

General information:

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Lecture notes and additional information can be downloaded from
LTI homepage (protected by a password)

Examination : oral (English or German)

Prerequisite: Quantum mechanics/Semiconductor devices/
 Passive components helpful

Outline of the course

1. Introduction
2. Optoelectronic properties of organic semiconductors
3. Organic light emitting diodes (OLEDs)
4. Device and display production
5. Organic FETs
6. Organic photodetectors and solar cells

What is plastic electronics ?

..we most likely know what electronics is so what is plastics ??

www.wordreference.com:

....any one of a large number of synthetic usually organic materials that have a polymeric structure.

→ it's organic ..

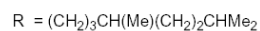
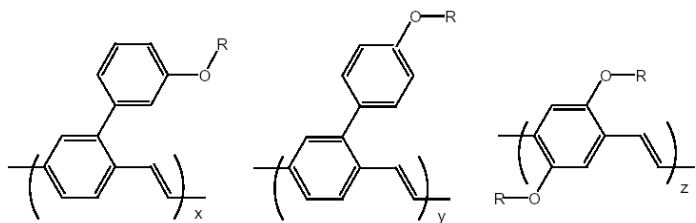
organic chemistry

www.wordreference.com:

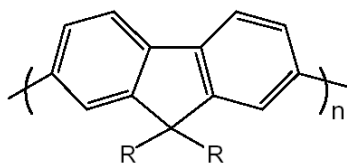
... the branch of chemistry concerned with the compounds of carbon: originally confined to compounds produced by living organisms but now extended to include man-made substances based on carbon, such as plastics.

Materials

Conjugated polymers

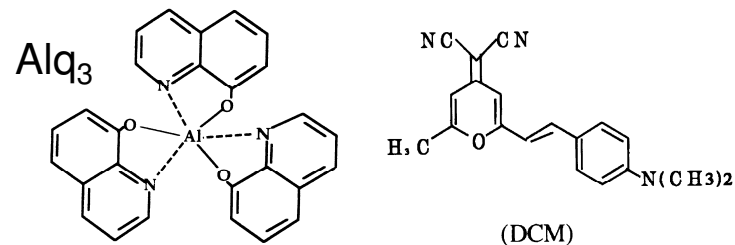


Covion PPV co-polymers

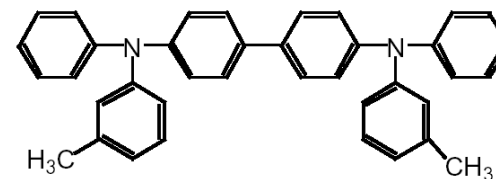


Polyfluorene (Dow)

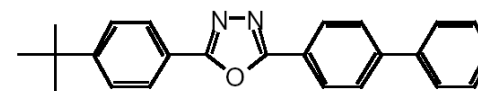
Small evaporated molecules



TPD

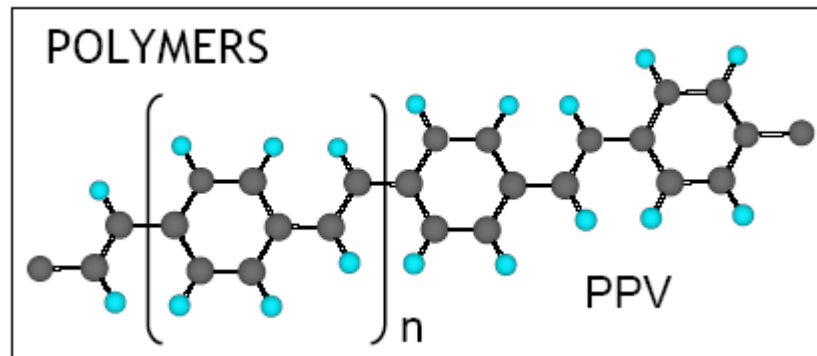


PBD

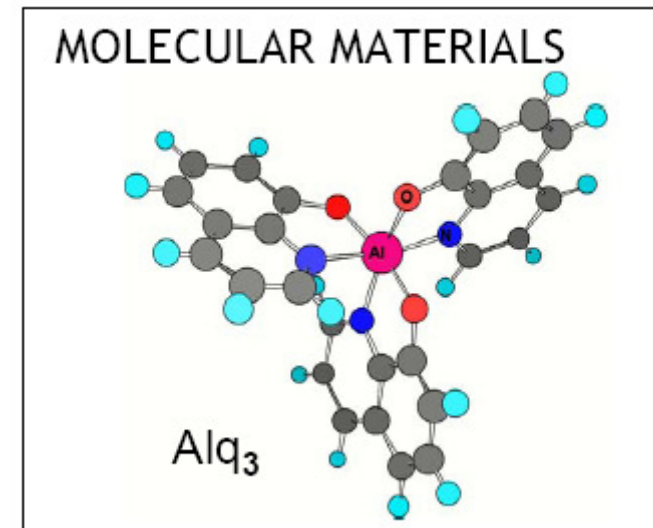


The preparation of the semiconductor film is very different. The electronic properties, however, are very similar.

What is plastic electronics ?



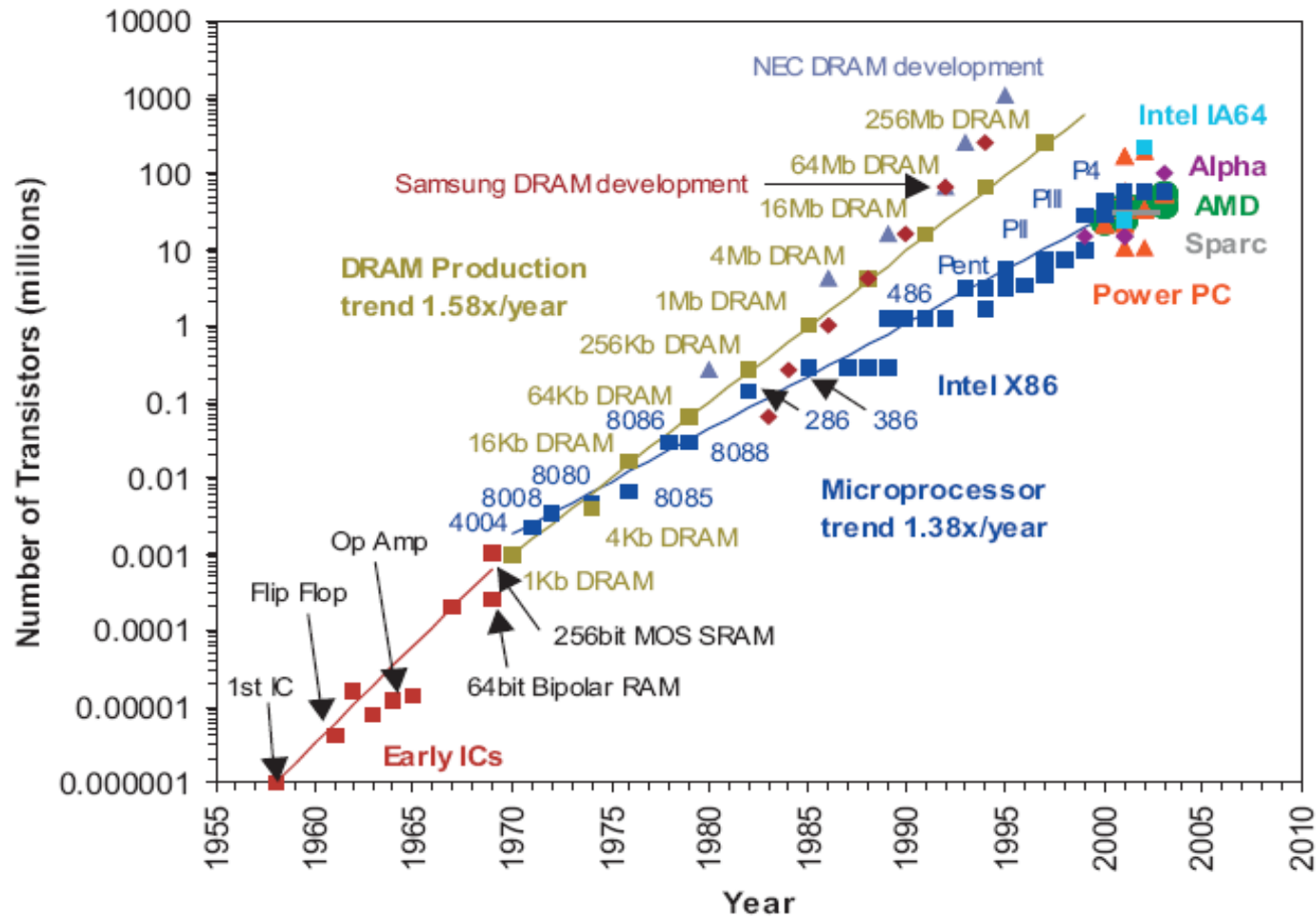
... this is real plastic electronics material



... this is an organic compound that can be deposited onto a plastic material

Why plastic electronics ?

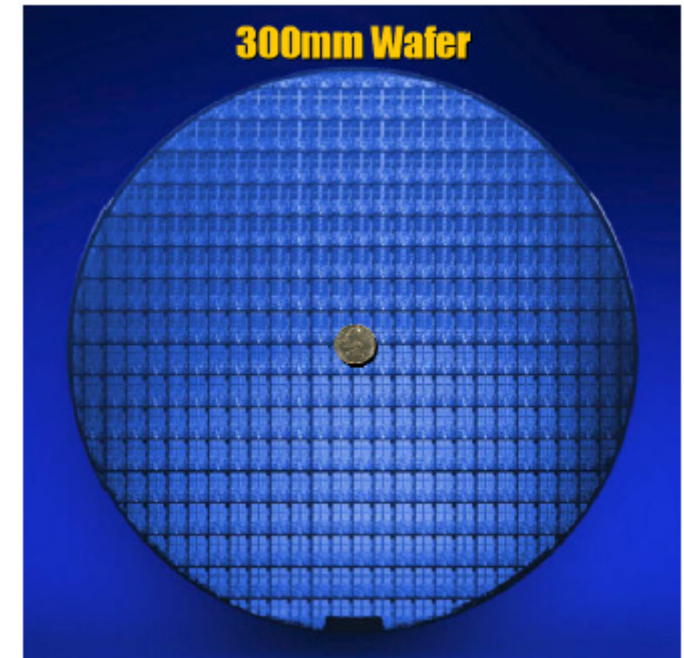
Silicon electronics works quite well and improves rapidly



Source: Icknowledge

Why plastic electronics ?

- ... Si-ICs are not produced at low cost
(Case study #1)
- ... c-Si-fabrication is not large area (≤ 300 mm)
- ... c-Si is pretty fragile
- ... Si does not emit light



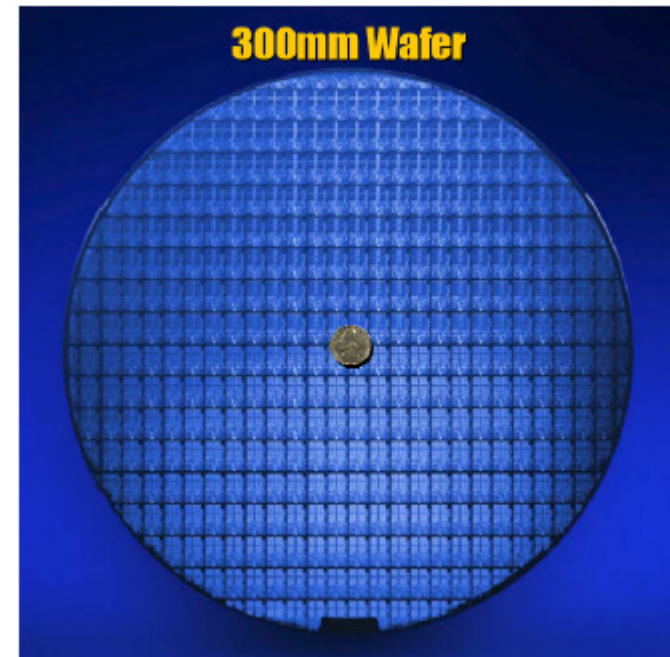
...hey, but how about III-V-semiconductors ??



...well, that's right, they do emit light
but they are even more expensive and less
large area than Si.

Case study #1

How much costs one transistor in CMOS-Technology ?



Why plastic electronics ?

Some good reasons:

- large area (opto)electronic applications
- low cost applications
- mechanical flexibility
- it can emit light in all colors
- organic chemistry offers many, many compounds (> two millions)
- plastic electronics is currently generating jobs in Germany

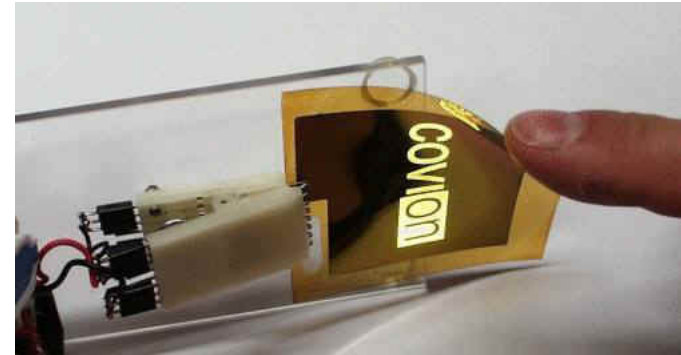
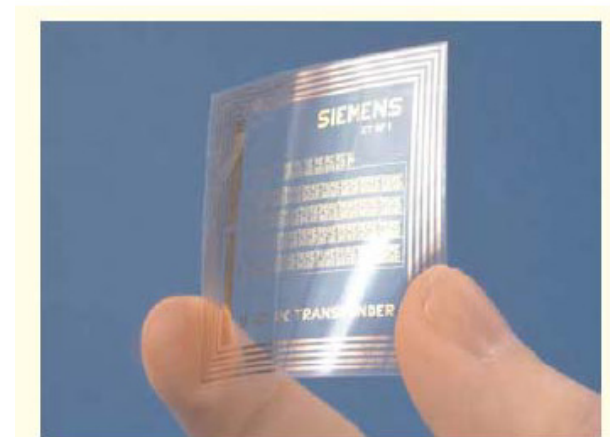


Bild einer OLED (Fa. Covion)



ID-Transponder auf flexiblem Substrat
(Quelle: Siemens)

WWW.merck-oled.de

Adresse <http://www.merck-oled.de/index.html>

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Organische Leuchtdioden revolutionieren Lichtmarkt

Taschenlampen im Scheckkartenformat oder Fenster, die bei Nacht als Lichtquellen dienen: Das ist die Technologie der Zukunft. BASF lässt diese Visionen aus sogenannten OLEDs (Organic Light Emitting Devices) in der gemeinsamen Forschung mit Partnern aus Industrie und Wissenschaft Realität werden.

Bei OLEDs handelt es sich um dünne, leuchtende Bauelemente aus organischen, halbleitenden Materialien. Trotz aller Technologie, die in ihnen steckt, sind sie nicht dicker als eine Plastikfolie und können biegsam gestaltet werden. Dadurch bieten sie völlig neue Möglichkeiten für Beleuchtungssysteme: So können die organischen Leuchtdioden als durchsichtige Lichtkacheln an Stelle von Fensterscheiben platziert und Vorhänge zum Leuchten gebracht werden.

OLEDs bieten aber noch handfestere Vorteile. Sie werden voraussichtlich nur halb so viel Strom wie konventionelle Energiesparlampen benötigen und eine längere Lebensdauer haben. Zurzeit sind OLEDs bereits in Displays von Autoradios und Handys eingesetzt. OLED-Lichtkacheln, die herkömmliche Lampen ersetzen können, werden voraussichtlich ab 2011 erhältlich sein.

BASF-Experten forschen gemeinsam mit Partnern aus Hochschule und Industrie im Joint Innovation Lab (JIL), das 2006 in Ludwigshafen eröffnet wurde, an Materialien für organische Elektronik. Mit den Projekten im JIL tragen wir dazu bei, die Position Deutschlands im Wachstumsmarkt "Organische Elektronik" zu stärken. Gemeinsam mit den BASF-Mitarbeitern bilden die Partner ein interdisziplinär zusammengesetztes Team aus Physikern, Ingenieuren und Chemikern.



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»The New OLED Generation«

New OLED Generation

- > world record in power efficiency
- > long life-time
- > ...

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Competitive Advantages

- for manufacturers using Novaled's
- > leading OLED technology
- > innovative OLED materials
- > ...

[more... >](#)


Ready for Mass Production

- with Novaled's customised offer on
- > technology transfer
- > OLED materials
- > ...

[more... >](#)

> What's New

- 10/22/2007 Sunic System and Novaled in Joint Development On Thin Film
- 10/19/2007 Novaled at FPD Yokohama
- 10/16/2007 ArcelorMittal and Novaled engaged in joint OLED-Development



www.microemissive.com



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Entwicklungsingenieur	05086	UNI Chemie	sofort	Info ▶
Entwicklungsingenieur	05085	- FH Verfahrenstechnik - FH Chemie - FH Mikrosystemtechnik	sofort	Info ▶

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... by fast printing
of electronic chips ...



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News

25.09.2007

Die Revolution mit gedruckter Elektronik beginnt – erste gedruckte RFID und Smart Objects für den Markt

25.09.2007

PRISMA: Ticketing-Feldtest läuft sehr erfolgreich

12.09.2007

Organische Elektronik Live - OE-A stellt neue Roadmap und Give-Aways vor

04.09.2007

Sechster PolyIC-Newsletter ic4u erschienen

Willkommen bei PolyIC - "the chip printers"


Erleben Sie die Möglichkeiten gedruckter Elektronik, ermöglicht durch eine neue Technologie, der "Polymerelektronik", mit elektrisch leitenden und halbleitenden Kunststoffen.




Seit dem 3. April 06 erreichen Sie uns unter folgender Adresse:

PolyIC GmbH & Co. KG
Tucherstraße 2
D- 90763 Fürth

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Telefax: +49 911 202 49-8001


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Konarka Builds Power Plastic™ That Converts Light To Energy – Anywhere.



Power Plastic™ made in Lowell, MA USA

Konarka develops light-activated power plastic that is flexible, lightweight, lower in cost and much more versatile in application than traditional silicon-based solar cells.

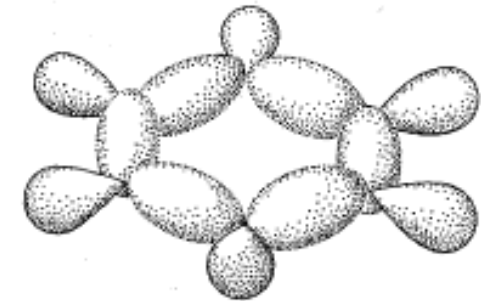
Materials Make It Possible
 These new materials are made from [conducting polymers](#) and [nano-engineered materials](#) that can be coated or printed onto a surface in a process similar to how photographic film is made.

World Without Wires™
 Anywhere there is light and a battery, power plastic makes it possible for [devices, systems and structures](#) to have their own low-cost embedded sources of renewable power. By combining energy generation and power consumption within the same device, Konarka

Media Alert :: [Konarka Amps Up Presence at Solar Power 2005 - Company and Chief Scientist Alan Heeger Featured in "The Power of the Sun" Documentary Premiering at the Event](#)

Press Releases	In The News	Events
Konarka's Founder and Chairman Honored With Mass High Tech's 10th Annual All-Star Award - October 19, 2005 Konarka's Founder and Nobel Laureate Receives 2005 POPULAR MECHANICS Breakthrough Award - October 11, 2005 ▲ More >>	Ultraportable Power Charges Ahead - BusinessWeek Army lightens load with solar power - MSNBC As solar gets smaller, its future gets brighter - San Francisco Chronicle ▲ More >>	Lux Executive Summit - October 24-25 Energy Venture Fair - November 2-3 Conference on Clean Energy - November 7-8 ▲ More >>

1. Introduction
2. Optoelectronic properties of organic semiconductors
3. Organic light emitting diodes (OLEDs)
4. Device and display production
5. Organic FETs
6. Organic photodetectors and solar cells



(b)

What is a π -electron
??
Are their differences
to inorganic
semiconductors ??

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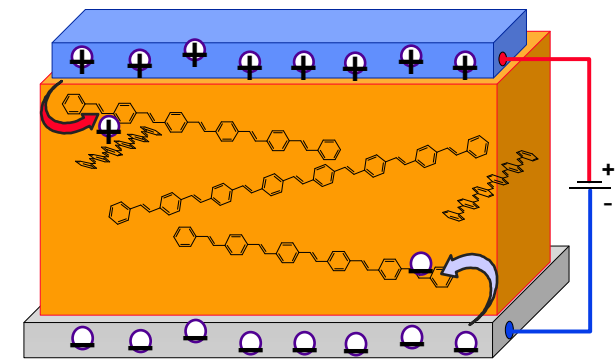


www.merck-oled.de

What
determines the
color of the
emission of an
OLED ?

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A typical device consists of 3 layers



How to drive electrons through
a thin piece of plastic ?

-
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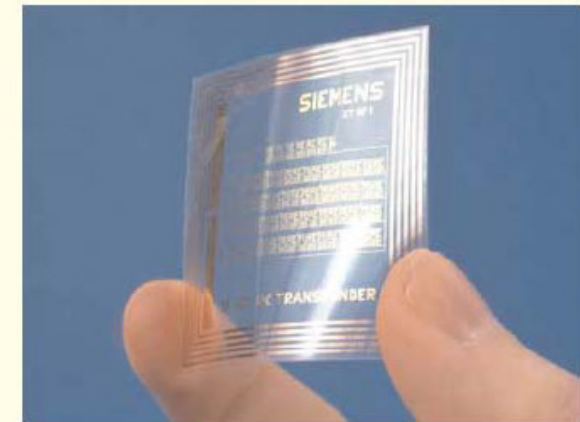
How do you get light
out of a piece of plastic ?

-
1. Introduction
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How do you produce OLEDs
on a large scale ?

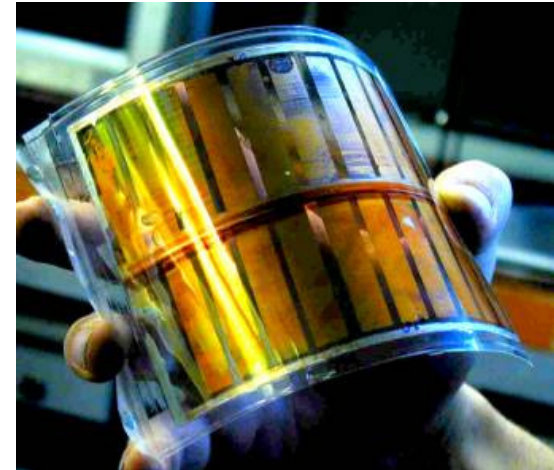
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ID-Transponder auf flexiblem Substrat
(Quelle: Siemens)

How do you use plastic for
information processing ?

-
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Large area and low cost ...
that could also be useful for
photovoltaics and sensors !

Some remarks on organic electronics history

Scientific Interest in Organic Materials

- 1828 - Wöhler first synthesized urea without the assistance of a living organism
- 1950's - steady work on crystalline organics starts
- 1970's - organic photoconductors (xerography)
- 1980's - organic non-linear optical materials
- 1987 - Kodak group published the first efficient organic light emitting device (OLED)
- Since then, the field has dramatically expanded both commercially and scientifically (OLEDs, transistors, solar cells, lasers, modulators, ...)

Source:
Bulovic, MIT

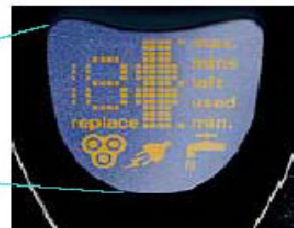
Some remarks on organic electronics history



-a piece of plastic electronics
in our daily life !



Some example products



Philips: Electrical Shaver

conjugated polymers



Samsung Electronics

Evaporated small molecules



A snapshot of the OLED-market

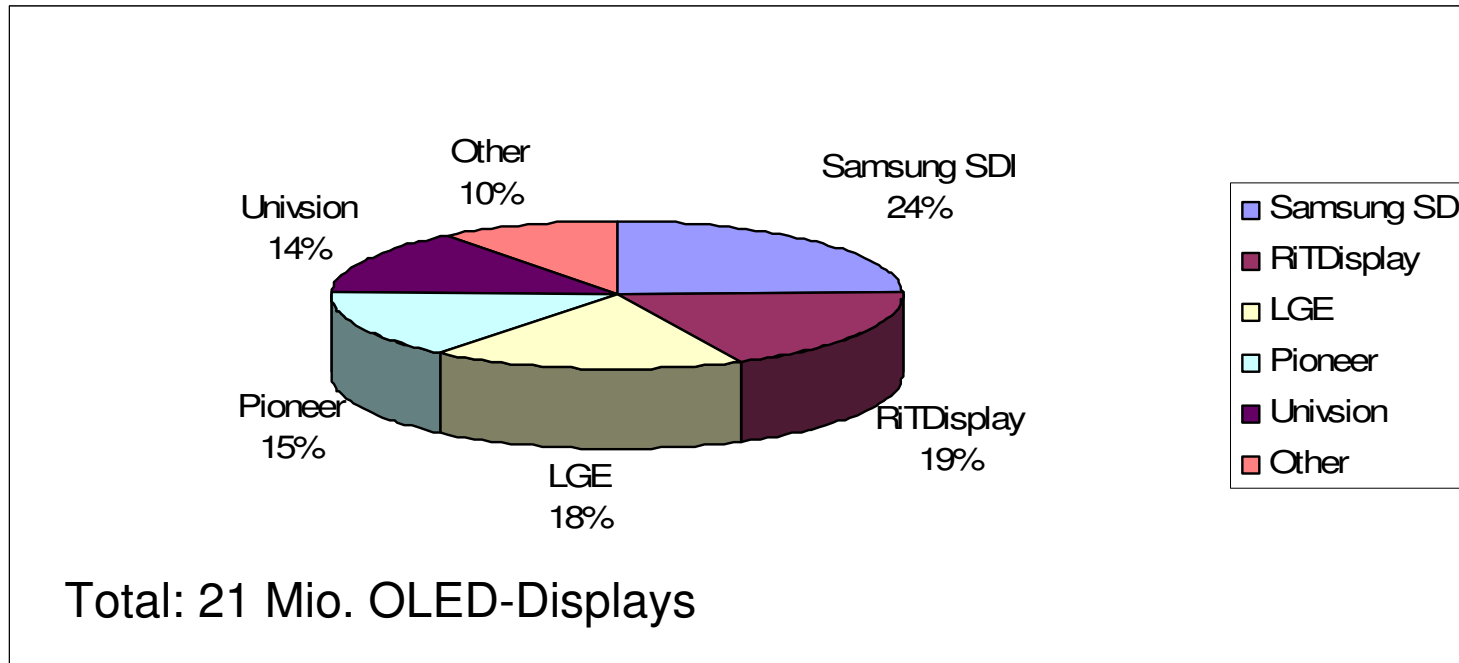
Top 5
Applications in
Q2 2005

Rank	Application	Shipments (000)
1	Subdisplay	7,073.0
2	MP3	6,143.0
3	Car Audio	435.0
4	Main Display	331.3
5	Auto Console	157.0
	Others	69.0
	Total	14,208.3

Top 5 revenue
Q2 2005

Rank	Manufacturer	Revenue (US\$M)
1	Samsung SDI	37.2
2	RiTdisplay	28.1
3	Pioneer	19.6
4	Univision	14.1
5	LGE	6.5
	Others	19.2
	Total	124.8

OLED-market: 3rd quarter 2006



Market shares in the 3rd quarter 2006, Source: DigiTimes

2nd quarter 2007:

Tabelle 1

Die Top 5 der OLED-Hersteller bilden im zweiten Quartal 2007 zusammen ein Umsatzvolumen von 109,8 Millionen US-Dollar, das entspricht einem Marktanteil von 88,9 Prozent. Speziell in den PMOLED-Display Markt (passive matrix organic light emitting diode) sind zwei Anbieter aus China neu eingestiegen: Visionox und Truly.

Rank	Company	Q2'07 Revenue (US\$M)	Market Share	Q/Q Growth	Y/Y Growth
1	Samsung SDI	33.8	27.4%	30%	50%
2	Pioneer	24.7	20.0%	-2%	62%
3	RiTdisplay	23.0	18.6%	-2%	67%
4	LGE	22.7	18.4%	-7%	-17%
5	TDK	5.6	4.5%	-5%	-29%
	Others	13.6	11.0%	-29%	-40%
	Total	123.4	100.0%	-1%	13%

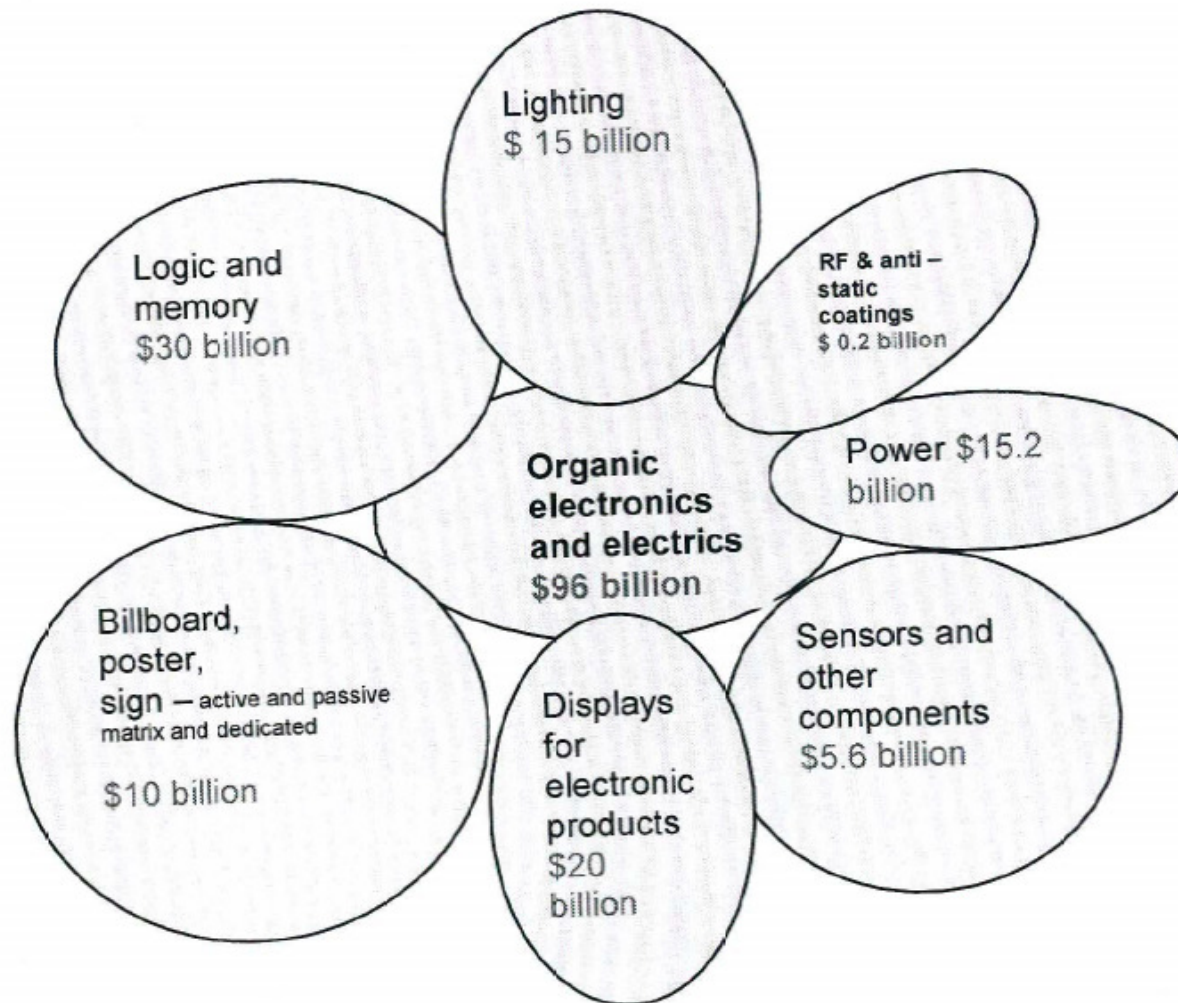
Tabelle 2

Die fünf größten Anwendungsgebiete von OLED-Displays im zweiten Quartal 2007

Rank	Application	Q2'07 Shipments (000)	Market Share	Y/Y Growth	Q/Q Growth
1	Sub-display	14,063	70.9%	77%	12%
2	MP3	3,465	17.5%	-47%	-14%
3	Main Displays	873	4.4%	16%	-11%
4	Car Audio	531	2.7%	35%	-11%
5	Industrial	762	3.8%	295%	-4%
	Other	140	0.7%	12%	0%
	Total	19,834	100.0%	24%	4%

A more optimistic view

Fig. 7.2 The potential annual global sales of each type by 2020



Some more introductory impressions

Let's watch what the Philips vision was and partly is on that ...

PHILIPS

State of the art



5 inch by Kodak in 2000

40 inch by Epson in 2004
and
Samsung in 2005

Sony 11 inch OLED TV
on the market in Dec. 2007



A visionary device ...not yet realized



THE ULTIMATE HANDHELD COMMUNICATION DEVICE

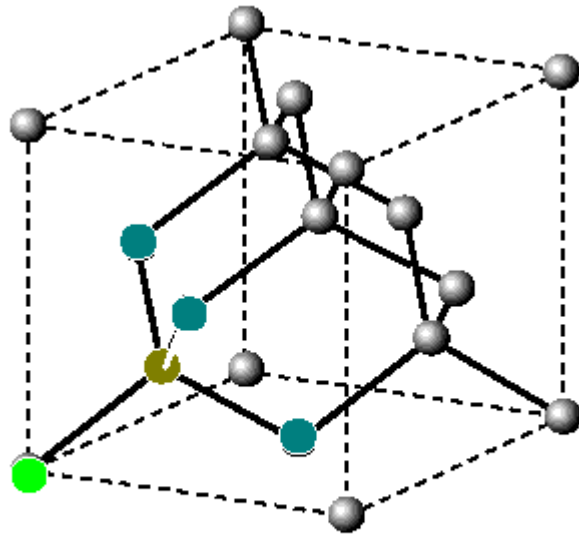
UDC, Inc.

Outline of the course

1. Introduction
2. Optoelectronic properties of organic semiconductors
 - 2.1 Basic electronic properties
 - 2.1.1 Molecular materials
 - 2.1.2 Electronic states in molecules
 - 2.1.3 π -electrons
 - 2.2 Optical properties
 - 2.3. Electronic transport
3. Organic light emitting diodes (OLEDs)
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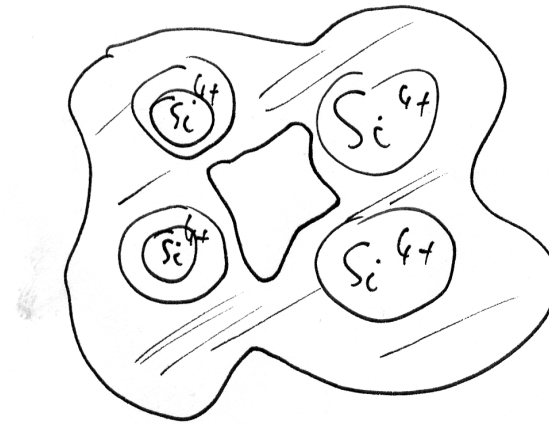
2.1.1: Molecular materials

Important differences to inorganic semiconductors:



diamond structure

Lattice structure of Si

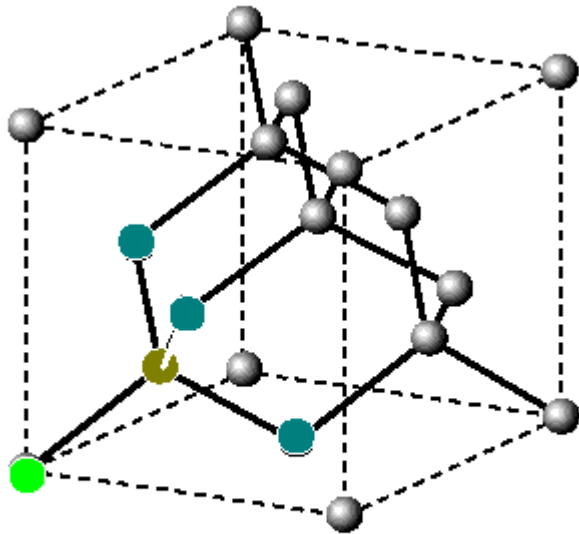


- covalent bond (electrons are shared by atoms)
- strong interaction from one unit cell to the other



- high melting point ($T_{\text{melt,Si}} = 1420 \text{ } ^\circ\text{C}$)
- delocalized electrons

2.1.1: Molecular materials



diamond structure

-Simplified description of the electronic properties of such crystals due to the periodic potential

$$U(\vec{r}) = U(\vec{r} + \vec{R}) \quad (\vec{R}: \text{lattice vector})$$

-electronic wavefunction can be classified according to the wavevector k and the band index n

$$\Psi_{nk}(\vec{r}) = e^{j\vec{k}\vec{r}} u_{nk}(\vec{r})$$

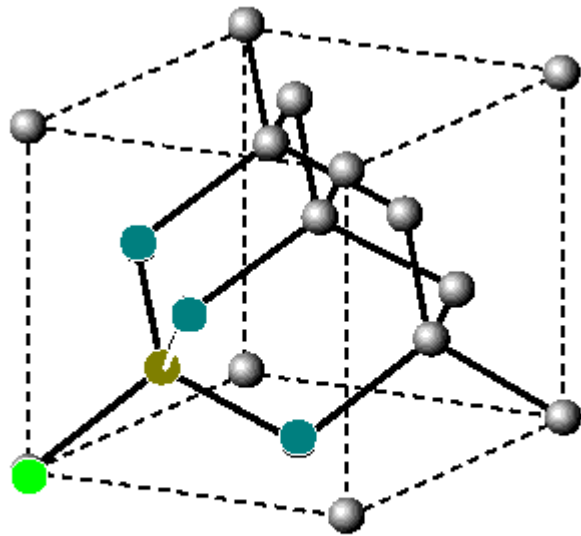
$$u_{nk}(\vec{r}) = u_{nk}(\vec{r} + \vec{R})$$

(periodic function)

2.1.1: Bloch electrons in inorganic semiconductors

1.37

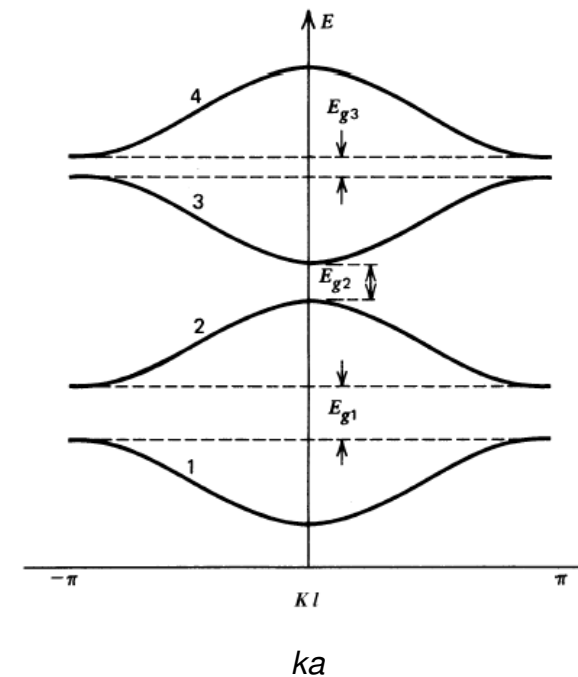
-description of electrons in terms of a *band structure*



diamond structure

„conduction band“

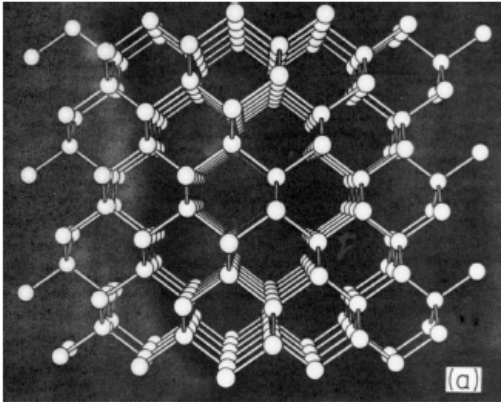
„valence band“



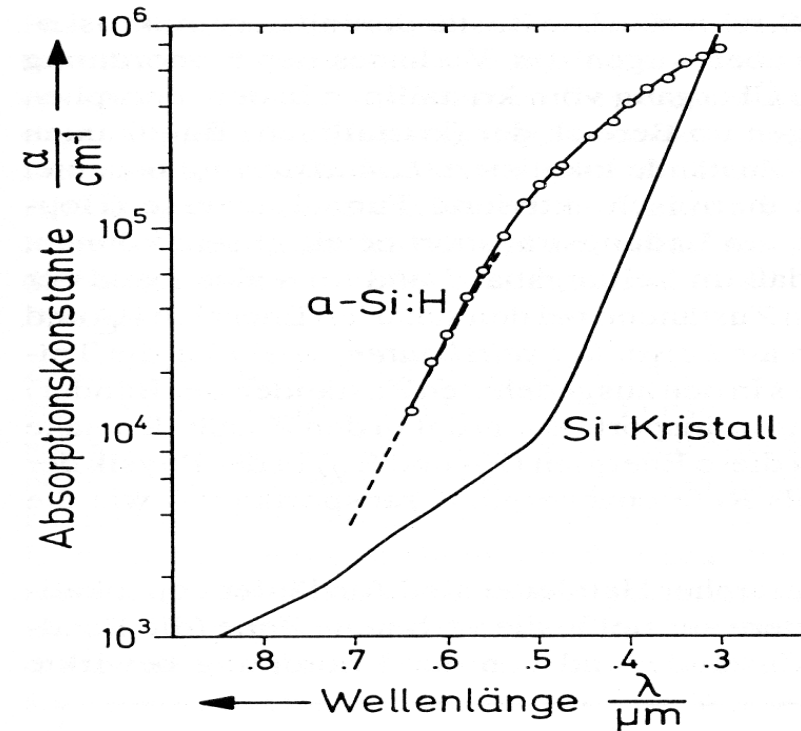
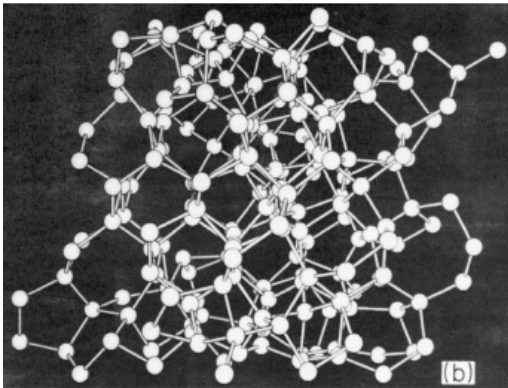
→ Electronic properties and optical transitions are determined by the crystallinity of the semiconductor material

2.1.1: Crystalline vs. amorphous

c-Si

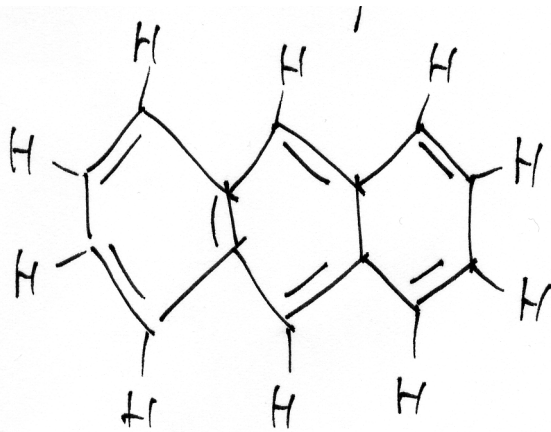


a-Si

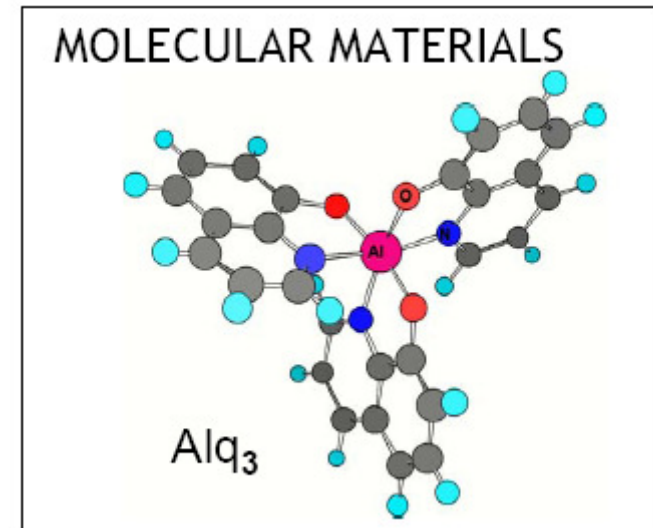


-strong changes when the solid is amorphous instead of crystalline
 ... and most organic semiconductors are amorphous

2.1.1: Organic solids



Anthracene

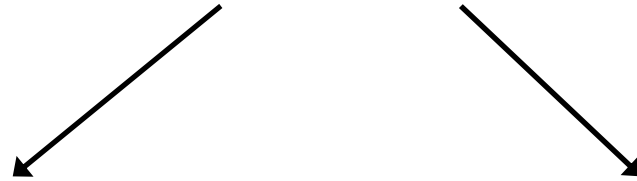


Organic semiconductors can be crystalline or amorphous

-solid is formed by van-der-Waals (dipole-dipole) interaction
i.e. electrons still belong to one unit cell

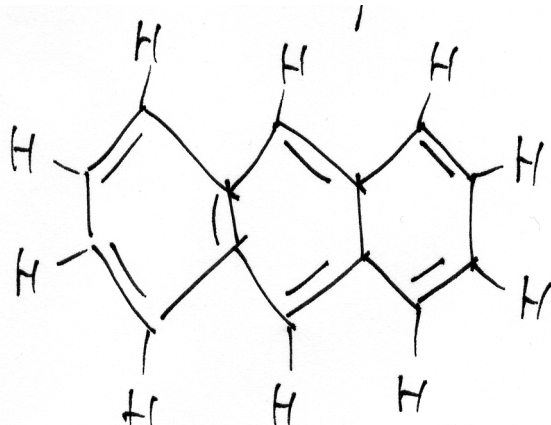
2.1.1: Organic solids

- weak interaction from molecule to molecule



low melting point
($T_{\text{melt, Anthr.}} = 217^\circ\text{C}$)

weak delocalization of electrons
(... transport might be hard)



-electronic properties do not strongly depend on the environment

-very similar optical properties in the solution and in the solid state