전자물리특강
Organic semiconductors and quantum dots (QD)
Introduction

2014. 3. 4.

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Syllabus

- **Professor:** Changhee Lee, 880-9093, chlee7@snu.ac.kr

- **Text & References**

  Text : Lecture slides

  References:
  - Organic Electronics, Edited by Hagen Klauk, Wiley-VCH, 2006, Weinheim
  - Review papers on OLEDs, OPVs, and QDs.

- **Grades**
  - Midterm Exam 35 %
  - Final Exam 35 %
  - Attendance 5 %
  - Term paper 25 %

- **Lecture room**: 301-106

- **Lecture Hour**: Tue & Thu. 9:30-10:45pm

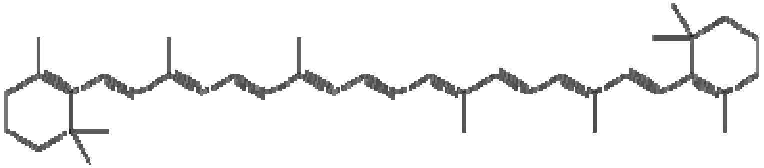
Lecture Schedule

Week	Lecture Plan
1	Introduction
2.	Electronic Structure of Organic Semiconductors
3.	Optical Properties of Organic Semiconductors
4.	Optical Properties of Organic Semiconductors
5.	Electrical Properties of Organic Semiconductors
6.	Optoelectrical Applications of Organic Semiconductors: OLED
7.	Optoelectrical Applications of Organic Semiconductors: OLED
8.	**Midterm Exam (4. 24)**
9	Optoelectrical Applications of Organic Semiconductors: Organic Solar Cells
10	Optoelectrical Applications of Organic Semiconductors: Organic Solar Cells
11	Basic Properties of Quantum Dots (QD)
12	Basic Properties of Quantum Dots (QD)
13	Optoelectrical Applications of Quantum Dots (QD): QD-LEDs
14	Optoelectrical Applications of Quantum Dots (QD): QD Solar Cells
15	**Final Exam (6. 10)**

Introduction:

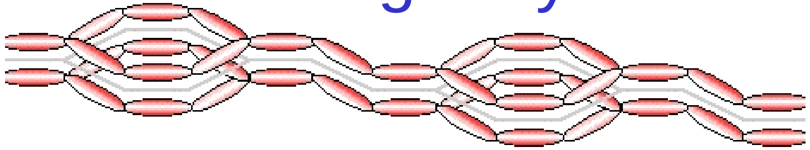
Organic semiconductors

Organic materials: new class of electronic materials



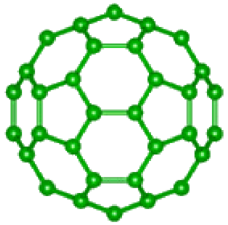
β-Carotene: can be found in yellow, orange, and green leafy fruits and vegetables such as carrots, tomatoes, sweet potatoes, oranges, etc..

Conducing Polymers



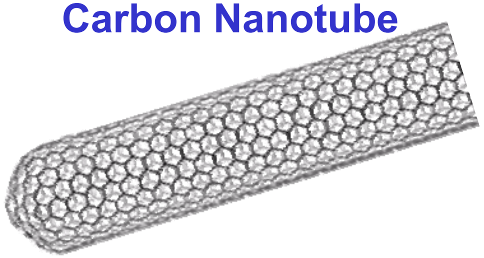
Nobel Prize in Chemistry 2000
Alan J. Heeger, Hideki Shirakawa, Alan G. MacDiarmid

Fullerene, C_{60}



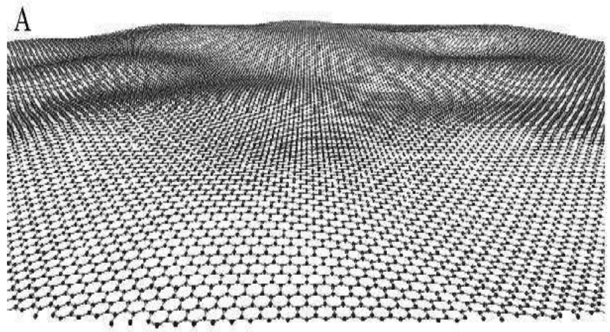
Nobel Prize in Chemistry 1996
Robert F. Curl Jr.
Sir Harold W. Kroto
Richard E. Smalley

Carbon Nanotube

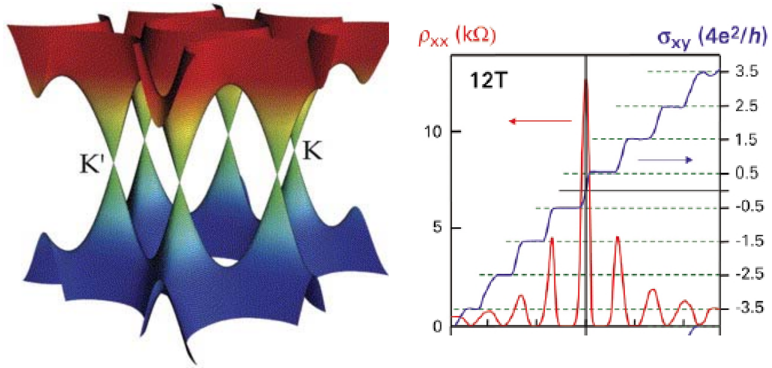


Discovered in 1991 by Sumio Iijima

Graphene sheet



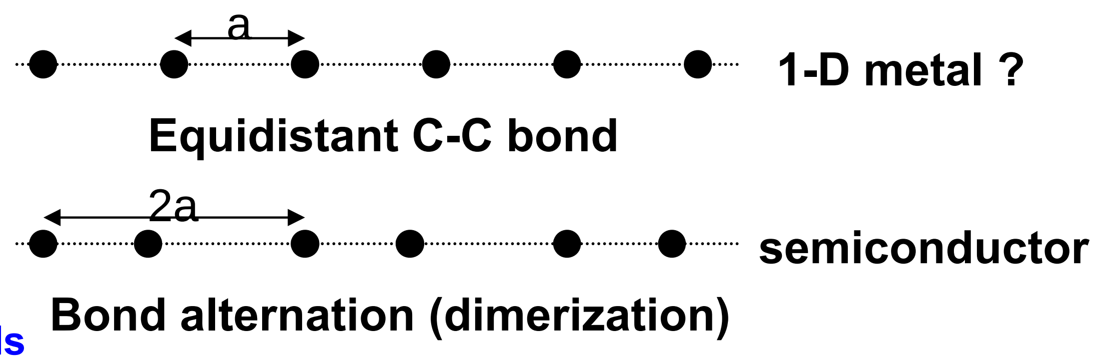
K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, I. V. Grigorieva, and A. A. Firsov, *Science 306*, 666 (*2004*)

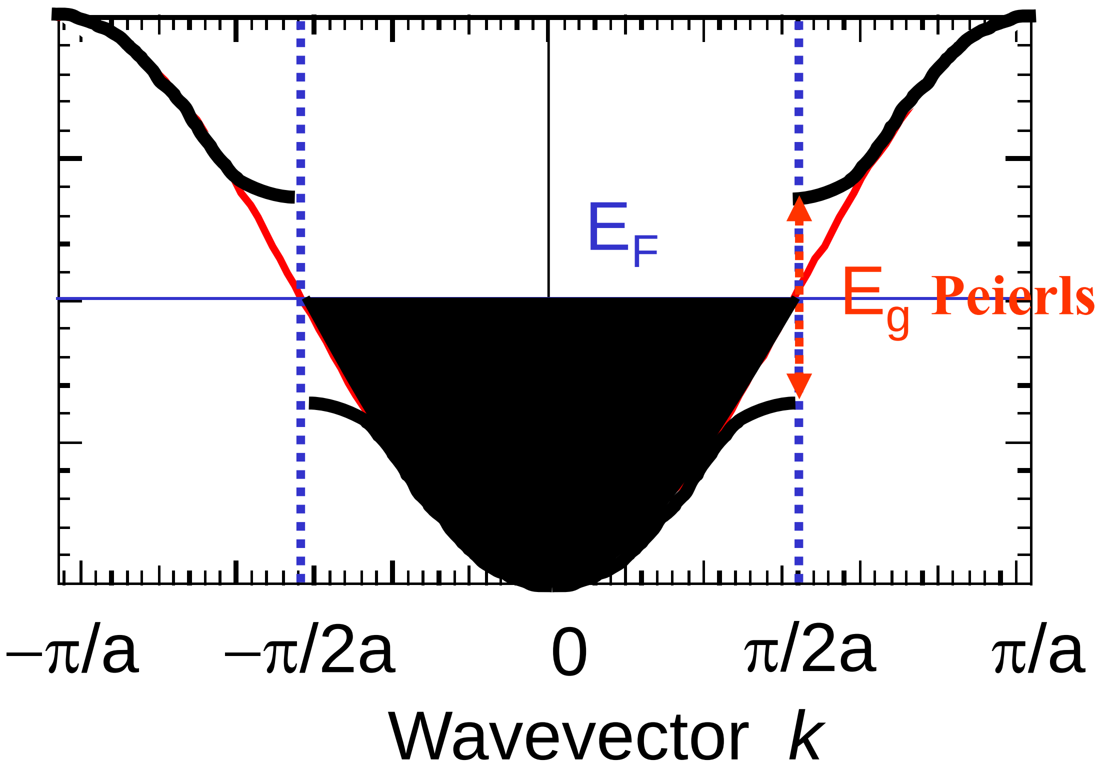


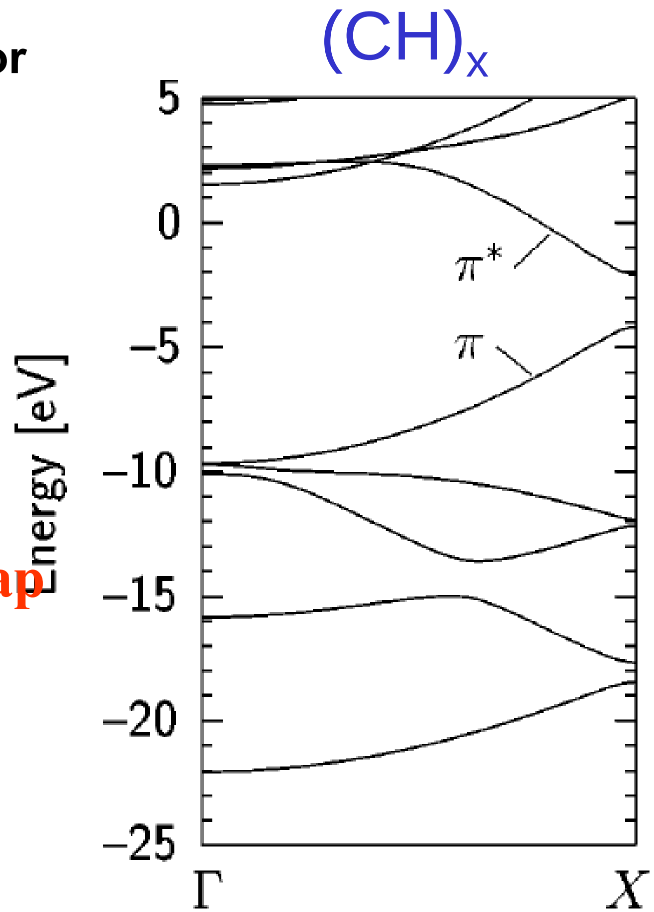
Left: Band structure of graphene. The conductance band touches the valence band at the K and K' points .Right: Resistivity (red) and Hall conductivity (blue) as a function of carrier concentration in graphene.
M.I. Katsnelson, Mater. Today 10, 20 (2007)

Peierls instability →Energy Band gap

Sir Rudolf E. Peierls
1907-1995

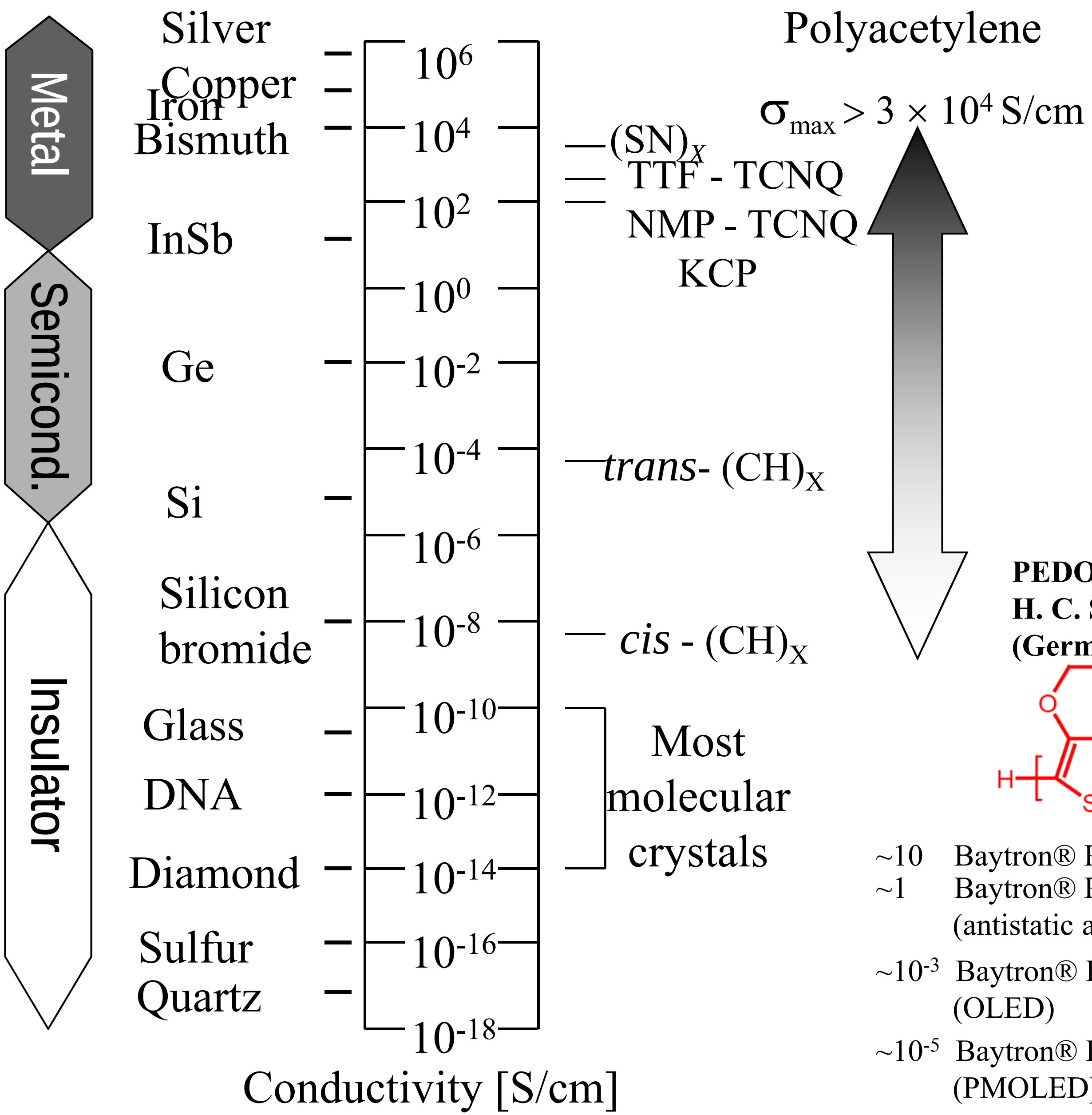




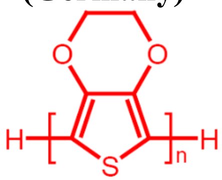


M. Rohlfing and S. G. Louie, *Phys. Rev. Lett.* **82**, 1959 (1999)

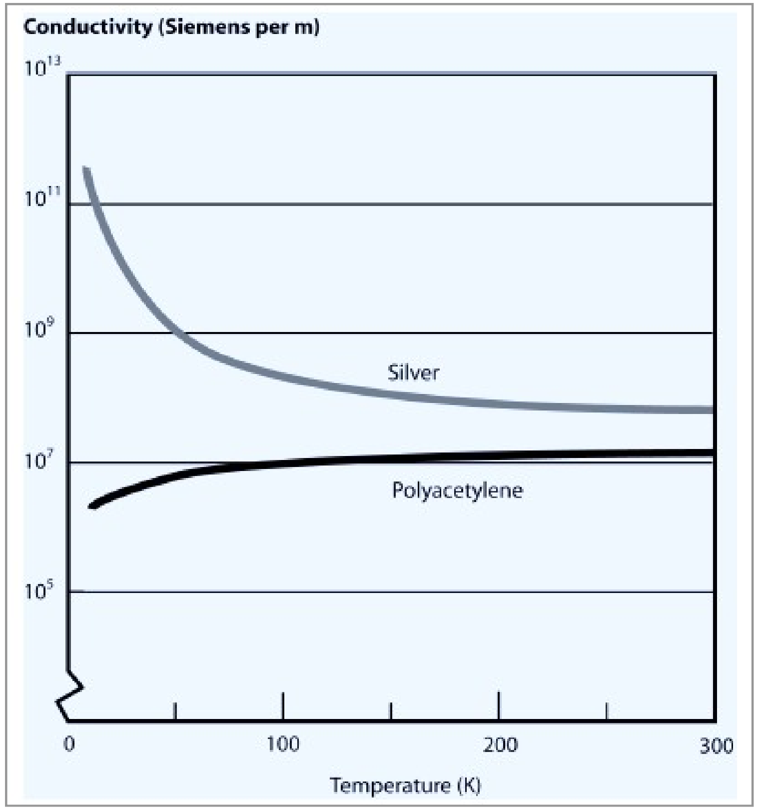
Conducting Polymers



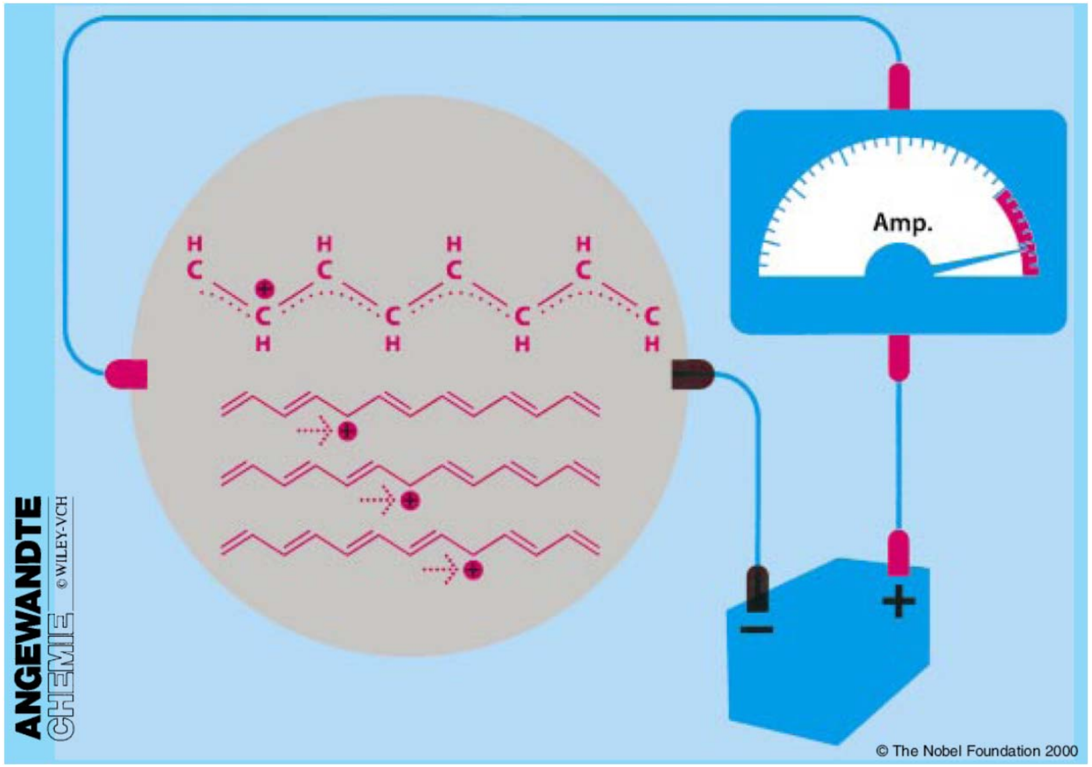
PEDOT:PSS
H. C. Starck
(Germany)

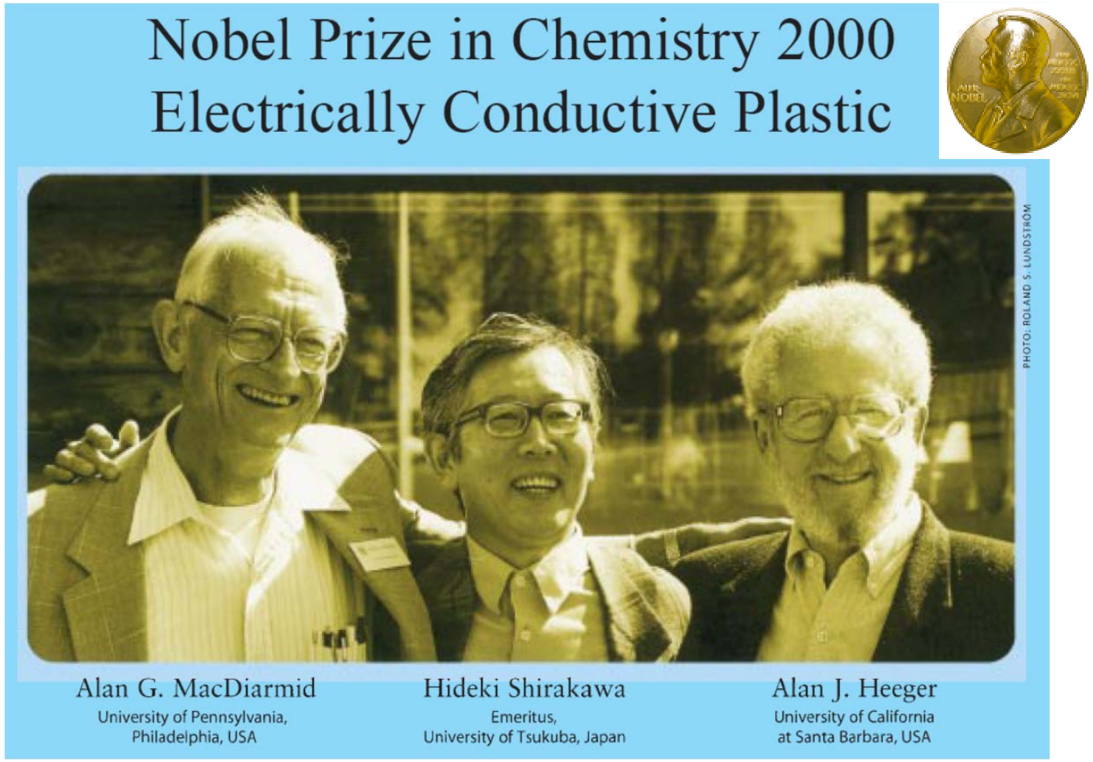


~10 Baytron® P HC
~1 Baytron® P
(antistatic applications)
$\sim 10^{-3}$ Baytron® P VP Al4083
(OLED)
$\sim 10^{-5}$ Baytron® P VP CH8000
(PMOLED)



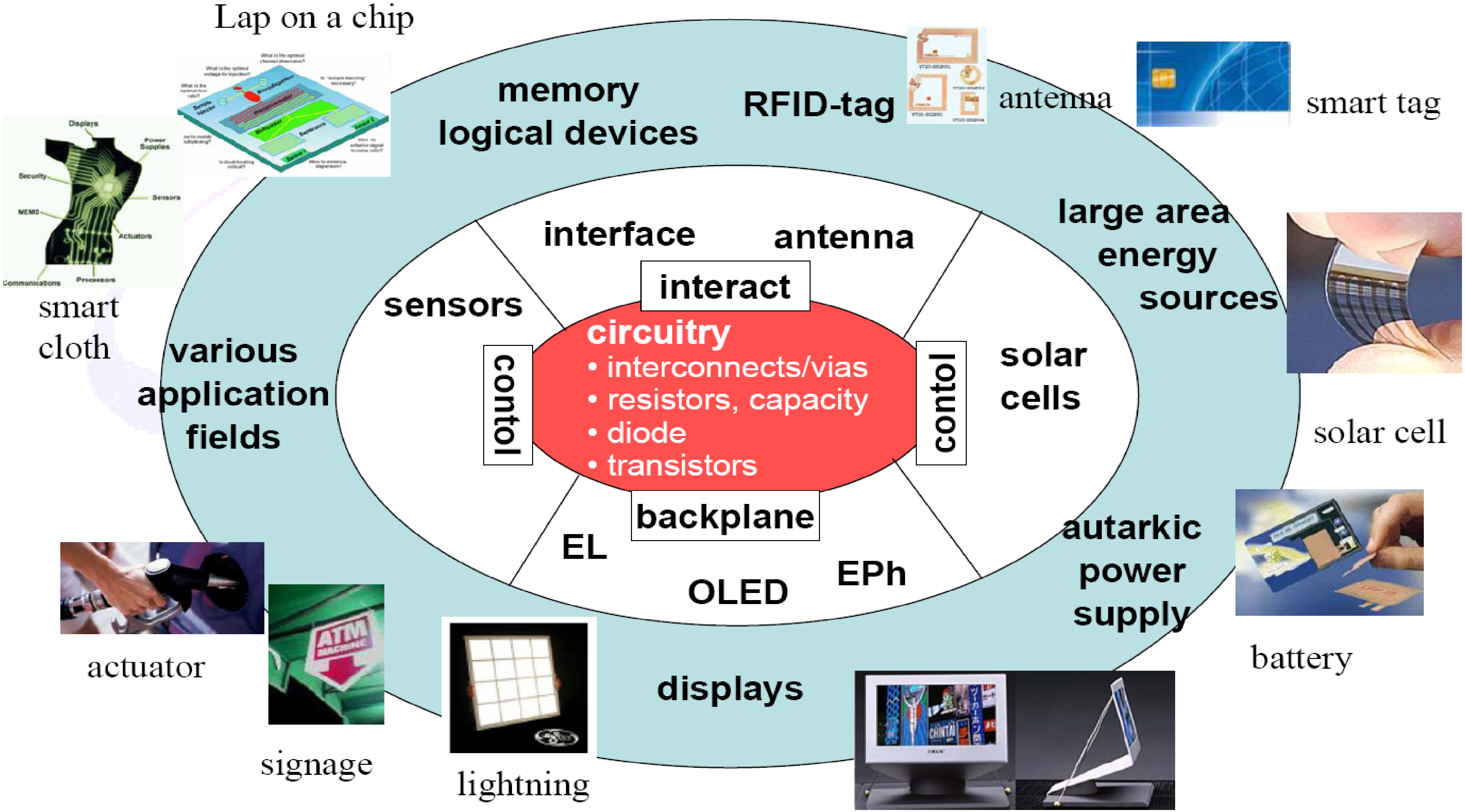
Nobel Prize in Chemistry 2000





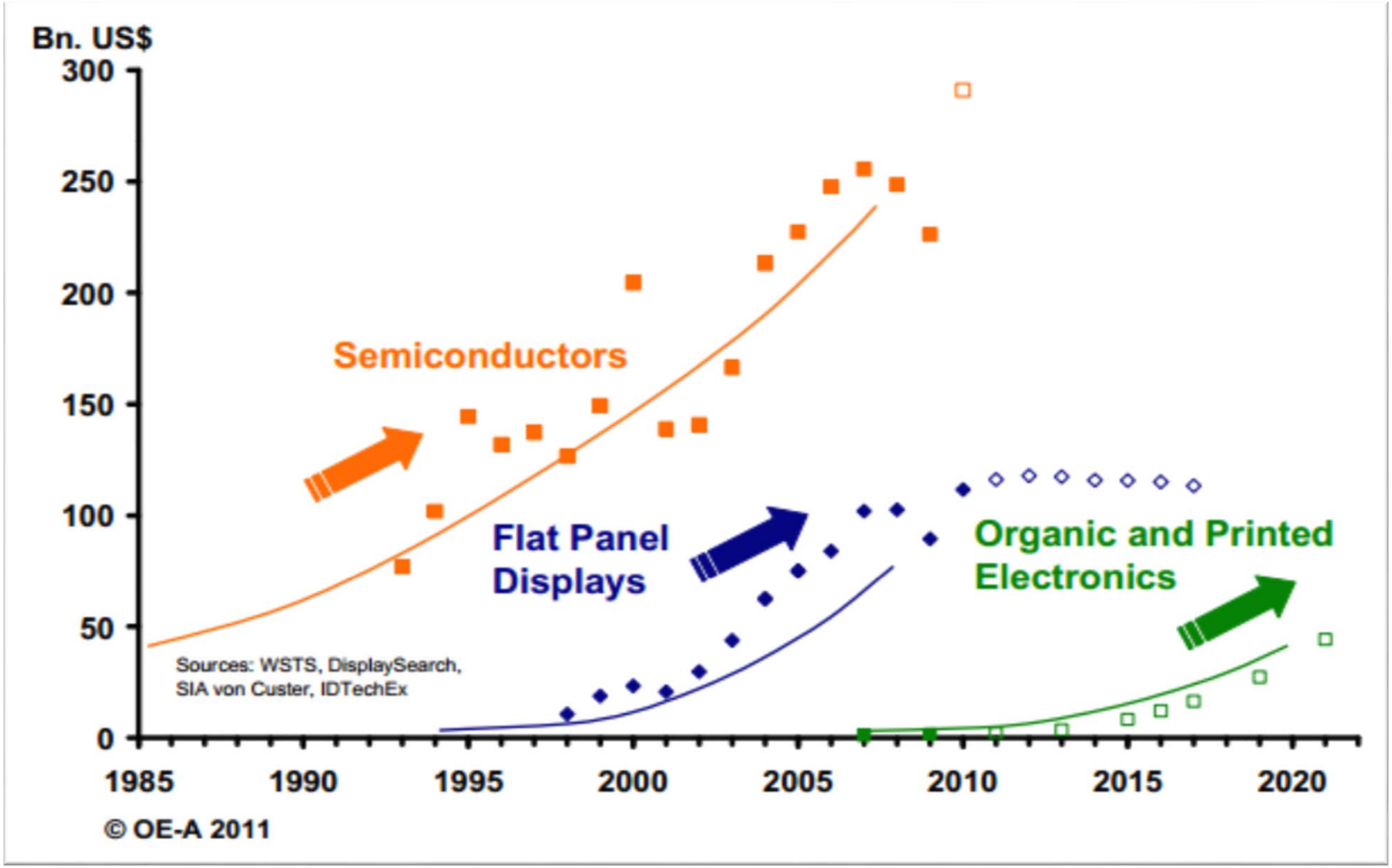
CHEM. COMMUN., 1 (2003)

Application of Organic semiconductors



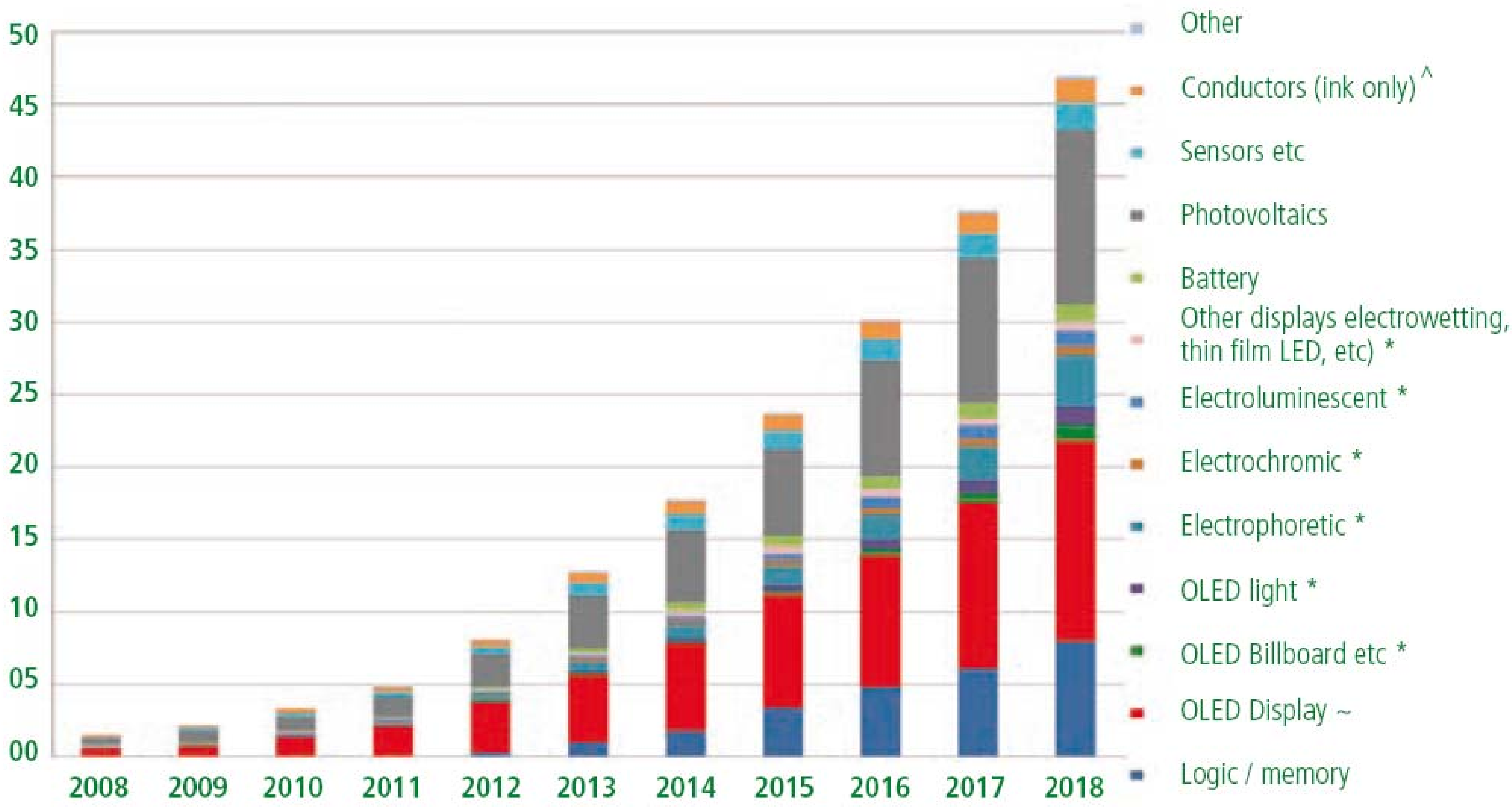
A. C. Huebler, *Printed Electronics Europe 06, Cambridge, 2006.*

Organic Electronics Market



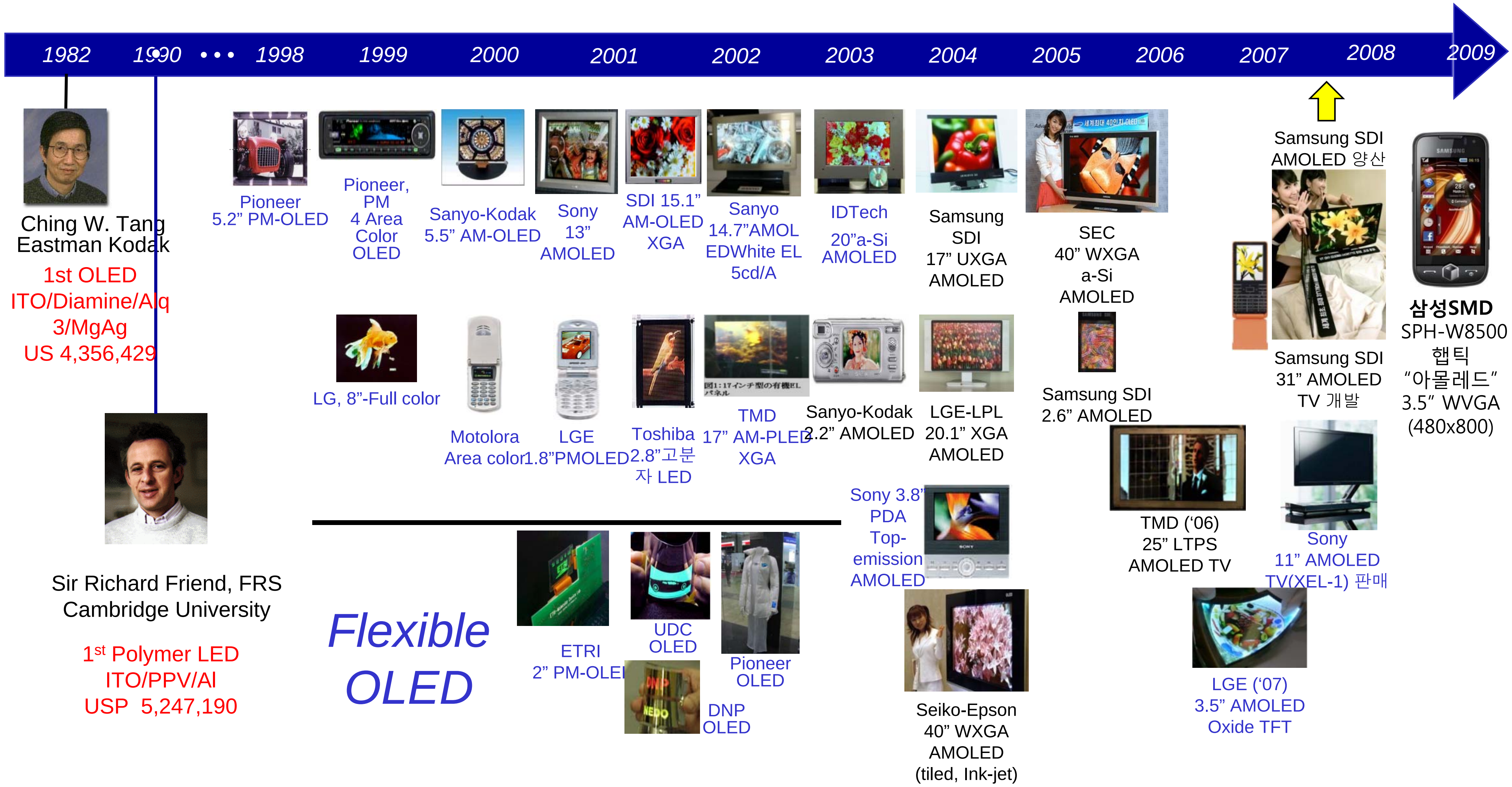
Organic Electronics Association (2011)

Organic electronics market



Strategic Research Agenda Organic & Large Area Electronics (OLAE, 2009. 12. 28; Original source: IDTechEx)

Development of OLED Displays



OLED Lightings

Philips Lighting/Novaled
25 lm/W @ 1000 cd/m²

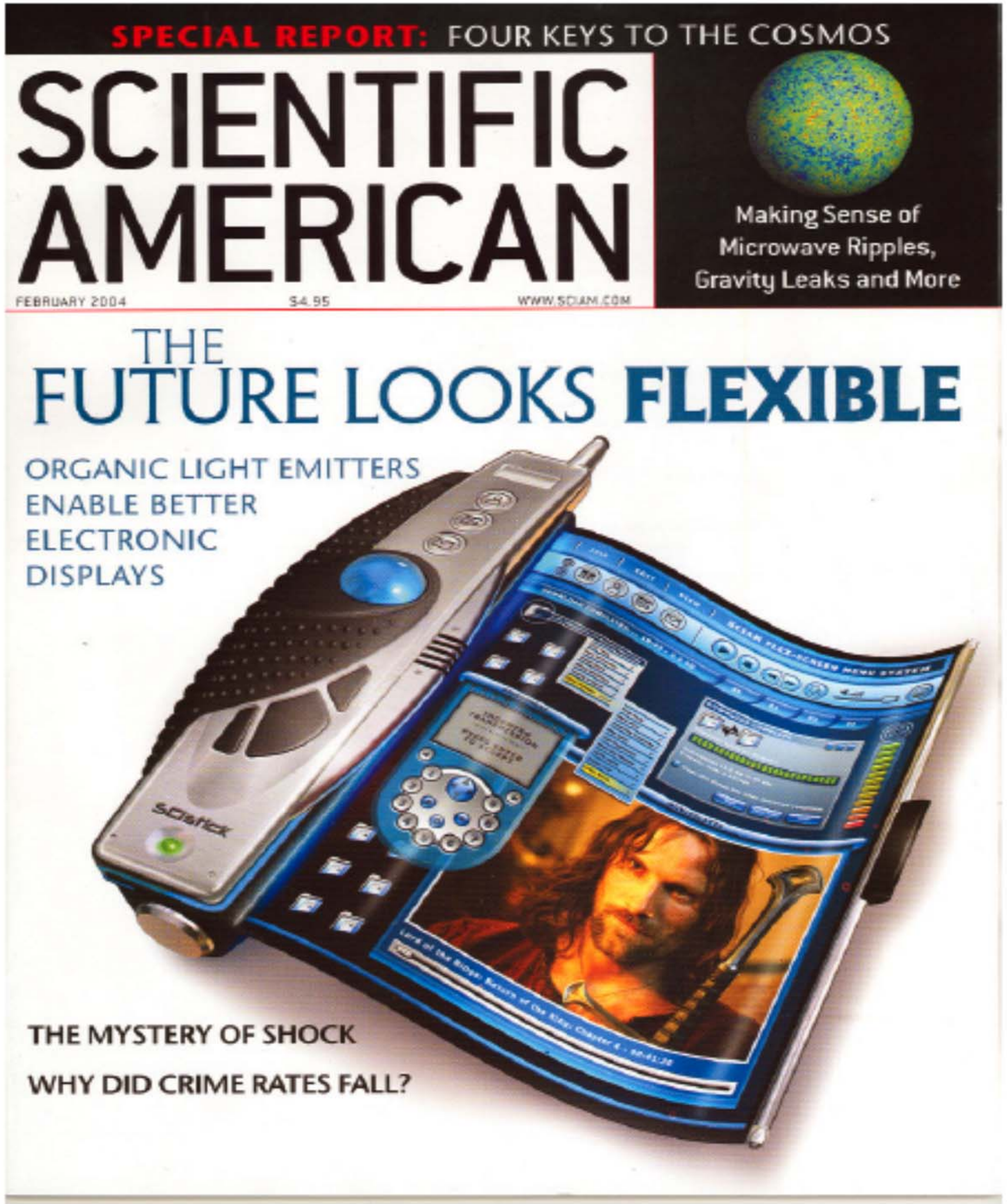
UDC
20 lm/W @ 800 cd/m²

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

8-ft. strip comprised of 6 x 6 in. lighting panels
GE / Energy Conversion Devices / NIST the 2008. 3.

The first OLED desk lamp
"Early Future"
Courtesy: Ingo Maurer

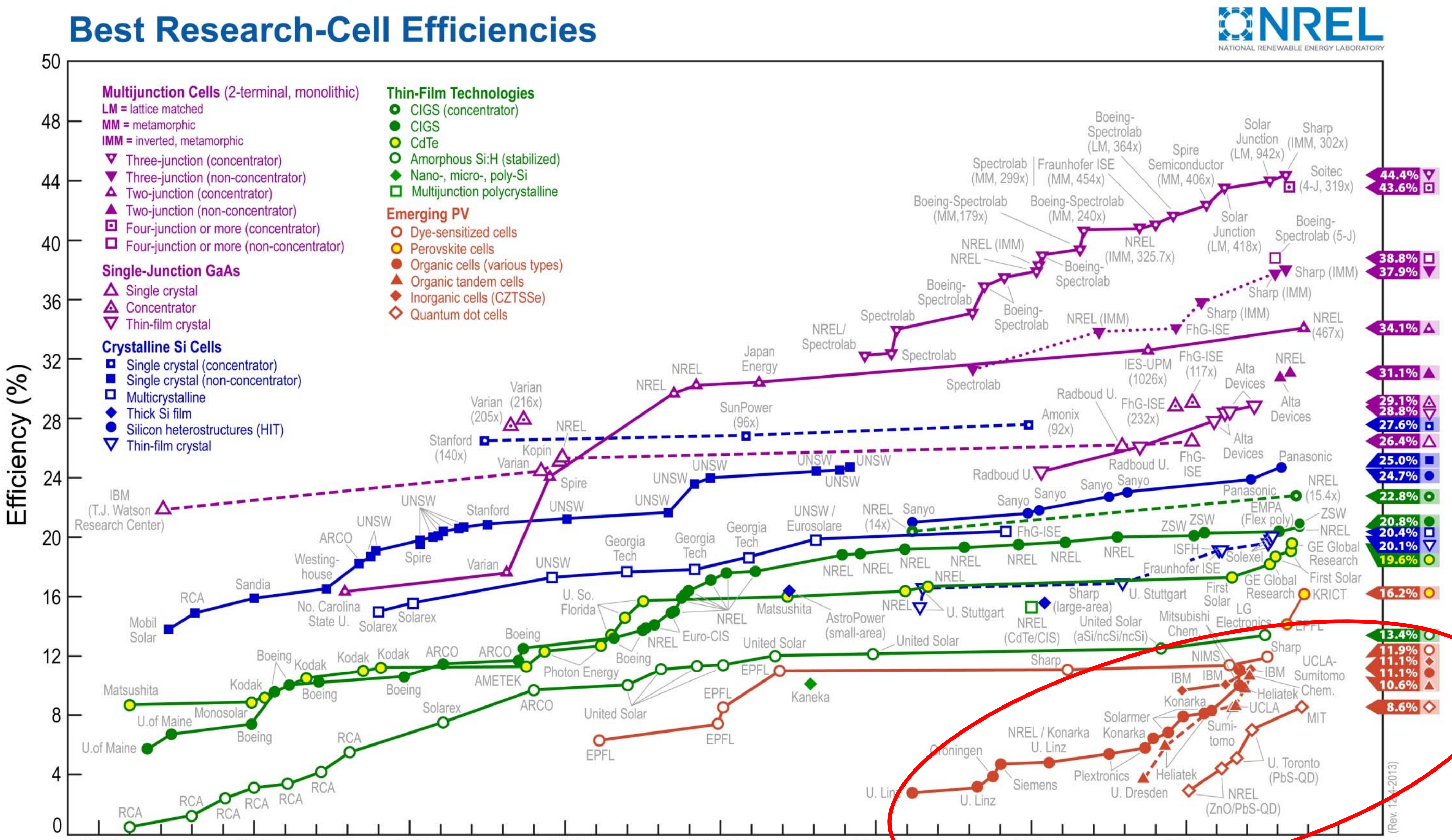
Future displays



Research Cell Efficiency Records (NREL rev. 2012. 2. 20)

http://www.nrel.gov/ncpv/

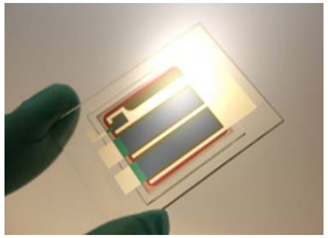
전자물리특강
EE 430.859
2014. 1st Semester



ea

Recent reports of OPVs and QD solar cells

Organic PVs

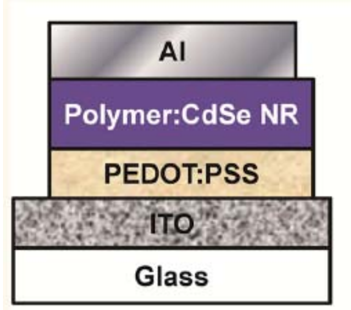


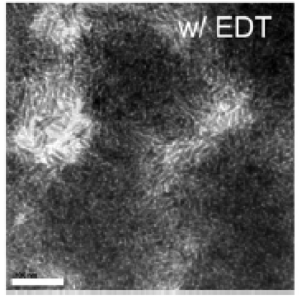
Heliatek
PCE=12.0%

Kolon
PCE=11.3%

Mitsubishi Chemical
PCE=11.1%

Organic-Inorganic Blend PVs

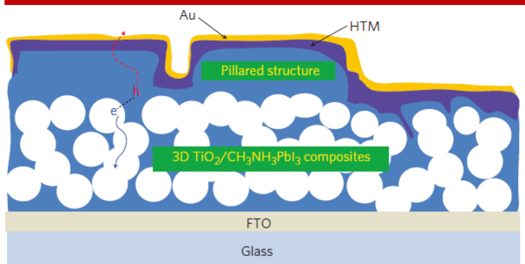


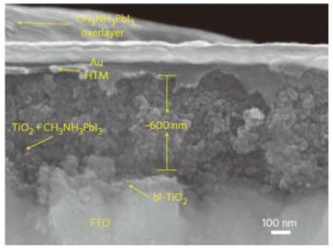


ACS Nano, online published (2013)

University of Florida (Jiangeng Xue)
PCE=4.7%, V_{OC}=0.74 V, J_{SC}=12.8 mA/cm^2, FF=0.50

QD-Sensitized Solar Cells

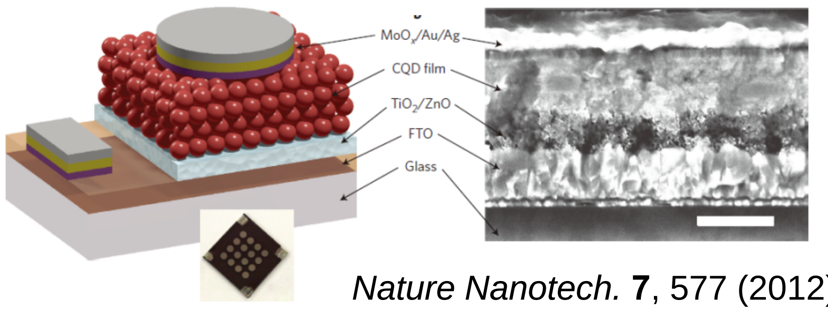




Nature Photon. online published (2013)

KRICT (Sang Il Seok) & EPFL (Michael Grätzel)
PCE=12%, V_{OC}=1.0 V, J_{SC}=16.5 mA/cm^2, FF=0.73

QD PVs

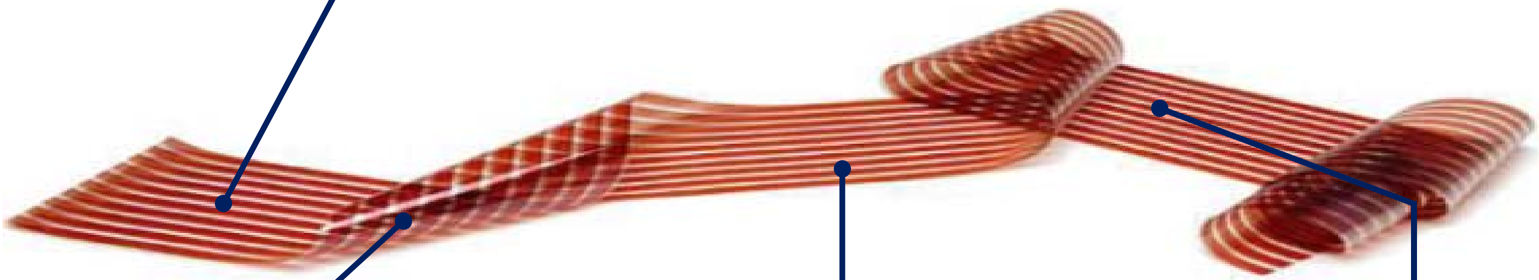


Nature Nanotech. **7**, 577 (2012)

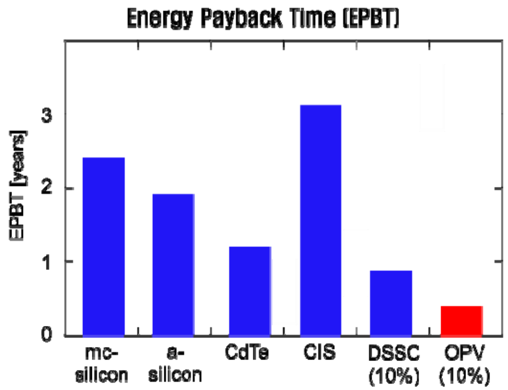
University of Toronto (Edward H. Sargent)
PCE=7.4%, V_{OC}=0.6 V, J_{SC}=21.8 mA/cm^2, FF=0.58

Advantage of organic solar cells

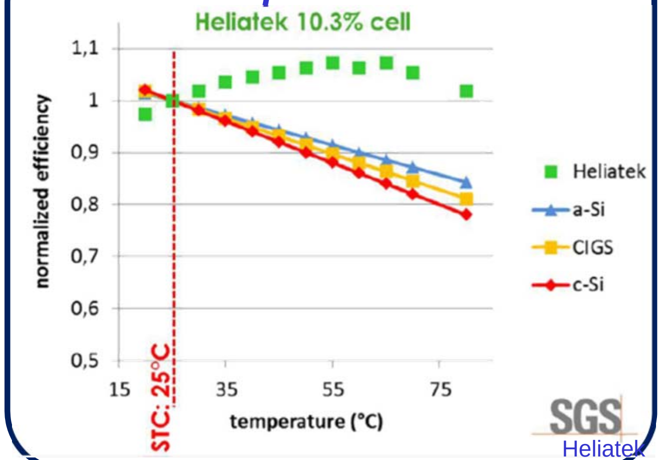
Flexible, Lightweight, Thin
Transparent, Color adjustable
Low material consumption
Compatible with large-area production technologies
…



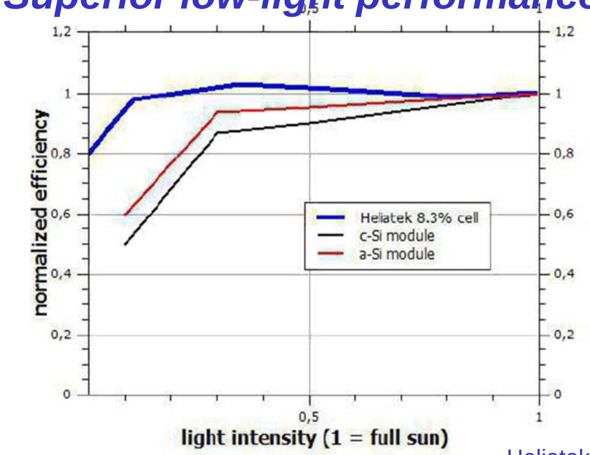
Low energy payback time



Positive temperature coefficient



Superior low-light performance



Applications of organic solar cells

Consumer

Off-Grid

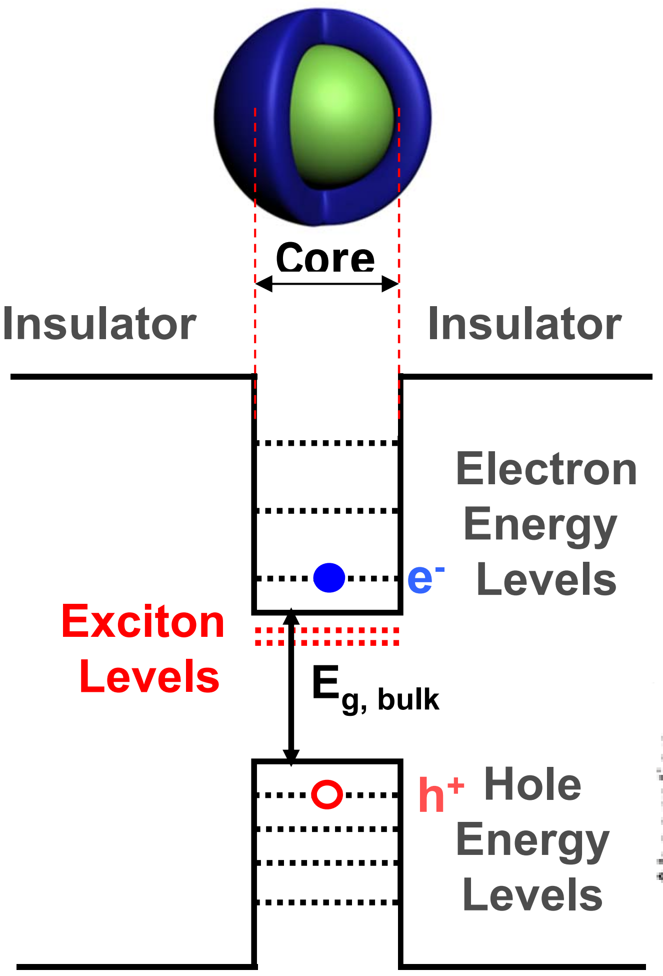
On-Grid

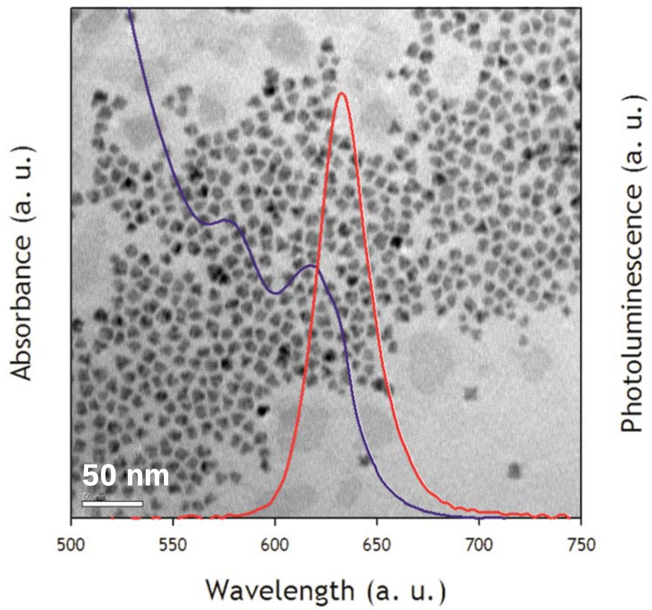
Current lifetime and performance allow to address consumer electronics and selected off-grid markets

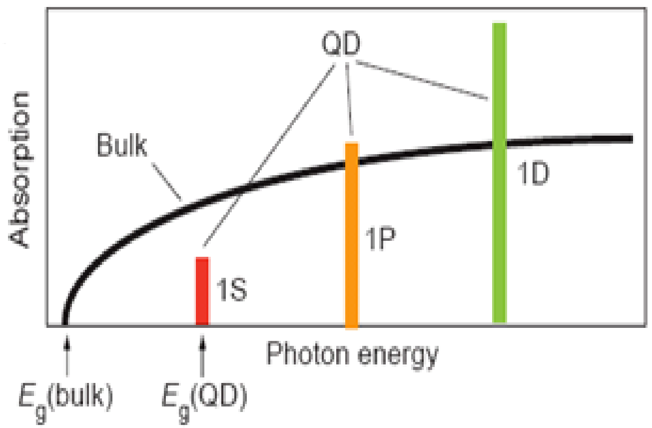
Introduction:

Quantum dots (QD)

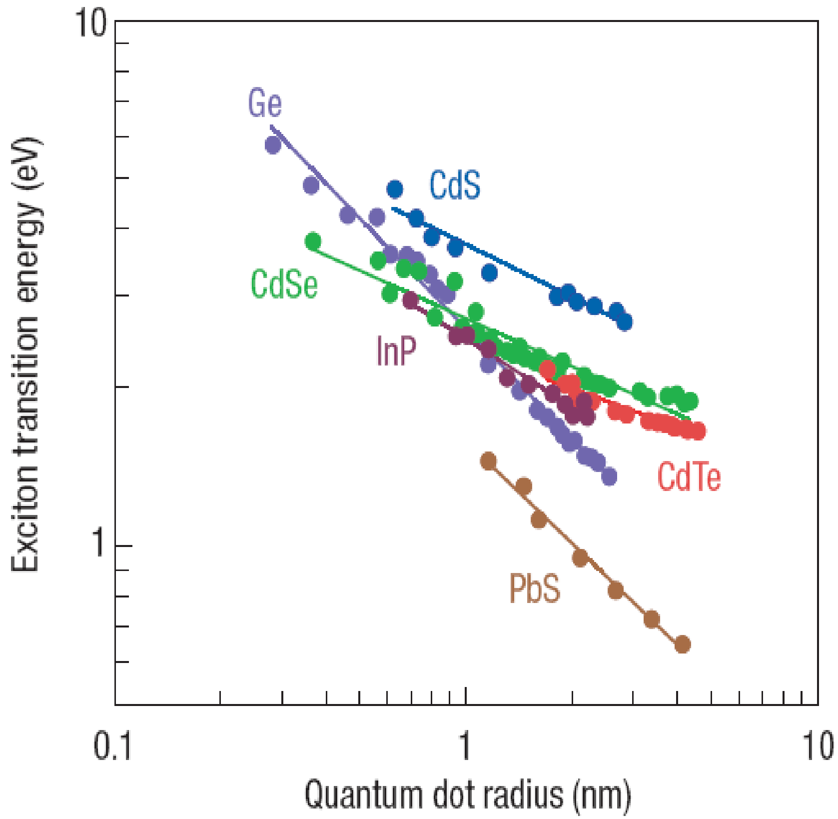
Quantum dot (QD) is a nanometer-scale semiconductor crystallite which confines the electron-hole pair (exciton) in all three dimensions.







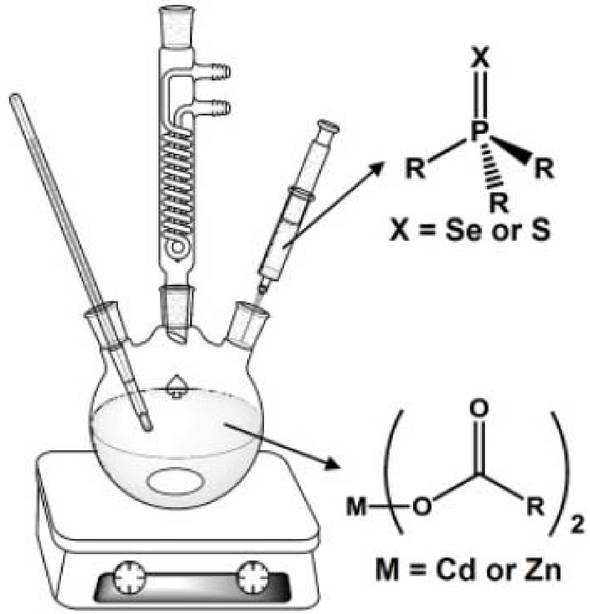
***Size matters**: In a material of a single chemical composition, fundamental properties of materials can be changed by the controlling the size of nanoclusters (QDs).*



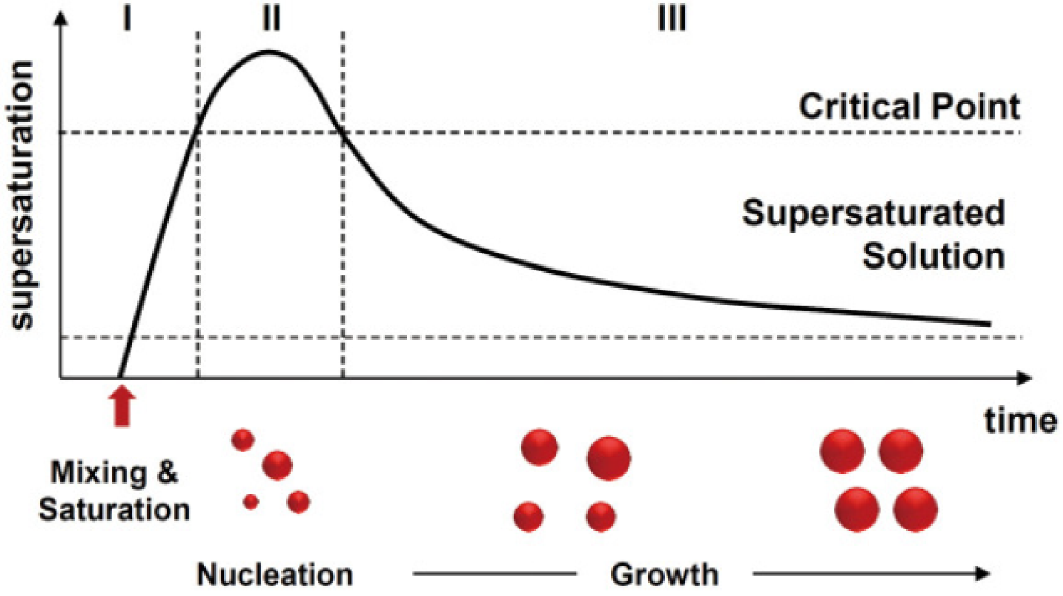
G. D. Scholes, G. Rumbles, Nat. Mater. **5**, 683 (2006)

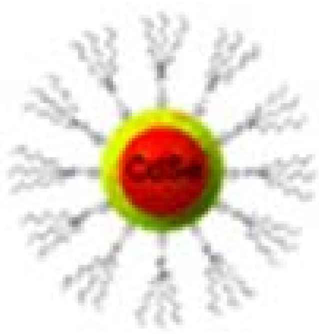
Colloidal Synthesis of QDs

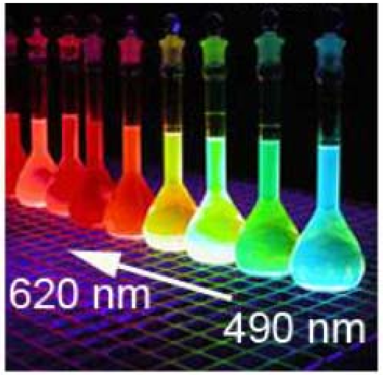
Schematic on conventional hot-injection method for group II-VI QDs)

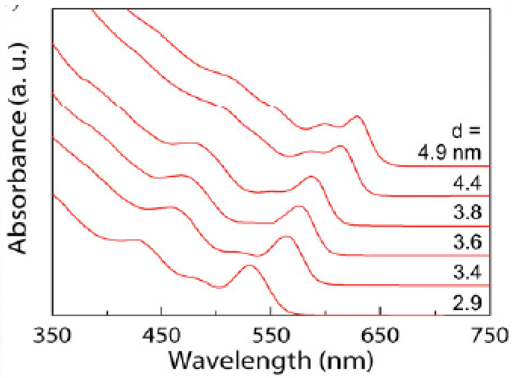


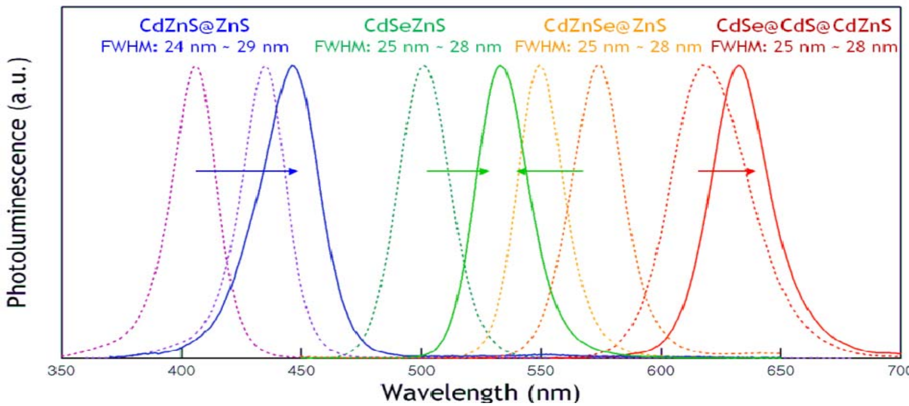
Temporal change in degree of supersaturation (The LaMer plot)







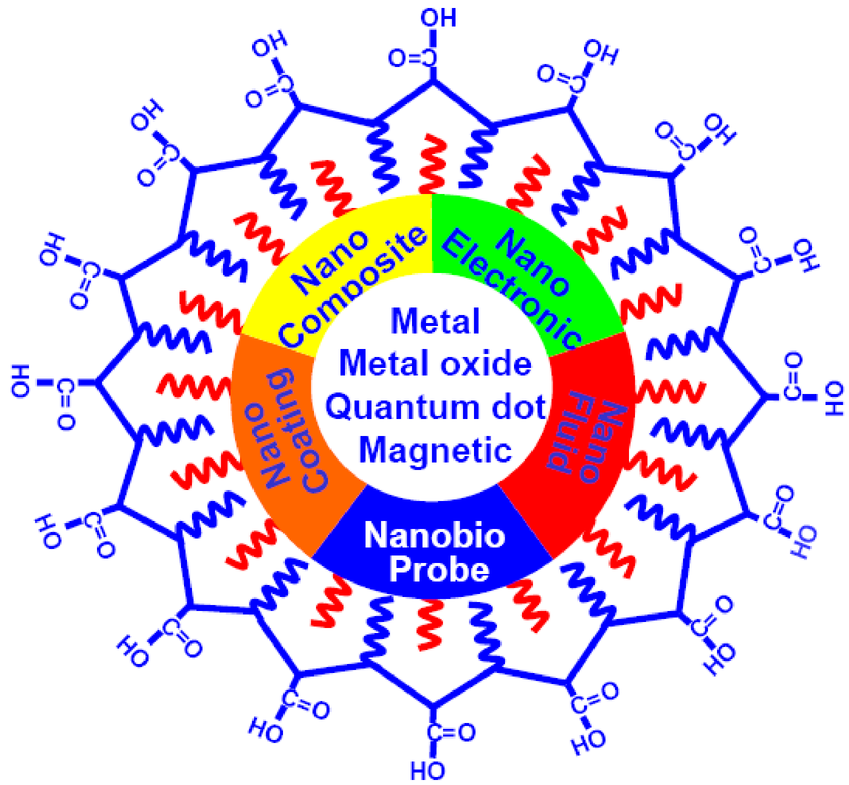


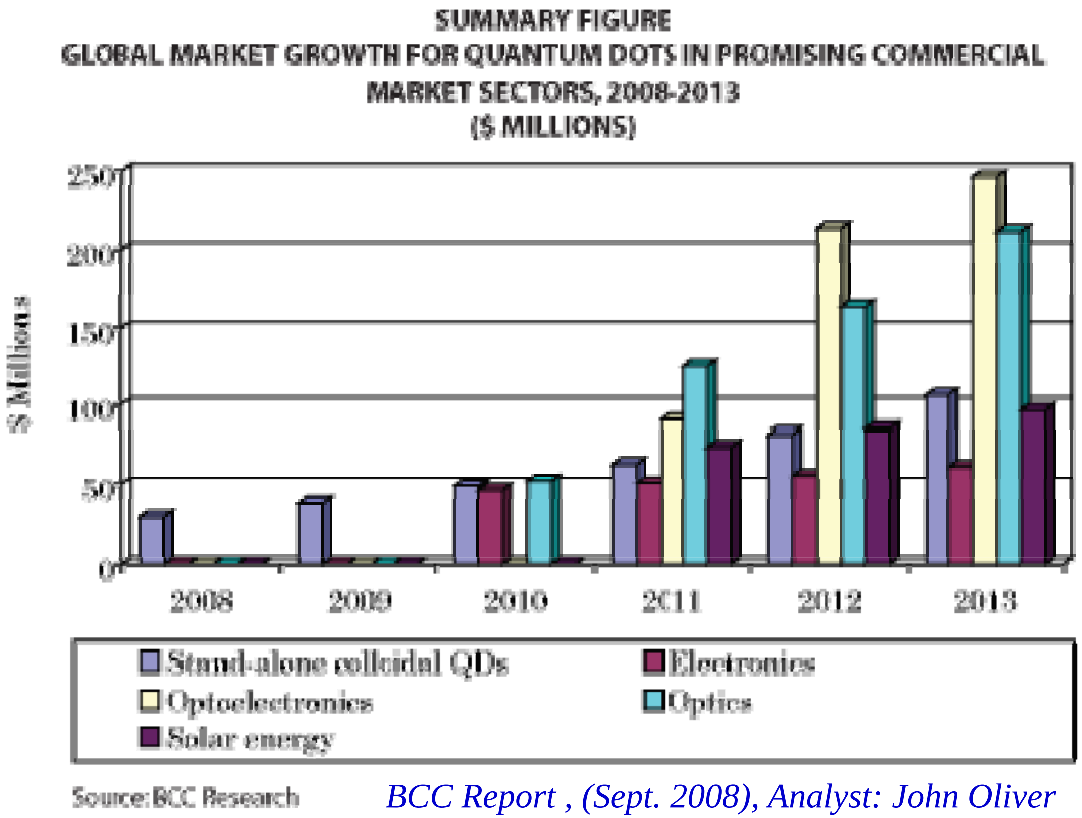


J. Lim, W. K. Bae, J. Kwak, S. Lee, C. Lee, K. Char, Optical Materials Express **2** (5), 594 (2012).

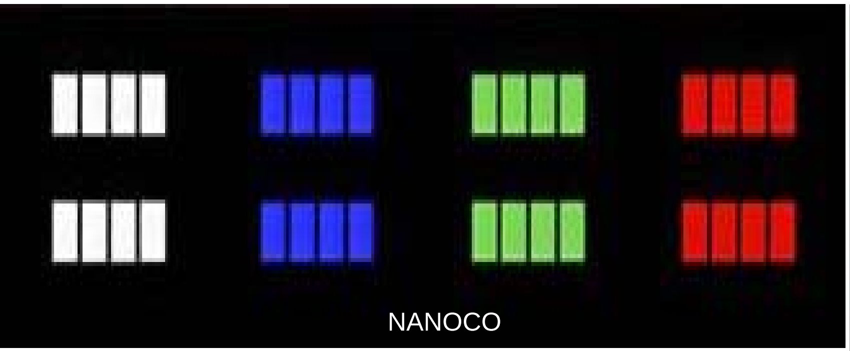
Application and market for QD technology

Application areas of QD technology

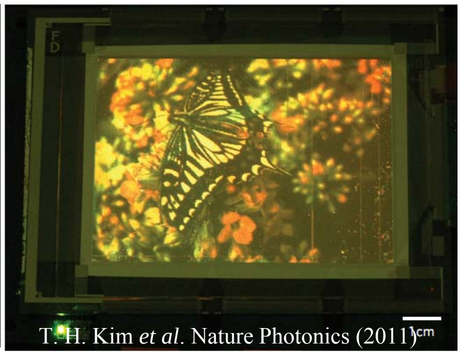




BCC Report , (Sept. 2008), Analyst: John Oliver
http://www.bccresearch.com/report/NAN027B.html

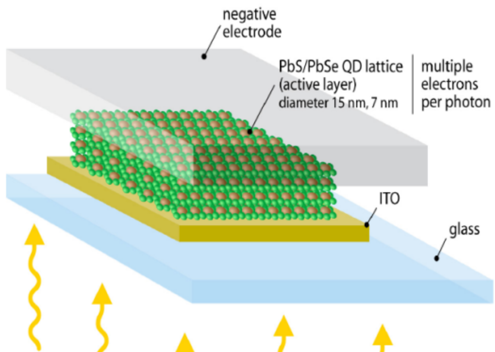


QD-LEDs and Lighting

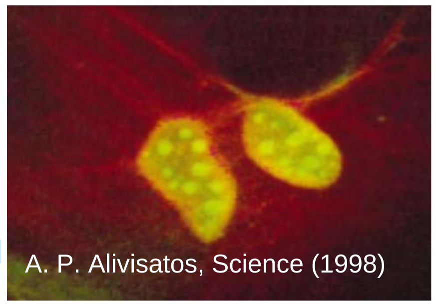


T. H. Kim *et al.* Nature Photonics (2011)

QD-LED Display



QD Solar Cells

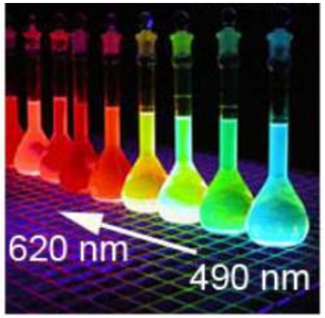


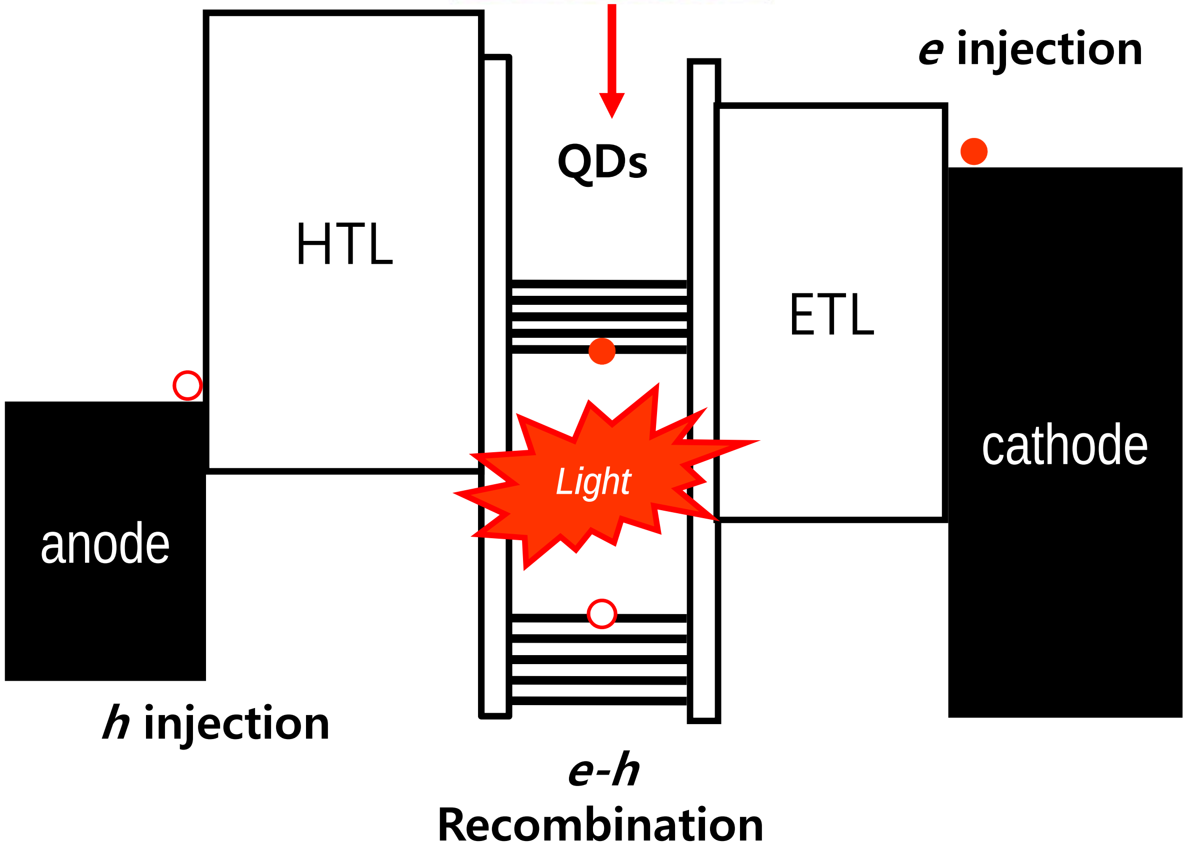
A. P. Alivisatos, Science (1998)

Bio-imaging

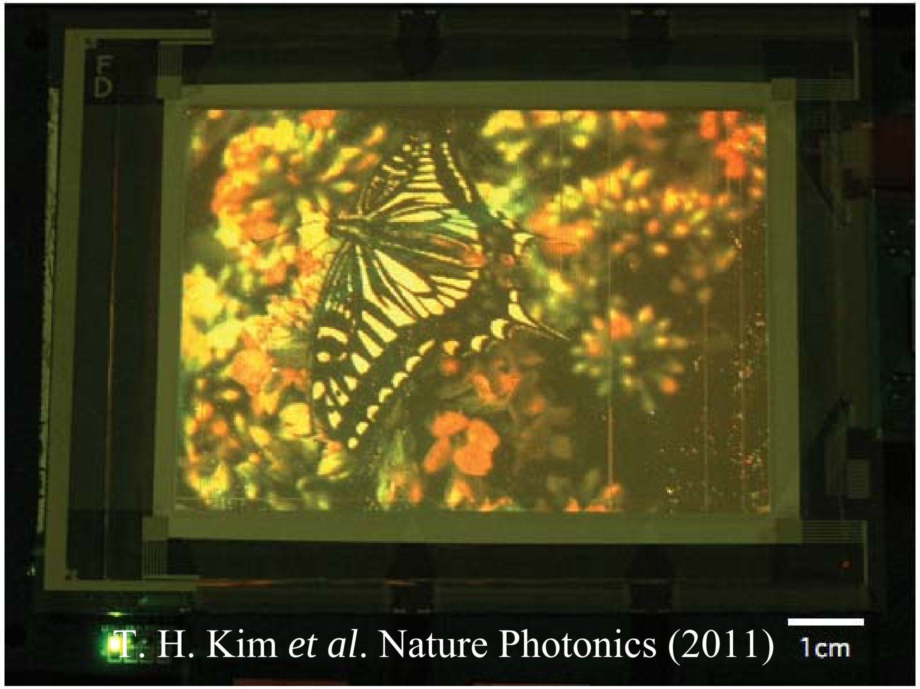
QLEDs: Operating Mechanisms and Advantages

QLEDs



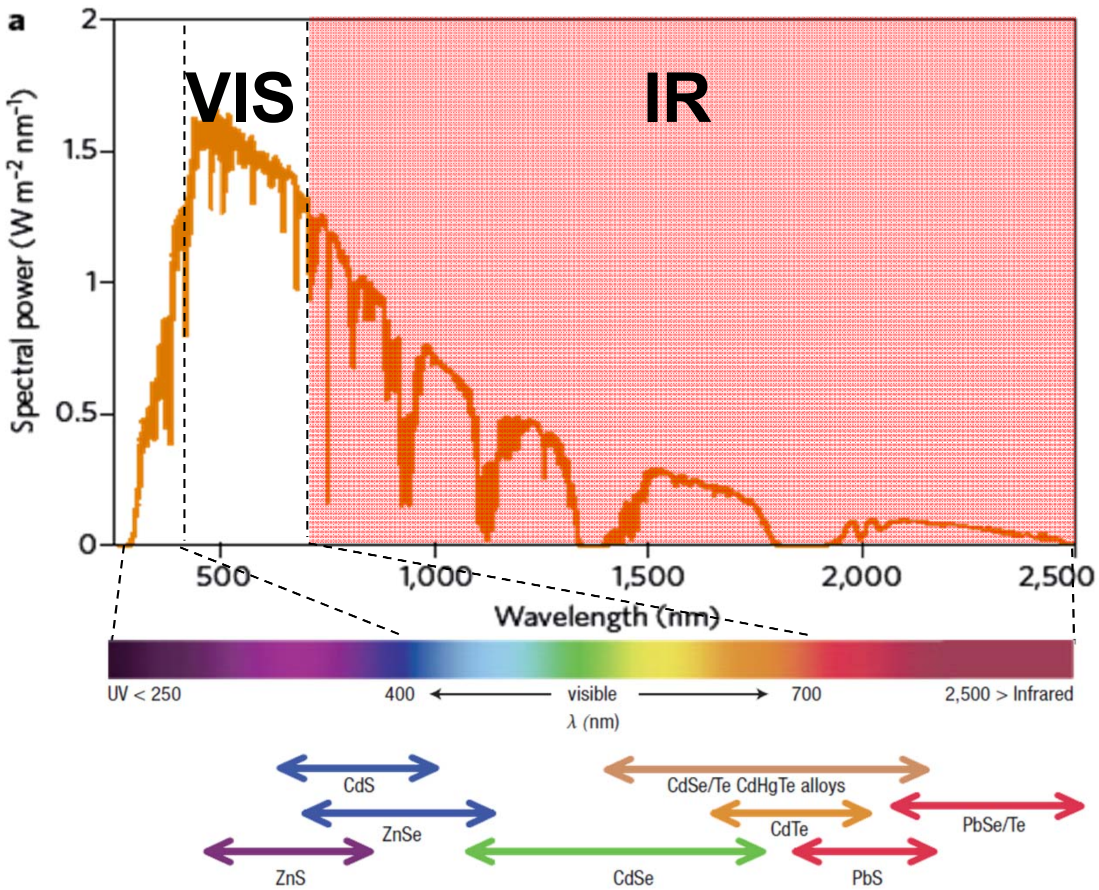


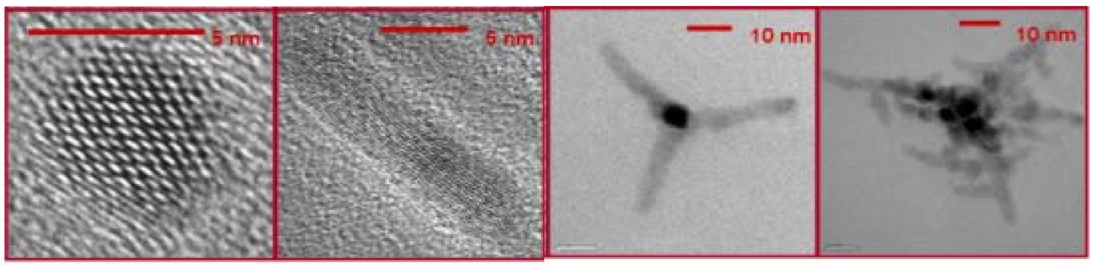
- Similar device architecture as OLEDs
- Size-tunable band-gaps (Color tunability)
- Narrow emission line widths (FWHM <30 nm)
- High PL quantum efficiency
- Good photostability
- Compatibility with solution processes



T. H. Kim *et al*. Nature Photonics (2011)

Semiconductor NCs for solar cells





- **Band gap & band position tunability**
  - ✓ 1.1 eV < E_g < 3 eV
  - ✓ dot, rods, tetrapods, dendritic shape

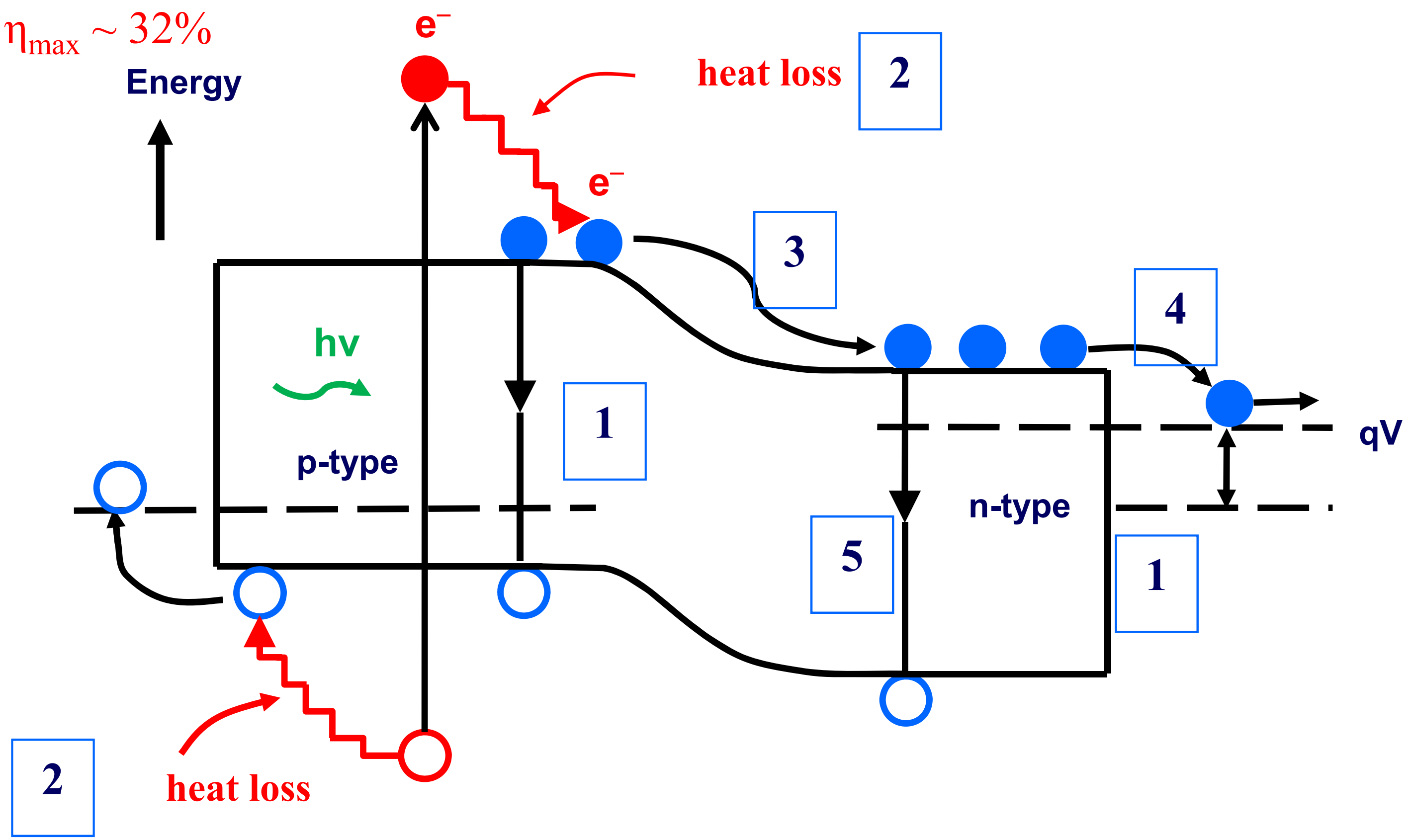
  → ***Wide Absorption Range (VIS ~ IR)***
- **Solution process capability**
  - ✓ Assembly into superlattices
  - ✓ Spin, dip, drop casting

  → ***Large area with cheap price***
- **Multiple exction generation**

  → ***1 photon to multiple excitons***

Loss processes in a standard solar cell

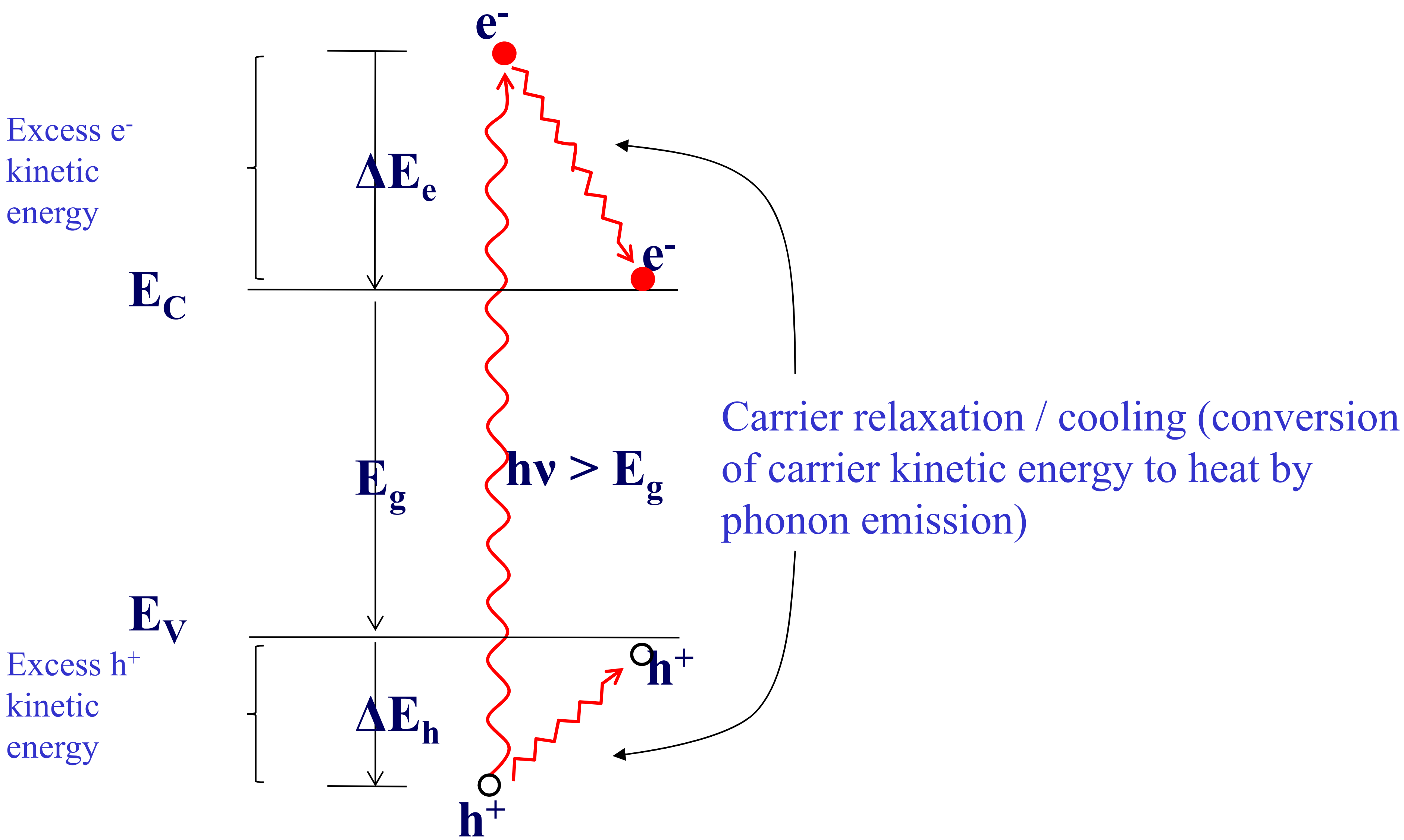
S-Q Limit: $\eta_{max} \sim 32\%$



1	No absorption below bandgap photons
2	Lattice thermalization loss
3	Junction voltage losses
4	contact voltage losses
5	recombination loss

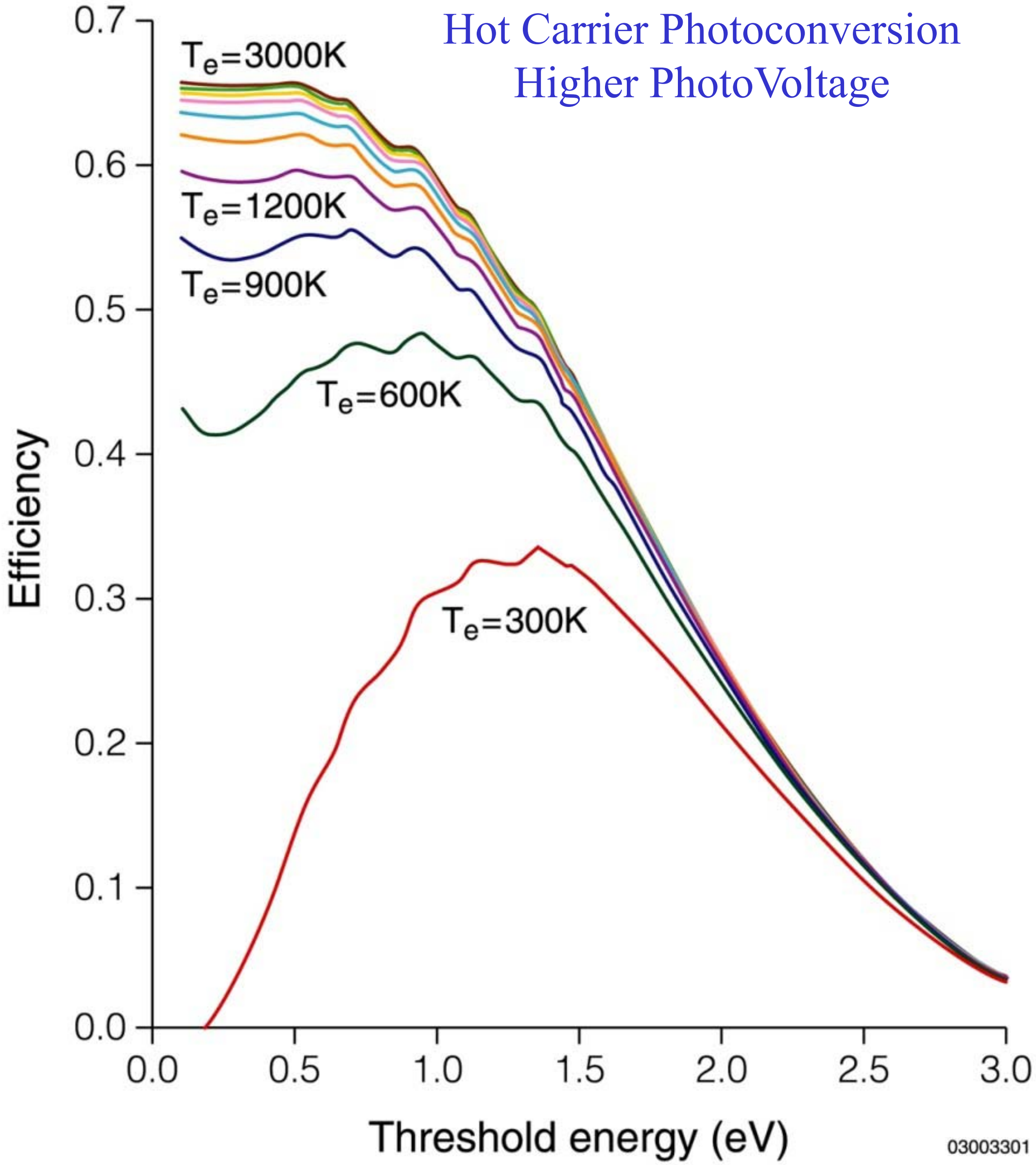
Hot carrier relaxation

Hot electron relaxation: Main process limiting conversion efficiency >50% loss)



Two ways to utilize photogenerated hot electron

Hot Carrier Photoconversion
Higher PhotoVoltage



Ross & Nozik, J. Appl. Phys. **53**, 3813 (1982)

Impact Ionization in QDs
(Higher Photocurrent)

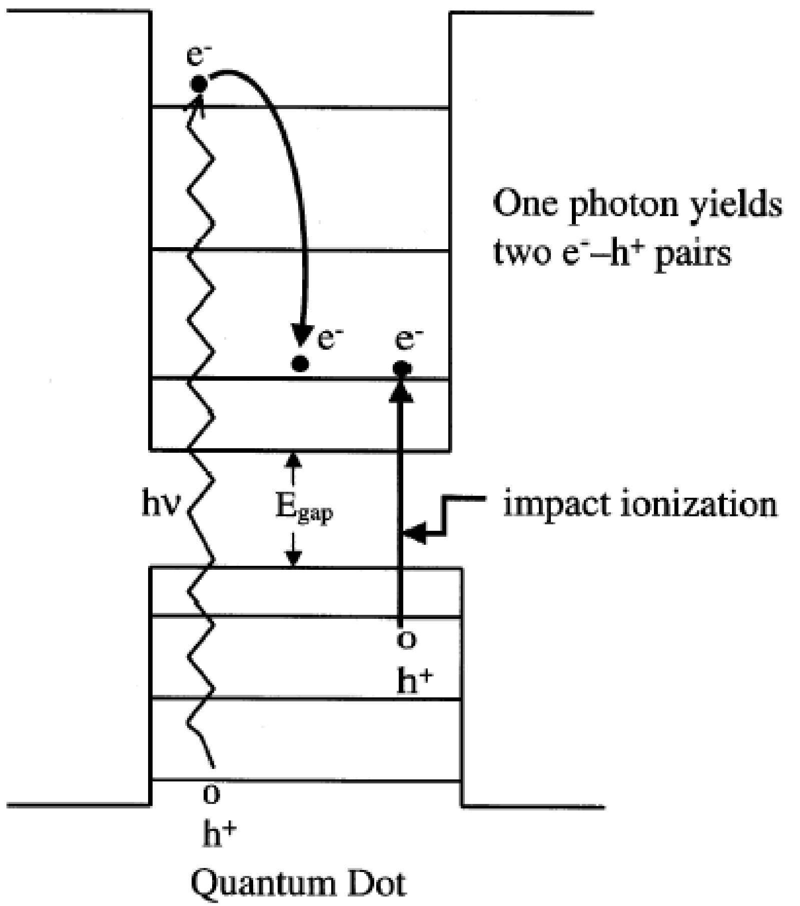
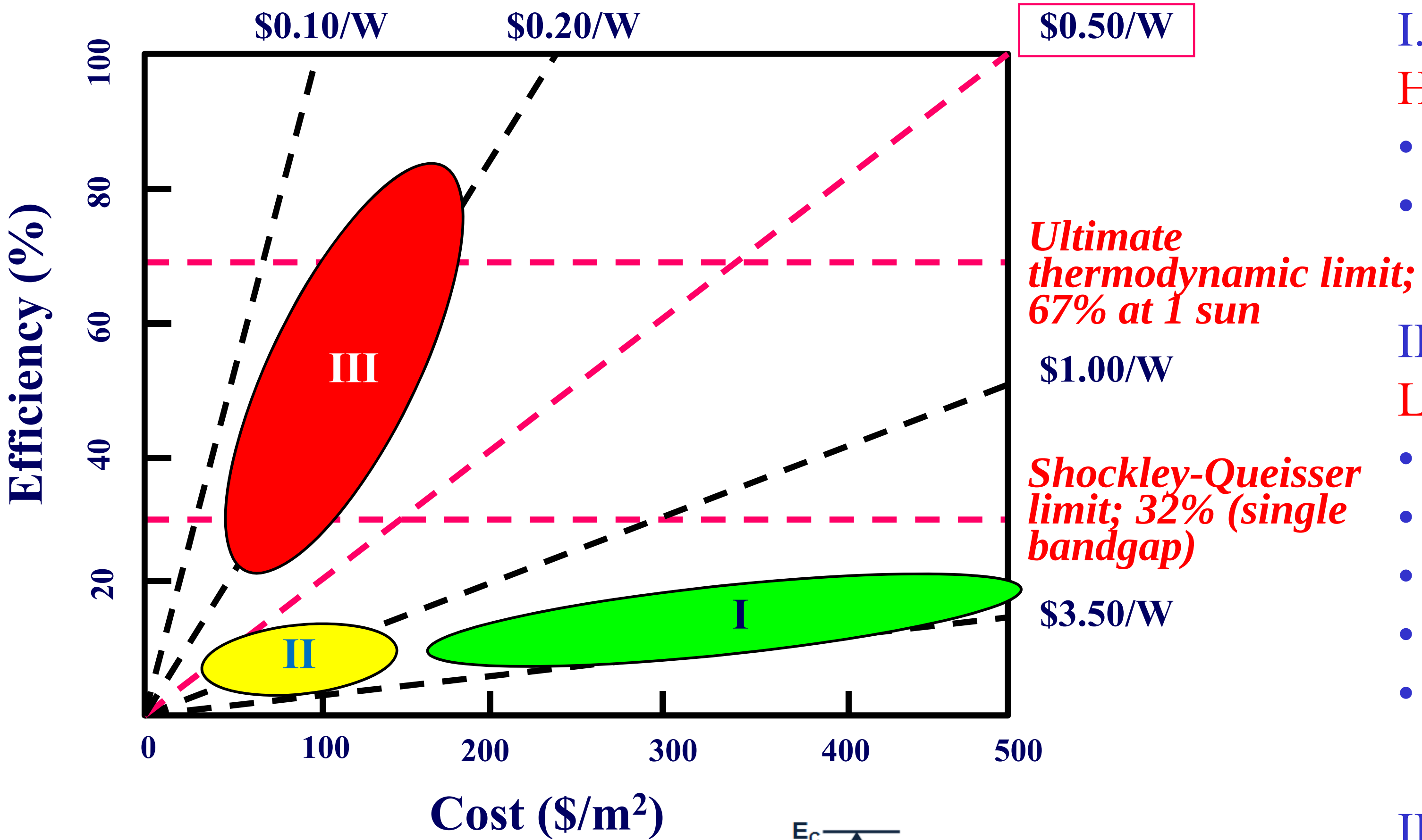


Fig. 1. Enhanced photovoltaic efficiency in QD solar cells by impact ionization (inverse Auger effect).

A. J. Nozik, Physica E 14 (2002), 115-120

Efficiency-cost curve of solar cells



I. 1st Generation:

High efficiency but high cost

- Single crystal Si, 24.7%
- Polycrystalline Si, 20.3%

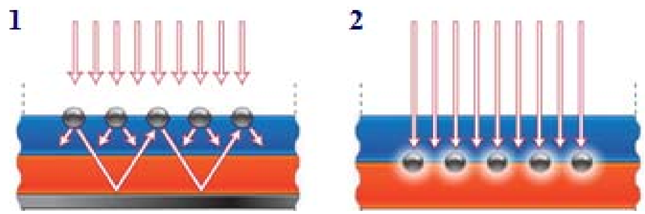
II. 2nd Generation:

Low cost but low efficiency

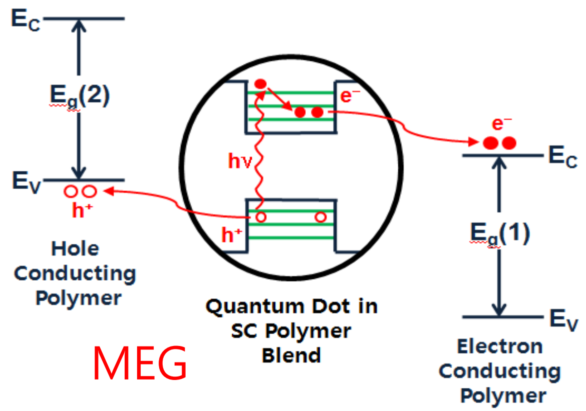
- Amorphous Si, 11.7%
- CuInSe2, 19.9%
- CdTe, 16.5%
- DSSC, 11.1%
- OPV, 8.3% (small cell)

III. 3rd Generation:

High efficiency (h>Q-S limit) & low cost (<$0.50/W)



Plasmonics: Enhance light absorption



MEG

Summary

Bright future for organic semiconductors and QDs:

- Displays: AMOLEDs, QD-LEDs
- Large area smart lighting
- Solar cells
- Photodetectors
- etc.