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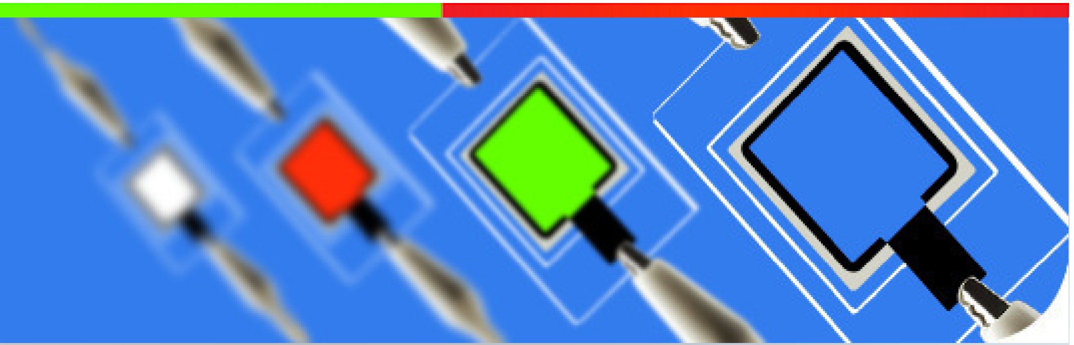
» The New OLED Generation «



Technology for Innovative OLED Applications

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at
Innovationsforum ‚OLED Beleuchtung‘, Jena, February 2008

Outline

- › Introduction OLED and Novaled PIN technology™
- › White OLEDs
- › OLED Demonstrators
- › Outlook – An OLED lighting Roadmap

OLED – an area light source we've been looking for

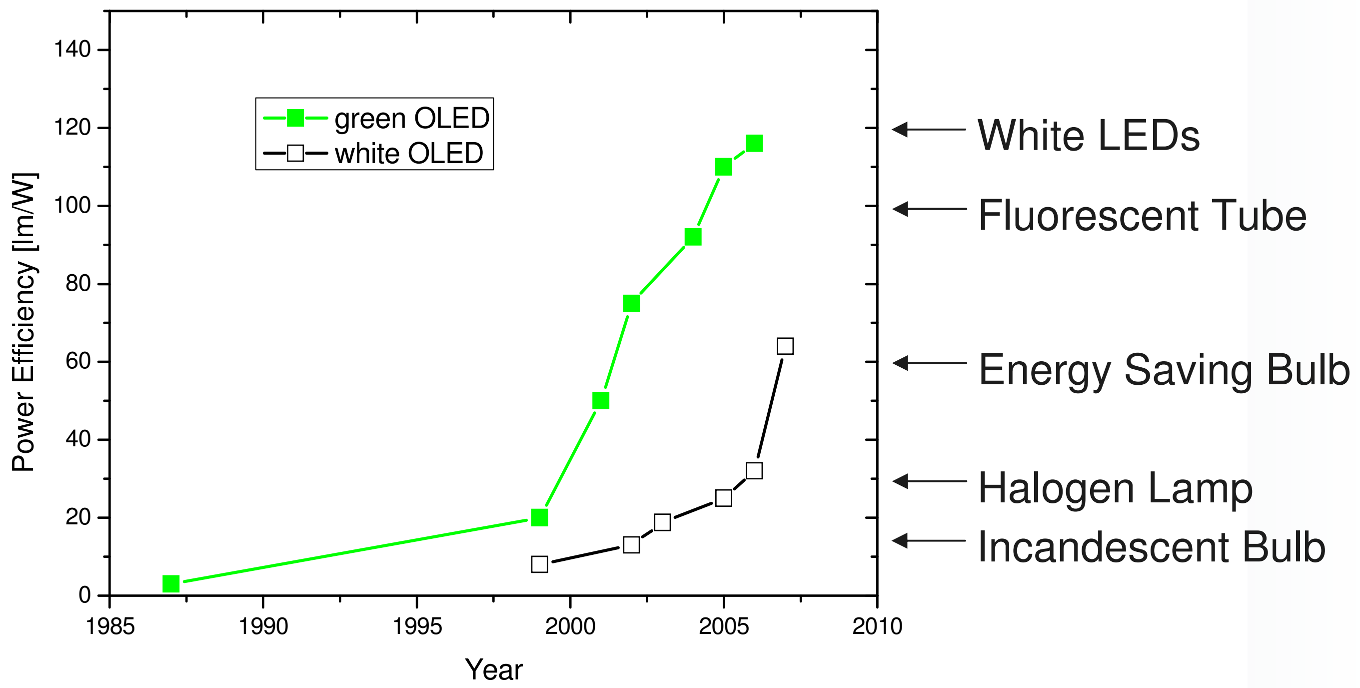
› **OLED is an area source of light**

› **Lighting**:
OLED (area source) competes with fluorescent bulbs (line source) and LED (point source)

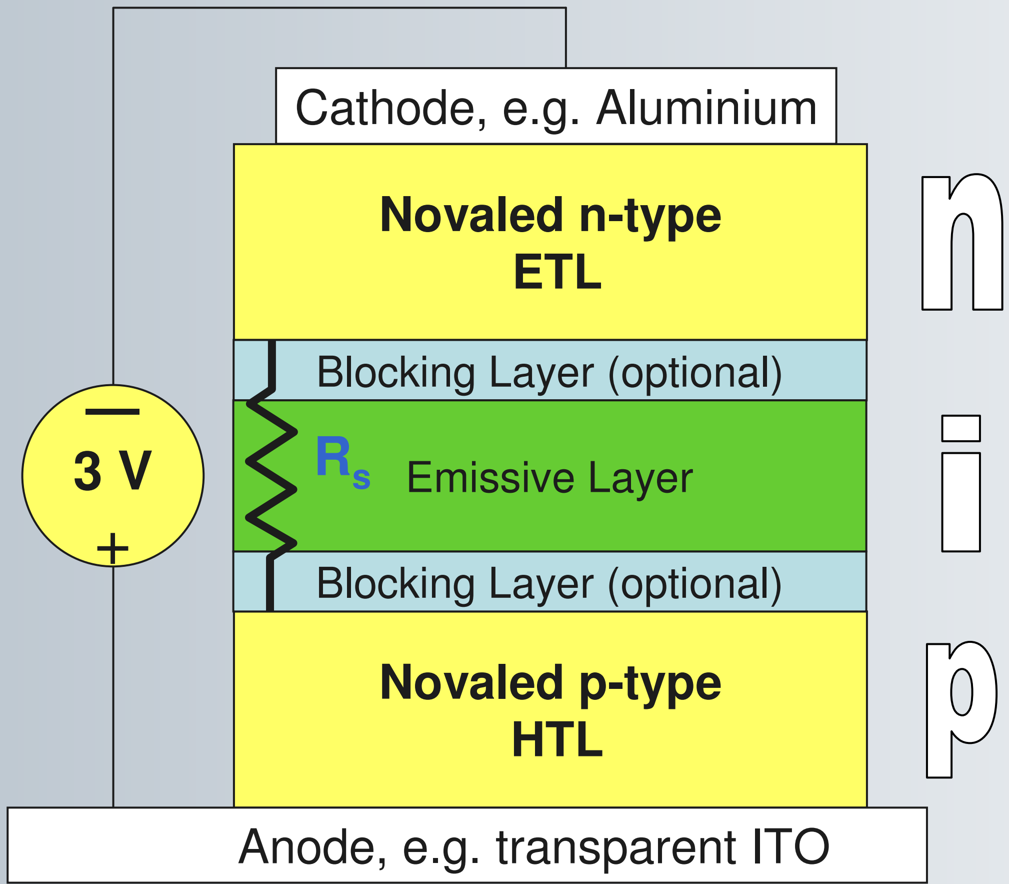
› **Display:**
OLED (self emitter) competes with LCD (light manipulator)

OLED Power Efficiency Development

Power efficiency **=** Voltage (Novaled PIN-OLED technology™)
Internal efficiency (singlet/triplet/PL)
Out-coupling

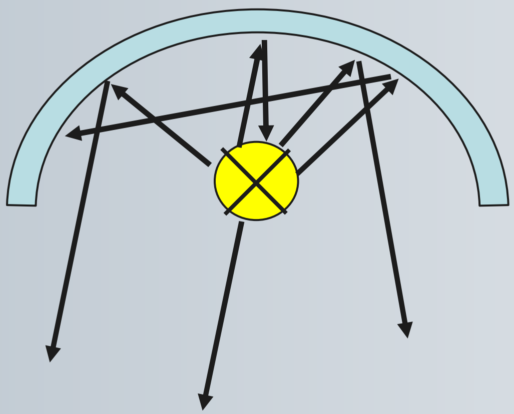


Novaled – Low Voltage PIN OLED Technology™

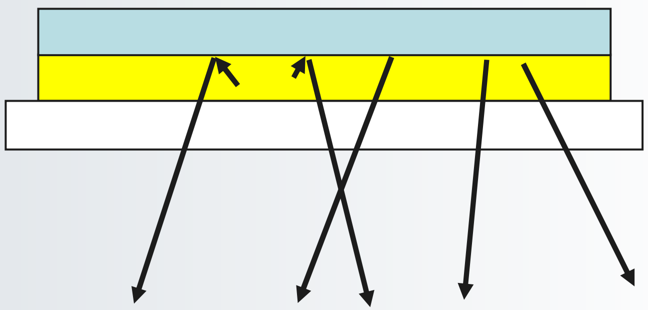


- Novaled focuses on doping of the charge carrier transport layers → lowest voltages and highest efficiencies are reached – Novaled PIN OLED Technology™
- PIN OLEDs allow for an easy integration and high design flexibility (e.g. transparent devices, OLED on metal foils…)
- PIN OLEDs can reach very high device lifetimes and improve system lifetimes

Wall - Plug Efficiency



Conventional **light source and reflector**



OLED with **integrated reflector** (highly reflective metal electrode)

→ **Integrated reflector gives rise to improved efficiencies!**

→ **Efficiencies of technologies have to be compared at system level!**

Wall - Plug Efficiency

OLEDs:

- Highly reflective electrode (e.g. Al, Ag) as internal reflector
- No luminaire needed
- Measured power efficiencies take only forward directed light into account

- **Values are close to final application efficiency** (under assumption scaling up is possible w/o loss of efficiency)

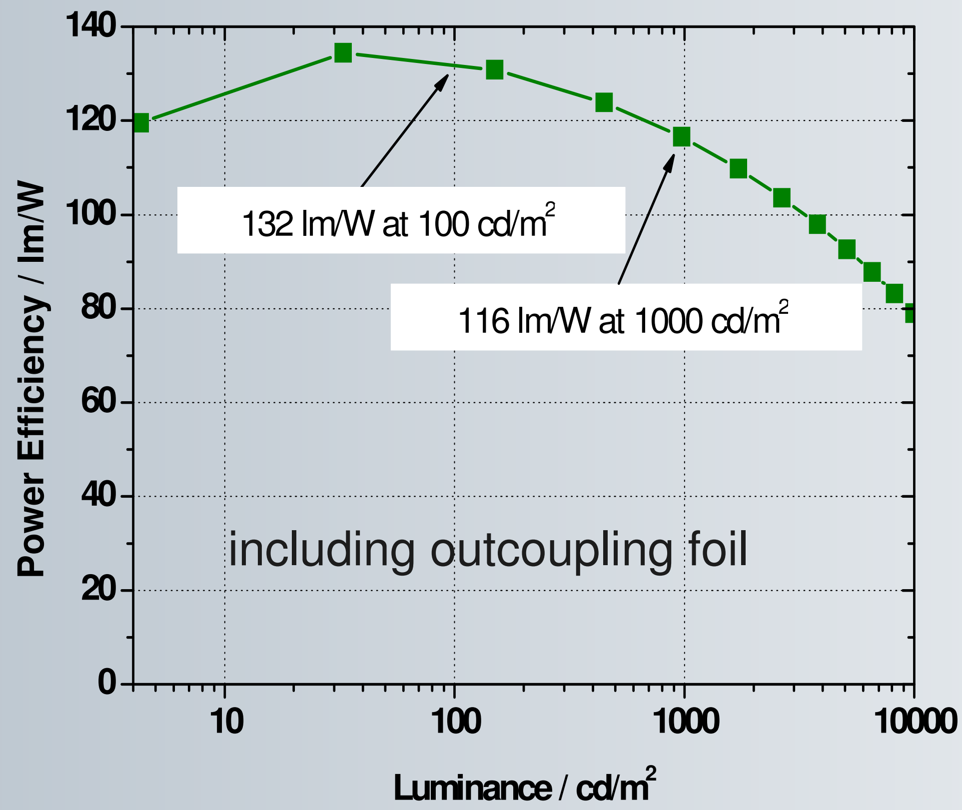
LEDs:

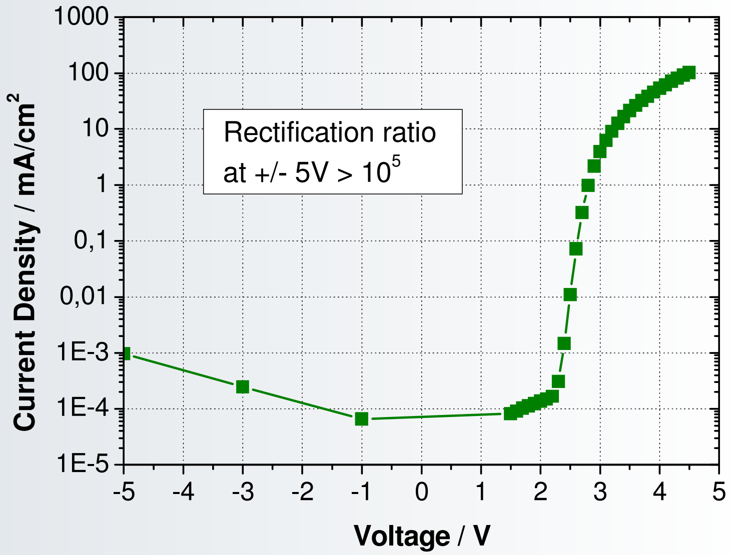
- According to DoE measurements LED luminaires reduce white LED efficiencies to 30 – 50 %

  (LEDs Magazine February 2007, http://www.netl.doe.gov/ssl/comm_testing.htm)

- **Efficiency of LEDs is significantly reduced for area emitters**

OLED Efficiency – Green Bottom Emission





- Phosphorescent emitter $Ir(ppy)_3$
- Bottom emission geometry

- **Record power efficiency**

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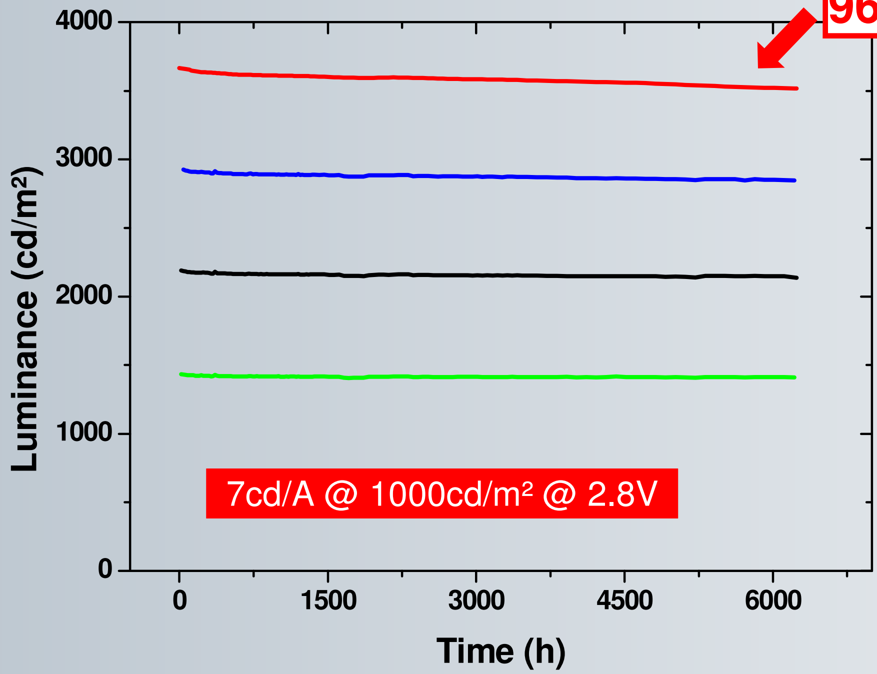
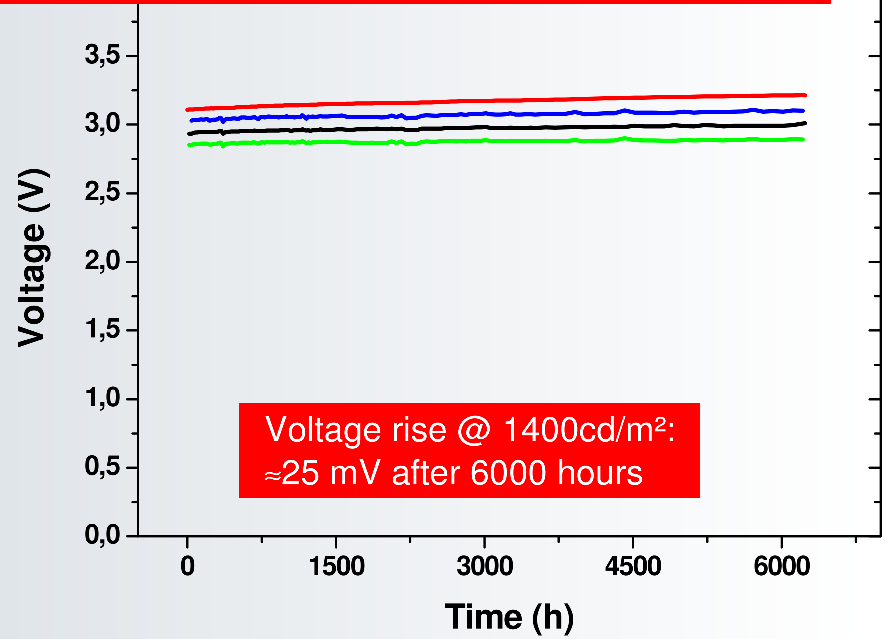
High Operational Stability: Red Bottom Emission PIN

96 % brightness after 6000 h (3700 cd/m²)





- Red fluorescent bottom emission CC (0.67/0.33) [7 cd/A @ 1000 cd/m² @ 2.8V]
- Lifetime at 1000 cd/m²: > 1,000,000 hours at room temperature
- Voltage increase at 1400 cd/m²: 4 µV / h

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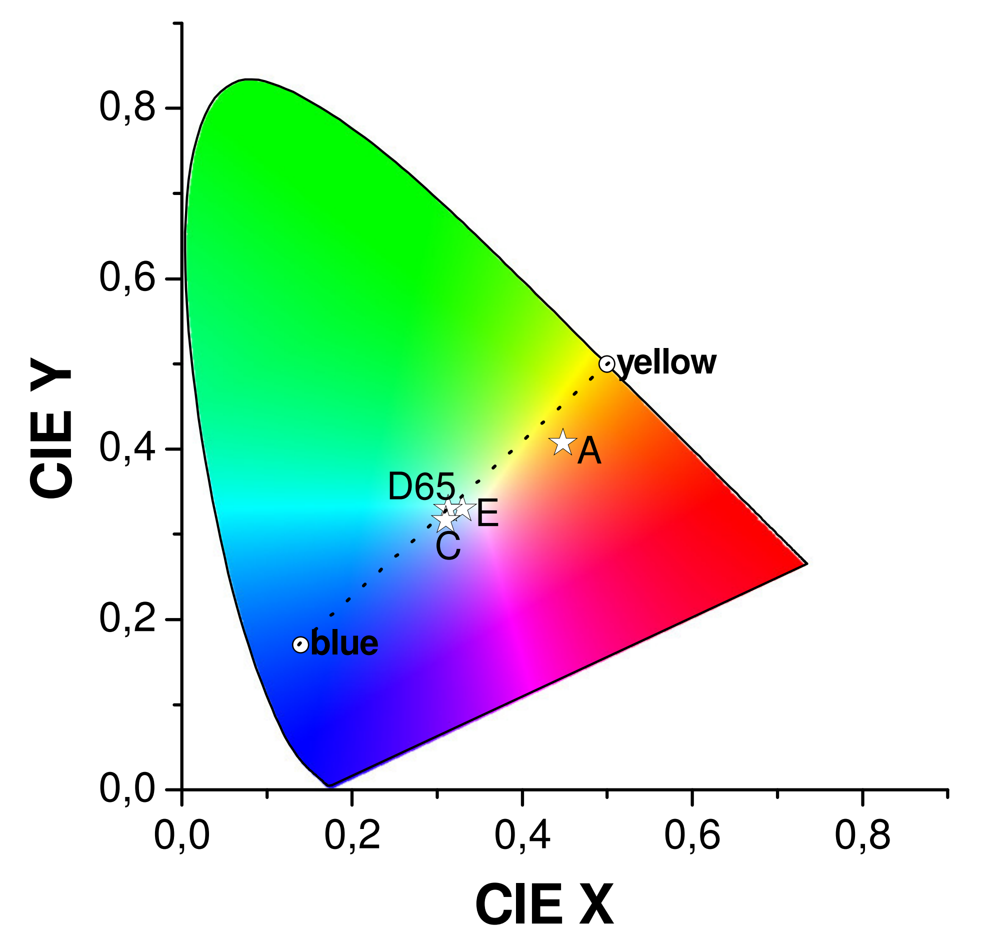
Color diagram



- **Color generation based on mixing monochrome emitter spectras**
  → Emission color can be tuned between primary colors used (here 2-color white example)

- Display white: around E
- Lighting white: region from color point A (yellowish) to C (white)

- **Application brightness**
  - Lighting 1000cd/m² to 4000cd/m²
  - Display 1000cd/m² to 2000cd/m²

Main routes to create white light OLEDs

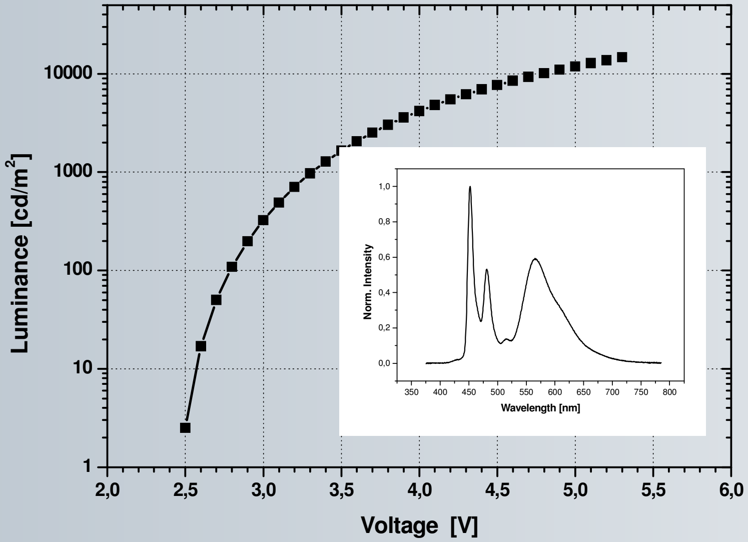
- Focus on lifetime
  - use singlet emitters
  - maybe: stacking for higher brightness
  - approx. 16lm/W (20lm/W with out-coupling) and >50kh lifetime achievable (Novaled, Kodak)
  - For signage/display applications
- Combine power efficiency and lifetime
  - hybrid emitters (blue singlet, red-green triplet)
  - preferentially stacking
  - up to 35lm/W (incl. out-coupling) and 100kh lifetime demonstrated (Novaled)
  - For general illumination
- Focus on power efficiency
  - all triplet emitter
  - up to 64lm/W and 10kh lifetime shown (Konica-Minolta)
  - experimental status
- Application driven OLED designs
  - Bottom emission (on glass substrates), transparent OLEDs, top emission (on metal substrates)

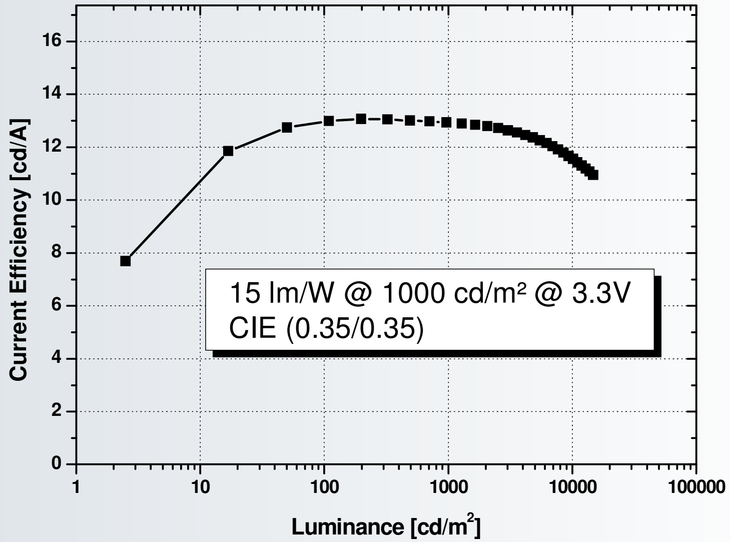
Display white – Longest Lifetime

White PIN OLED based on Kodak ***fluorescent*** emitter materials:

Efficiency at 1000 cd/m²: 13 cd/A, 15 lm/W *; CIE: (0.35/0.35)

*measured in integrating sphere with outcoupling enhancement

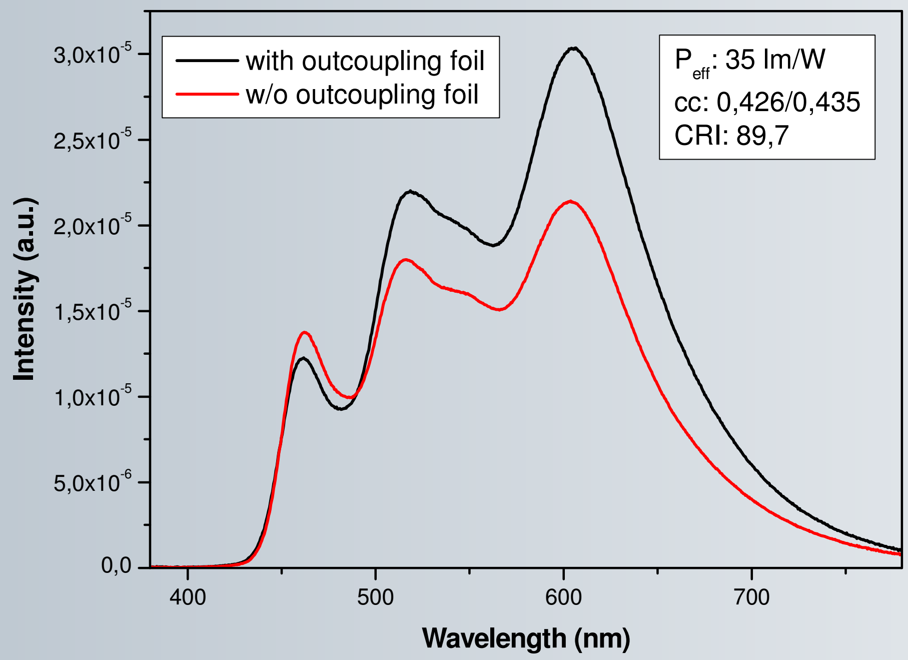


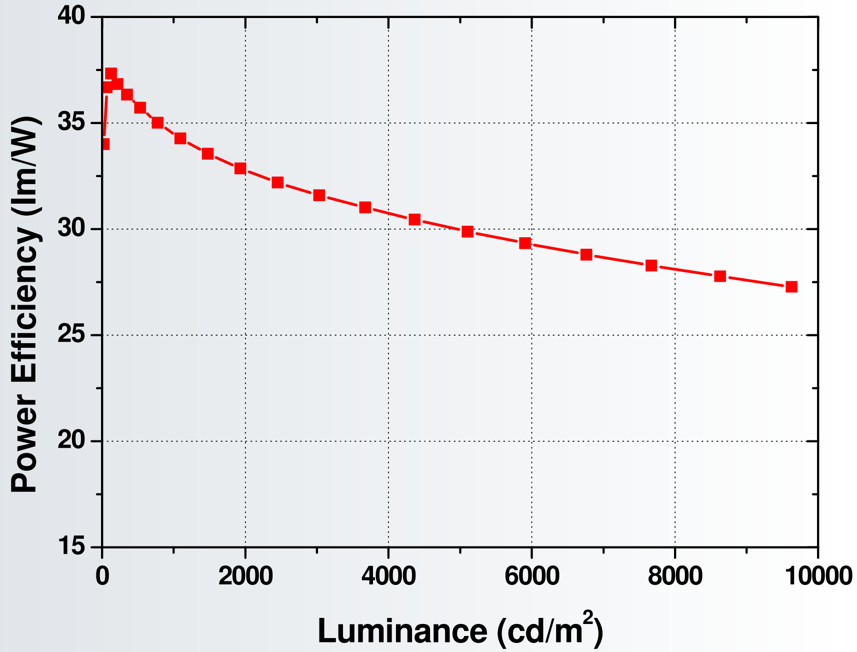


Lifetimes:

- such OLED structures achieve between 20.000h and 50.000h (5 years) at 1000cd/m²

Stacked White – highest lifetime AND efficiency





- High power efficiency: 35lm/W @ 1000cd/m²
- Long Lifetime: 100,000 hours at 1000 cd/m²
- cc: 0.43/0.44 , CRI 90

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Market Penetration by Innovative OLED Lighting Solutions: Example

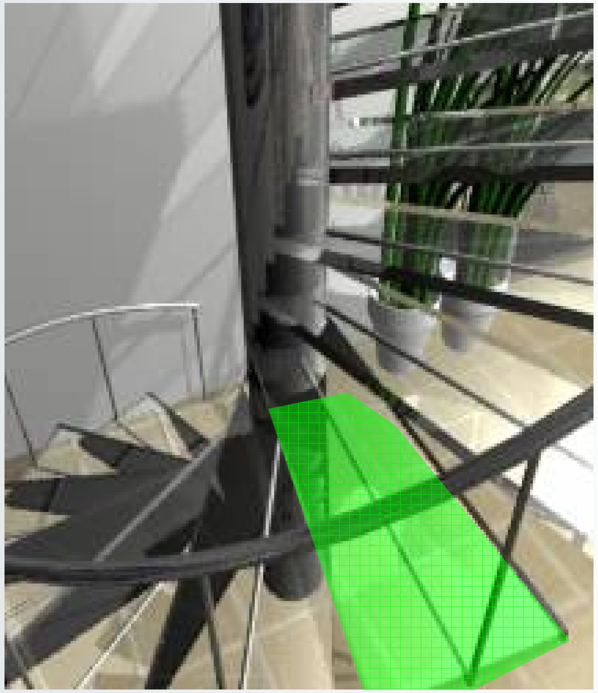
Headlight Demonstrator (Novaled/Automotive Lighting)

Novaled PIN OLED ™

OLEDs used for parking light: flat, area source, good white, low power

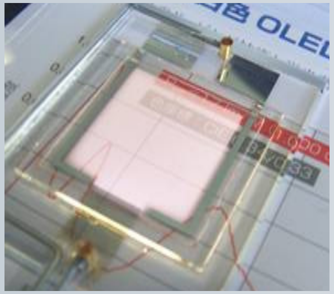
Future Innovative OLED Lighting Applications

- architecture
- indoor



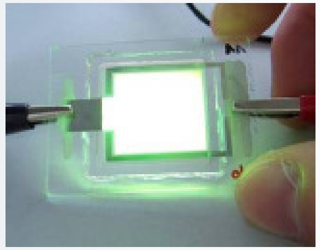
PIN: Freedom of Device Architecture

Transparent PIN OLED



PIN OLED in headlight
(with Magneto-Marelli)

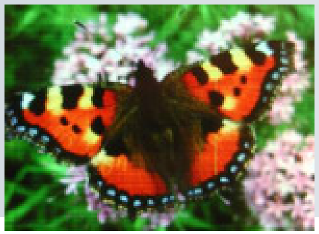
PIN OLED on Printed ITO
(with Degussa)



stacked
top & bottom emission
inverted & non-inverted
transparent

PIN OLED for Lighting
(with IPMS, Optrex)

PIN AM OLED
(with ITRI, Tomson)



PIN PM OLED
(with Thomson)

PIN OLED on Steel Substrate
(with Arcelor)

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How OLED Will Enter The Market

Short term:

› Niche applications for high price segment using unique design options

Mid term:

› Flexible and transparent solutions for enhanced designs

Long term:

› Price competitive large area high efficiency light sources for general lighting

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Market Entry Applications

- First products will be relatively high cost (~ 10-100 ct/cm^2)
- Products will be non-transparent with one reflective electrode (“mirror effect”)
- Devices will have an efficiency of 15 – 30 lm/W
- Applications will be small to medium size (~ 5 - 20 cm^2)

Technological Evolution Of OLED

- Classic design (OLED on glass substrates) will be followed by:
  - **Flexible OLEDs on metal and plastic foils**
  - **Transparent OLEDs**
- Total light output will grow via size and operation brightness
- Efficiencies of 75 – 150 lm/W will be reached
- OLED price per cm^2 (active area) will decline to 0,01 – 1 ct/cm^2

Timeline

- Market entry for niche applications between 2008 and 2010
- Flexible and transparent solutions available from 2010 onwards
- Estimated efficiency & lifetime of mass production devices (partially from Photonics21 roadmap):
  - **2010: 30-60 lm/W, 10.000-30.000 h**
  - **2015: >100 lm/W, 50.000 – 100.000 h**
  - **2025: > 150 lm/W, > 100.000 h**

Summary

- Novaleds PIN OLED Technology™ is a key to highest efficiencies and lifetimes in OLED
- SoA OLEDs reach lifetimes of up to 1 million hours; efficiencies of up to 116 lm/W (green) are reached
- White OLEDs for lighting with best combination of Lifetime and power efficiency reach 100kh and 35lm/W (all at 1000cd/m^2)

- First products will be small to medium size and based on glass substrates
- Large area, flexible and transparent devices will mature in the next decade

Acknowledgement

Thanks to: The Novaled team

and

- IAPP (TU Dresden), FhG-IPMS, University of Kassel (Prof. Salbeck)
- Philips Lighting/Philips Research
- Merck Organic Semiconductors, Germany
- Kodak
- UDC
- EU-project OLLA
- financial funding: Free State of Saxony, European Union, BMBF.


Thank you for your attention

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