전자물리특강: OLED Introduction

2007. 9. 10.

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강의 계획

- 교재 및 참고서
  - 주교재 :
    - J. Kalinowski, Organic Light-Emitting Devices: Principles, Characteristics, and Processes, (Marcel Dekker, New York, 2005).
    - Organic Light-Emitting Devices, J. Shinar Ed. (Springer-Verlag, NY, 2004).
  - 참고서 :
    - M. Pope and C. E. Swenberg. Electronic Processes in Organic Crystals and Polymers, 2nd Ed. (Oxford, NY, 1999)
    - K. C. Kao and W. Hwang, Electrical Transport in Solids, Pergamon Press, Oxford, 1981)
    - J. D. Wright, Molecular Crystals, 2nd Ed., (Cambridge University Press, Cambridge, 1995).

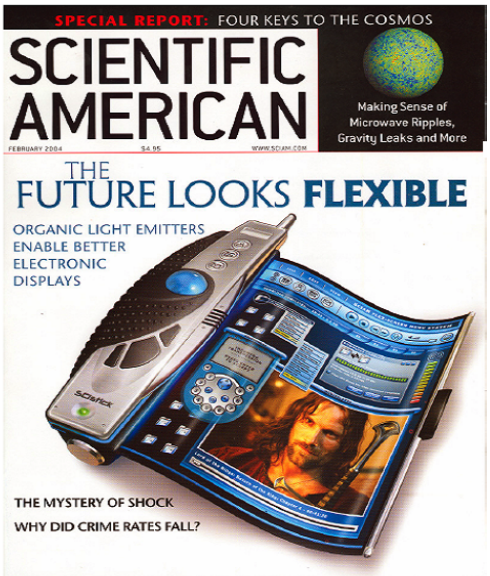
- 강의계획

  1주: Introduction, OLED 개발 역사
  2주: 유기반도체의 전자 구조
  3주: 유기반도체의 광학적 특성
  4주: 유기반도체의 전기적 특성
  5주: 유기반도체 박막 형성 및 패턴 제조공정
  6주: OLED 디스플레이 구조 및 제조 방법
  7주: OLED 소자의 계면 특성
  8주: 중간고사
  9주: OLED 소자의 동작 원리 - 전기적 특성
  10주: OLED 소자의 동작 원리 - 전기적 특성
  11주: OLED 소자의 동작 원리 - 광학적 특성
  12주: OLED 소자의 발광 효율 향상 방법
  13주: OLED 소자의 열화 원인 및 장수명화 방법
  14주: 백색 OLED 소자; 디스플레이 및 광원으로의 응용
  15주: 기말고사

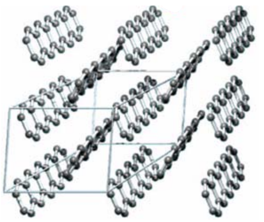
- 성적평가방법

  중간고사 (40%), 기말고사 (40%), 출석 5% Term Paper 15%

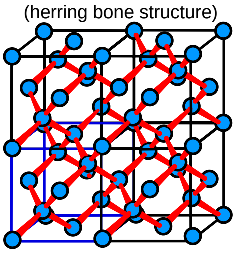
Future electronics



Organic molecular crystal *vs* covalent crystal



Organic Crystals
Weak Van der Waals interaction
(herring bone structure)



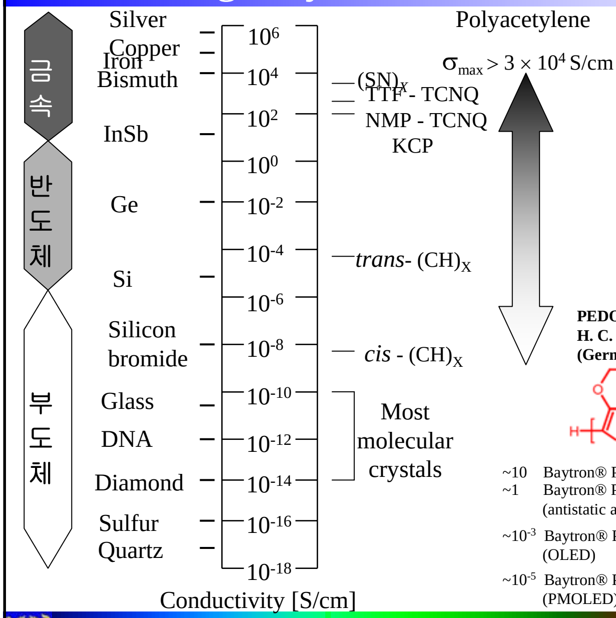
Inorganic Crystals
Strong covalent bond
(diamond structure)

TEM image of F_{16}-CuPC
- Electrons are localized in a molecule

Inorganic Semiconducor		Organic Semiconductor
Covalent (2 ~ 4 eV)	Interaction Energy	Weak Van der Waals (10^{-3} ~ 10^{-2} eV)
Band	Transport Mechanism	Hopping
100 ~ 10,000	Mobility (cm^2/Vs), RT	10^{-6} ~ 1
l ~ (100 ~ 1000) a_o	Mean free path	l ~ a_o = lattice constant
$m_{eff} \leq m_e$	Effective mass	$m_{eff}=(10^2 \sim 10^3)m_e$, (Polaron)
Wannier-Mott	Exciton	Frenkel

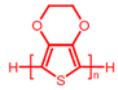
E. A. Silinsh and V. Capek, Organic Molecular Crystals,(AIP, NY, 1994)

Conducting Polymers



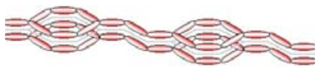
Nobel Prize in Chemistry 2000
Hideki Shirakawa, Alan G. MacDiarmid, Alan J. Heeger

PEDOT:PSS
H. C. Starck (Germany)



~10 Baytron® P HC
~1 Baytron® P (antistatic applications)
~10^{-3} Baytron® P VP Al4083 (OLED)
~10^{-5} Baytron® P VP CH8000 (PMOLED)

Conducing Polymers



π- π* Energy Gap of Conjugated Polymers

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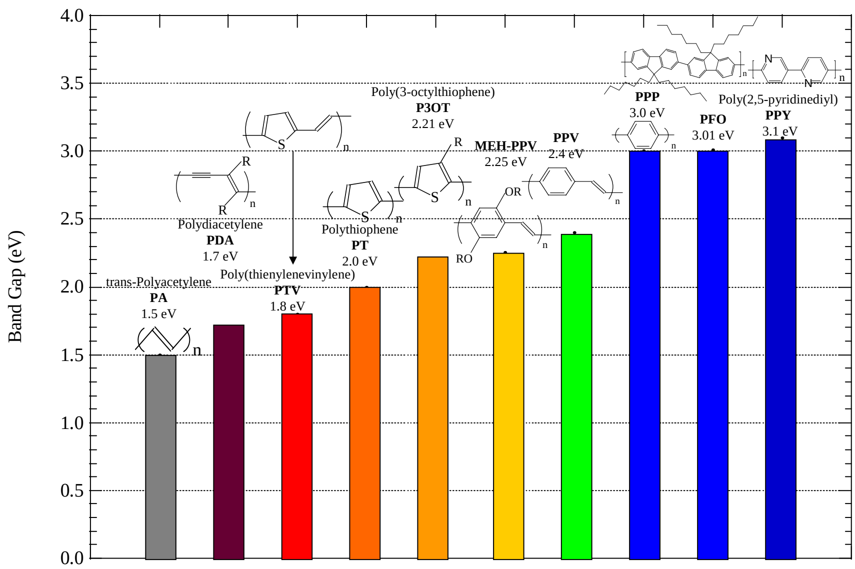

Ref. N. C. Greenham and R. H. Friend, Solid State Physics **49**, 1 (1995) p.13; A. Monkman et al., Phys. Rev. Lett. **6**, 1358 (2001)

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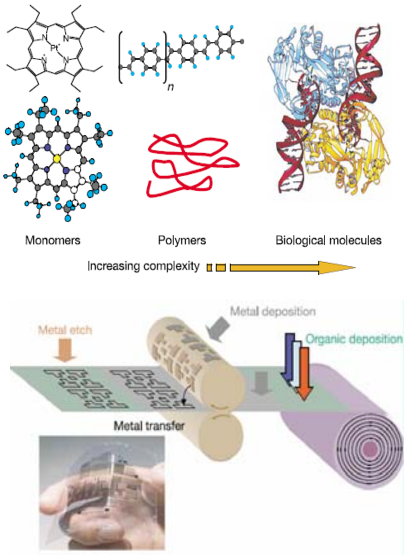
Changhee Lee, SNU, Korea

Organic Materials as New Semiconductors

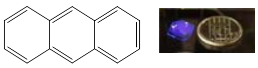


Stephen R. Forrest, “The path to ubiquitous and low-cost organic electronic appliances on plastic”, Nature 428, 911 (2004).

Research on organic semiconductors

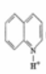
1906. Photoconductivity in anthracene:
A. Pochettino, *Acad. Lincei Rendic*. 15, 355 (1906).

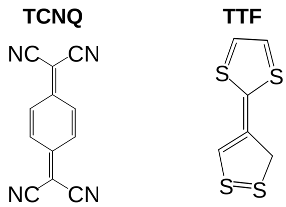
Anthracene



1960. TCNQ: R. G. Kepler, P. E. Bierstedt, R. E. Merrifield, Phys. Rev. Lett. 5, 503 (1960).

Table I. Electronic properties of representative radical-anion salts.

Material	Electrical conductivity: Value at 300°K ($ohm^{-1}\ cm^{-1}$)	Electrical conductivity: Activation energy (ev)	Magnetic susceptibility: Value at 300°K ($emu\text{-}mole^{-1}$)	Magnetic susceptibility: Temperature dependence
 [TCNQ·]⁻ [TCNQ][a]	100[a]	<0.01	$+2.2\times10^{-4}$	Decreases gradually to $+1.0\times10^{-4}$ at 77°K
$[(C_2H_5)_3NH]^+$ [TCNQ·]⁻ [TCNQ][a]	4.0[a]	0.14	$+6.4\times10^{-4}$[b]	Eq. (1) with $J=0.041$ ev
K^+ [TCNQ·]⁻	1.9×10^{-4}[c]	0.36	-1.3×10^{-4}	Temperature independent from 77° to 450°K[d]

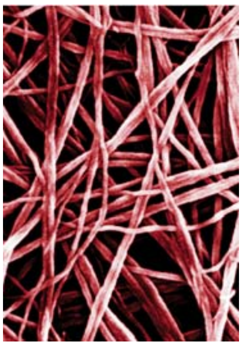


1973. TTF-TCNQ: L. B. Coleman, et al, Solid State Comm. 12, 1125 (1973).
σ~8,000 S/cm

1977. Doped $(CH)_x$: C. K. Chiang, C. R. Fincher, Jr., Y. W. Park, A. J. Heeger , H. Shirakawa, E. J. Louis, S. C. Gau, and Alan G. MacDiarmid, Electrical Conductivity in Doped Polyacetylene, Phys. Rev. Lett. 39, 1098 (1977).

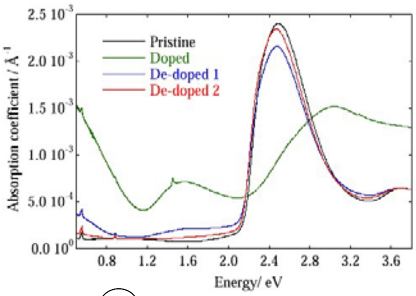
Chemical Doping

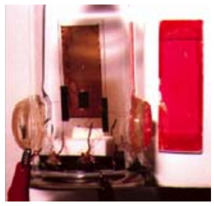
Change in Absorption Spectrum

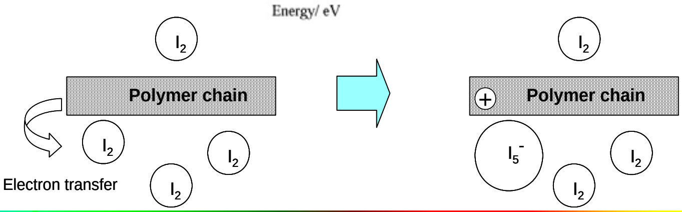


SEM of polyacetylene fibrils. (From K. Araya, A. Mukoh, T. Narahara, H. Shirakawa, Synth. Met., 1986, 14, 199, Fig. 3b)

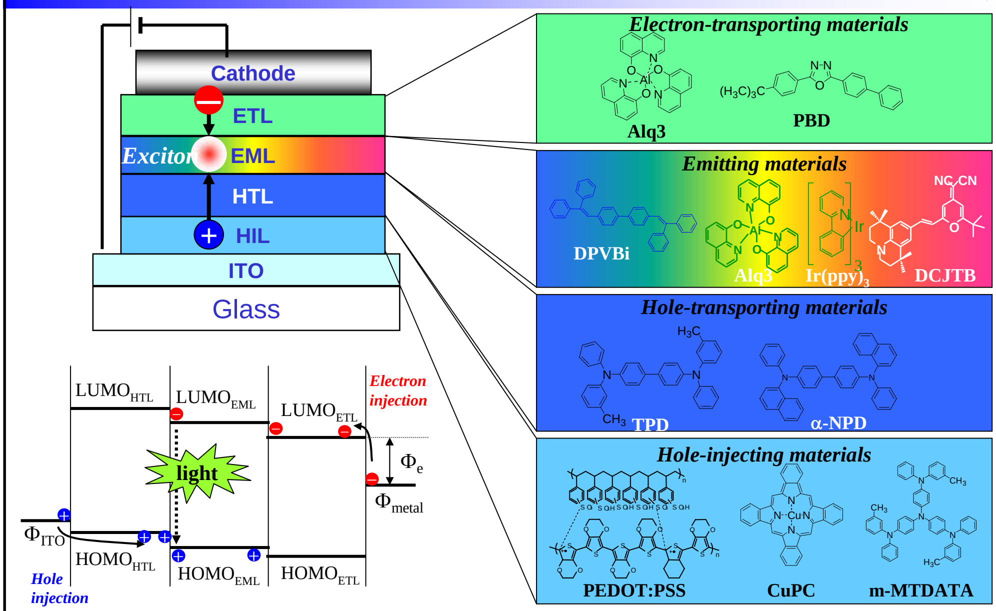
- Main $\pi\pi^*$ transition blue-shifted and reduced in strength
- Additional peaks appear in the red and IR







OLED: device structure & materials



C. W. Tang (Kodak): 1st OLED

Organic electroluminescent diodes

C. W. Tang and S. A. VanSlyke
Research Laboratories, Corporate Research Group, Eastman Kodak Company, Rochester, New York 14650

(Received 12 May 1987; accepted for publication 20 July 1987)

A novel electroluminescent device is constructed using organic materials as the emitting elements. The diode has a double-layer structure of organic thin films, prepared by vapor deposition. Efficient injection of holes and electrons is provided from an indium-tin-oxide anode and an alloyed Mg:Ag cathode. Electron-hole recombination and green electroluminescent emission are confined near the organic interface region. High external quantum efficiency (1% photon/electron), luminous efficiency (1.5 lm/W), and brightness (> 1000 cd/m^2) are achievable at a driving voltage below 10 V.

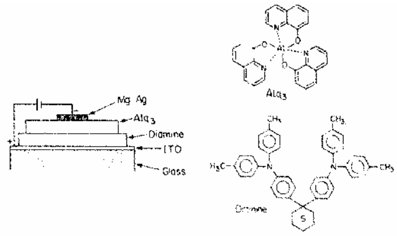


FIG. 1. Configuration of EL cell and molecular structures.

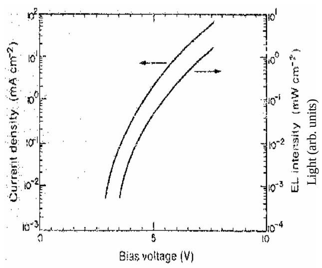
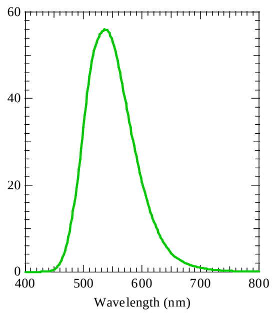
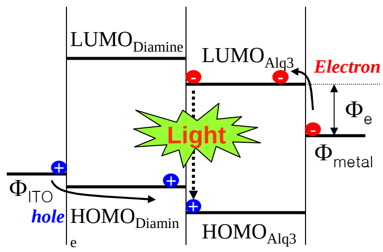


FIG. 2. Brightness-current-voltage characteristics of an ITO/diamine/Alq$_3$/Mg:Ag EL cell.

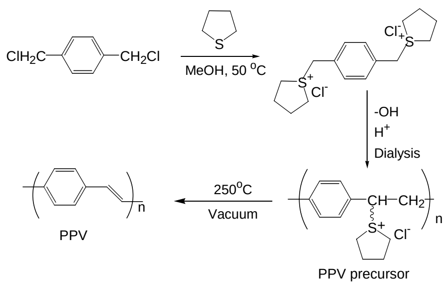


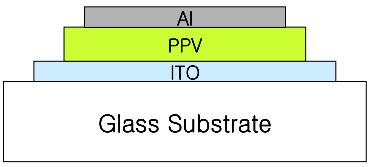


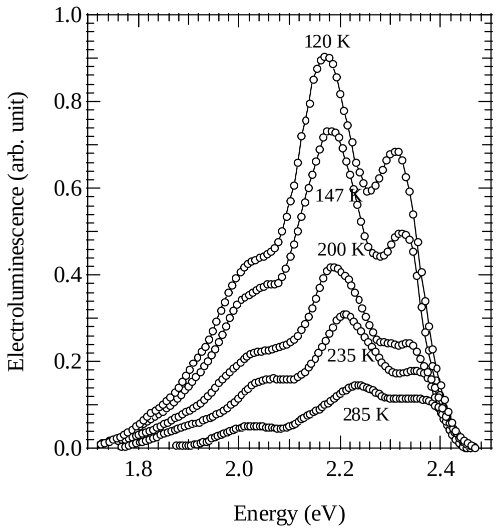
C. W. Tang and S. A. VanSlyke, Appl. Phys. Lett. **51**, 913 (1987)

Cambridge Group: 1st Polymer LED

Synthetic route of PPV

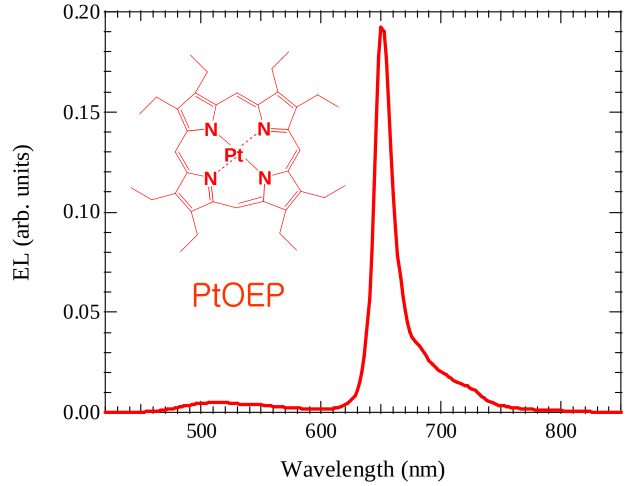


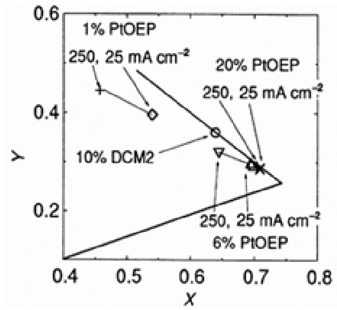




J. H. Burroughes, D. D. C. Bradley, A. R. Brown, R. N. Marks, K. Mackay, R. H. Friend, P. L. Burns, and A. B. Holmes, Nature **347**, 539 (1990).

Princeton/USC Group: Phosphorescent OLED





Efficient red EL emission from triplet excitons: η_{ext} ~ 2.2% @ 100 cd/m^2

M. A. Baldo, *et al*, Nature **395**, 151 (1998)

Quantum Efficiency

Singlet
spin anti-symmetric

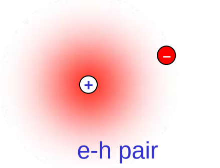
$|\chi_1\chi_2> = \frac{1}{\sqrt{2}}|\uparrow\downarrow> - |\downarrow\uparrow>$

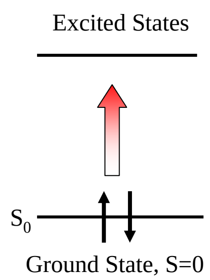
Triplet
spin symmetric

$|\chi_1\chi_2> = \frac{1}{\sqrt{2}}|\uparrow\downarrow> + |\downarrow\uparrow>$

$|\chi_1\chi_2> = |\uparrow\uparrow>$

$|\chi_1\chi_2> = |\downarrow\downarrow>$





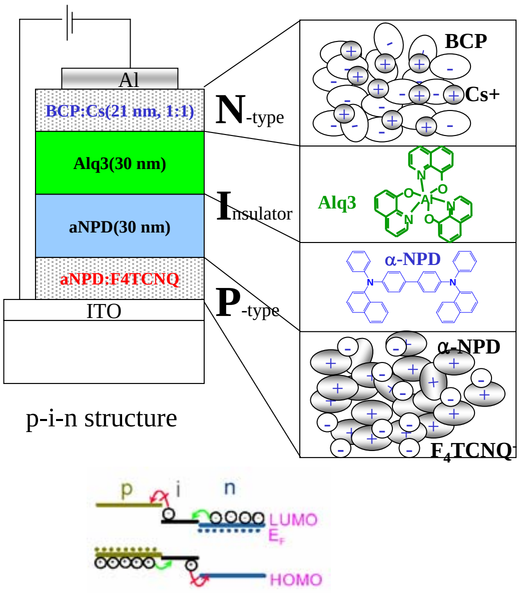
Spin selection rule: no change in spin multiplicity

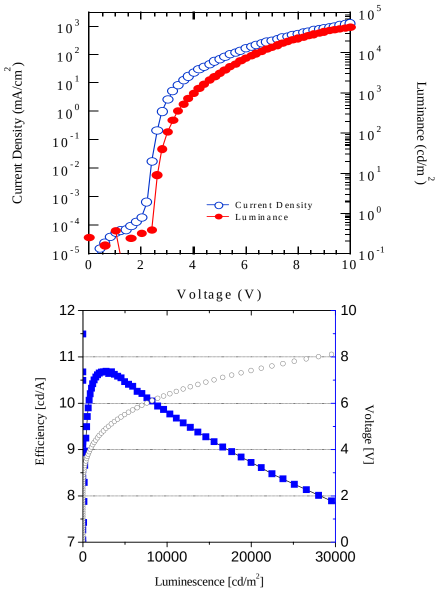
(The spin-orbit coupling allows the mixing of singlet and triplet states)

$$H_{SO} = \frac{Ze^2}{2m^2c^2}\frac{1}{r^3}\mathbf{L}\bullet\mathbf{S} \propto Z^4$$

Fluorescence : Radiation restricted to singlet excitons, → η ~25%
Phosphorescence : Radiation is from triplets → η ~ 100%.

OLED with a p-i-n Structure





Progress of OLED performance

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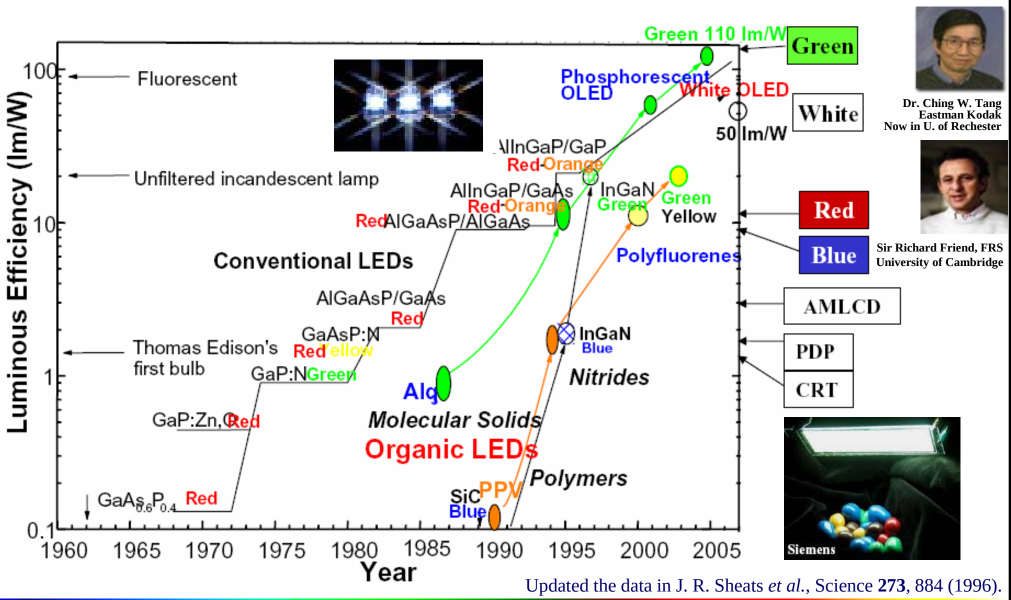

Updated the data in J. R. Sheats *et al.*, Science **273**, 884 (1996).

High efficiency white OLEDs

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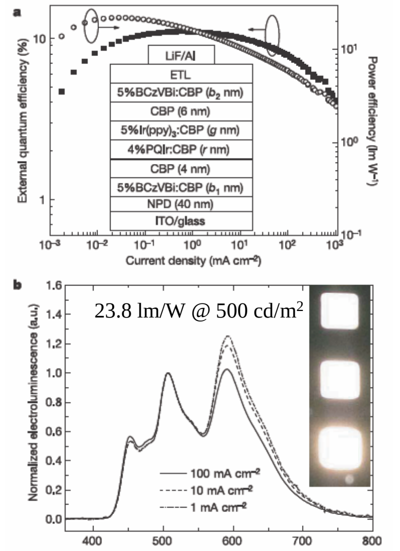

Y. Sun, N. C. Giebink, H. Kanno, B. Ma, M. E. Thompson, S. R. Forrest, Nature **440**, 908 (2006)

Philips Lighting/Novaled
25 lm/W @ 1000 cd/m^2

UDC
20 lm/W @ 800 cd/m^2

General Electric
15 lm/W (2 ft. x 2 ft.) @ 1200 lumen

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PMOLED and AMOLED

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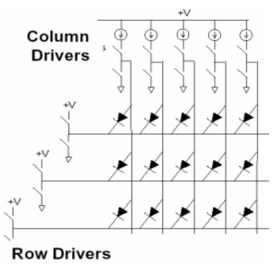
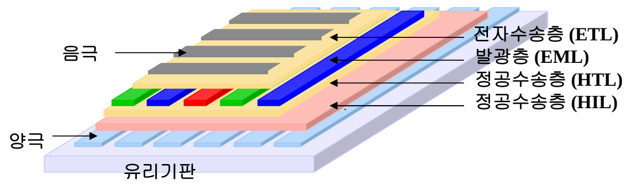
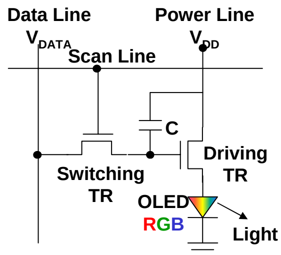
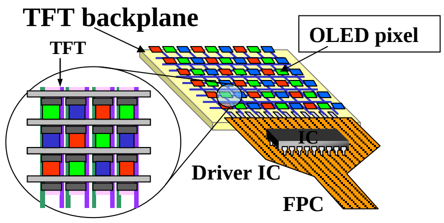
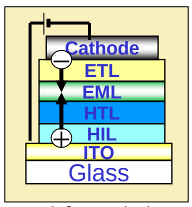




PMOLED 구조







Light Emission

AMOLED 구조

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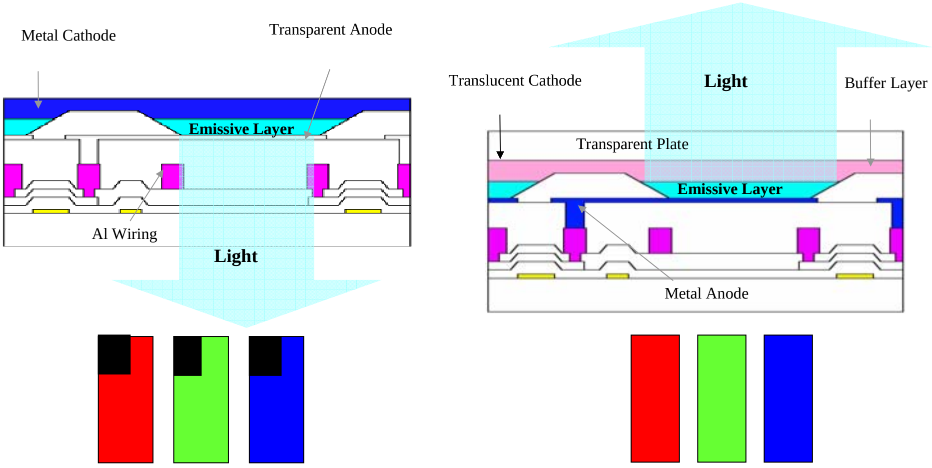
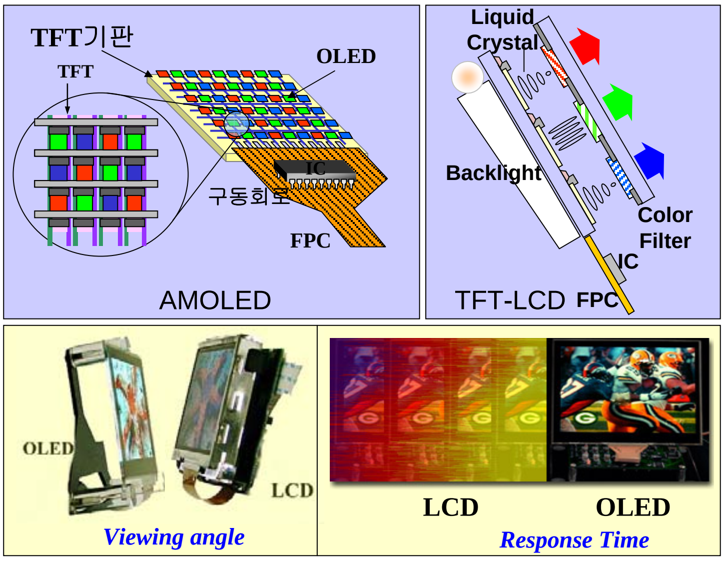
AMOLED



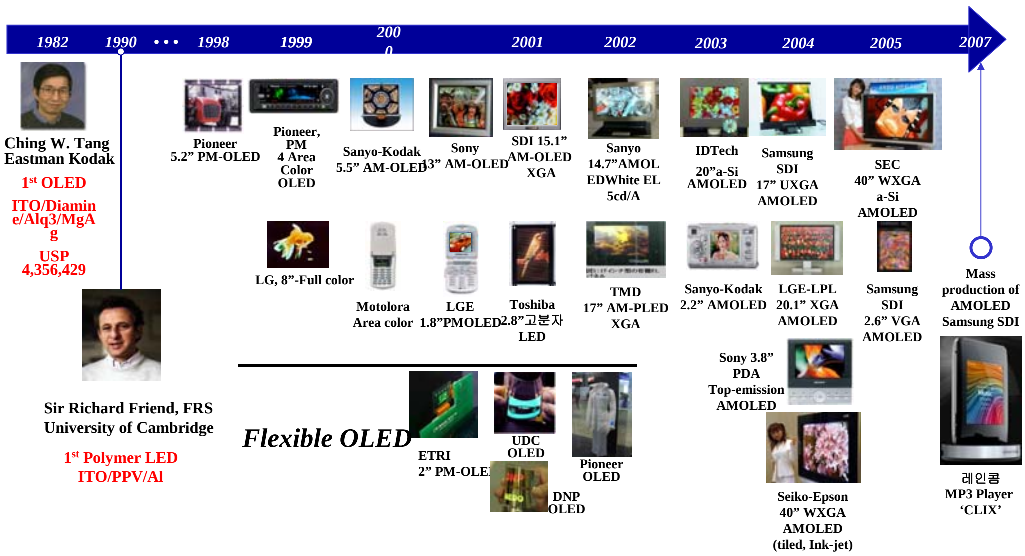
Bottom Emission **Top Emission**

OLED display characteristics



Kodak website

OLED 디스플레이 시제품 개발 현황



Comparison of CRT, PDP, LCD, and OLED - TV

Classification		CRT	PDP	LCD Present	LCD 2-3 년 후	OLED
Large Size		□	◉	○	◉	○
High Resolution		○	○	◉	◉	◉
Luminance	Full Black	◉	◉	○	○	◉
	Peak White	◉	◉	□	○	◉
Contrast	Bright condition	□	□	◉	◉	◇
	Dark condition	◉	◉	○	◉	◉
Viewing Angle		◉	◉	○	◉	◉
Response time		◉	○	□	○	◉
Image Sticking		◉	□	◉	◉	□
Color Fidelity		◉	◉	◉	◉	◉
Power consumption		□	□	○	◉	◉
Weight/Thickness		◇	○	○	○	◉
Lifetime		◉	○	○	◉	◇

◉ 아주 좋음 ○ 좋음 □ 보통 ◇ 나쁨

Cost Reduction of OLEDs

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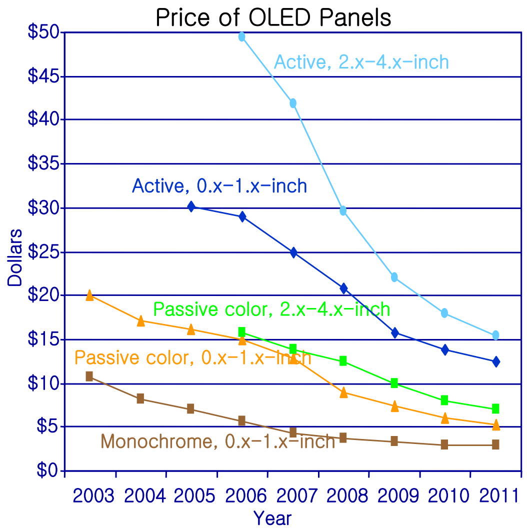
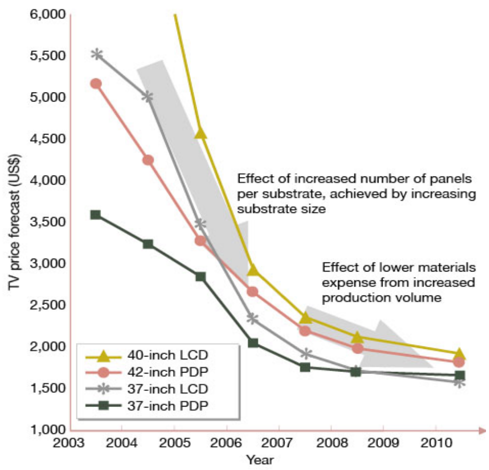


iSupply, H1 2005



NE Asia JAN 2005 Issue
(http://neasia.nikkeibp.com/neasia/000003)

Organic Semiconductor Lab

Changhee Lee, SNU, Korea

Generation of Glass Size for Displays

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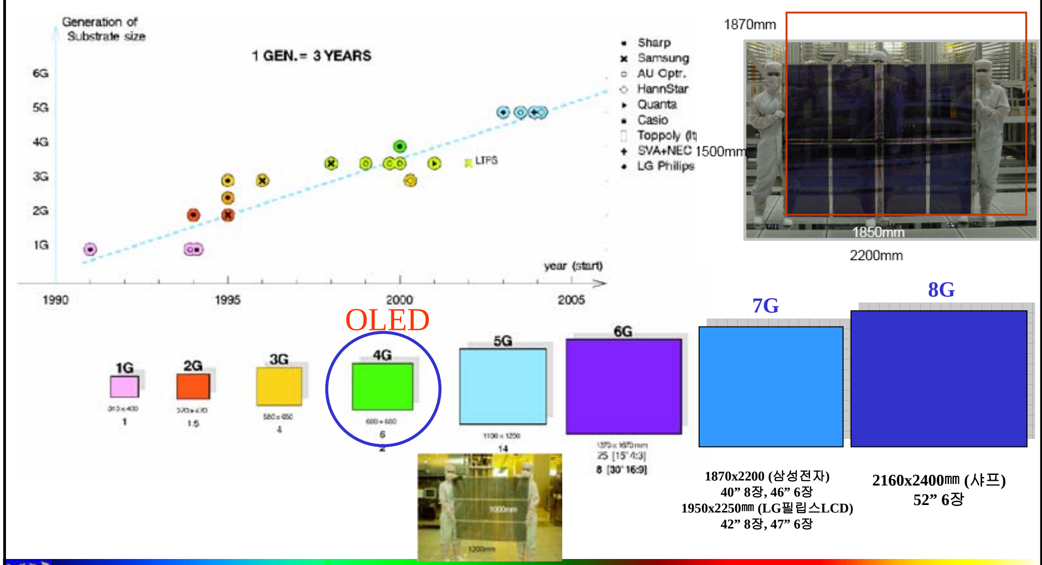

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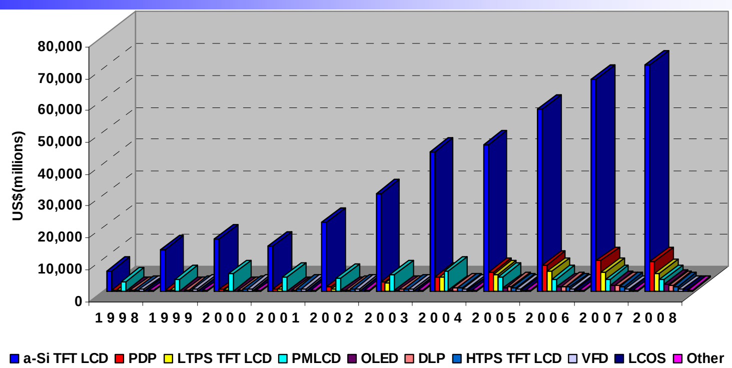
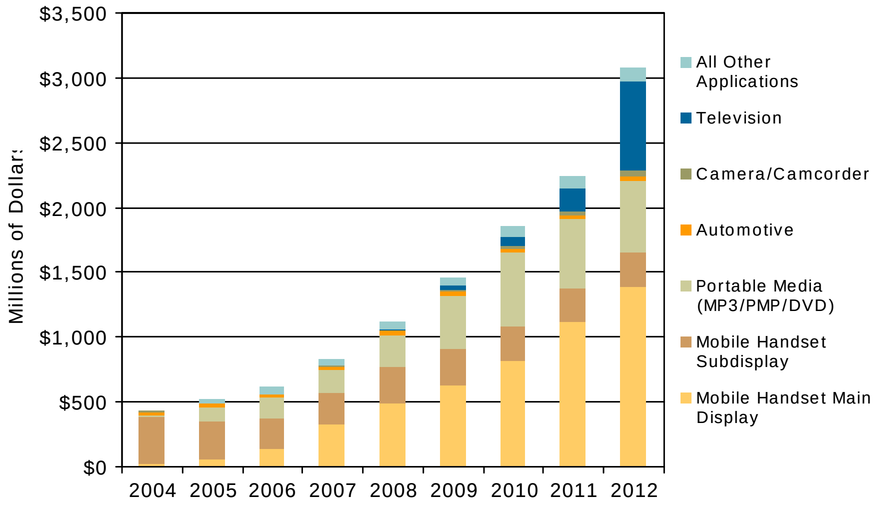
Worldwide Flat Panel Display Forecast



Master Technology	2003	2004	2005	2006	2007	2008	2009	CAGR
a-Si TFT LCD	$30,782	$44,251	$46,784	$53,862	$58,109	$60,874	$66,378.3	8.4%
PMLCD	$5,207	$6,295	$5,666	$4,671	$4,286	$4,244	$4,096.3	-8.2%
LTPS TFT LCD	$2,897	$4,844	$5,700	$6,689	$7,172	$7,108	$7,970.6	10.5%
PDP	$2.816	$4.262	$4.892	$6.331	$7.074	$6.932	$6.328.1	8.2%
VFD	$699	$705	$622	$603	$585	$568	$536.5	-5.3%
HTPS TFT LCD	$619	$574	$534	$529	$514	$476	$400.7	-6.9%
DLP	$419	$613	$674	$753	$797	$858	$832.7	6.3%
LCOS	$56	$70	$147	$193	$258	$332	$308.6	34.7%
EL	$145	$141	$115	$94	$74	$58	$38.8	-22.8%
EINK		$3	$13	$30	$39	$54	$55.6	77.0%
Total	$43,869	$62,088	$65,596	$74,587	$80,950	$86,049	$92,489.0	8.3%
Y/Y Growth	47%	42%	6%	14%	9%	6%	7%	

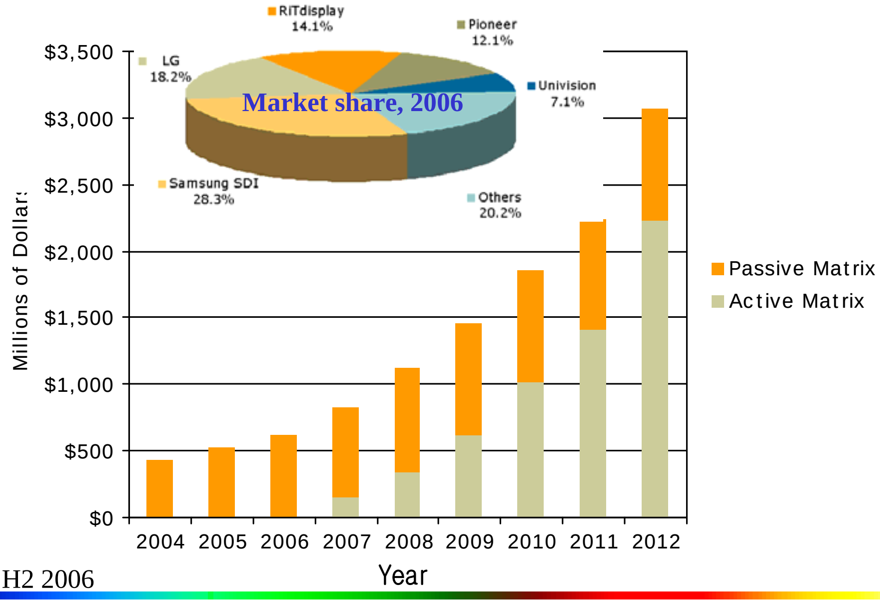
DisplaySearch, July 2005

Worldwide OLED Display Shipment Value by Application, 2004-2012



iSupply, H2 2006

OLED Market



iSupply, H2 2006