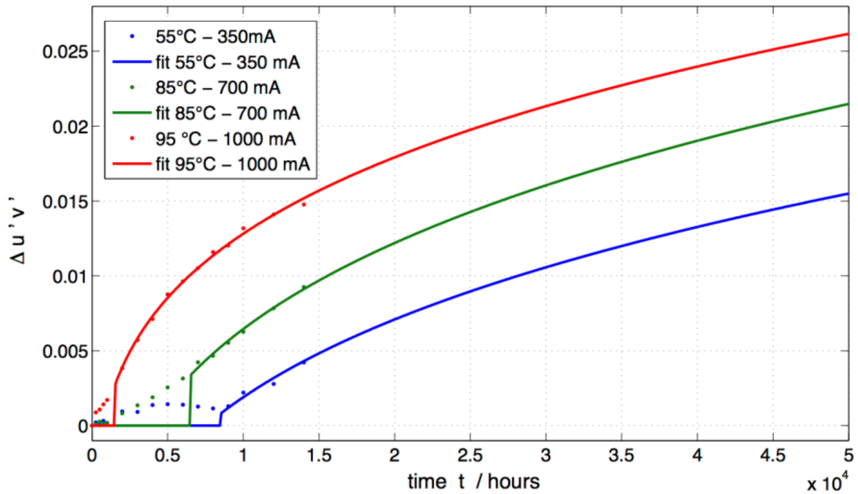
95 °C, 1000 mA



Comparison to another LED type



Source: Wagner, LpS 2016



$$\Delta u'v'(t) = \Theta(t-d)\cdot a\cdot t^{0.25}+c$$

Ratio blue/yellow is changing

Color shift is much higher by a factor of ten

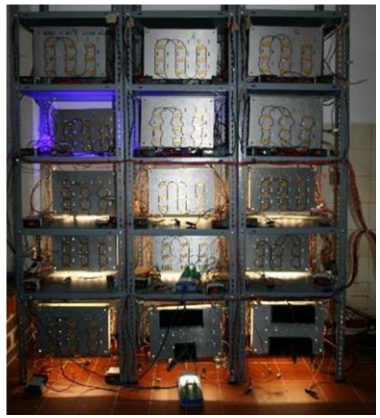
Color shift is dependend on temperature and current
→ after starting point: description by root function

Conclusion

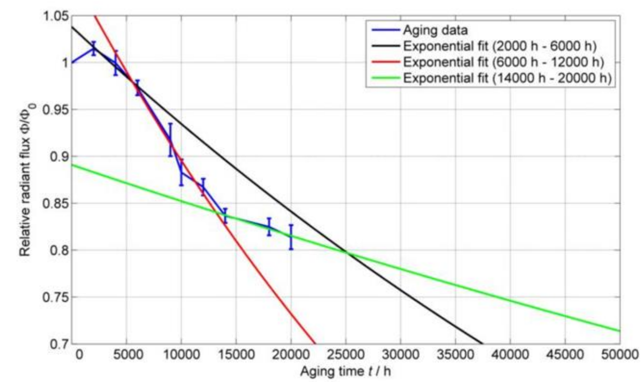
International Methods

63013

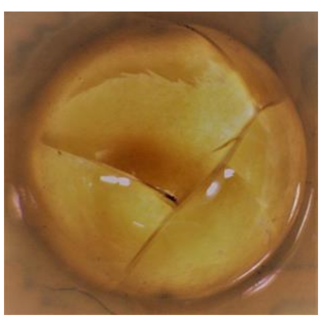
Aging test

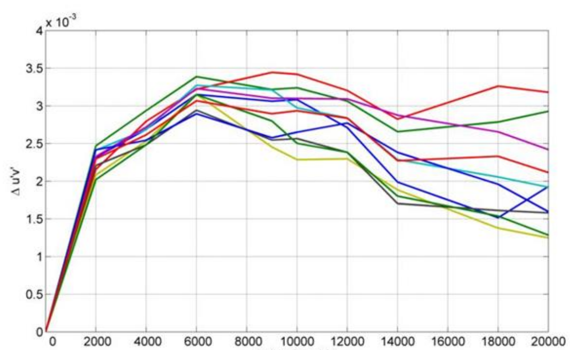


Long-time results



Aging effects





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- Statistic…
- Aging of other package technologies

Thank you for your attention!

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