

# Organische Leuchtdioden: Stand der Technik und Limits

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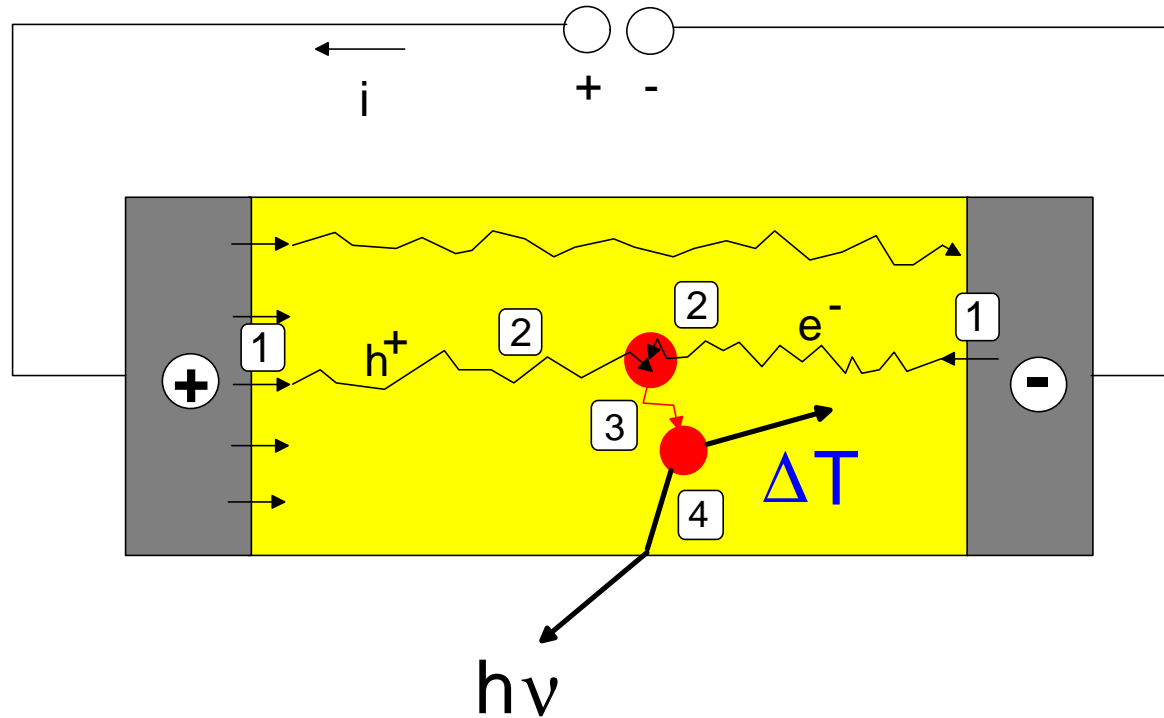
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Farbe

Effizienz

Polarisation

# Basic Mechanisms in Electroluminescence



① Charge injection

② Charge diffusion and recombination

③ Exciton diffusion

④ Exciton recombination and photon emission

## Dusty Lab May Revolutionize LEDs



PRINCETON, N.J. — You may think that your cleanroom should be clean, but a serendipitous bit of grime that interfered with an experiment at Princeton University could lead to the production of cheaper, higher-quality LEDs.

The accident occurred in the lab of Stephen Y. Chou, a professor of electrical engineering, during the imprinting of polymer-based diodes. Where a speck of dust had prevented contact between the mask and the polymer, a regular structure had grown, creating a photonic bandgap material: rows of pillars less than 1  $\mu\text{m}$  high. Further experiments showed that the size and distribution of the pillars depend on the gap between the mask and the developing surface, which could enable manufacturers to tailor the material to their needs.

The technique may find its initial application in the manufacture of computer monitors. Because fine control of the height and distribution of the pillars is possible, the

colors emitted by the LED, which are determined by microcavities formed in the polymer, can be made to range from blue to red. Instead of manufacturing each color with different light-emitting materials, the entire range of colors could be produced with one material by controlling the height and distribution of the pillars. Further, a display made with the process would be much sharper than those now on the market, because each pixel would be a composite of many pillars acting as a group of tiny dots, rather than a monolithic block.

The researchers are completing research on the application of the technique to LED manufacturing and expect to publish their results soon. Other potential applications include controlling the manufacture of integrated circuits and sorting DNA fragments based on their size. Princeton has applied for US and international patents on the process, which the researchers call lithographically induced self-assembly. □

*Steve Miller*

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Photonics  
Technology World

# Limits of Quantum-Efficiency

$$h_{\text{int}}(EL) = h(PL) f_S f_R \leq 25\%$$

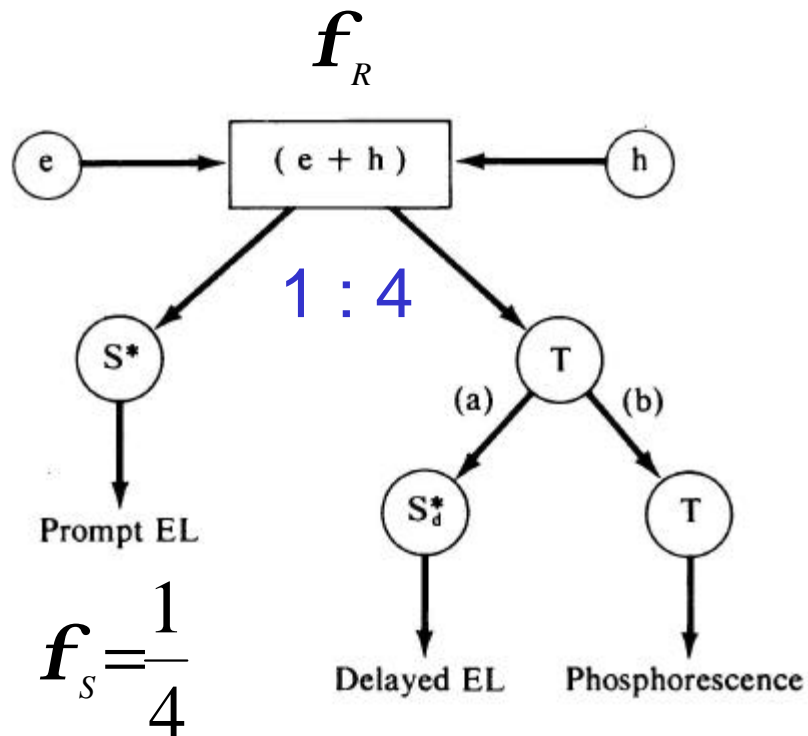
$$h_{\text{ext}}(EL) = \frac{h_{\text{int}}(EL)}{2n^2}$$

ideal conditions and  $n = 1.7$ :

$$h_{\text{ext}}(EL) = 5\%$$

**Power efficiency:**

light power versus electrical power

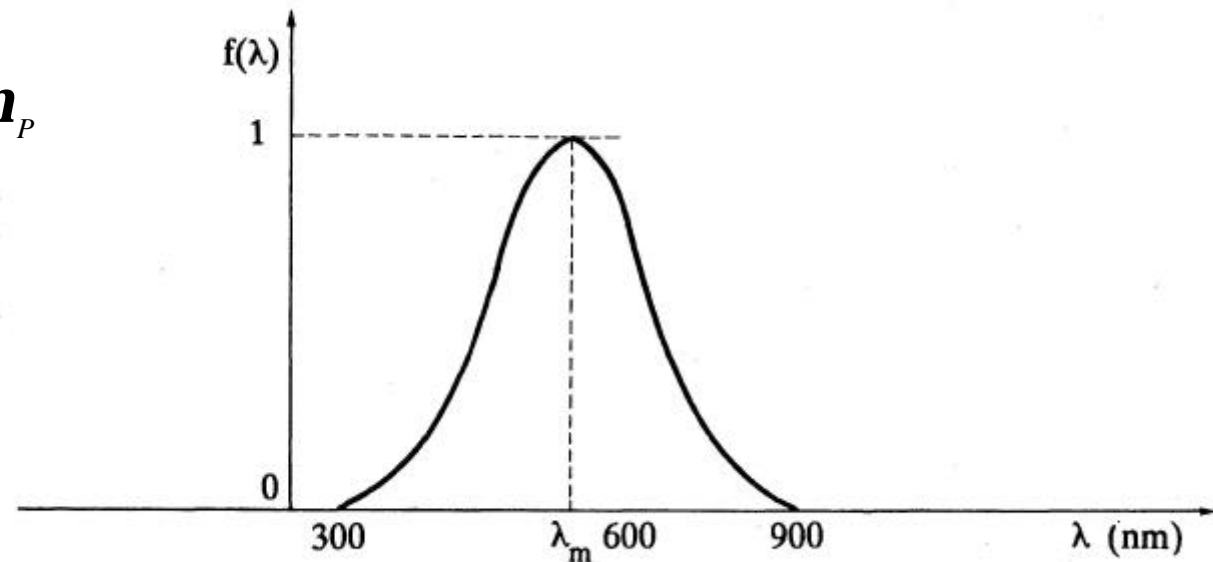


$$h_p(EL) = \frac{\hbar\omega}{eU} h_{\text{ext}}(EL) \leq 5\%$$

# Limits of Luminous Efficiency

Luminous efficiency: luminous flux versus electrical power

$$f_v [\text{lumen}] = f(\lambda) \times 680 \frac{\text{lm}}{\text{W}} \times h_p$$
$$\leq 34 \text{lm/W}$$



**What is needed?**

Computer display, 100 cd/m<sup>2</sup>, 14", U = 4V,  $h_p = 5\%$

blue: 900 mA (7 cd/A)

green: 330 mA (19 cd/A)

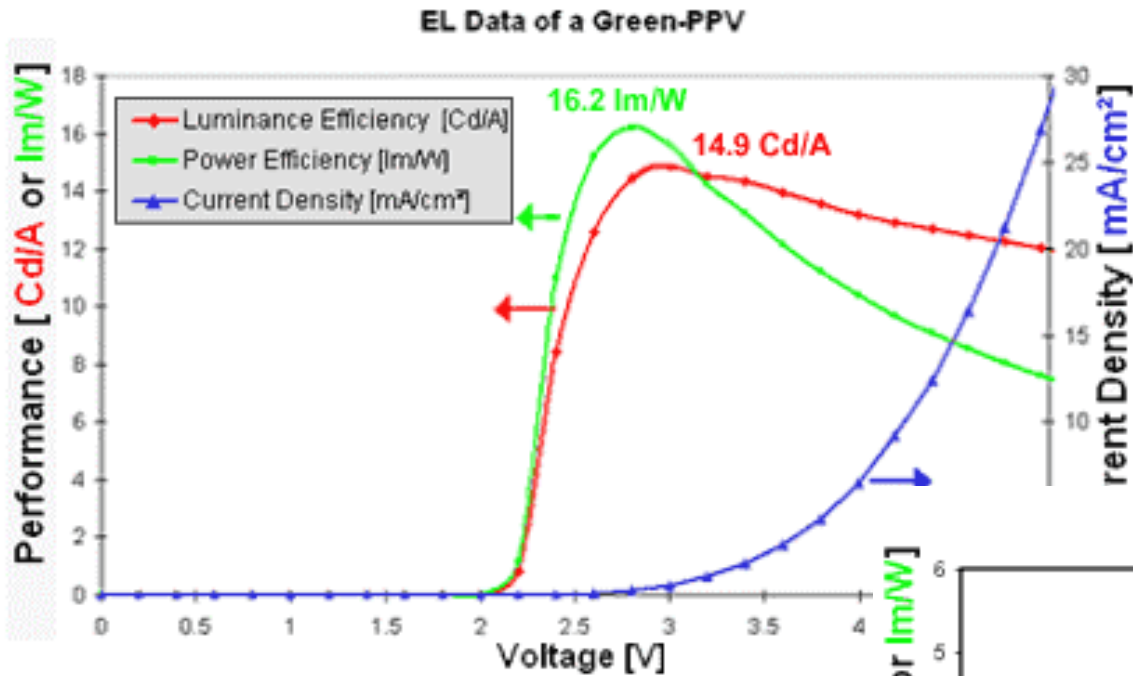
red: 800 mA (7.8 cd/A)

## CDT - LED Performance Data

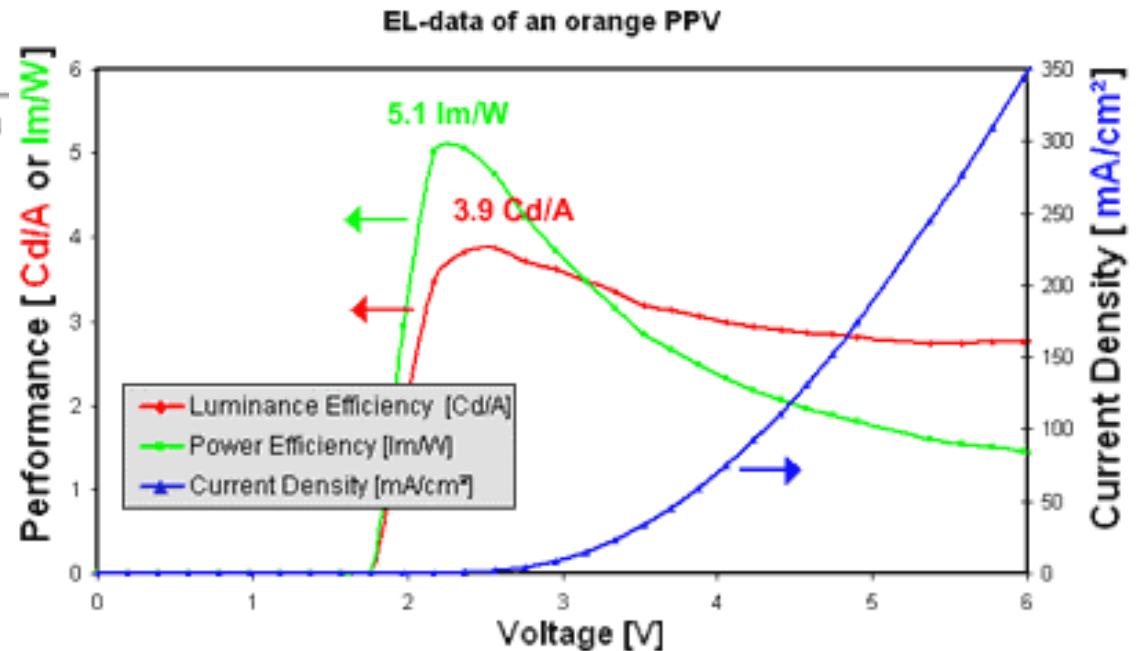
Colour	Deep Blue	Blue	Green	Orange	Red
CIE-x	0.162	0.180	0.379	0.612	0.674
CIE-y	0.099	0.240	0.581	0.385	0.324
Maximum Cd/A	1.90	4.09	14.9	3.5	1.20
Maxi Lm/W	1.32	3.47	17.5	4.6	1.82
mum V	4.40	3.60	2.60	2.4	2.40
Cd/m <sup>2</sup>	570	156	29	105	30
Lm/W mA/cm <sup>2</sup>	30.834	3.93	0.2002	2.9882	2.1579
@ 20 Lm/W	1.29	2.95	7.30	3.4	1.30
mA/c Cd/A	1.70	2.35	9.50	3.3	1.50
m <sup>2</sup> Cd/m <sup>2</sup>	340	860	1900	650	300
V	4.13	4.53	4.07	3.0	3.50
@ Lm/W	0.77	3.41	10.6	2.8	1.30
3.5V Cd/A	0.90	2.14	11.6	3.2	1.50
Cd/m <sup>2</sup>	56	123	830	1200	300
mA/cm <sup>2</sup>	6.24	3.18	7.17	38	20

# Covion Green and Orange Emitters

October 2000



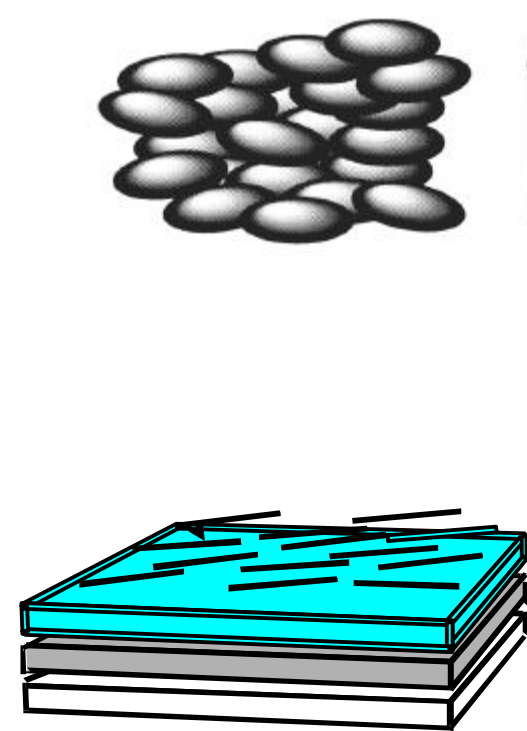
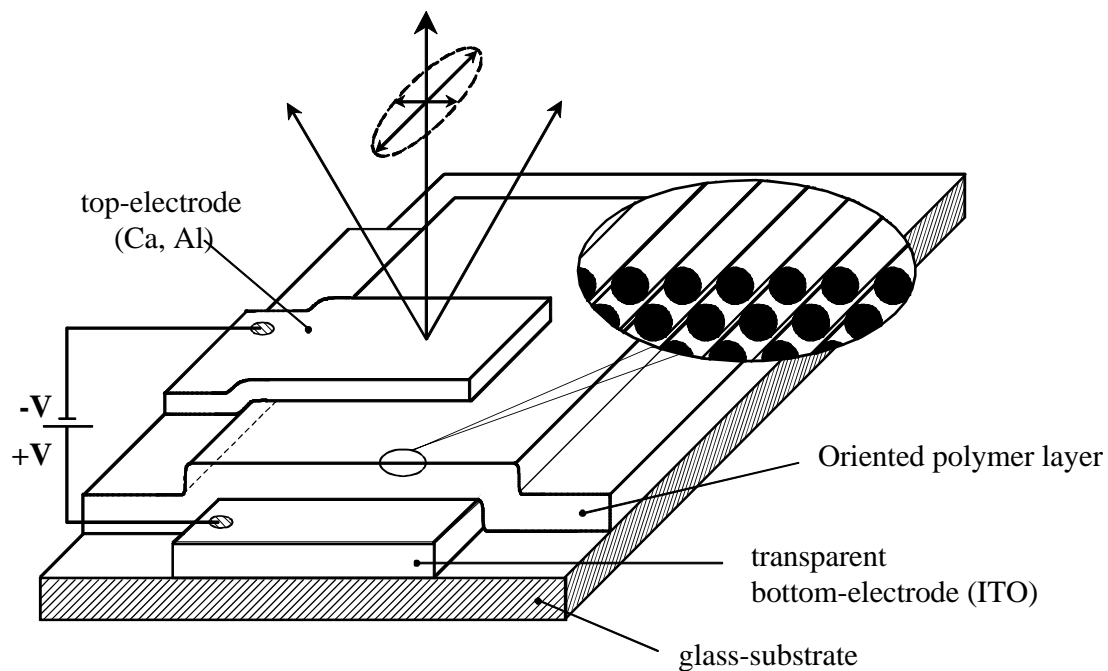
PLEDs are on the way to reach quantum limit



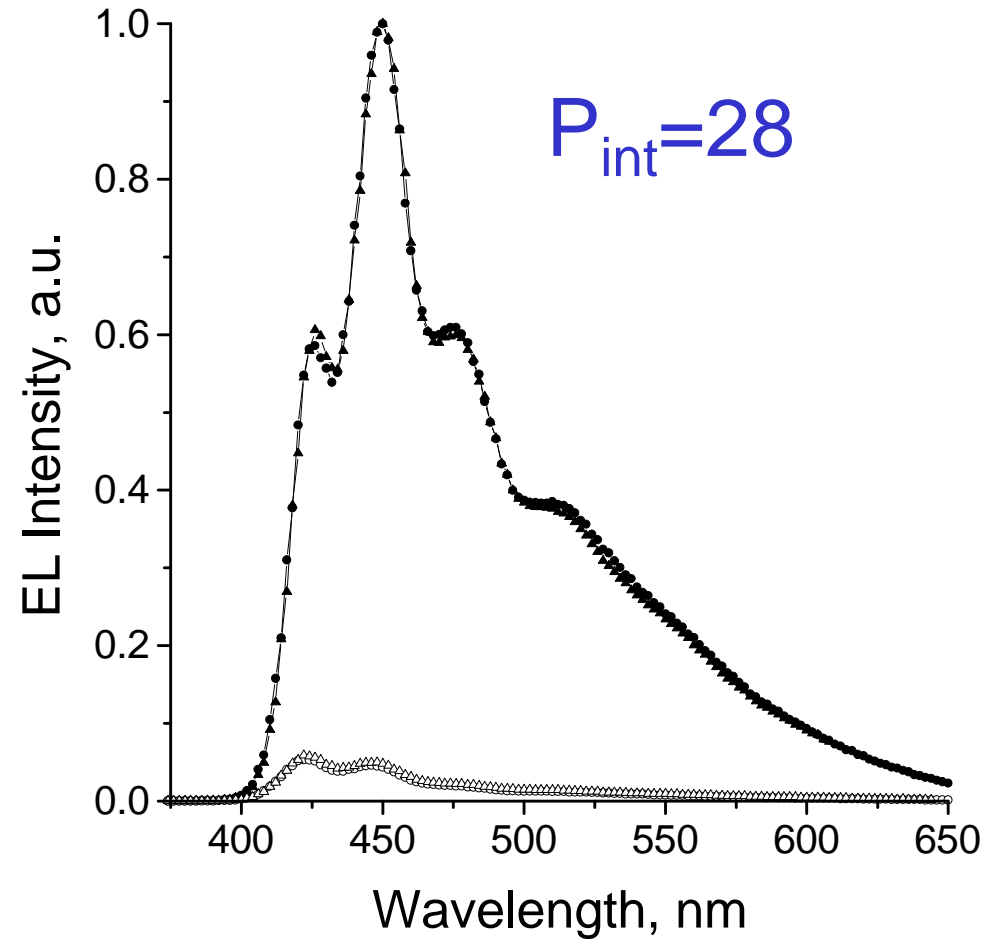
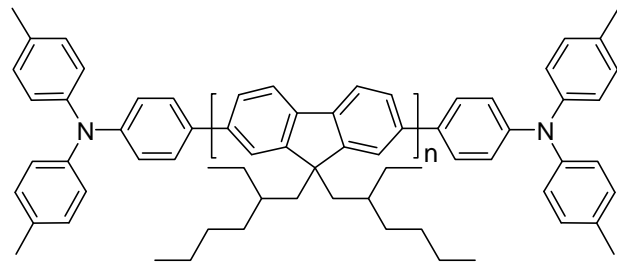
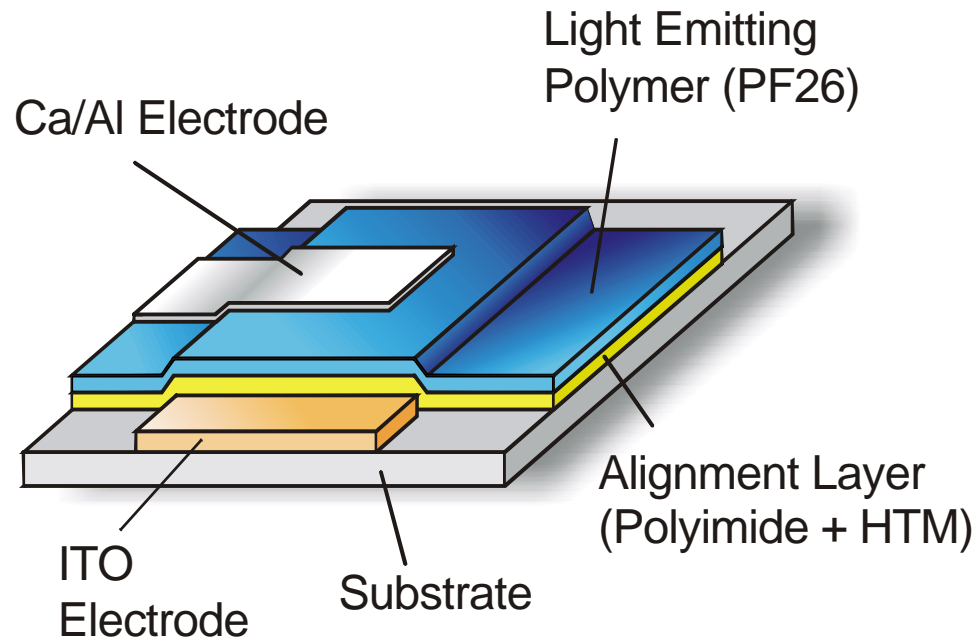
# Light-Emitting Diodes with Polarized Emission

## Commercial interest:

LEDs with polarized light emission for LCD backlights  
( $I_{\parallel} / I_{\perp} \approx 50$  required)



# Polarized Light-Emitting Diode



Luminance: 700 Cd/m<sup>2</sup>, 0.3 cd/A

# Linearly-Polarized Electroluminescence

Polarization ratio  $P = I_{||} / I_{\perp}$

Method/Year	1995	1996	1997	1998	1999	2000	2001
<i>Direct mechanical alignment</i>							
Stretched polymers	2.4	8					
Direct rubbing	1.6	4.0		2.6	7	12	
Langmuir-Blodgett		3-4	1.5				
<i>Use of an alignment layer</i>							
Epitaxial growth	5						
Liquid crystals			6.0	2.4	15*	22*	25*28*
Casting							10

\* using liquid-crystalline polyfluorene

## LEDs with Circularly-Polarized Emission

Commercial interest:

LCD backlights (higher contrast, lower onset field)<sup>1</sup>

Optical data storage using chiral molecular switches<sup>2</sup>

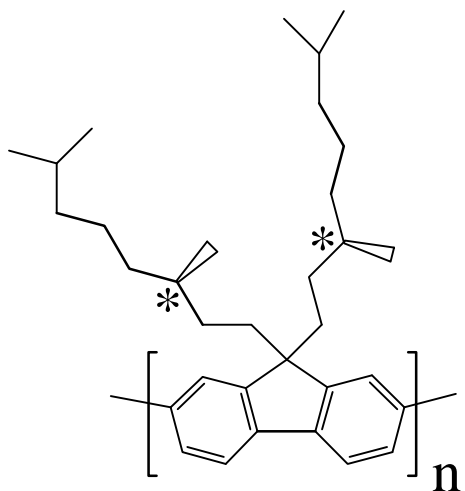
Dissymmetry factor:  $g_e$ ,  $-2 \leq g_e \leq 2$

$$g_e = \frac{2(I_L - I_R)}{I_L + I_R}$$

<sup>1</sup> M. Schadt, *Ann. Rev. Mater. Sci.* 27 (1997) 305

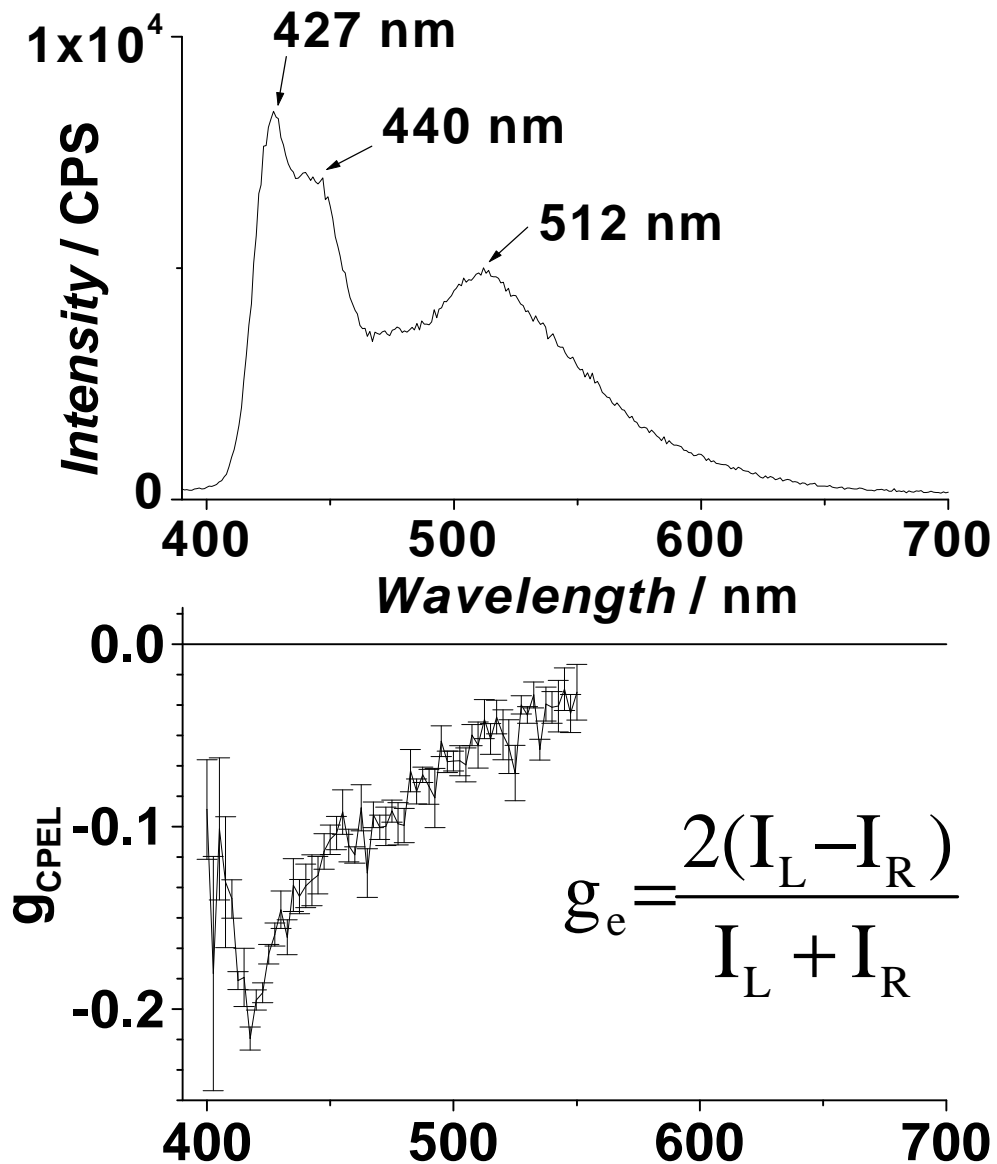
<sup>2</sup> B.L. Feringa et al., *Science* 273 (1996) 1686

# Circularly-Polarized Electroluminescence

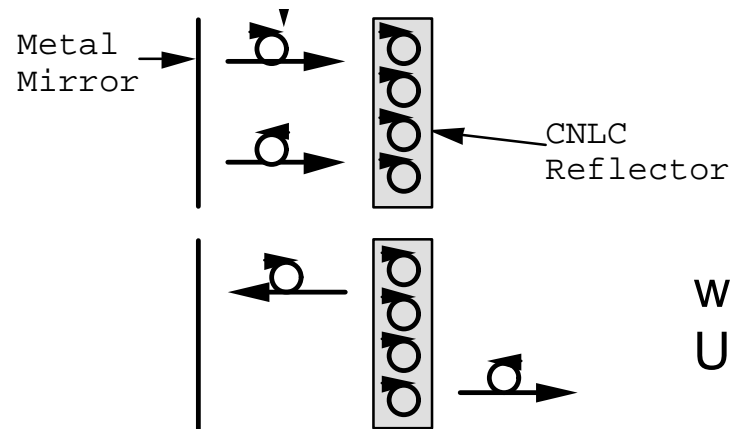
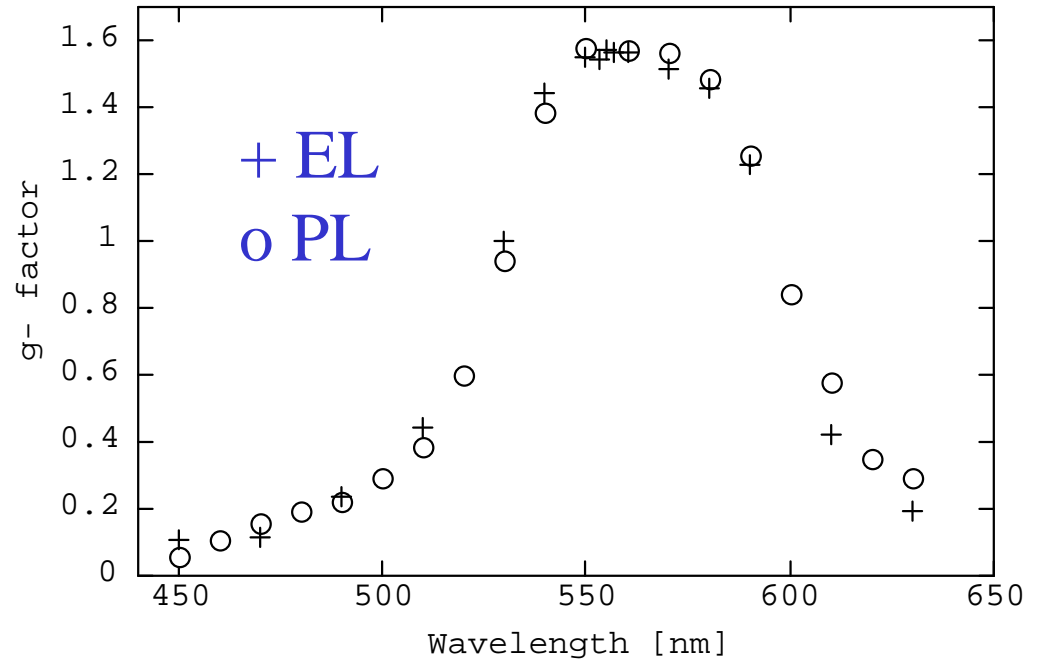
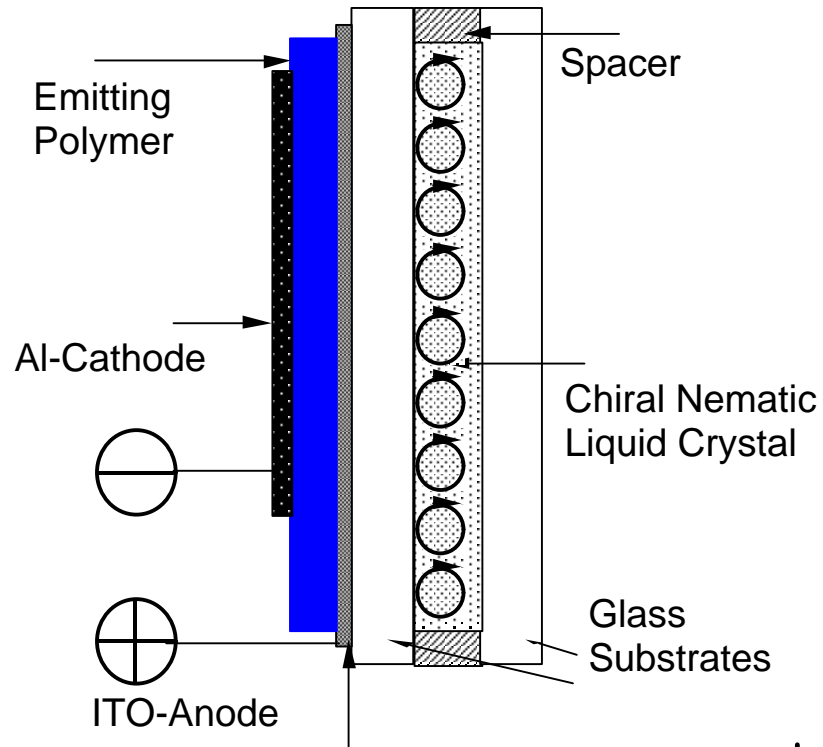


right-handed emission  
ca. 30 % stronger than  
left-handed

M. Oda, D. Neher et al.,  
Adv. Mater. **12** (2000) 362-365.



# Photon-Recycling-Mode



with M. Grell, D. Bradley.  
Univ. Sheffield

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