

"A Breakthrough in the promising OLED world"



High Power Efficiencies at Record Lifetimes:

NOVALED's PIN-OLEDs

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Outline

- **Introduction:** Doping Technology, PIN-Concept, Novaled's Materials
- **Bottom Emission Examples:** Long Lifetime at High Efficiency, Operation at 80°C, Passive Matrix Application
- **Top Emission Examples:** Active Matrix Application, Long Lifetime at High Efficiency
- **Record Lifetimes, Display Demonstration, White Emitters**
- **Conclusion, Acknowledgement, References**

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Introduction

Roadblocks to OLED Production

1. Power Efficiency

→ NOVALED ☒

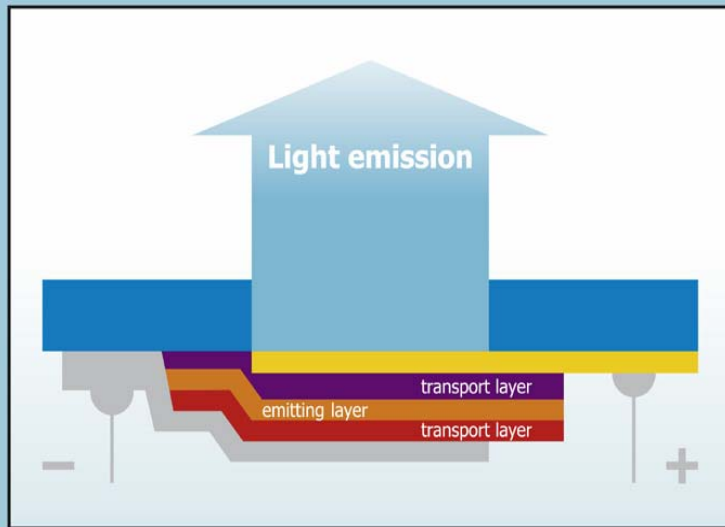
2. Reliability, e.g. Lifetime

→ NOVALED ☒

3. Production Implementation

→ NOVALED's Partners ☒

Our Technology: Doping of Transport Layers



- | | |
|---|--|
|  transparent conductor (ITO) |  electron transport layer |
|  hole transport layer |  metal cathode |
|  emitting layer |  glass substrate |

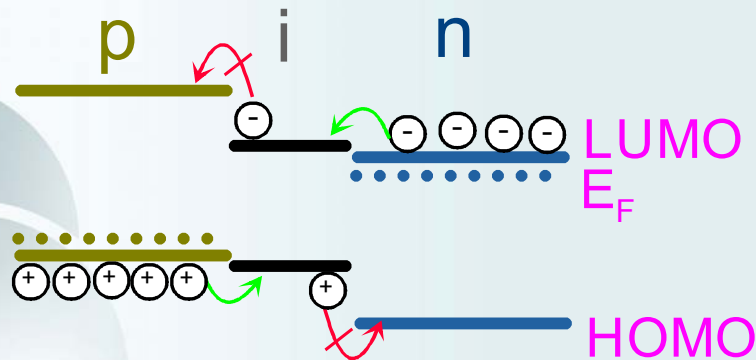
OLEDs with doped transport layers enable.....

- unprecedented power efficiencies
- lowest operating voltages
- inverted, top-emitting structures
- transparent OLEDs
- compatible with all electrodes
- optimized micro-cavities
- sputter damage protection
- planarization of rough substrates

PIN Concept: High Efficiency at Long Lifetimes

High Efficient OLEDs require PIN-Structures:

1. **Hole Transport Layer:** p-type doped matrix (injection & transport)
2. **Intrinsic Emission Layer:** dye sandwiched between interlayers*
3. **Electron Transport Layer :** n-type doped matrix (injection & transport)



*prevent exciplexes

Novaled's Material Overview

Material Requirements:

- evaporation temperature in reasonable range $\Rightarrow$ simple process control
- low vapor pressure $\Rightarrow$ no cross-contamination
- no diffusion of dopants in matrix at elevated temperatures $\Rightarrow$ device reliability

Hole Side

Dopable hole transport matrix material with high T_g : NHT-5

- $T_g > 145^\circ\text{C}$
- no cross-contamination

Temperature & diffusion stable molecular p-dopant (strong acceptor): NDP-2

- $T_{\text{evap}} > 150^\circ\text{C}$
- no cross-contamination
- enhanced lifetime

Electron Side

Dopable electron transport matrix material with high T_g : NET-5*

- $T_g > 105^\circ\text{C} \Rightarrow$ superior to Bphen ($T_g = 63^\circ\text{C}$) at the same electron mobility $\Rightarrow$ superior to Alq₃
- no cross-contamination

*experimental evaluation of further materials with higher T_g in progress

Temperature & diffusion stable molecular n-dopant (strong donor): NDN-1

- $T_{\text{evap}} > 200^\circ\text{C}$
- no cross-contamination
- enhanced lifetime
- molecular dopant $\Rightarrow$ no alkali-metals!!!

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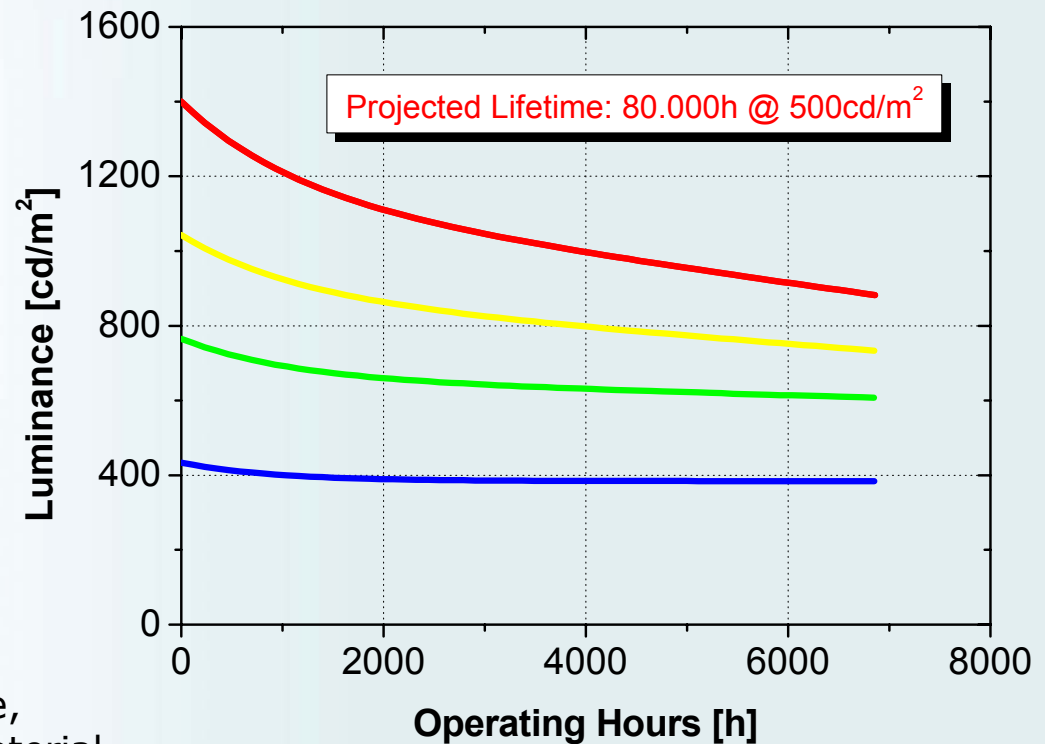
Bottom Emission

Lifetime at Room Temperature: **Red Emitting PIN-OLED**

- **continuous measurement for more than 6800 hours** (>9 month)

- **low voltage increase** (typically less than 20% over whole lifetime)

measurement conditions:
DC-driven at room temperature,
encapsulated *without* getter material



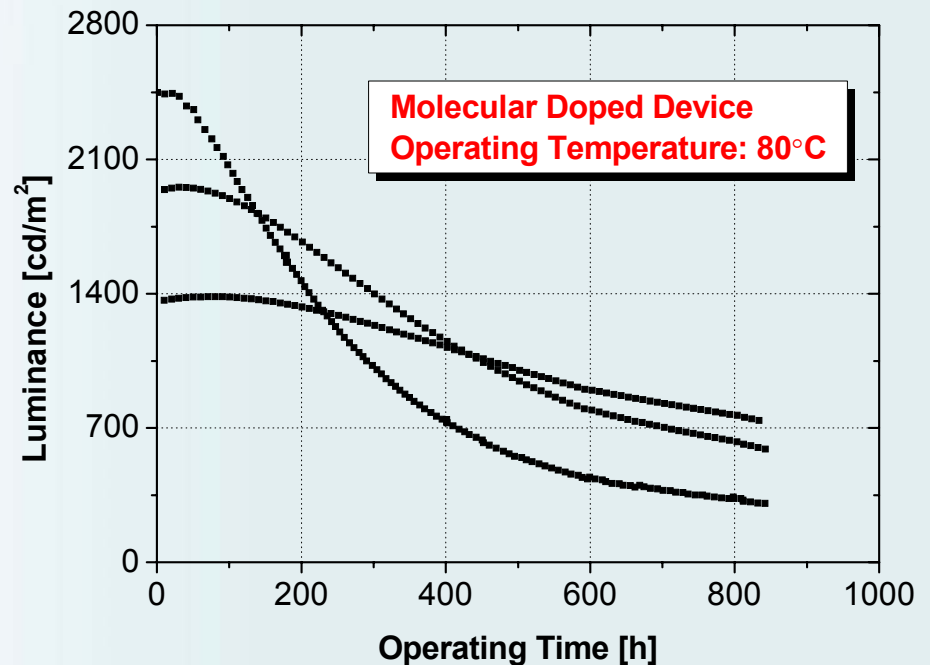
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Lifetime at 80°C: **Red Emitting PIN-OLED**

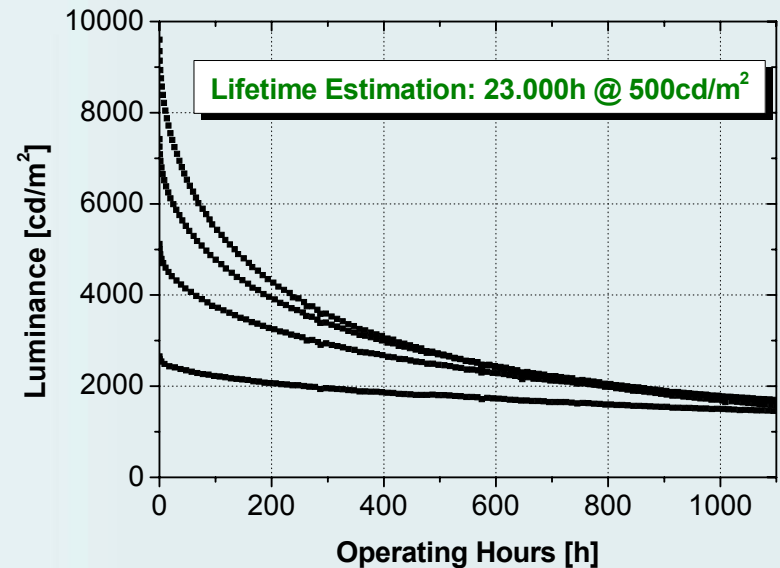
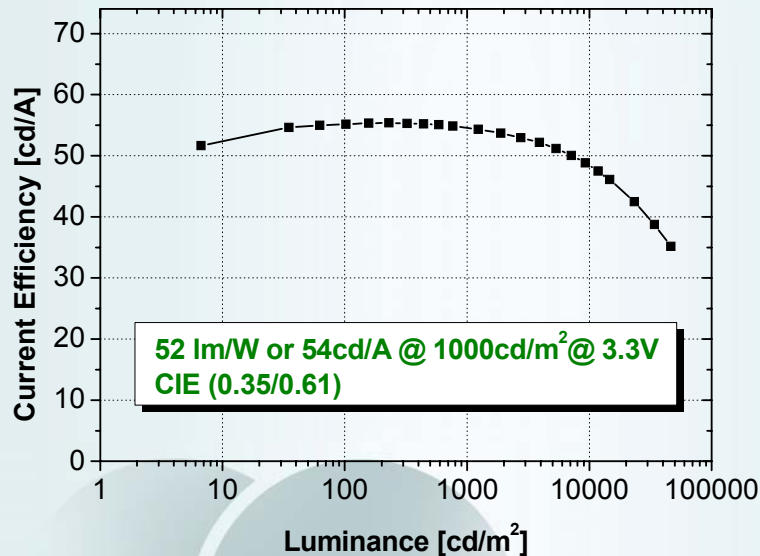
**Extrapolated lifetime of
molecular* doped device:**

6400h @ 80°C @ 500cd/m²



*Cs-doped device ceased operation after a few hours

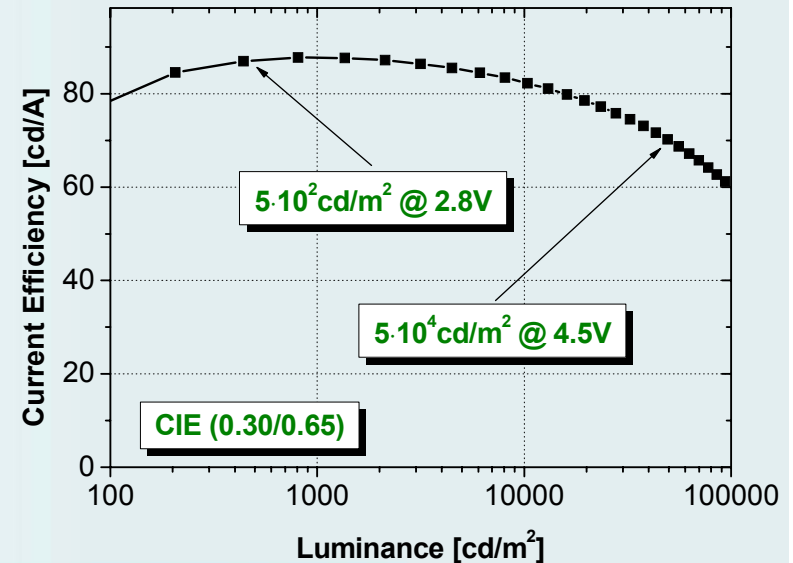
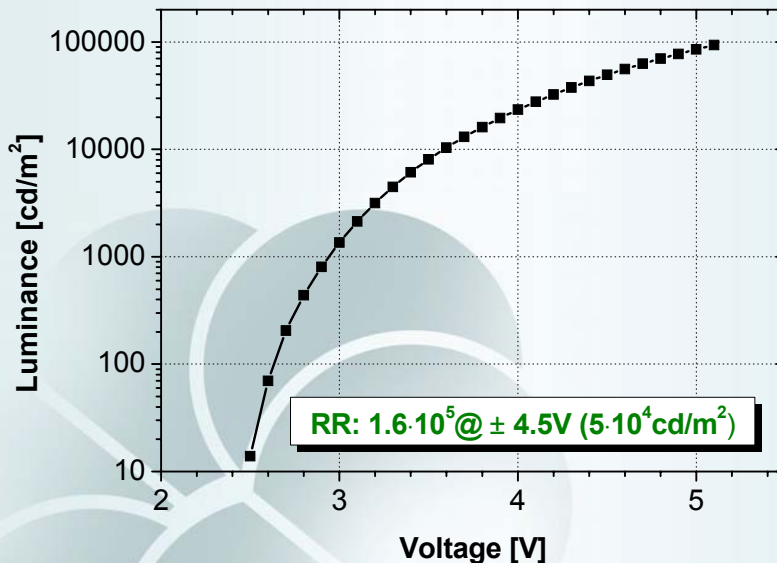
High Efficiency @ Long Lifetime: **Green Emitting PIN-OLED**



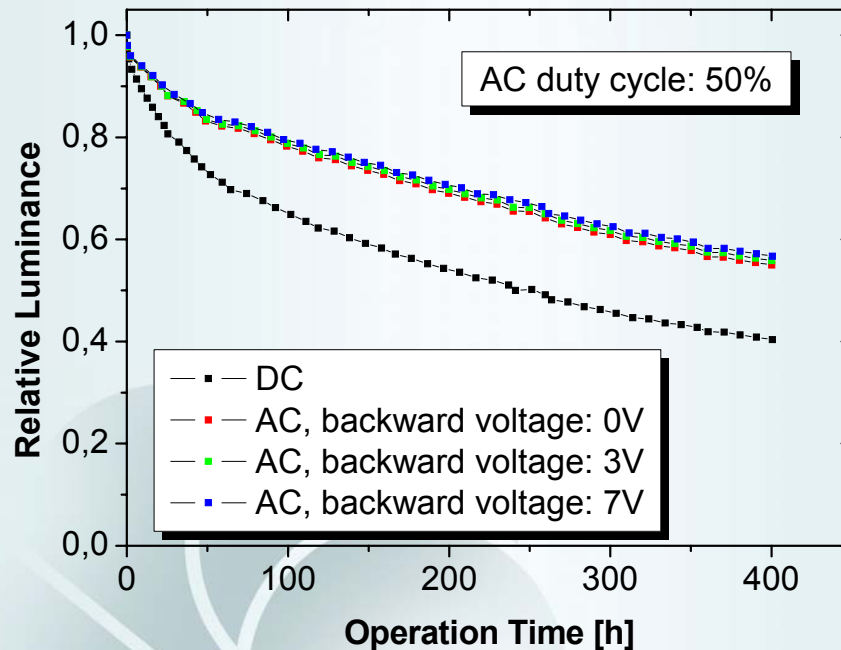
- **high efficiency: 52lm/W @ 1000cd/m² @ 3.3V**
@
- **long lifetime: 23.000h @ 500cd/m²**

PIN-OLEDs tailored to Passive Matrix Applications

- low operating voltages @ high luminance
(e.g. green: $<5V$ @ 50.000cd/m^2)
- minimal backward currents
- low roll-off (optimized doping concentration)



PIN-OLEDs tailored to Passive Matrix Applications



- **minimal backward currents**

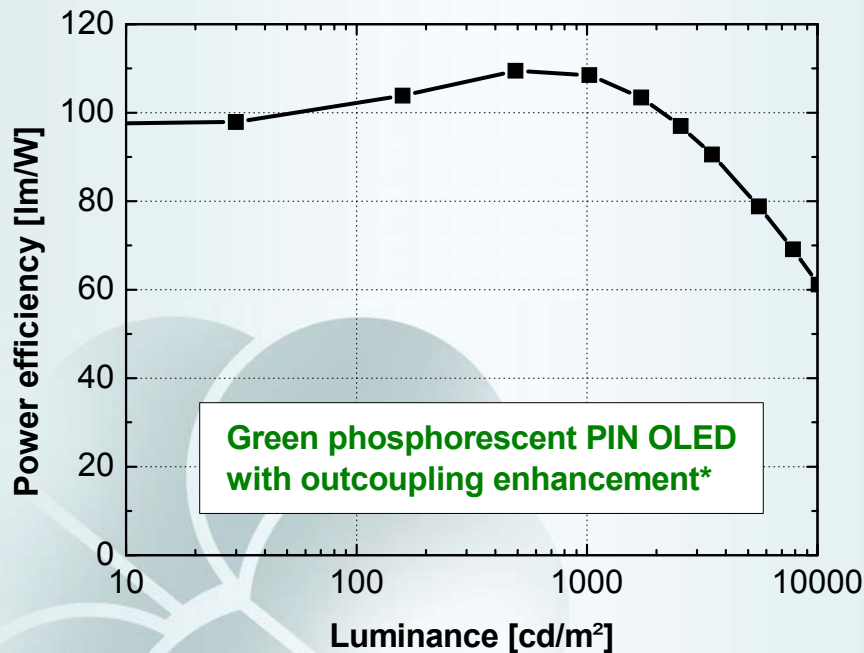
- **first order approximation:**

$$\frac{DC_lifetime}{duty_cycle} \approx AC_lifetime$$

- **lifetime independent of backward voltage**

Unprecedented Light Efficiencies: **Green Emitting PIN-OLED**

Record efficiencies by proprietary doping technology:



Efficiency at 1000 cd/m²:

110 lm/W

Measured in integrating sphere
(side walls of device: covered)

* plastic foil

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Top Emission

Top Emission: Large Apertures for Active Matrix Backplanes

Top Emission $\Rightarrow$ Large Apertures

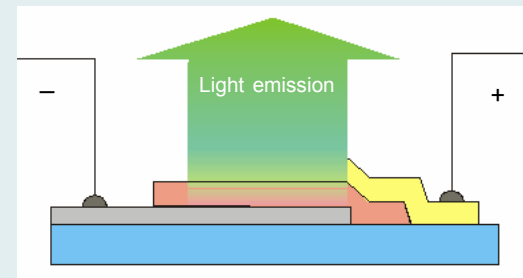
- $\Rightarrow$ Low Current Densities
- $\Rightarrow$ Prolonged Lifetimes

1. p-channel TFTs:
poly-Si $\Rightarrow$ non-inverted device
2. n-channel TFTs:
a-Si $\Rightarrow$ inverted device

Doping approach enables.....

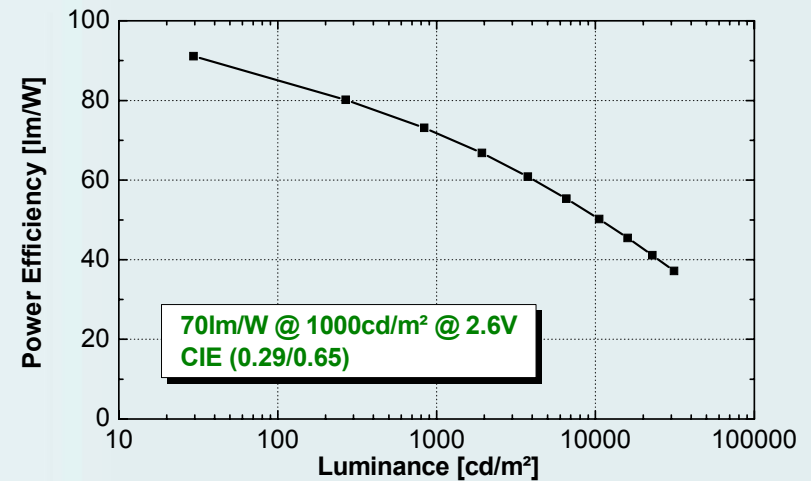
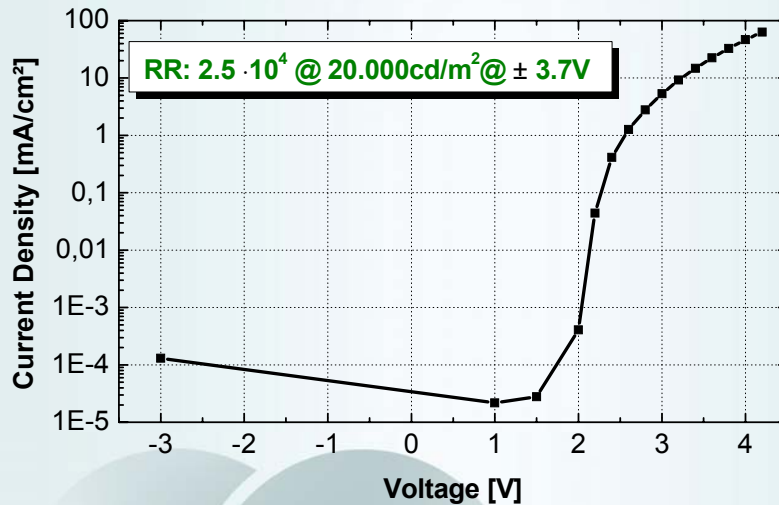
- inverted and non-inverted devices
- variety of contact materials

Inverted, top-emitting OLED:



-  transparent conductor (ITO)
-  organic layers
-  metal cathode
-  active matrix substrate

High Efficiency @ Long Lifetime: **Green Top Emission PIN**



- **high efficiency: 70lm/W @ 1000cd/m² @ 2.6V**
@
- **long lifetime: 13.000h @ 500cd/m²**

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Record Lifetimes, Display Demonstration, White Emitters

Record Lifetimes of PIN-OLEDs

Current status:

phosphorescent **red** (0.68, 0.32): **>100,000 h at 500 cd/m²**

phosphorescent **green** (0.26, 0.68): **>50,000 h at 500 cd/m²**

fluorescent **blue** (0.15, 0.17): **>6,000 h at 500 cd/m²**

- Novaled has improved state-of-the-art OLED lifetimes for RGB utilizing standard emitters, e.g. Irppy₃
- Lifetime top emission $\approx$ bottom emission

Novaled's Doping Technology: Display Demonstration

- Active matrix OLED made by **ITRI** (Taiwan, Backplane) and **Thomson** (France, OLED processing and module integration)
- Panel emitting in both directions on n-channel LTPS backplane (3.25", QVGA, 130dpi) based on PIN structure

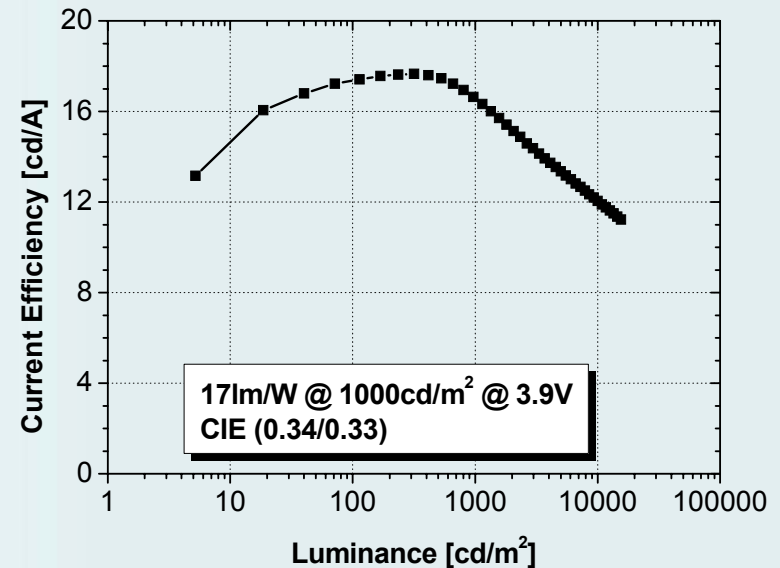
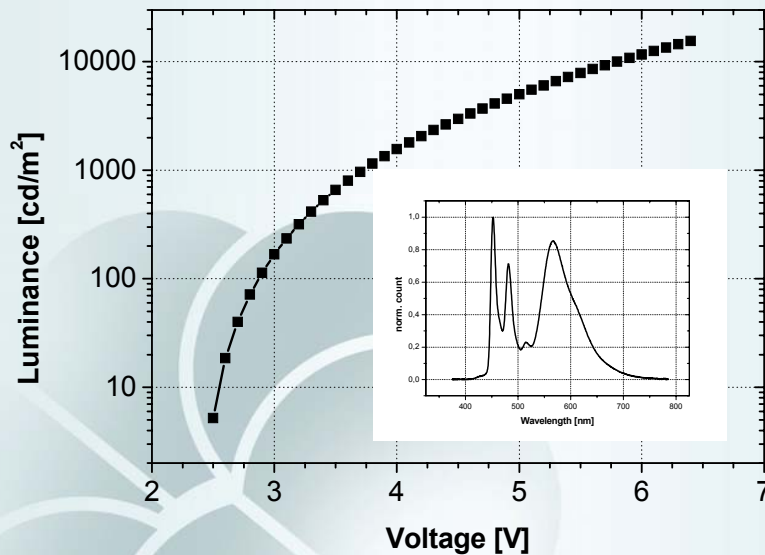


Performance:

- operating voltage for 100cd/m²: **around 7V** (OLED + backplane)
- power consumption: **240mW@100cd/m²** (in forward direction only, video mode)
≈ 60% of equivalent LCD

White Fluorescent Emitter

White PIN OLED based on state of the art **fluorescent** emitter materials:
⇒ **Efficiency at 1000 cd/m²: 17 lm/W, color coordinates: 0.34/0.33**



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Conclusion, Acknowledgement, References

Conclusion

- **Molecular n-Dopant:**

- ⇒ High Temperature Stability

- ⇒ Replaces Cs

- **PIN-OLEDs:**

- ⇒ Record Power Efficiencies @ Long Lifetimes

- ⇒ Top Emission Performance $\approx$ Bottom Emission

- ⇒ Suitable for AM- and PM-Displays

- ⇒ High Efficiencies @ Long Lifetime for White OLEDs

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- Merck/Covion Organic Semiconductors
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Thank you for your attention !

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