Organic Electronics: A Story of Science and Technology

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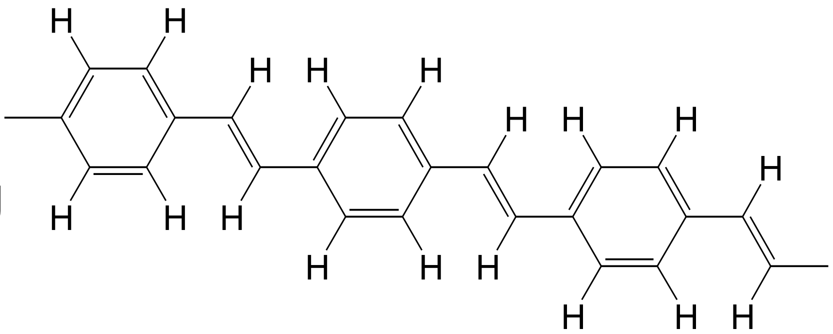
Cambridge Society for the Application of Research 13 May 2013

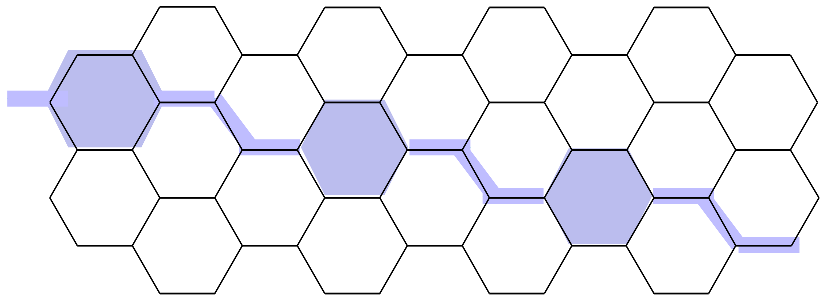
PPV: the prototypical semiconducting polymer:



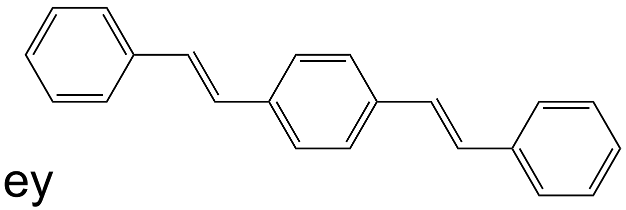
Delocalised π-electrons provide both conduction and valence bands

length scales for electronic wavefunctions?

π electrons – delocalized, as in graphene?

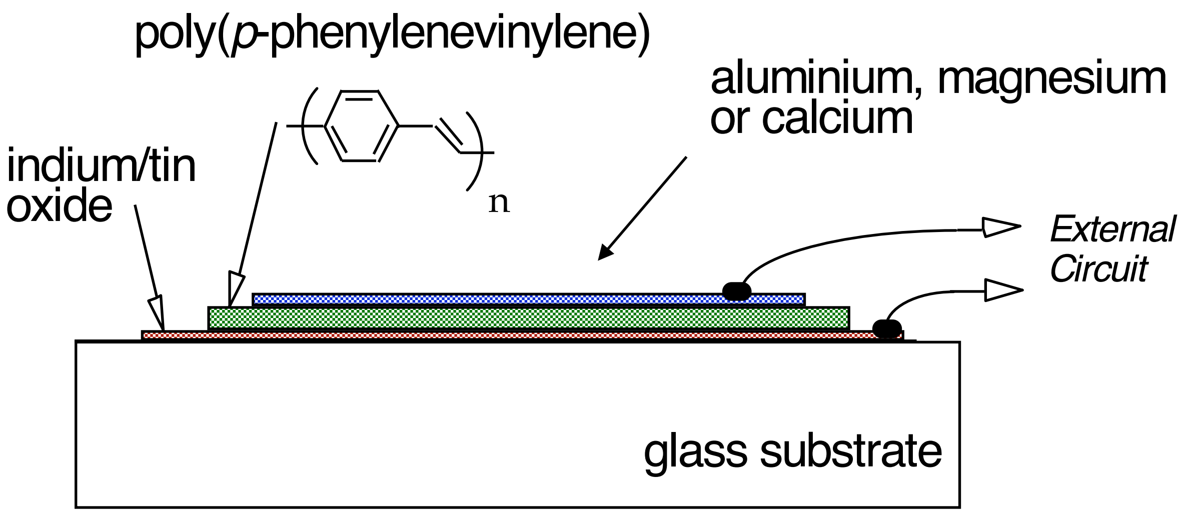


π electrons – localized, as in distyrylbenzene?



LEDs: Jeremy Burroughes, Donal Bradley et al. Nature, **347**, 539 (1990)

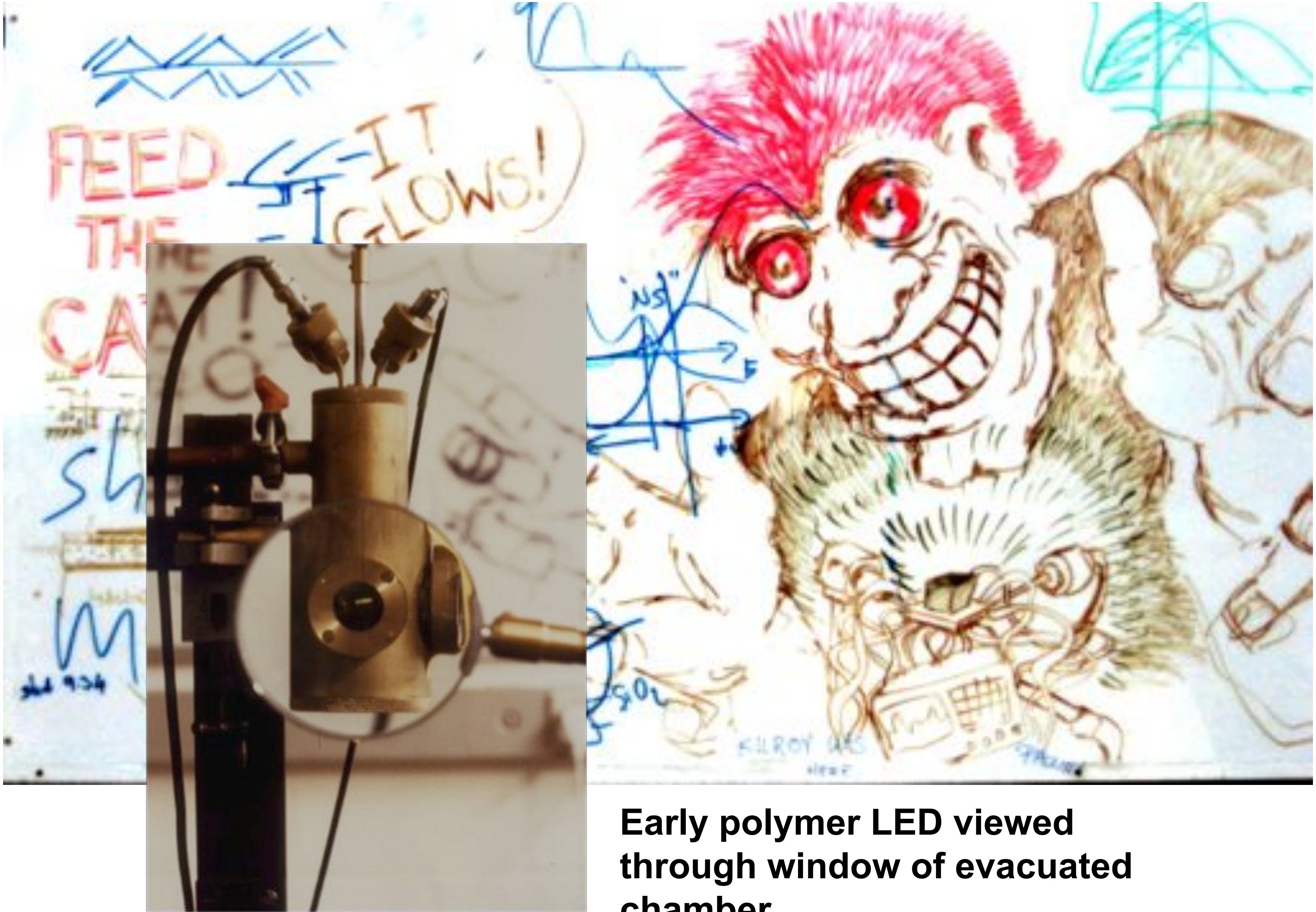
Polymer Light-Emitting Diodes



Jeremy Burroughes, Donal Bradley et al.

Nature, **347**, 539 (1990), US patent 5,247,190

1992 - foundation of Cambridge Display Technology, CDT



Early polymer LED viewed through window of evacuated chamber….

OLED technology

Engineering: chemical synthesis

[Merck – formerly Covion, formerly Hoechst]

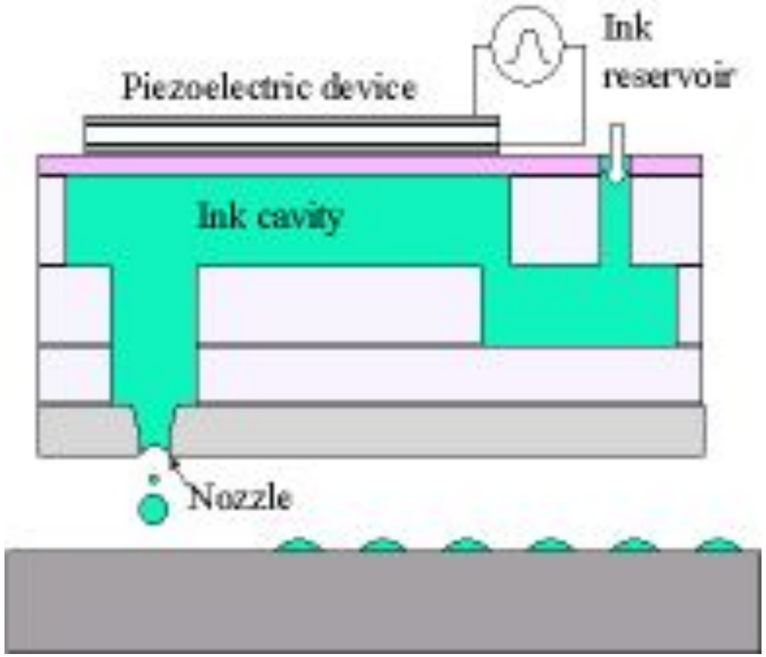
[CDT partnership with/acquisition by Sumitomo Chemical Company]

‘semiconductor’ purity levels achieved,
detailed chemical modifications made to improve efficiency and lifetime.

LED lifetimes: 1990 - few minutes
1996 - 1000 hours
2010 > 100,000 hours (projected)

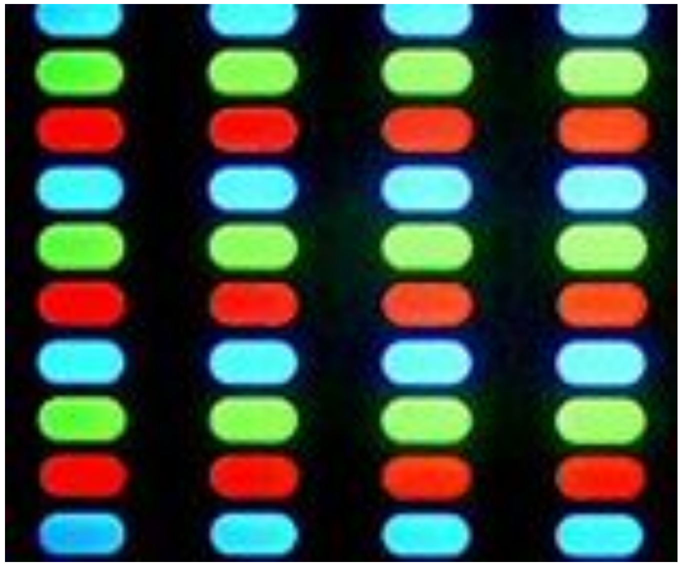
How to pattern the red, green and blue pixels: direct printing

Inkjet Deposition Process:



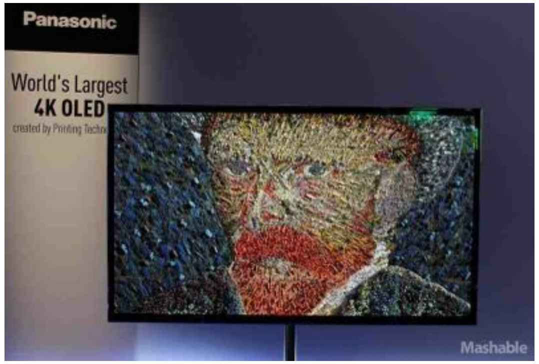
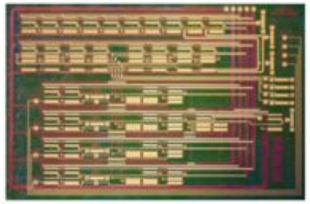
Direct patterning deposition
Non-contact printing
Minimum material

- Polymer deposition by ink-jet printing



Printed Polymer in Bank Holes

Organic electronics – Status

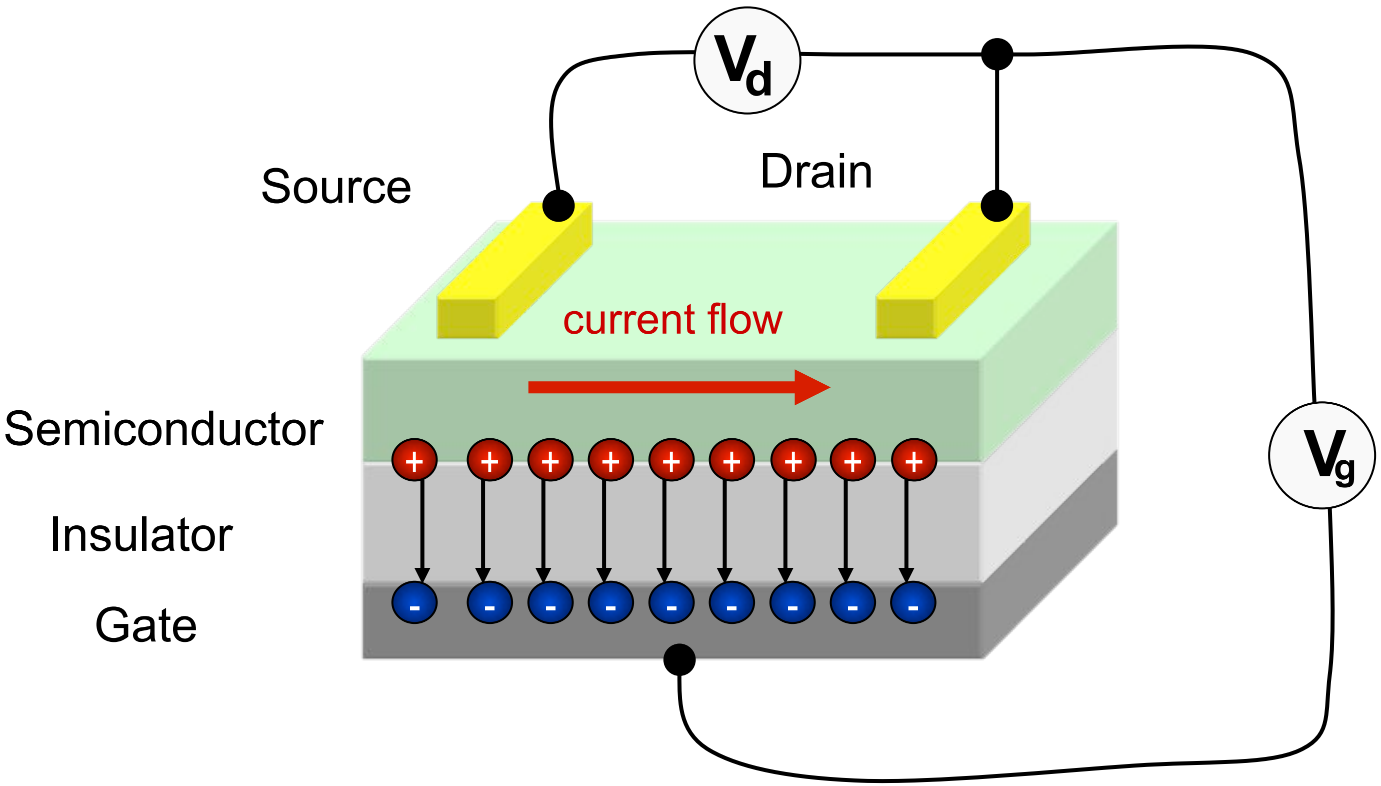
	Existing markets	Emerging applications Advanced prototypes	Next generation applications Demonstrators, but technology challenges
OLED	Phones (45M units in 2010) MP3, camera  	 Panasonic 56 inch printed OLED	 Lighting, wall-side TV
OTFT	-	 Paper-like flexible displays Source: Plastic Logic	 All-polymer & next gen. displays; RFID circuits sensors Source: PolyIC
OPV Solar Cells		 Mobile Power; building Integrated PV	

Panasonic Develops 56-inch 4k2k OLED Panel

Osaka, Japan - Panasonic Corporation has developed a 56-inch organic light-emitting diode (OLED) panel with 4k2k resolution (3,840 x 2,160 resolution, 8.29 million pixels), the world's largest OLED panel produced through the “RGB all-printing method.”[1] Prototype panels will be exhibited at the 2013 International CES in Las Vegas, Nevada, from January 8 to 11, 2013.

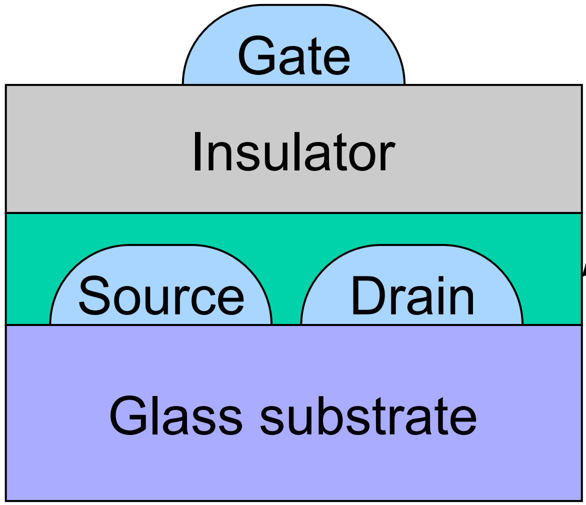
In the printing method of production of OLED panels, OLED materials are applied to the substrate through a printing technique to form an electroluminescent (EL) layer. Due to the simplicity of the production process, it is expected that the technology will be easily adaptable to the production of OLED panels in a variety of screen sizes. Through the printing method, it is also possible to apply just the right amount of organic material to where it is needed, reducing waste material and shortening production lead time, making the printing method of production more economical.

Field-Effect Transistor

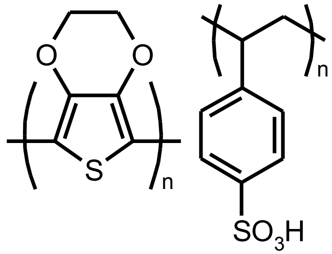


Inkjet-Printed All-Polymer Transistors

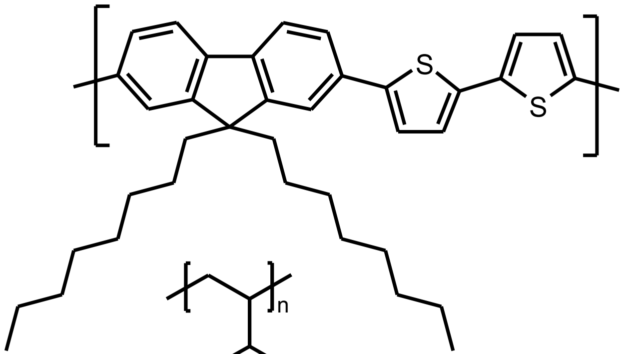
Structure of Device:



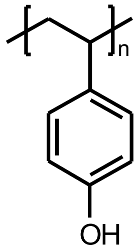
Source, drain and gate
Inkjet Printing
PEDOT:PSS



Semiconductor
Spin coating
F8T2

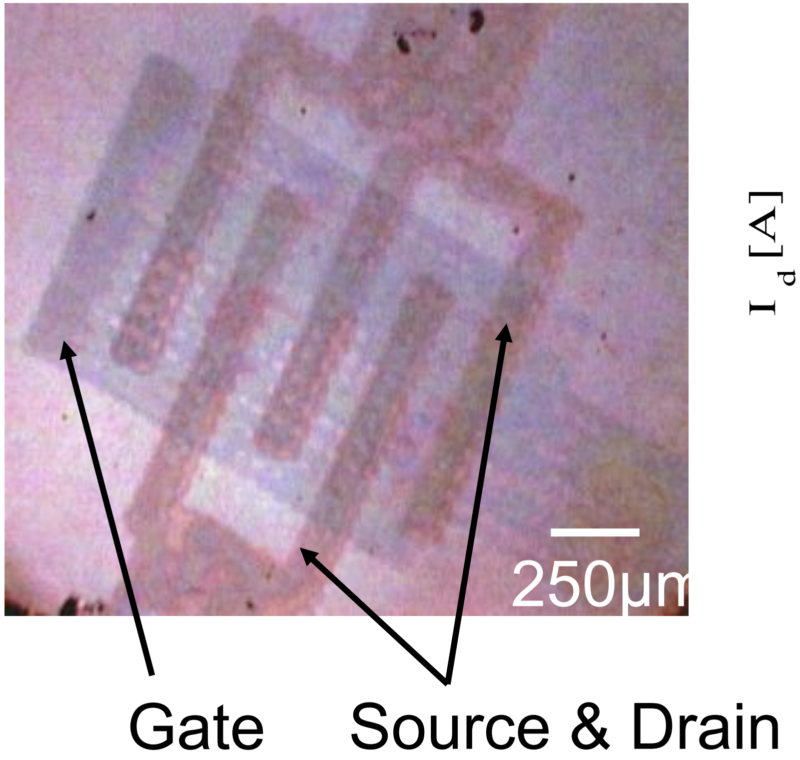


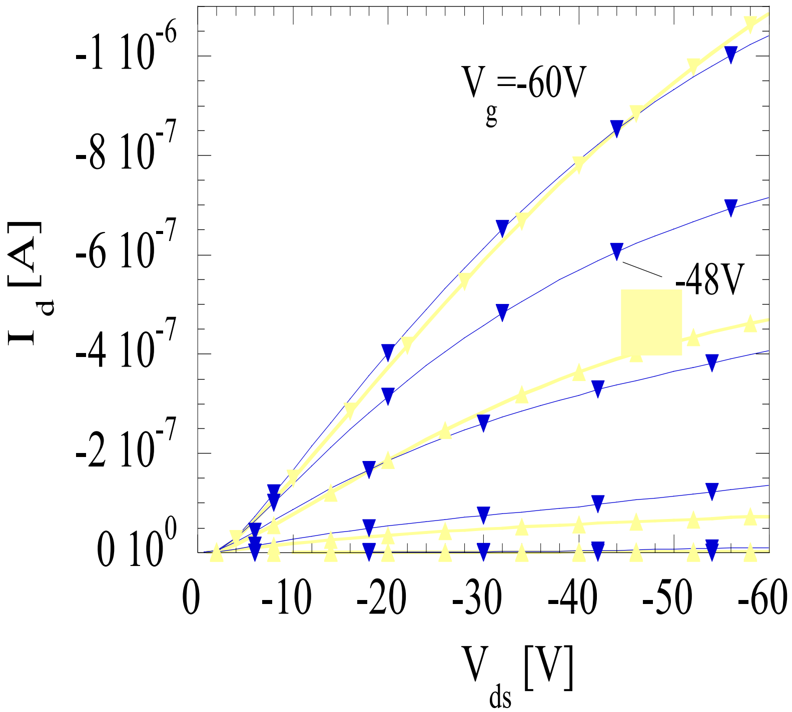
Insulator
Spin coating
PVP



Sirringhaus, Kawase et al. Science **290**, 2123 (2000)

The First Inkjet Printed TFT

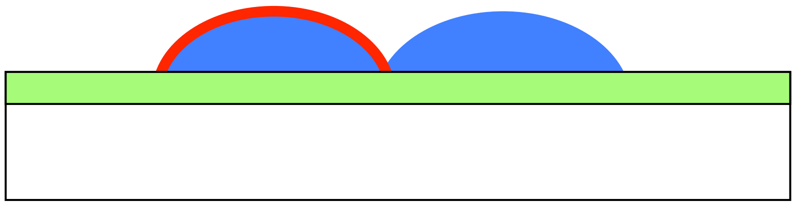




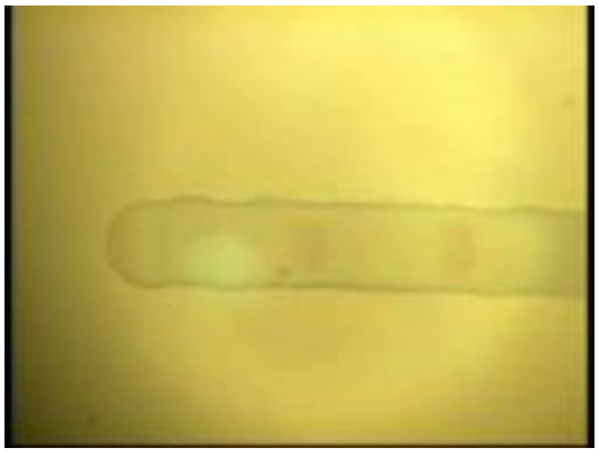
L=200µm, W=2mm

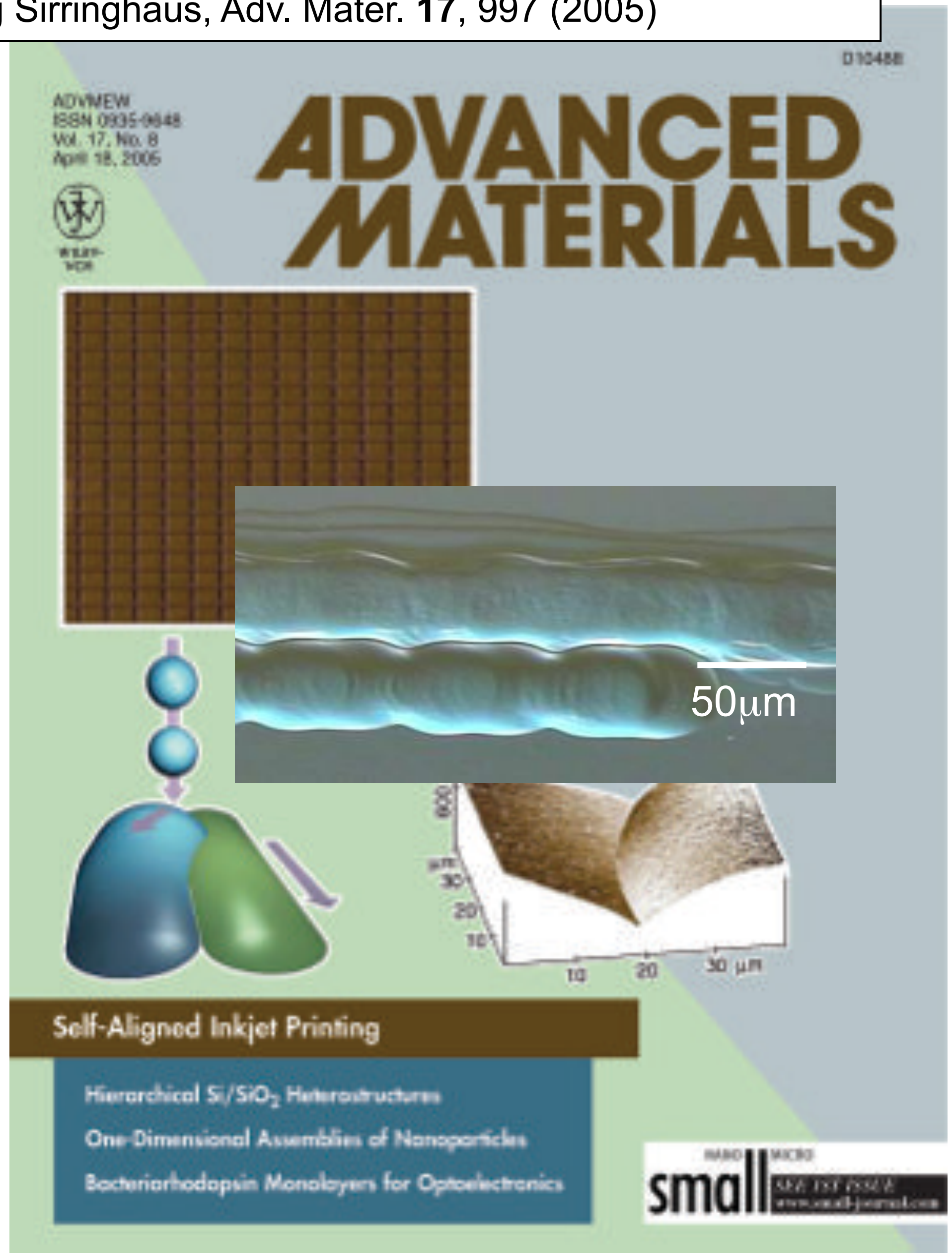
Christoph Sele, Timothy von Werne, Henning Sirringhaus, Adv. Mater. **17**, 997 (2005)

Self-aligned printing



remove requirement for pre-patterning:





Active-matrix backplane for e-ink electrophoretic display

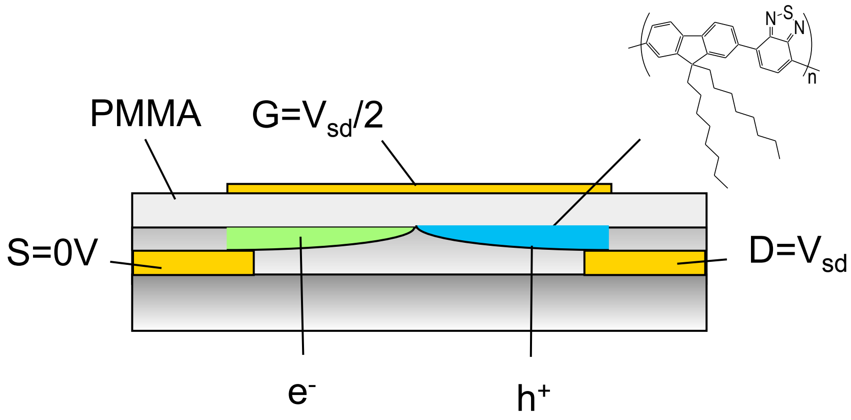
•multi-level patterning without mask alignment (needed for photolithography)

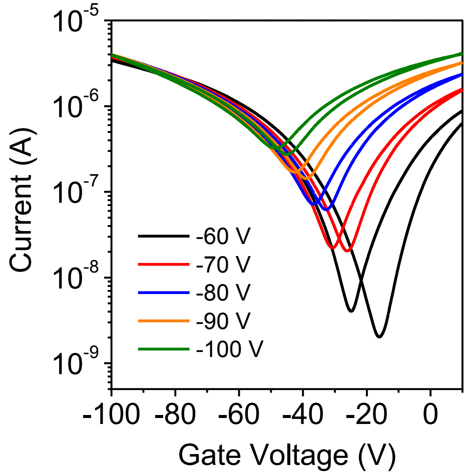
•active, real-time distortion correction for shape changes to substrate (PET film)

CES Las Vegas January 2013

Plastic Logic colour e-paper display

Ambipolar, light-emitting organic field-effect transistors





Zaumseil, et al., Nature Mat. 5, 69 (2006)

Organic Solar Cells?

π-conjugated molecules used in nature for photosynthesis, but:

- green plants construct a very complex multiple 'heterojunction' structure to separate electron and hole

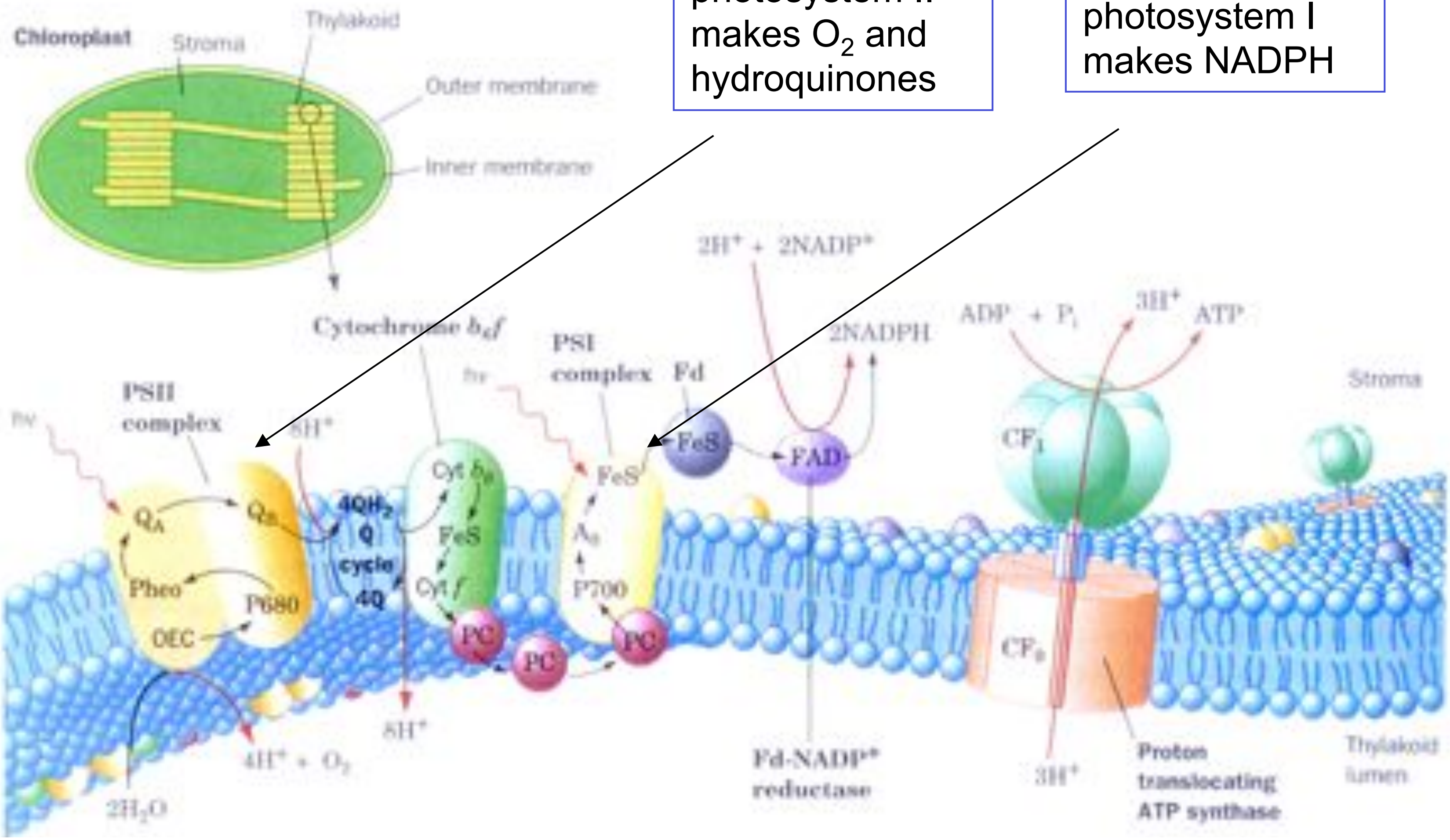
Current research and development:

- 'crude' single heterojunction devices work much better than they should….

Green plant photosynthesis:

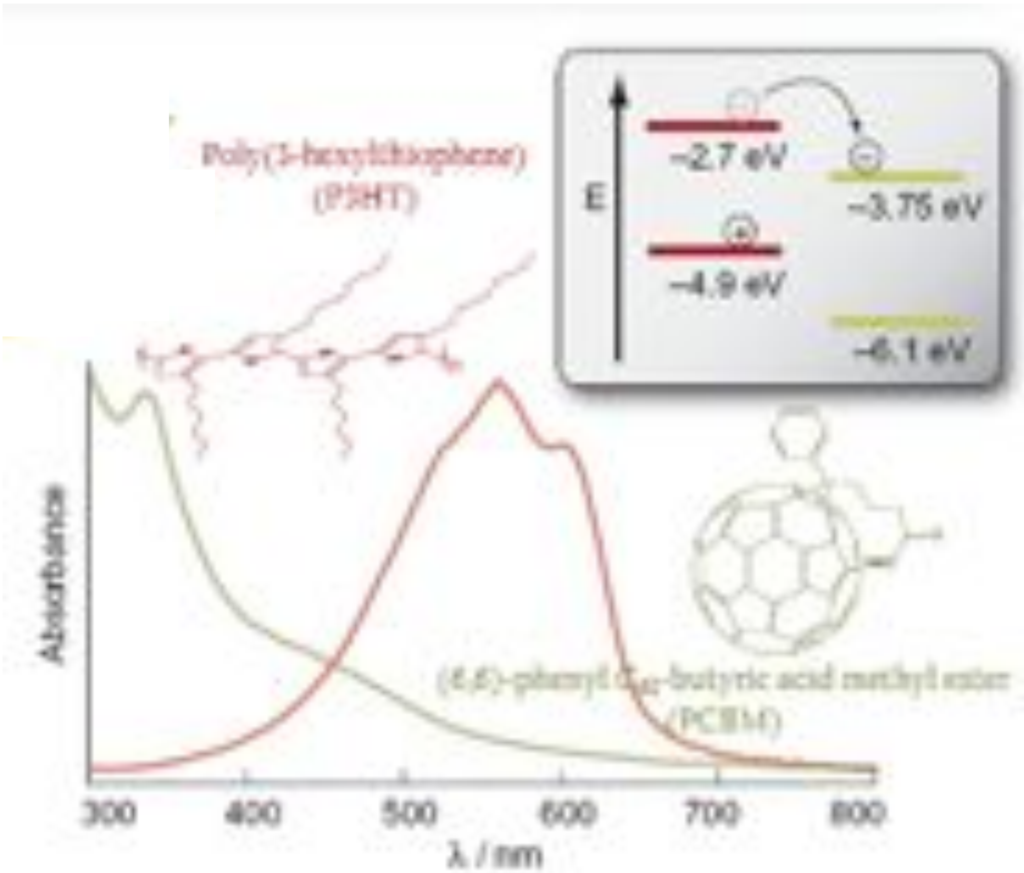
photosystem II makes O_2 and hydroquinones

photosystem I makes NADPH



Organic solar cells: simple recipe!

mix the two semiconductors together so that there is a lot of interface between electron donor and acceptor

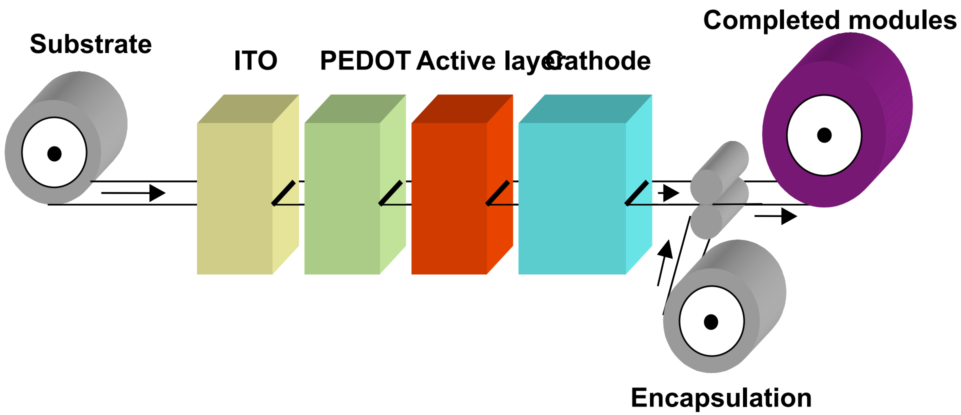


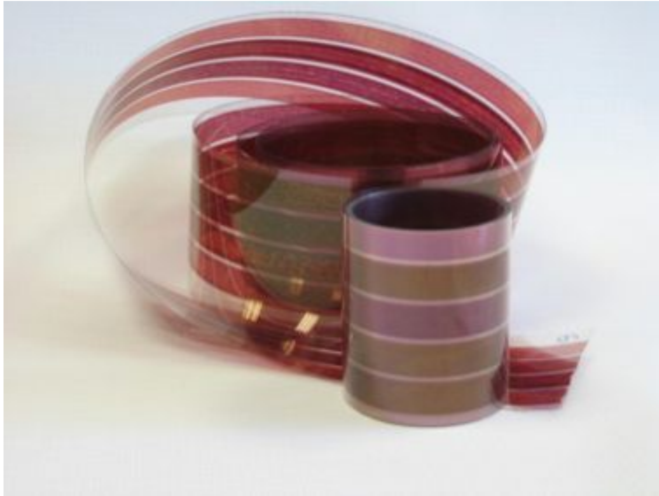
Poly(3-hexyl thiophene) – hole acceptor

Fullerene – electron acceptor

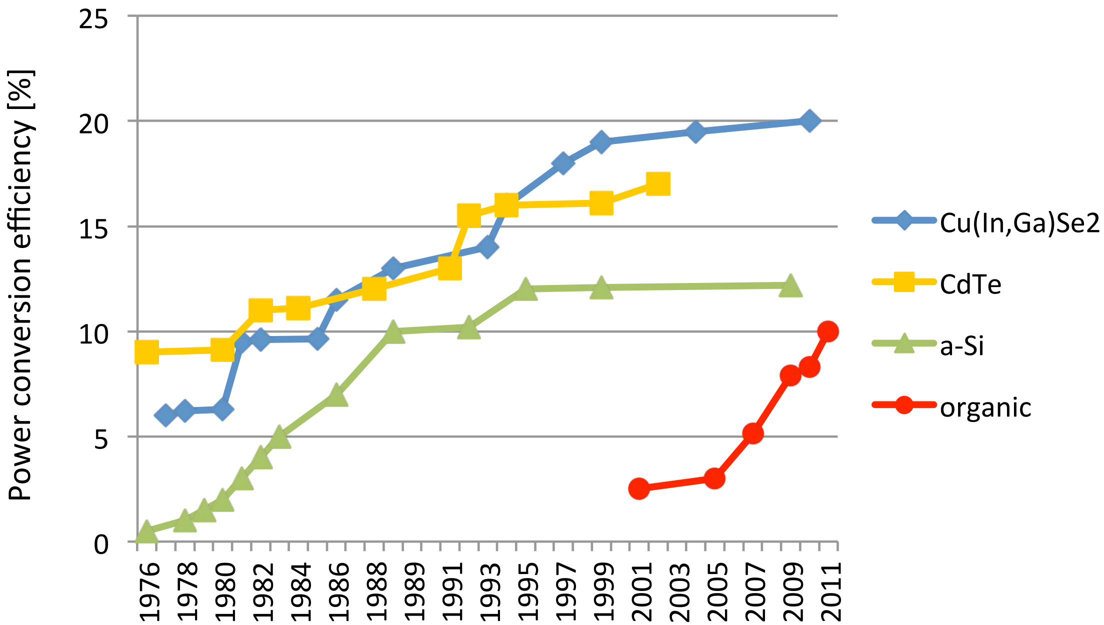
Solar energy conversion efficiencies now up to 10% with red-shifted polymers (2012)

roll-to-roll solar cells:





Manufacture of organic PV modules made on a flexible substrate using roll-to-roll methods

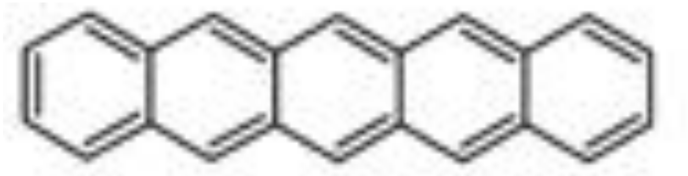


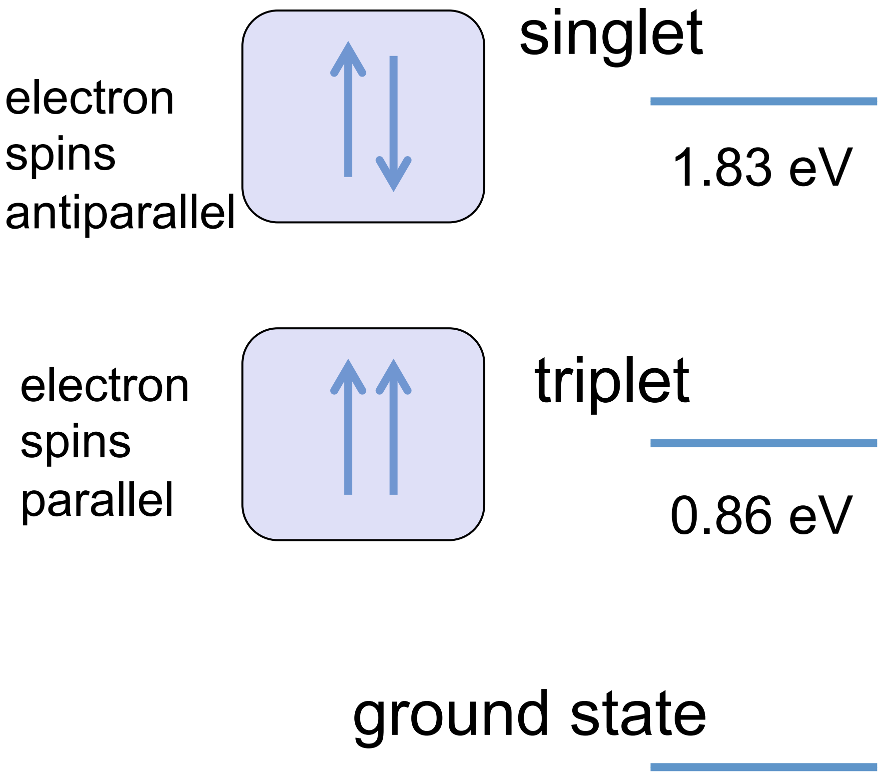
750 million ‘off-grid’ cell phones……

http://www.azuri-technologies.com

Current Research: Spin triplet excitons:

pentacene energy levels:





$2T_1 < S_1$

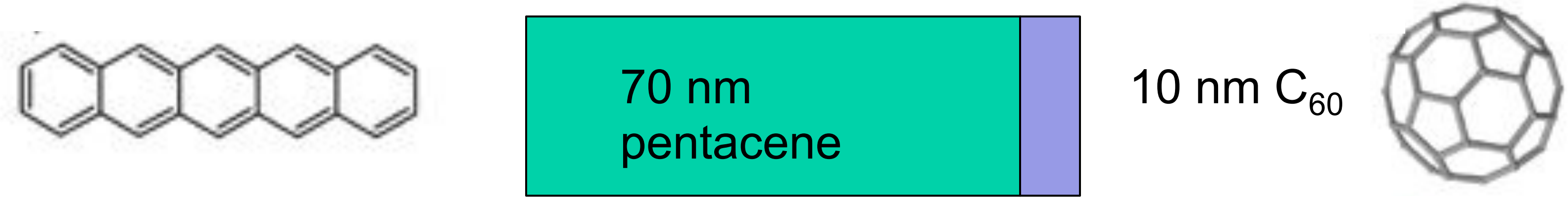
fission of S1 to two triplets energetically allowed.

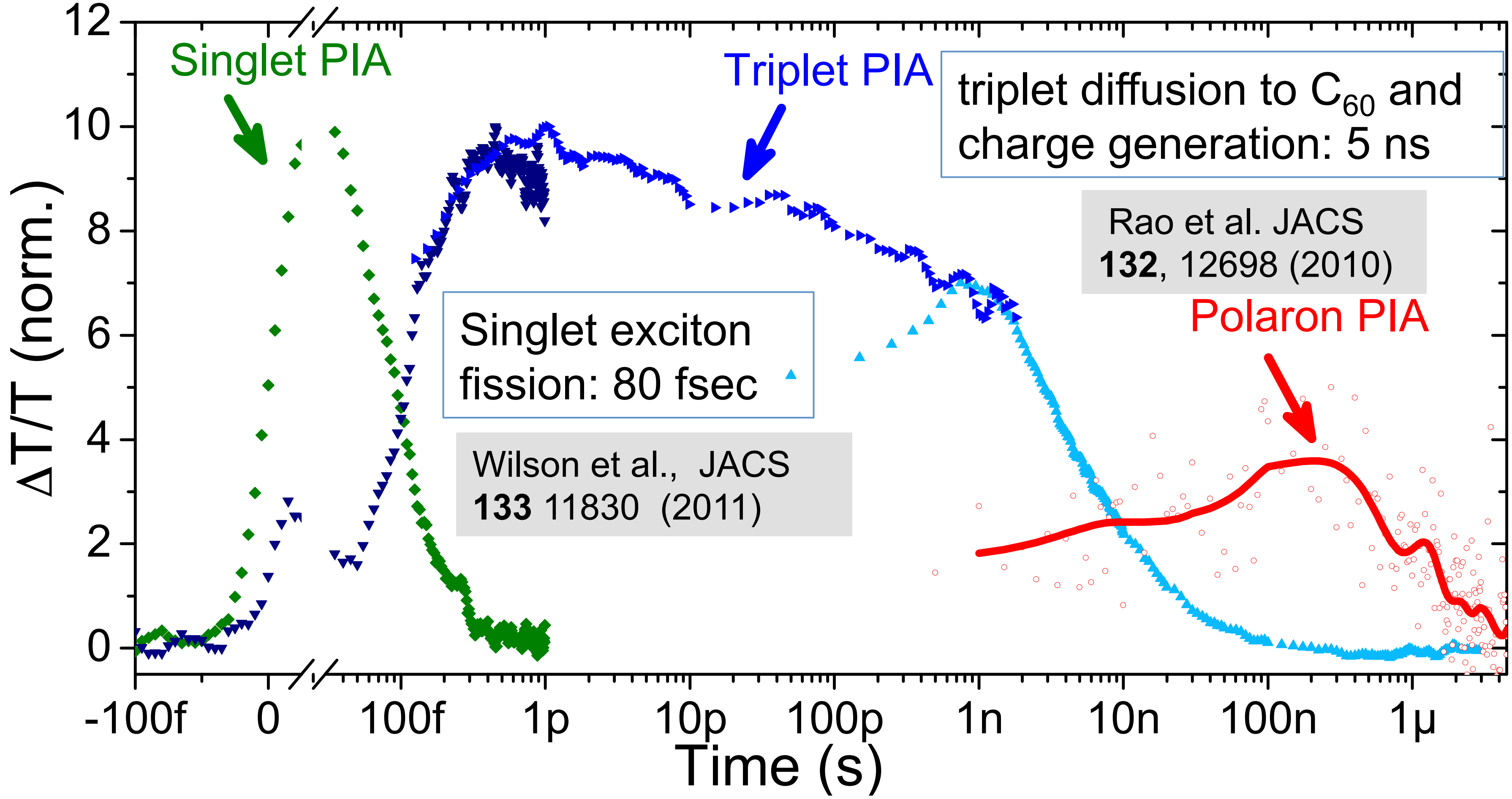
(Martin Pope 1969)

$$S_1 \rightarrow T_1 + T_1$$

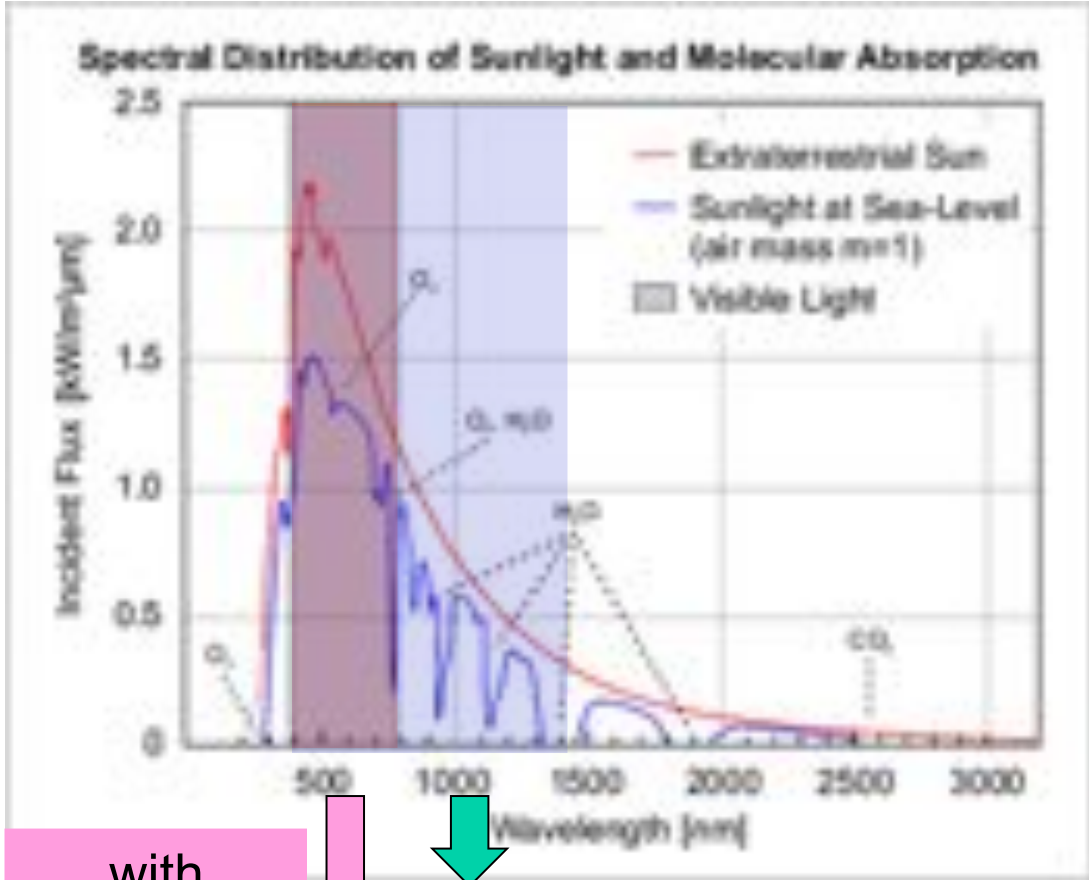
Fission

Pentacene-C_{60}: from singlet to triplet to charges





How to use multiple exciton generation in a solar cell?

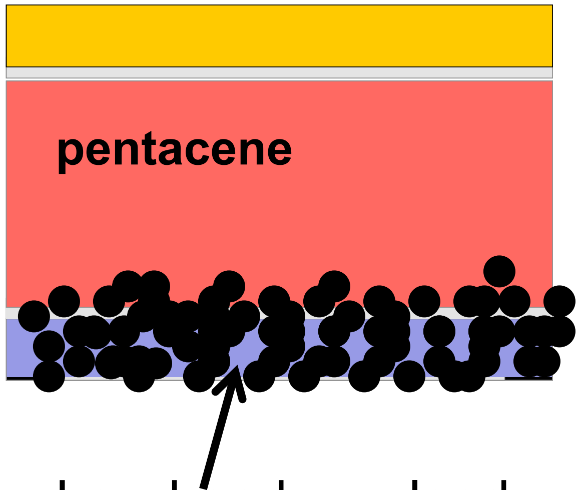


with pentacene

1 exciton/photon

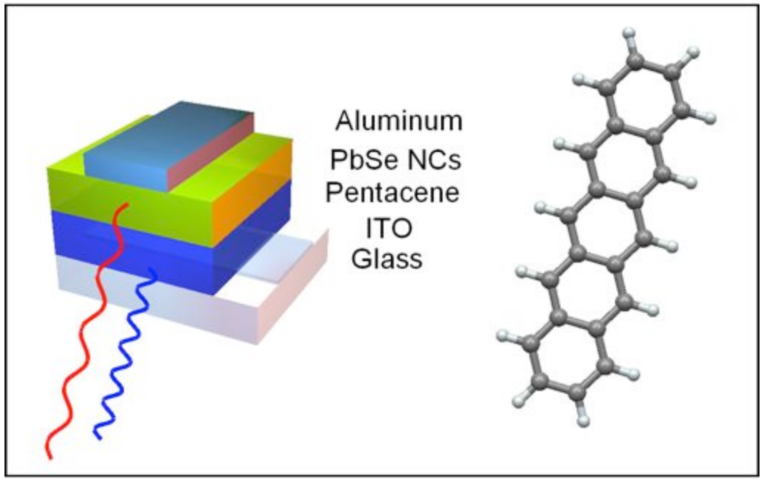
2 excitons/photon ?

Possible scheme:



Low band-gap lead sulfide/selenide nanocrystals (absorb in the IR)

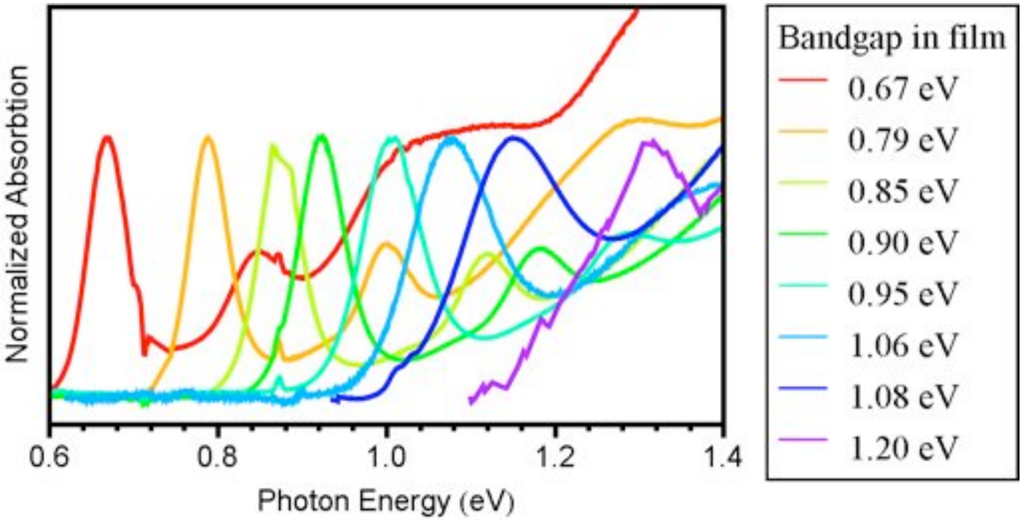
Efficiency limit raised from Shockley-Queisser limit of 32% to 46% (Hanna and Nozik *J. Appl. Phys.* *2006*, ***100***, *074510*)



pentacene – PbSe PV diodes:

Bruno Ehrler, Brian Walker, Marcus Böhm, Mark Wilson, Yana Vaynzof, Richard Friend and Neil Greenham, Nature Commun. **3**, 1019 (2012)

also: Ehrler et al. Nano Letters **12**, 1053 (2012)



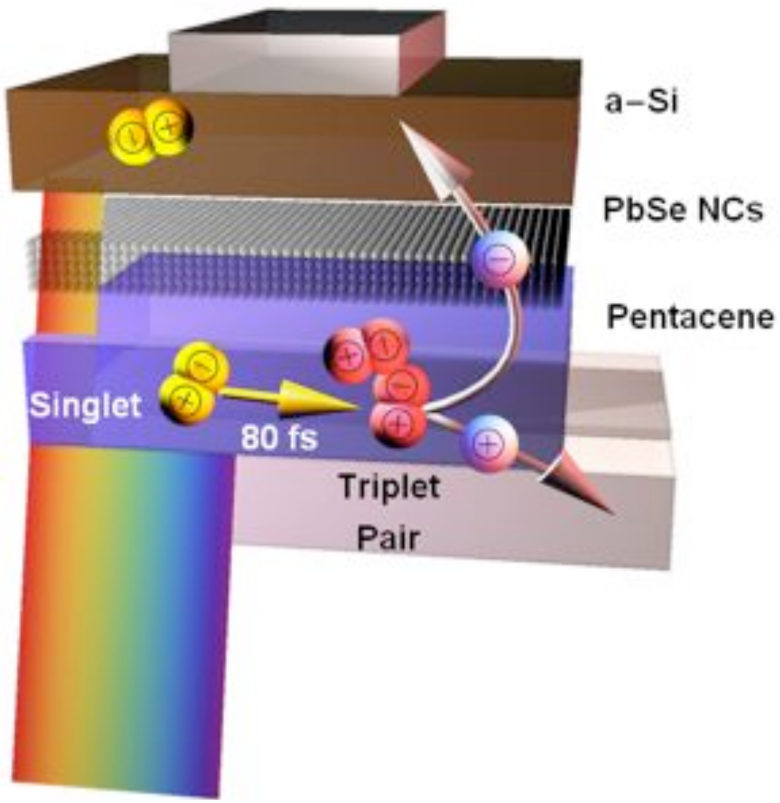
Absorption spectra of the lead selenide (PbSe) semiconductor nanocrystals used during this study, in solution. The nanocrystals range in monodispersity from 3-6%.

APPLIED PHYSICS LETTERS **101**, 153507 (2012)

Hybrid pentacene/a-silicon solar cells utilizing multiple carrier generation via singlet exciton fission

Bruno Ehrler, Kevin P. Musselman, Marcus L. Böhm, Richard H. Friend, and Neil C. Greenham[a)]
Cavendish Laboratory, JJ Thomson Avenue, Cambridge CB3 0HE, United Kingdom

(Received 18 July 2012; accepted 19 September 2012; published online 10 October 2012)



Pentacene/PbSe/a-Si device structure and proposed working mechanism. Visible range photons are absorbed by pentacene and split into pairs of low energy triplet excitons. IR photons are absorbed in silicon and the thin PbSe layer.