**Institute of Organic Chemistry**
**Justus-Liebig University Giessen**

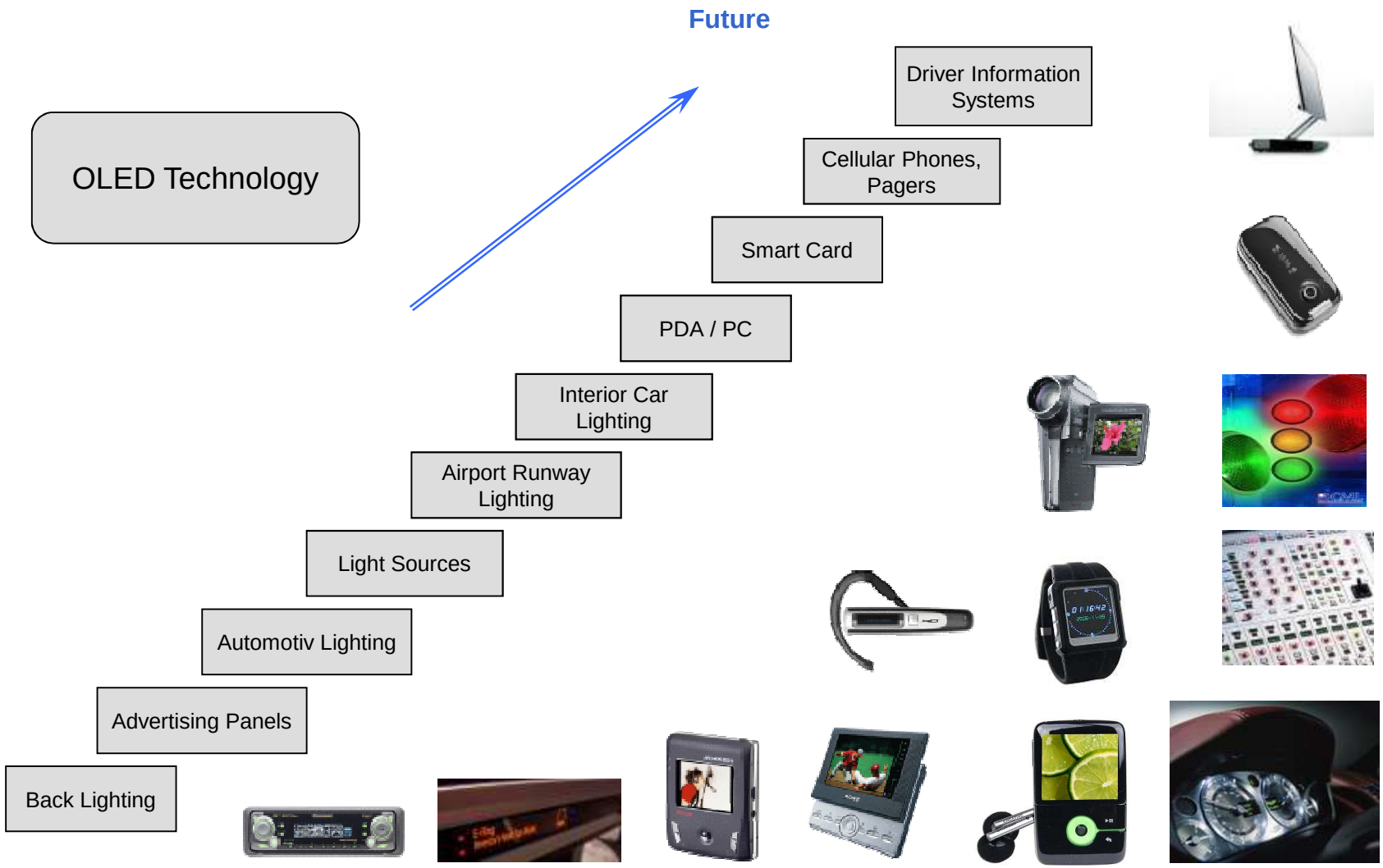
# Organic Light Emitting Diodes: Past, Present, Future


Dr. Nataliya Fokina

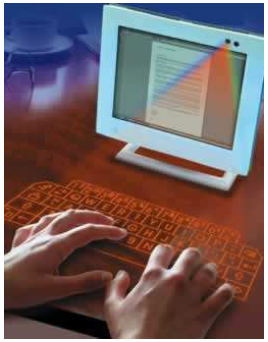
**PRS Group Seminar**
**November 30, 2007**

## Contents




Future
OLED Technology
Driver Information Systems
Cellular Phones, Pagers
Smart Card
PDA / PC
Interior Car Lighting
Airport Runway Lighting
Light Sources
Automotiv Lighting
Advertising Panels
Back Lighting

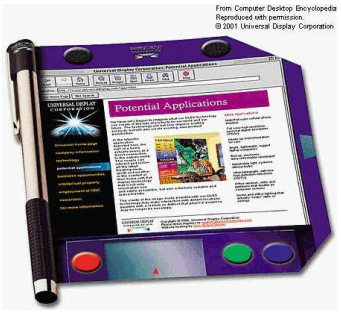
## What is Possible with OLEDs?



Entering data a virtual keyboard. LED emits the image of a keyboard and infrared motion detector will detect the movement of your fingers.


Cash cards with luminescent displays made of OLEDs may show how much money is left

Because of their ultra thin profile, OLED screens wii be implemented mostly in portable computers.




This pen prototype with built-in OLED screen. It is possible to bend it and it is touch-sensitive. This smart pen also enables direct connection to the Internet.


This newspaper concept that has come out of IBM research laboratory is built of a plastic OLED screen with a wireless Internet connection, through which news are continually downloaded. And you can fold the paper to fit into your briefcase or pocket after use.

***Advantages of OLEDs over today's LCD or plasma displays:***

•The plastic, organic layers of an OLED are thinner, lighter and more flexible than the crystalline layers in LCD

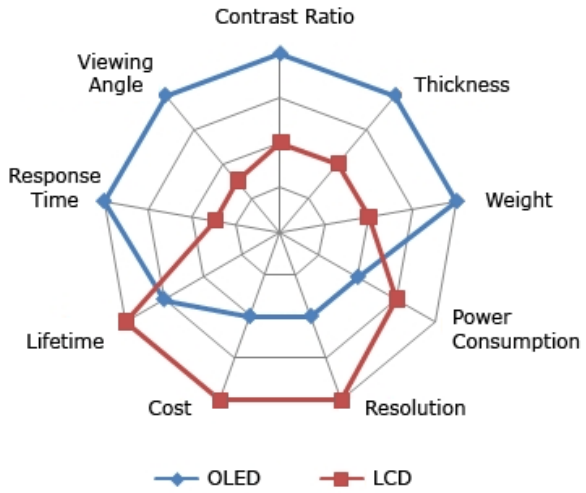
•OLED materials can be plastic, which is more processable than glass used for LCDs

•OLEDs are brighter than LCDs, which require glass for support, and glass absorbs some light

•OLEDs are self-luminous and do not require backlighting like LCDs, as a result they consume much less power

•OLEDs have wide viewing angle, up to 170 degrees

•Technological possibility to make displays of large size



## History

### A Note on Carborundum.

*To the Editors of Electrical World:*

SIRS:—During an investigation of the unsymmetrical passage of current through a contact of carborundum and other substances a curious phenomenon was noted. On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light. Only one or two specimens could be found which gave a bright glow on such a low voltage, but with 110 volts a large number could be found to glow. In some crystals only edges gave the light and others gave instead of a yellow light green, orange or blue. In all cases tested the glow appears to come from the negative pole. a bright blue-green spark appearing at the positive pole. In a single crystal, if contact is made near the center with the negative pole, and the positive pole is put in contact at any other place, only one section of the crystal will glow and that the same section wherever the positive pole is placed.

There seems to be some connection between the above effect and the e.m.f. produced by a junction of carborundum and another conductor when heated by a direct or alternating current; but the connection may be only secondary as an obvious explanation of the e.m.f. effect is the thermoelectric one. The writer would be glad of references to any published account of an investigation of this or any allied phenomena.

NEW YORK, N. Y. H. J. ROUND.

H. J. Round, *Electrical World,* **1907**,*49,* 309

Fig. 1.1. Publication reporting on a "curious phenomenon", namely the first observation of electroluminescence from a SiC (carborundum) light-emitting diode. The article indicates that the first LED was a Schottky diode rather than a p-n-junction diode (after H. J. Round, *Electrical World* **49,** 309, 1907).



Класс 21 а, 27 № 12191

### ПАТЕНТ НА ИЗОБРЕТЕНИЕ

ОПИСАНИЕ

светового реле.

К патенту О. В. Лосева, заявленному 28 февраля 1927 года (заяв. свид. № 14672).

О выдаче патента опубликовано 31 декабря 1929 года. Действие патента распространяется на 15 лет от 31 декабря 1929 года.

Предлагаемое изобретение использует общеизвестное явление свечения в карборундовом детекторе и состоит в том, что в световом реле для быстропишущего телеграфного или телефонного приема, передачи изображений на расстояние и других целей, в качестве модулируемого электрическим током источника света, применяется свечение в точке контакта карборундового детектора, включенного непосредственно в цепь модулирующего тока.

На чертеже фиг. 1 изображает схему предлагаемого светового реле и фиг. 2—схему устройства для фотографической записи сигналов с применением светового реле.

К зажимам *A* источника тока сигналов, подлежащих записи, через потенциометр P включается светящийся карборундовый детектор *D*, в цепь которого включена батарея *B*, дающая дополнительное постоянное напряжение для наложения его на напряжение тока сигналов и усиления действия реле; путем регулировки этой батареи создаются наивыгоднейшие условия работы детектора *D*. Оптическая система *L* предназначена направлять световой поток, излучаемый карборундовым детектором, на движущуюся фотографическую пластинку *F*, на которой производится запись изменений этого потока. Детектор *D*, оптическая система *L* и пластинка *F* заключены в светонепроницаемую камеру. Примерное включение светового реле показано на чертеже 2, где *E*—приемник-усилитель высокой частоты, *T*—автотрансформатор высокой частоты, а остальная часть схемы аналогична только-что описанной.

Предмет патента

1. Световое реле для быстропишущего телеграфного или телефонного приема, передачи изображений на расстояние и для других целей, характеризующееся применением, в качестве модулируемого электрическим током источника света, свечения в точке контакта карборундового детектора общеизвестного устройства, каковой детектор включен непосредственно в цепь модулирующего тока.

2. Видоизменение охарактеризованного в п. 1 светового реле, отличающееся тем, что последовательно с указанным детектором *D* включен источник дополнительного напряжения постоянного тока *B* (фиг. 1 и 2) с целью усиления действия реле.

O. V. Losev. *Wireless Telegraphy and Telephony* **1927**.

Patent N 12191

## History

**1955** – R. Braunstein, Radio Corporation of America, reported about infrared emission from GaAs

**1961** – B. Biard and G. Pittman, Texas Instruments, patented infrared light-emitting diod

**1962** – N. Holonyak Jr., General Electric Company, University of Illinois, developed the first practical visible-spectrum LED is seen as the "father of the light-emitting diode"

**1972** - M. George Craford, the first yellow LED and 10x brighter red and red-orange LEDs

In **1990th** - S. Nakamura, Nichia (Japan) demonstrated the first high-brightness blue LED based on InGaN, then white LED, which went to the production in **1993**, in **2006** was awarded with Millenium Technology Prize

**1963** - Electroluminescence from organic crystals was first observed for anthracene

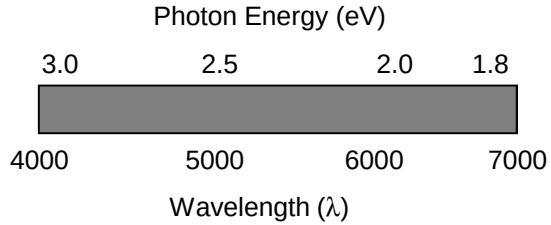
## *How do OLED Emit Light?*

| Cathode |
| --- |
| „Organic“ LEM |
| Anode |
| Substrate |

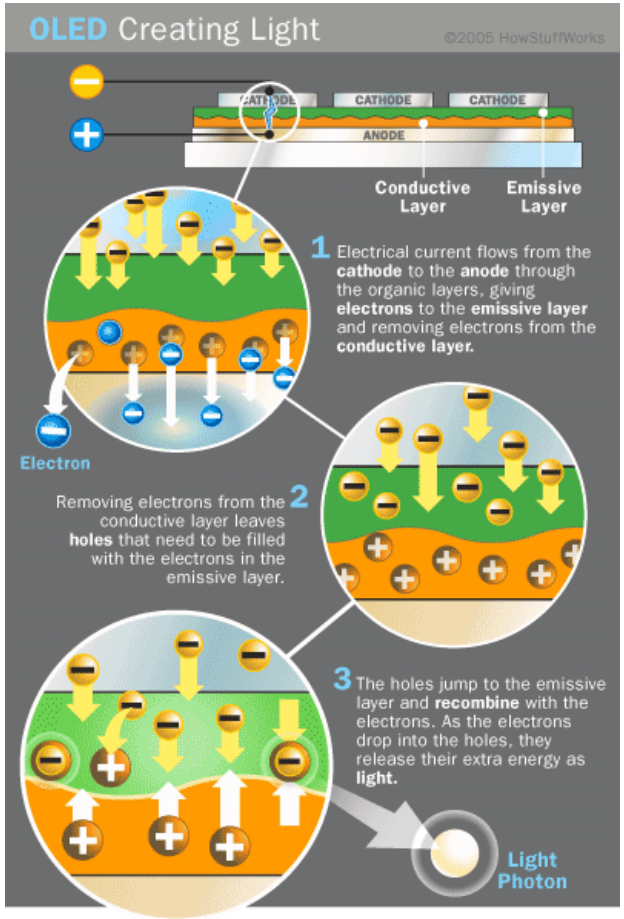
A simple single-layer OLED
Containing an organic
light-emitting material

| Cathode |
| --- |
| ETL |
| „Organic“ LEM |
| HTL |
| Anode |
| Substrate |

A multilayer OLED with
hole transport (HTL) and
electron transport (ETL)
layers designed to balance
charge injection and transport




Visible emission can be provided by semiconductors
with energy gap Eg from 1.72 eV to 3.1eV and they are suitable for OLEDs



## OLED Components

**Substrate** (clear plastic, glass, foil)
The substrate supports the OLED

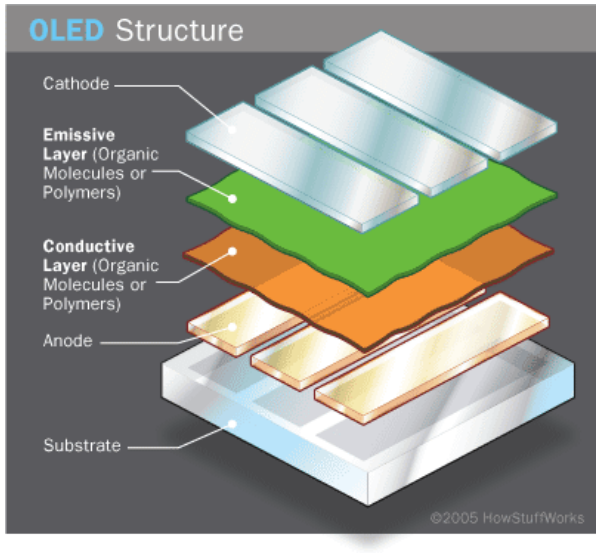
**Anode** (transparent)
The anode removes electrons (adds electron "holes") when a current flows through the device

**Organic layers** (are made of organic molecules or polymers)

**Conducting layer** (organic plastic molecules)
Transport "holes" from the anode

**Emissive layer** (organic plastic molecules, different from the conducting layer)
Transport electrons from the cathode; this is where light is made

**Cathode** (may or may not be transparent depending on the type of OLED)
Injects electrons when a current flows through the device

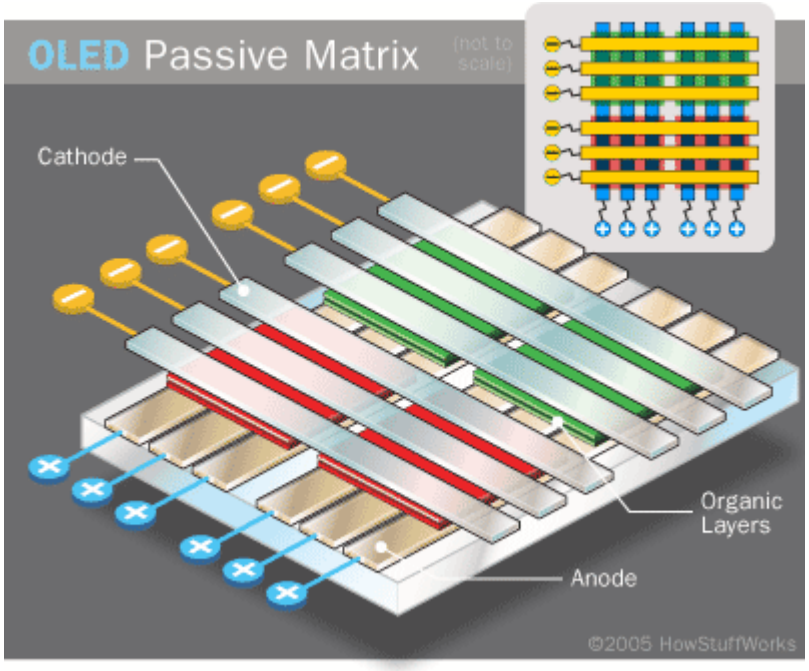



Two-layer design

## Types of OLEDs

### Passive-matrix OLED (PMOLED)

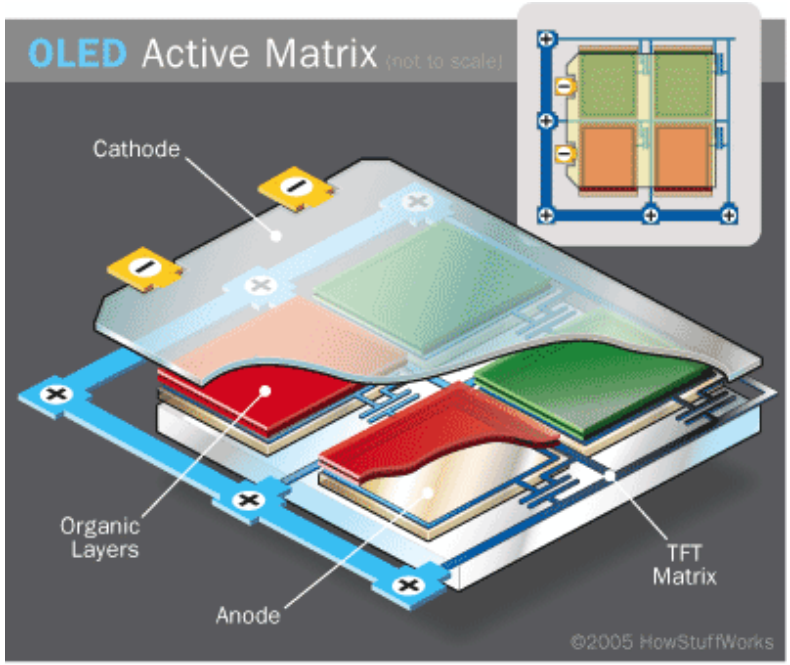
External circuitry applies current to selected strips of anode and cathode, determining which pixels get turned on and which pixels remain off




Most efficient for text and icons and are best suited for small screens (2- to 3-inch diagonal) as in cell phones, PDAs and MP3 players

### Active-matrix OLED (AMOLED)

The anode layer overlays a thin film transistor (TFT) array that forms a matrix. The TFT array is the circuitry that determines which pixels get turned on to form an image

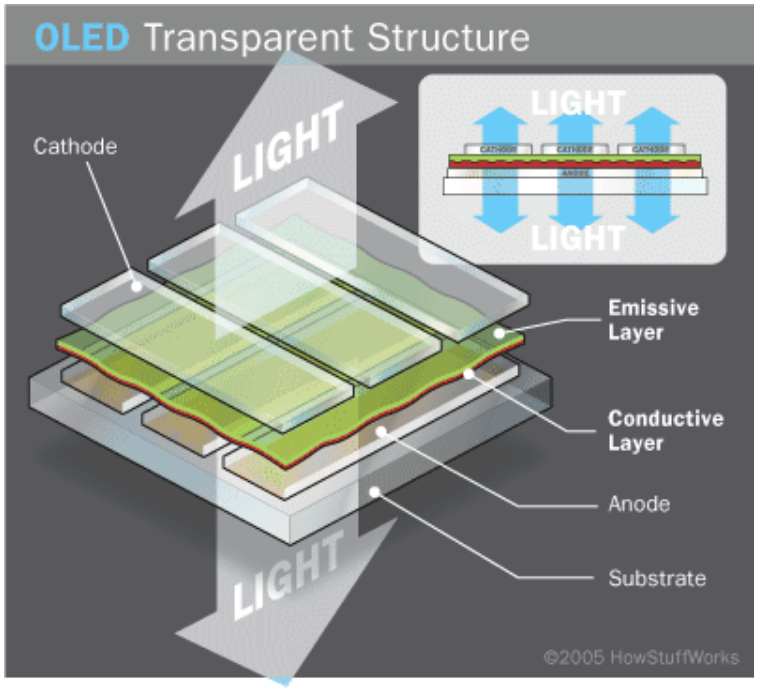



Consume less power and have faster refresh rates suitable for video. The best uses for AMOLEDs are computer monitors, large-screen TVs and electronic signs or billboards

## Types of OLEDs

### Transparent OLED

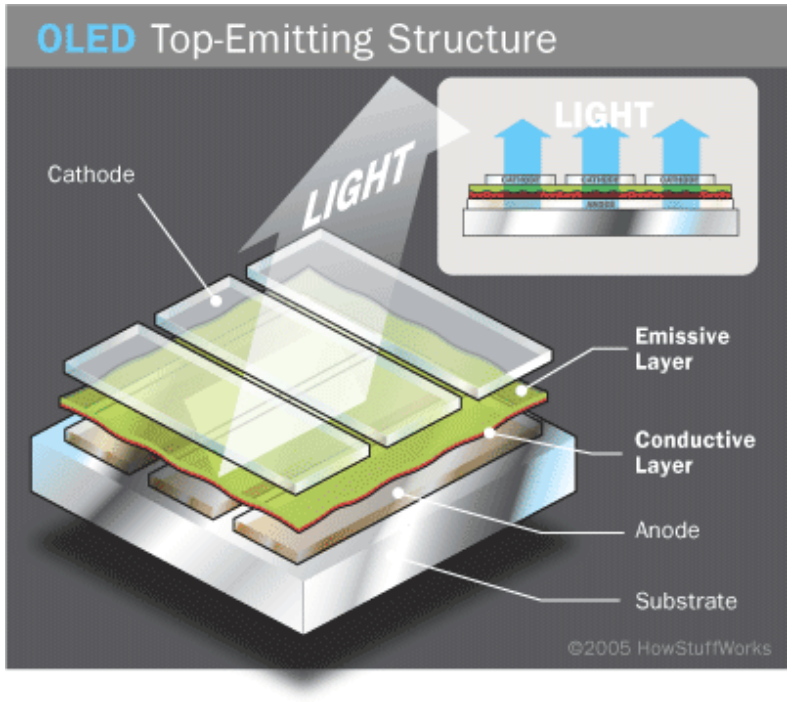
When turned off, are up to 85 percent as transparent as their substrate. When is turned on, it allows light to pass in both directions




This technology can be used for heads-up displays

### Top-emitting OLED

They have a substrate that is either opaque or reflective, and are best suited to active-matrix design




Can be used for smart cards

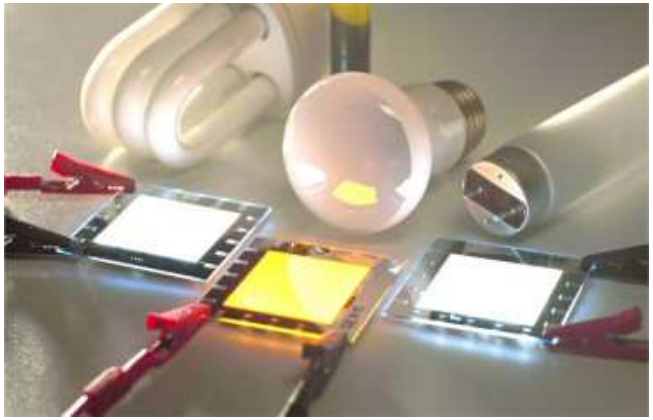
## Types of OLEDs

### Foldable OLED

Foldable OLEDs have substrates made of very flexible metallic foils or plastics


### White OLED

Emit white light that is brighter, more uniform and more energy efficient than that emitted by fluorescent lights. Have the true-color qualities of incandescent lighting



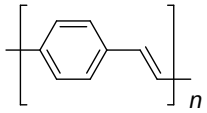
## Conjugated Polymers in OLEDs

***The Nobel Prize in Chemistry 2000***

"for the discovery and development of conductive polymers"

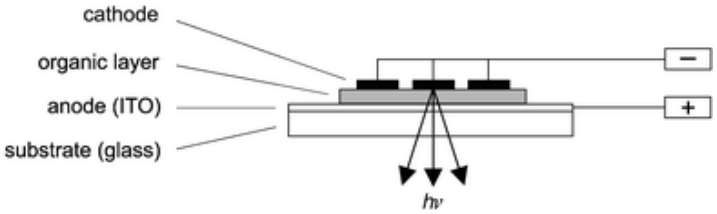
***A. J. Heeger, A. G. MacDiarmid, H. Shirakawa***

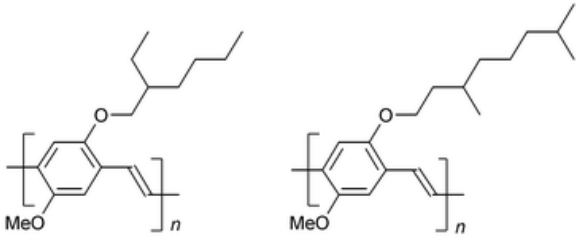
First research on OLED fabricated with the PPV film:



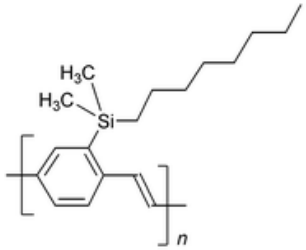
Poly(p-phenylene vinylene)
**PPV**
Emission maxima at 551nm (2.25 eV)

- Single-layer OLED
- High quality films, ease of processing
- Moderate quantum efficiency

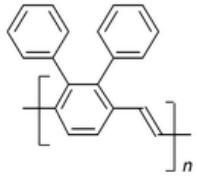


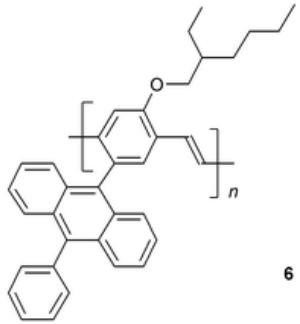

MEH-PPV **2** **3**




**4**




**5**




**6**

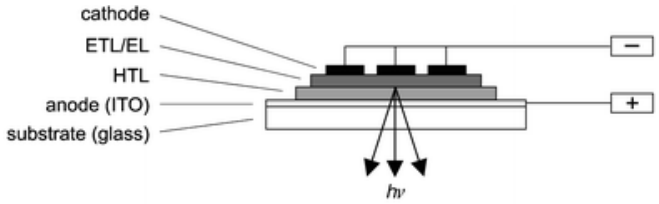
The unsymmetrically substituted soluble PPV derivative **2** was used in a simple single-layer device (ITO/MEH-PPV/Ca) with an external quantum yield of 1% The highest external quantum efficiency for a single-layer OLED based on **3** reached 2.1%

Burroughes, J. H.; Bradley, D. D. C.; Brown, A. R.; Marks, R. N.; Mackay, K.; Friend, R. H.; Burns, P. L.; Holmes, A. B. *Nature*, 1990, **347**, 539-541.

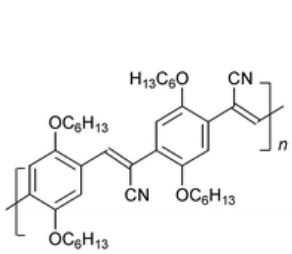
Salbeck, J. *Ber. Bunsenges. Phys. Chem.*, **1996**, *100*, 1666.

Schoo, H. F. M.; Demandt, R. C. J. E.; Vleggaar, J. J. M.; Liedenbaum, C. T. H. *Macromol. Symp.*, **1997**, *125*, 165.

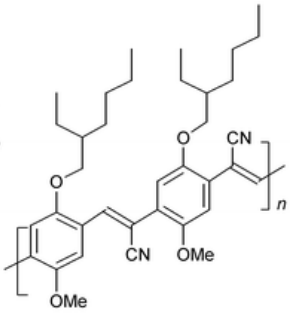
## Conjugated Polymers in OLEDs



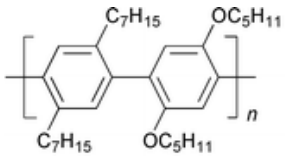

Schematic configuration of a two-layer OLED;
ETL/EL = electron transporting/emitting layer;
HTL = hole transporting layer



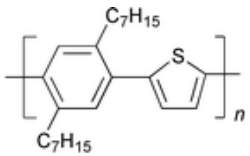
CN-PPV **7**



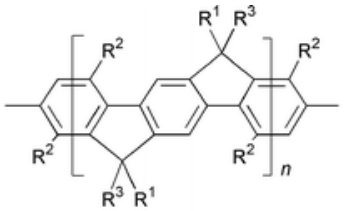
MEH-CN-PPV **8**



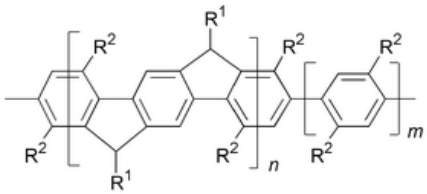
**13**



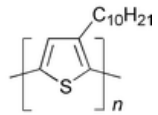
**14**



**15** $R^1$ = H, $R^2$ = $C_6H_{13}$, $R^3$ = *p*-*t*Bu$C_6H_4$ (**a**), *p*-$C_{10}H_{21}C_6H_4$ (**b**)
**16** $R^1$ = $CH_3$, $R^2$ = $C_6H_{13}$, $R^3$ = *p*-*t*Bu$C_6H_4$ (**a**), *p*-$C_{10}H_{21}C_6H_4$ (**b**)



**17** $R^1$ = *p*-$C_{10}H_{21}C_6H_4$, $R^2$ = $C_6H_{13}$



**18**

The extraordinarily high efficiency of a mixture of polymers **13**, **14** exceeds the values obtained for single layer devices based on each polymer alone

External efficiency beyond 4% was achieved with a blend of poly(p-phenylene) derivative **16b** and polythiophene derivative **18** In a single-layer configuration

Birgerson, J.; Fahlman, M.; Bröms, P.; Salaneck, W. R. *Synth. Met.*, **1996**, *80*, 125

List, E. J. W.; Holzer, L.; Tasch, S.; Leising, G.; Scherf, U.; Müllen, K.; Catellani, M.; Luzzati, S. *Solid State Commun.*, **1999**, *109*, 455

## Conjugated Polymers in OLEDs

***Poly(3-alkylthiophene)s***

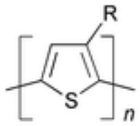
**23** - exhibit red emission

**24** - incorporation of ether, ester or urethane functions to alkyl side chains lead to yellow and orange emission

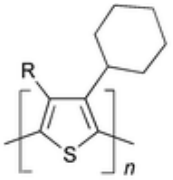
**25** - with increasing steric demand in substituents emission is shifted stepwise to green and blue

**26**, **27** – increased solubility due to aryl substituents

Two-layer OLEDs based on **25b** revealed blue electroluminescence with an external quantum yield of 0.6%

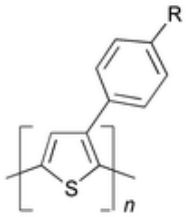



**23** R = $C_6H_{13}$ (**a**), $C_8H_{17}$ (**b**), $C_{12}H_{25}$ (**c**), $C_{18}H_{37}$ (**d**), $C_{22}H_{45}$ (**e**)

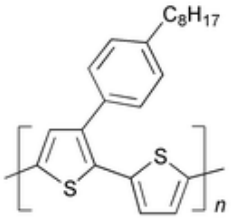



**25** R = H (**a**), $CH_3$ (**b**)

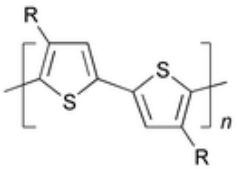
**24** R = $CO_2C_6H_{13}$ (**a**), $CO_2C_8H_{17}$ (**b**), $C_{10}H_{20}OMe$ (**c**), $C_2H_4CO_2NHCH_2CO_2C_4H_9$ (**d**)




**26** R = H (**a**), $C_8H_{17}$ (**b**)




**27**




**28** R = $C_6H_{13}$ (**a**), $C_8H_{17}$ (**b**), $C_{10}H_{21}$ (**c**)

Pomerantz, M.; Cheng, V.; Kasim, R. K.; Elsenbaumer, R. L. *J. Mater. Chem.*, **1999**, *9*, 2155.

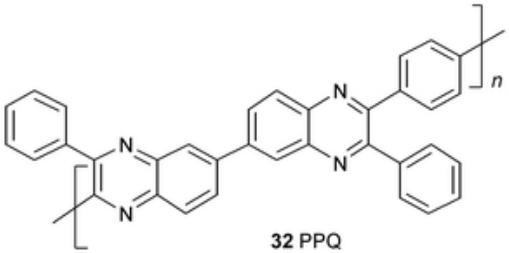
Jung, S.-D.; Zyung, T.; Kim, W. H.; Lee, C. J.; Tripathy, S. K. *Synth. Met.*, **1999**, *100*, 223

Andersson, M. R.; Thomas, O.; Mammo, W.; Svensson, M.; Theander, M.; Inganäs, O. *J. Mater. Chem.*, **1999**, *9*, 1933

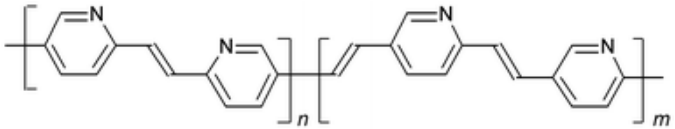
## Conjugated Polymers in OLEDs

Conjugated polymers based on electron-deficient heterocyclic units:

- are used as electron-transporting layers
- have high electron affinities
- increase efficiency of multilayer devices

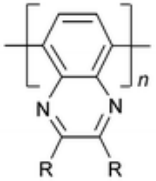


32 PPQ



PPyV **31**

Poly(pyridinevinylene)



33 R = $C_7H_{15}$ (**a**), Ph (**b**)

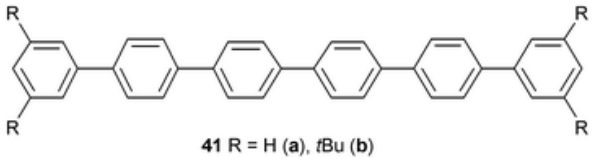
Polyquinoxalines (PQxs):

- low refractive indices
- good thermal stability
- good processability

Chen, L. C.; Nguyen, T. P.; Wang, X.; Sun, M. *Synth. Met.*, **1998**, *94*, 239

Yamamoto, T.; Sugiyama, K.; Kushida, T.; Inoue, T.; Kanbara, T. *J. Am. Chem. Soc.*, **1996**, *118*, 3930

## Conjugated oligomers in OLEDs

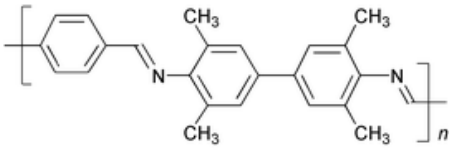



**41** R = H (**a**), *t*Bu (**b**)

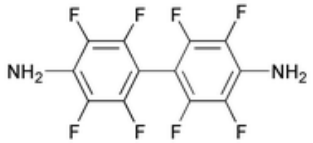
sexi(*p*-phenylene)

In a single-layer device (ITO/**41a**/Al) emit blue light,

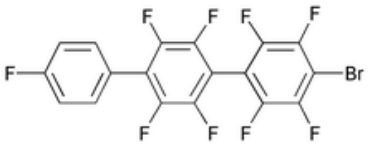
the external quantum yield 1-2%



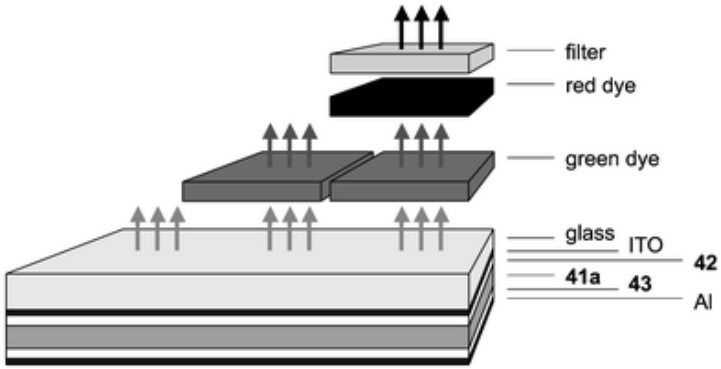

**42**




**43**




**44**



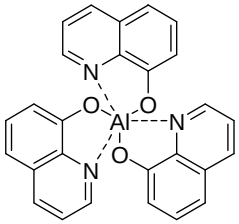

An efficient red-green-blue electroluminescent device (ITO/**42**/**41a**/**43**/Al)

with multilayer configuration, external quantum efficiencies up to 2%

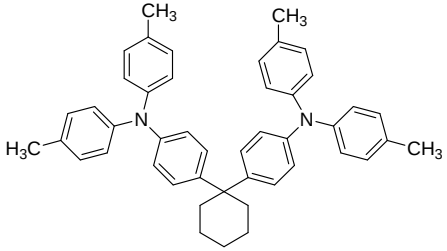
Koch, N.; Pogantsch, A.; List, E. J. W.; Leising, G.; Blyth, R. I. R.; Ramsey, M. G.; Netzer, F. P. *Appl. Phys. Lett.*, **1999**, *74*, 2909.
Meghdadi,F.; Tasch, S.; Winkler, B.; Fischer, W.; Stelzer, F.; Leising, G. *Synth. Met.*, **1997**, *85*, 1441.
Leising, G.; Tasch, S.; Meghdadi, F.; Athouel, L.; Froyer, G.; Scherf, U. *Synth. Met.*, **1996**, *81*, 185

## Low Molecular Weight Materials in OLEDs

***First research on light-emitting diods based on organic fluorescent dyes, 1987***



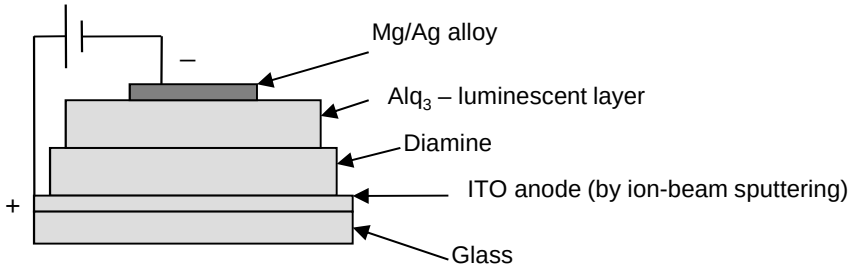

Aluminum-tris(8-hydroxyquinolate)
**$Alq_3$**
electron transport and emitting layer




Bis(triaryl)amine

hole transport layer

- Deposited by vacuum deposition: organic layers and metal electrode
- Double-layer OLED
- High quantum efficiency, 1%

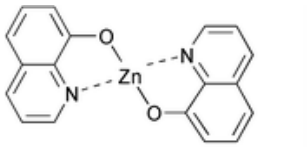



Tang, C. W.; VanSlyke, S. A. *Appl. Phys. Lett.* **1987**, *51*, 913-915.
Burroughes, J. H.; Bradley, D. D. C.; Brown, A. R.; Marks, R. N.; Mackay, K.; Friend, R. H.; Burns, P. L.; Holmes, A. B. *Nature*, 1990, **347**, 539-541.

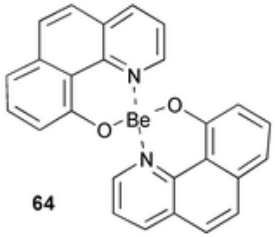
## Low Molecular Weight Materials in OLEDs

### *Electron transport emitters*

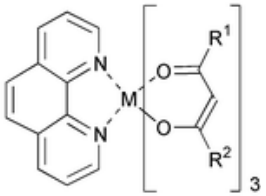
Metal chelates form stable vacuum deposited thin films, exhibit good charge transport mobilities and high luminescent yields.




**63**




**64**



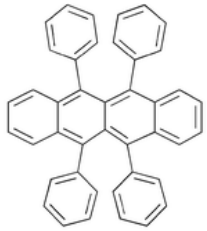

**65** M = Tb, Eu, Dy, Gd

$R^1$ = $CH_3$, phenyl, 2-thienyl

$R^2$ = $CH_3$, $CF_3$, phenyl

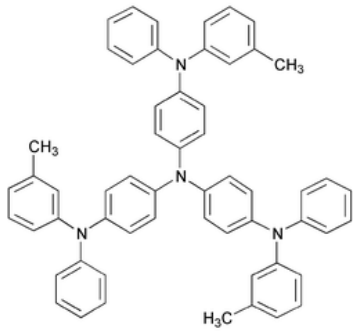
### *Dopant emitters*

Doping with highly fluorescent dyes increases morphological stabilities of materials, resulting in devices with enhanced electroluminescence quantum efficiencies and prolonged lifetimes.



**70**

**71**



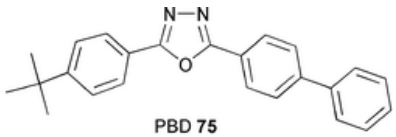

**72**

Sanyo: multilayer device containing decacyclene **71** as a dopant and the triarylamine **72** as hole transport layer (ITO/**72**/TPD:**71**/**64**/Mg:In)

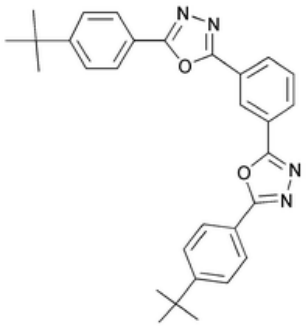
Sano, T.; Fujii, H.; Nishio, Y.; Hamada, Y.; Takahashi, H.; Shibata, K. *Synth. Met.*, **1997**, *91*, 27
Okada, K.; Wang, Y.-F.; Nakaya, T. *Synth. Met.*, **1998**, *97*, 113

## Low Molecular Weight Materials in OLEDs

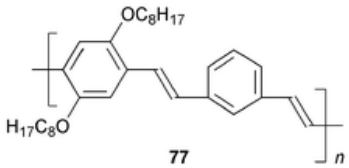
### *Electron transport and hole blocking materials*



PBD **75**



**76**

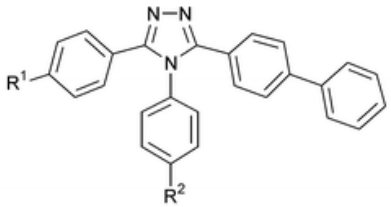


**77**

oxadiazoles

Major requirements for electrooptical applications:

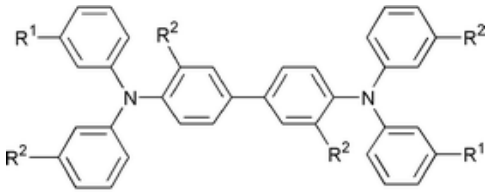
- uniform vacuum sublimed thin films
- reveal high electron affinity and mobility
- exhibit large ionization potentials for efficient hole blocking



**81** $R^1$ = *t*Bu, $R^2$ = H (**a**); $R^1$ = $N(CH_3)_2$, $R^2$ = $C_2H_5$ (**b**)

triazoles

### *Hole transport materials*



**85** $R^1$ = $CH_3$, $R^2$ = H (**a**, TPD); $R^1$ = $R^2$ = $CH_3$ (**b**)

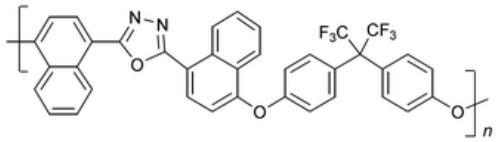
Insertion of the amine **72** layer close to the anode facilitates the charge transport of the device

Tak, Y.-H.; Bässler, H.; Leuninger, J.; Müllen, K. *J. Phys. Chem. B*, **1998**, *102*, 4887.
Kido, J.; Ontaki, C.; Hongawa, K.; Oknyama, K.; Nagai, K. *Jpn. J. Appl. Phys.*, **1993**, *32*, L917.
Giebeler, C.; Antoniadis, H.; Bradley, D. D. C.; Shirota, Y. *J. Appl. Phys.*, **1999**, *85*, 608

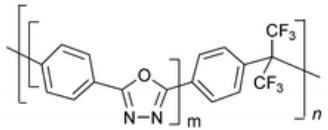
# Main chain polymers with isolated chromophores and side chain polymers with linked chromophores in OLEDs

## *Main chain polymers with isolated chromophores*

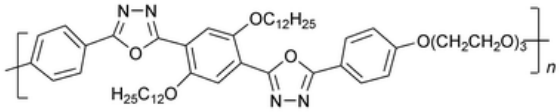
The introduction of non-conjugated segments into polymer backbones results in π-electron confinement in the conjugated part.
By choice of appropriate chromophores and spacers, the conjugation length and hence emissive colour of a multiblock copolymer can be effectively tuned.



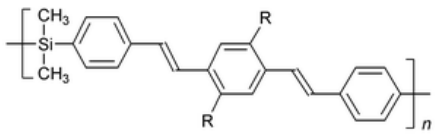
**96**



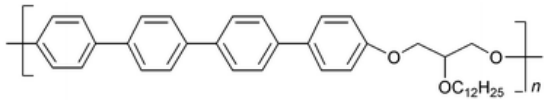
**97** *m* = 1 (**a**), 2 (**b**)



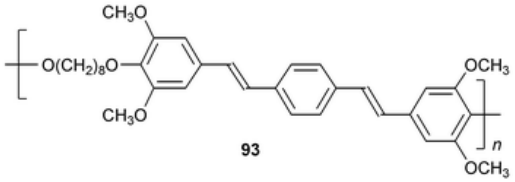
**98**



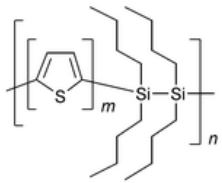
**92** R = $OC_4H_9$ (**a**), $C_8H_{17}$ (**b**)



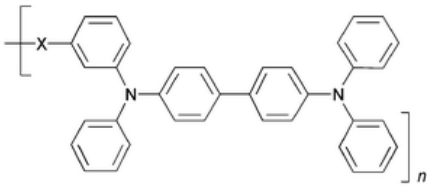
**94**



**93**



**95** *m* = 3 (**a**), 4 (**b**), 5 (**c**), 6 (**d**), 7 (**e**)

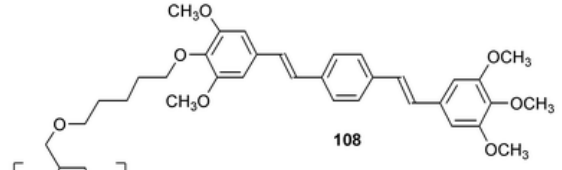


**103** X = OCOO (**a**), $OCO(OCH_2CH_2)_2OCOO$ (**b**), O (**c**)

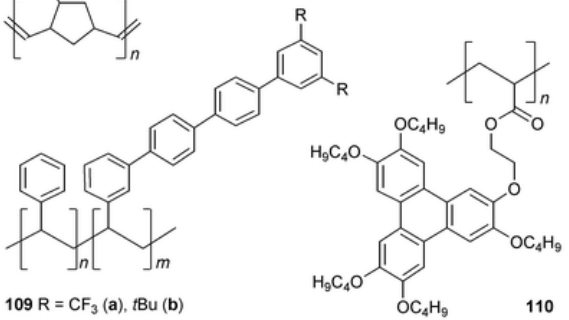
Garten, F.; Hilberer, A.; Cacialli, F.; Esselink, E.; van Dam, Y.; Schlatmann, B.; Friend, R. H.; Klapwijk, T. M.; Hadziioannou, G. *Adv. Mater.*, **1997**, *9*, 127.
Yoshino, K.; Fujii, A.; Nakayama, H.; Lee, S.; Naka, A.; Ishikawa, M. *J. Appl. Phys.*, **1999**, *85*, 414.
Yamamori, A.; Adachi, C.; Koyama, T.; Taniguchi, Y. *J. Appl. Phys.*, **1999**, *86*, 4369.
Bacher, A.; Bleyl, I.; Erdelen, C. H.; Haarer, D.; Paulus, W.; Schmidt, H.-W. *Adv. Mater.*, **1997**, *9*, 1031.

## Main chain polymers with isolated chromophores and side chain polymers with linked chromophores in OLEDs

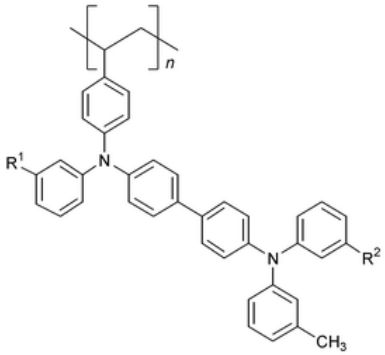
### *Side chain polymers with linked chromophores*



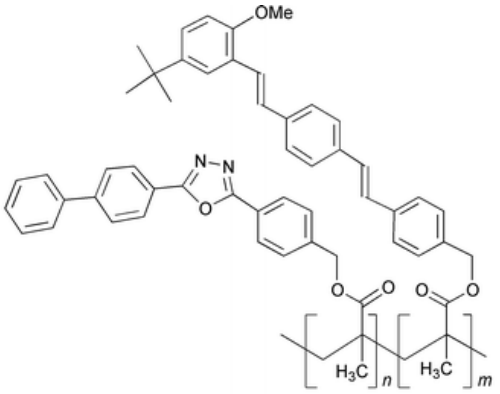
**108**



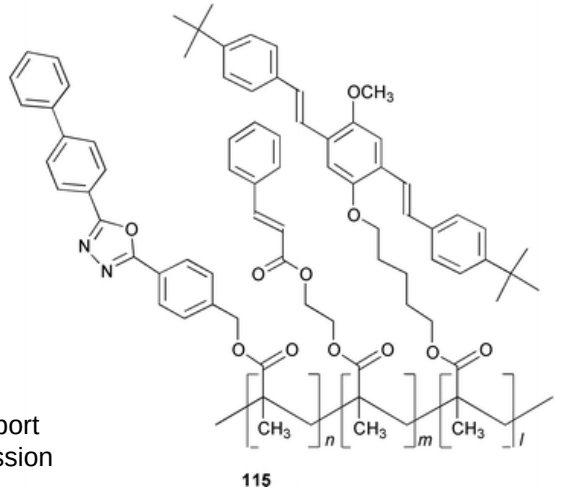
**109** R = $CF_3$ (**a**), *t*Bu (**b**)



**116** $R^1 = CH_3$, $R^2 = H$ (**a**); $R^1 = R^2 = F$ (**b**)



**114**



**115**

Poly(methacrylate) copolymer **115** was used in single-layer devices:

- oxadiazole moiety – electron transport
- distyrylbenzene moiety – blue emission

Li, X.-C.; Cacialli, F; Giles, M.; Grüner, J.; Friend, R. H.; Holmes, A. B.; Moratti, S. C.; Yong, T. M. *Adv. Mater.*, **1995**, *7*, 898.
Li, X.-C.; Yong, T.-M.; Grüner, J.; Holmes, A. B.; Moratti, S. C.; Cacialli, F.; R. H. Friend, R. H. *Synth. Met.*, **1997**, *84*, 437.
Shaheen, S. E.; Jabbour, G. E.; Kippelen, B.; Peyghambarian, N.; Anderson, J. D.; Marder, S. R.; Armstrong, N. R.; Bellmann, E.; Grubbs, R. H. *Appl. Phys. Lett.*, **1999**, *74*, 3212.
Pommerehne, J.; Selz, A.; Book, K.; Koch, F.; Zimmermann, U.; Unterlechner, C.; Wendorff, J. H.; Heitz, W.; Bässler, H. *Macromolecules*, **1997**, *30*, 8270.

## Towards applications and commerzialization - stability and optimization of OLEDs

***Current efforts in increasing the performance of OLEds*:**

•understanding of the fundamental processes of charge injection, transport and recombination
•improvement of device design
•development of the materials

***Device lifetime*** - red and green OLED films have lifetimes from 46,000 to 230,000 hours
blue organics currently have lifetimes up to 14,000 hours

***Ageing processes*** - lead to gradual rise in drive voltage required to maintain constant current
caused by reduced carrier mobility in the polymer

***Solid state morphology is affected by:***
•variations of side chain length of the polymer
•weight percentage of composites and
•solvent choice during processing

***Impurities in the emissive zone:***
•may cause non-radiative decay of charge carriers
•ionic impurities might build up an internal field during device operation

***The effect of nanostructure*** of used materials on charge transfer dynamics is under investigation now

Mitschke, U.; Bauerle, P. *J. Mater. Chem.* **2000**, *10*, 1471-1507.
Mayer, A. C.; Scully, Sh. R.; Hardin, B. E.; Rowell, M. W.; McGehee, M. D. *MaterialsToday* **2007**, *10*, 28-33.

## Applications and commerzialization

*Kodak* was the first to release a digital camera with an OLED display in March **2003**

*Samsung Electronics* in May 2005 announced a prototype of a 40-inch set, ultra-slim TV

On December 2007, *Sony* is going to offer for sale an organic light-emitting diode TV (OLED TV), an 11-inch model with a screen 3 millimeters thick. The set would cost about $1,700

*Toshiba* and *Panasonic* are working jointly on OLED TVs – research and development stage

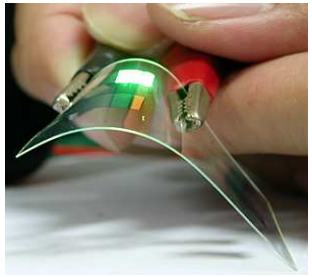
The Sony 11-inch XEL-1

***The market*** for organic lighting is going to exceed US$2.9 billion by 2012, and US$5.9 billion by 2014.

***Usage***: backlighting, general illumination, architectural and industrial lighting products


Kodak LS633 EasyShare

***Leading developing and marketing firms***:
AU Optronics, Applied Nanotech, Avery Dennison, Cambridge Display Technology, Canon, Delta Electronics, Dow Corning, DuPont, Eastman Kodak, Elumin8, General Electric, Idemitsu Kosan, ISE/Noritake, Kodak, Konica Minolta, Merck, Mitsui, Nippon Printing, Nippon Steel, Novaled, Osram, Pelikon, Philips, Rogers Corp., Samsung, Seiko Epson, Shimane Masuda, Sumation, Sumitomo, Toppan Printing, Toshiba-Matsushita, Universal Display, Vitex Systems

# Thank you

*To be continued at nano-level...*