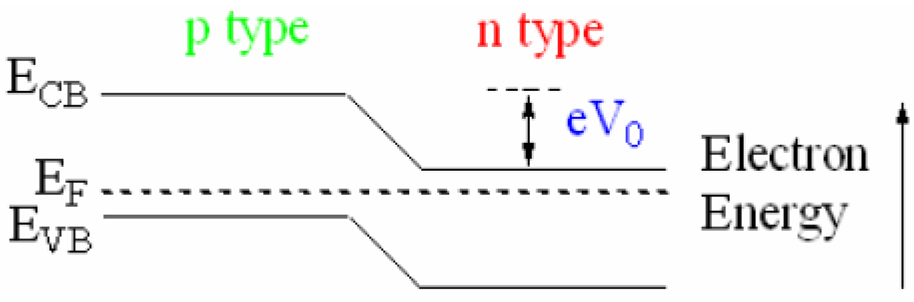
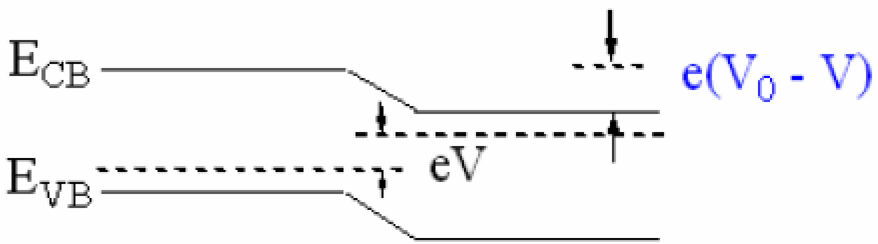
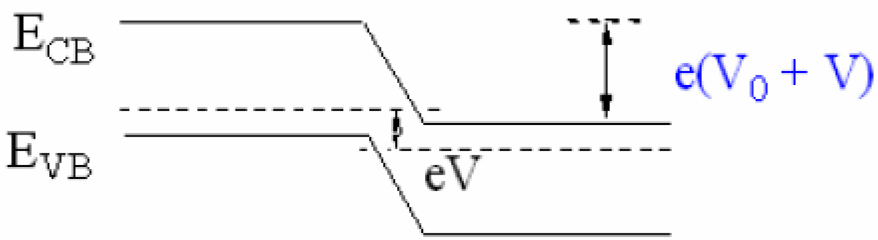


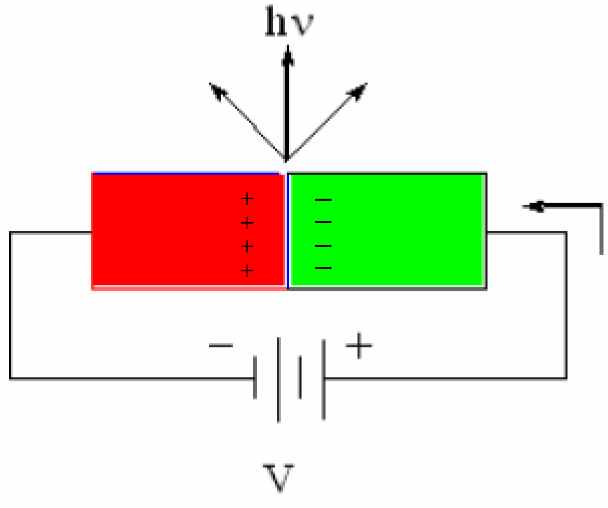


positive bias

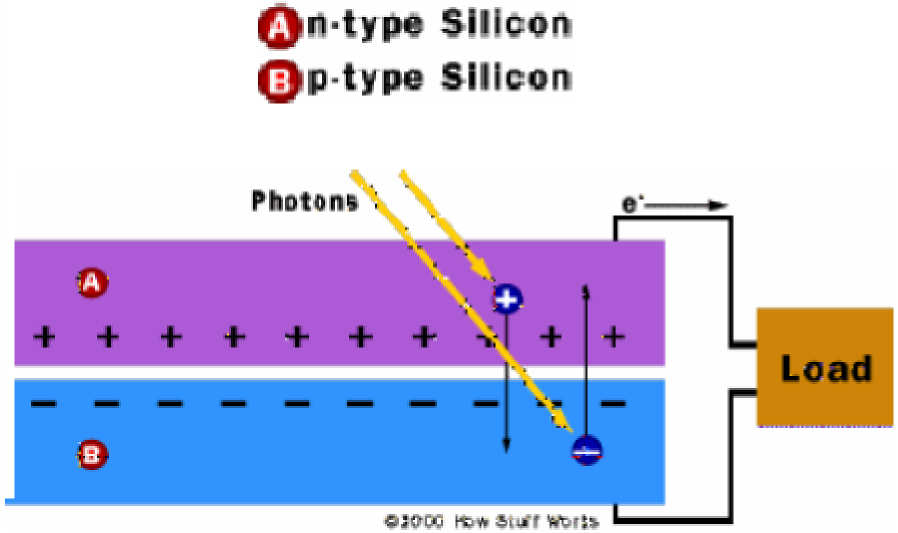


negative bias

Semiconductor Light Emitting Diodes



positive bias



$$FF = I_{PP}V_{PP}/I_{SC}V_{OC}$$

The energy conversion efficiency (Y%) is given by

$$\eta\% = (\text{Output energy/Total incident energy}) \times 100\%$$
$$= (I_{PP}V_{PP}/\text{Total incident energy}) \times 100\%$$
$$= (I_{SC}V_{OC}FF/\text{Total incident energy}) \times 100\%$$

The quantum efficiency (Q) is given by

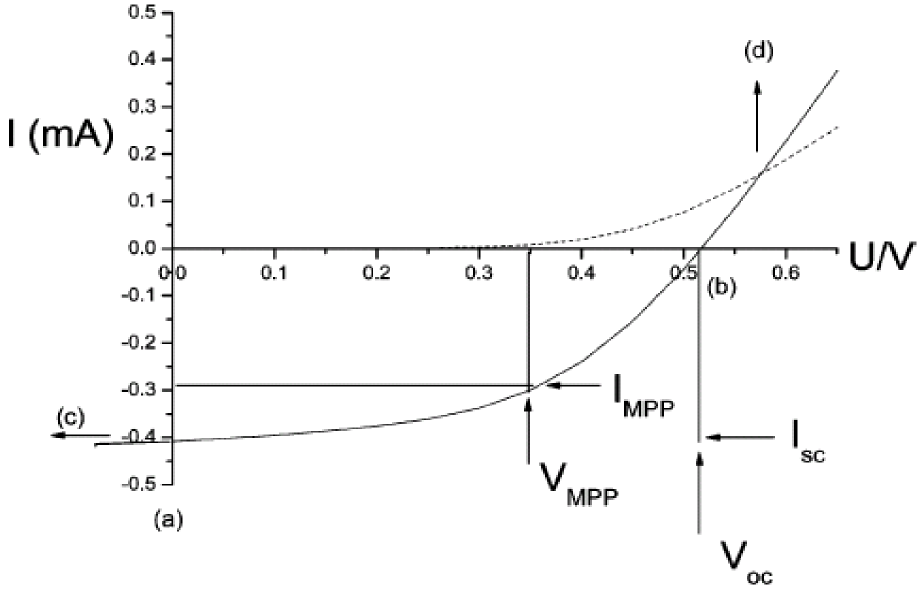
IPCE (incident photon conversion efficiency) = Q

$$Q = \frac{\text{Number of photons effectively used}}{\text{Number of photons absorbed}}$$

$$= \text{Output energy/Absorbed energy}$$

$$Q = \frac{[1.24 \times 10^3 \times \text{Photocurrent density } (\mu A/cm^2)]}{[\text{Wavelength (nm)} \times \text{Photon flux } (W/m^2)]}$$

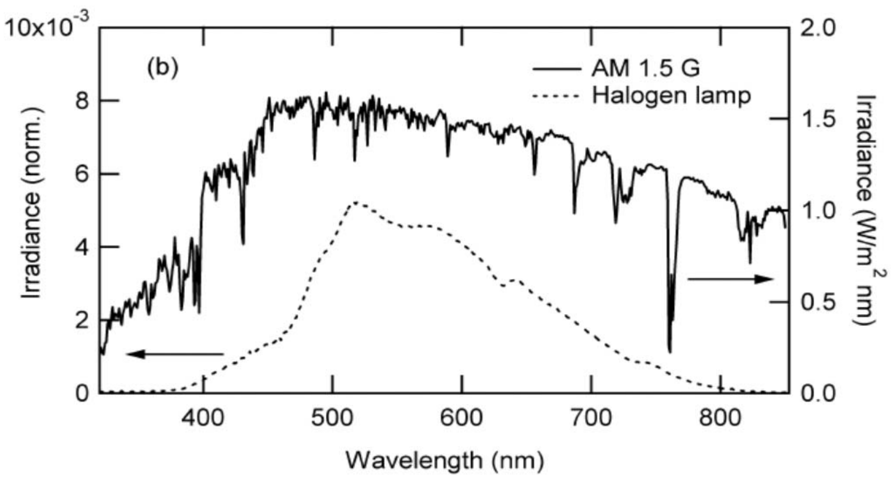
Monochromatic light is used to determine Q, and tungsten, tungsten halogen, or xenon lamps are used to determine η.

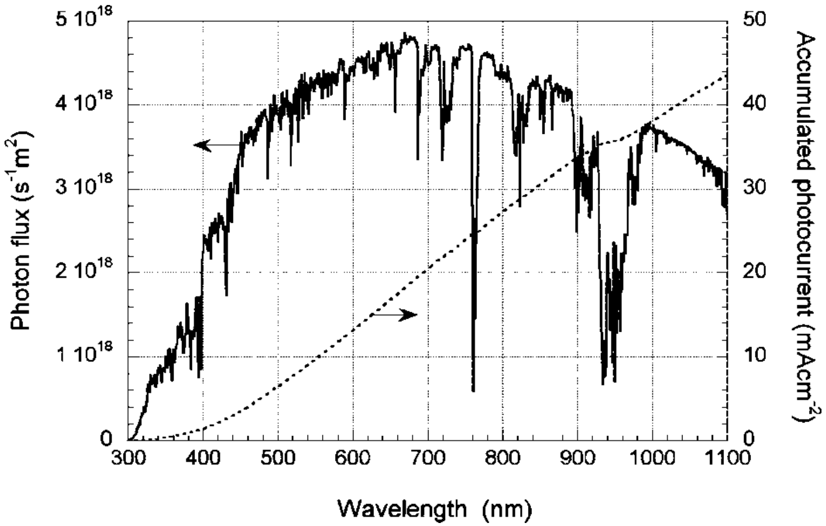


$$\mathrm{IPCE}(\lambda) = \frac{n_{\mathrm{electrons}}(\lambda)}{n_{\mathrm{photons}}(\lambda)} = \frac{I(\lambda)hc}{P_{\mathrm{in}}(\lambda)e\lambda} \approx \frac{1239I(\lambda)}{P_{\mathrm{in}}(\lambda)\lambda}$$

$$\eta_{\mathrm{e}} = \frac{V_{\mathrm{oc}}*I_{\mathrm{sc}}*FF}{P_{\mathrm{in}}} \qquad FF = \frac{I_{\mathrm{mpp}}*V_{\mathrm{mpp}}}{I_{\mathrm{sc}}*V_{\mathrm{oc}}}$$

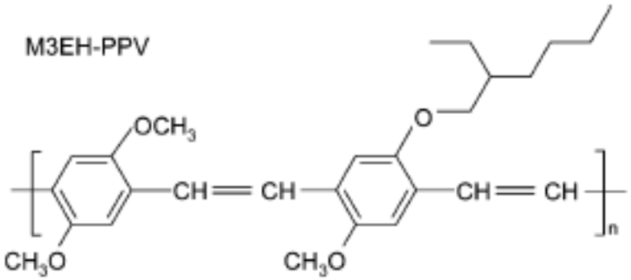
$$I_{\mathrm{sc}} = ne\mu E$$



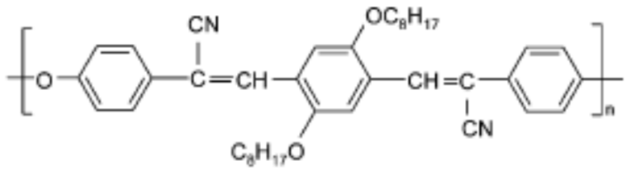


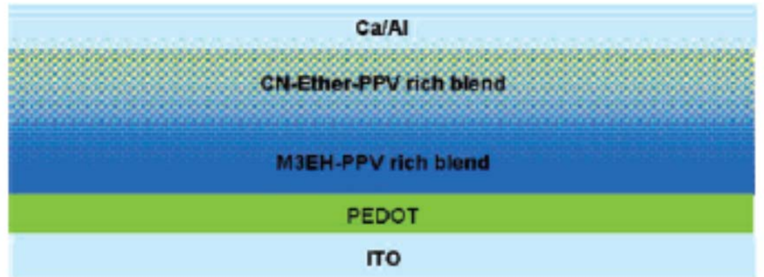
T. Kietzke *Chem. Mater.* **2005**, *17*, 6532

M3EH-PPV

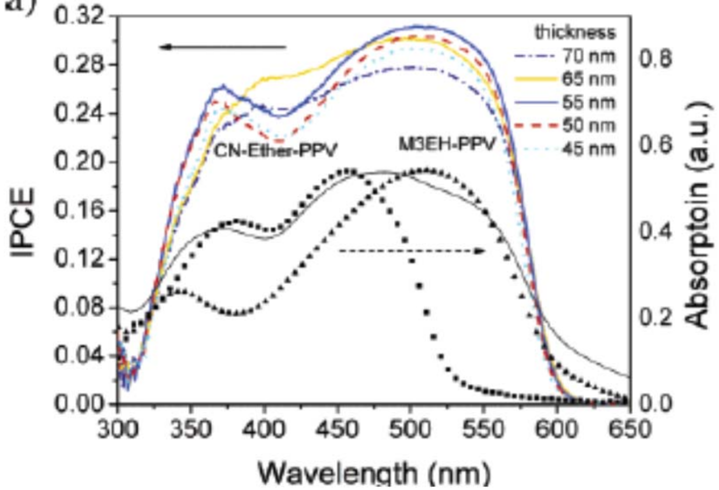


CN-Ether-PPV

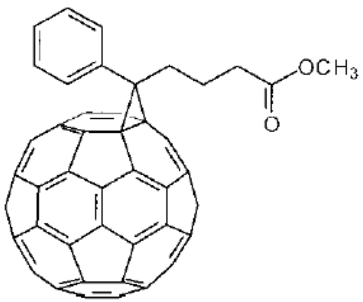




a)

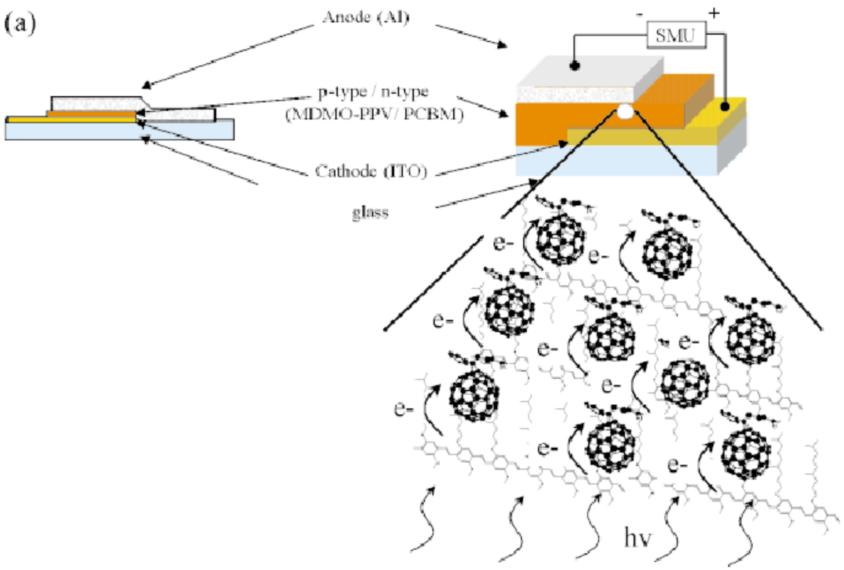


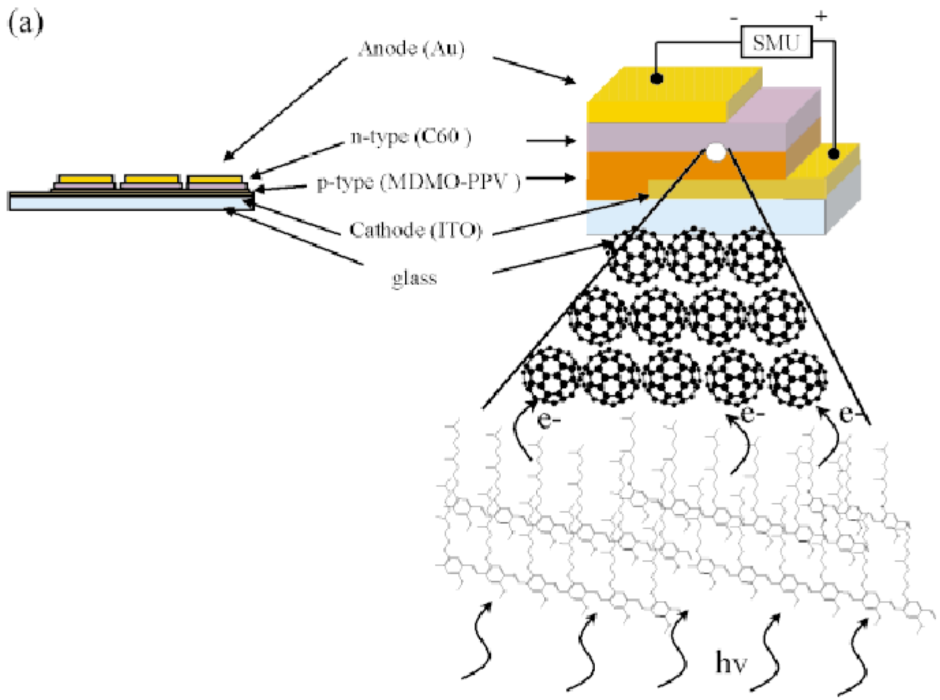
structure		V_{OC}, V	FF, %	IPCE, %	I_{SC}, mA	ECE, %
blend	1:1 M3EH−PPV:CN−ether−PPV	1.36	35.4	31	3.57	1.70
bilayer	M3EH−PPV:CN−ether−PPV	1.31	32.4	28	3.12	1.33



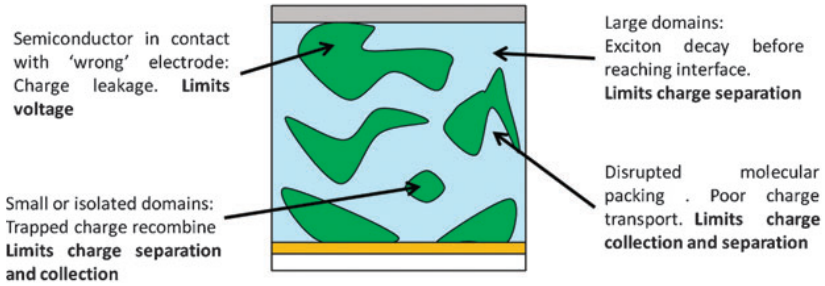
PCBM

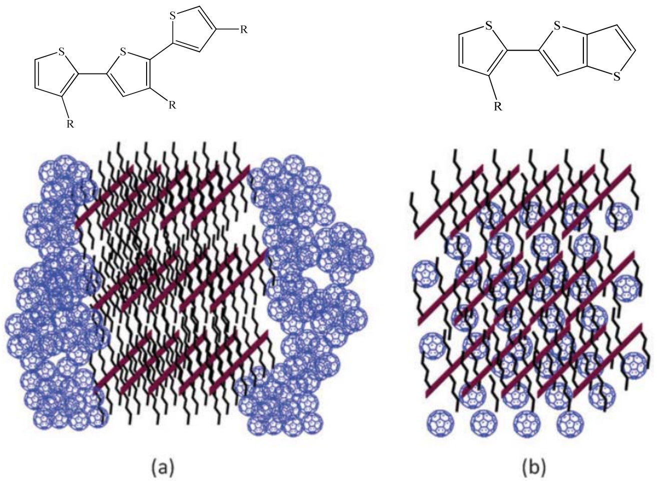
BHJ (bulk heterojunction)



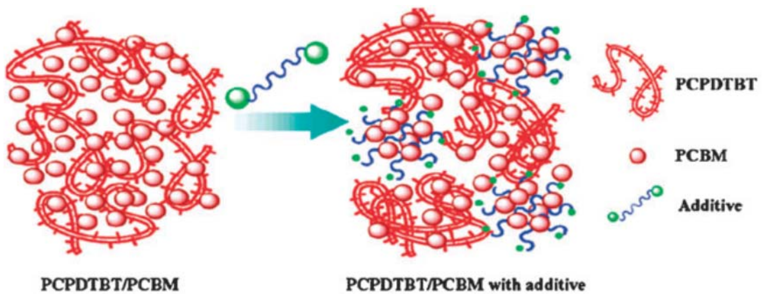


HJ (heterojunction)

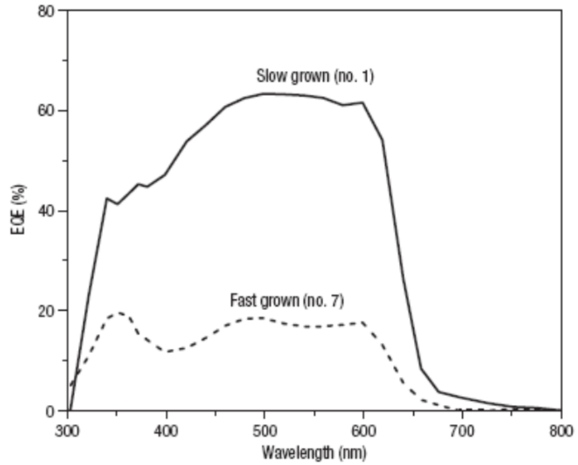




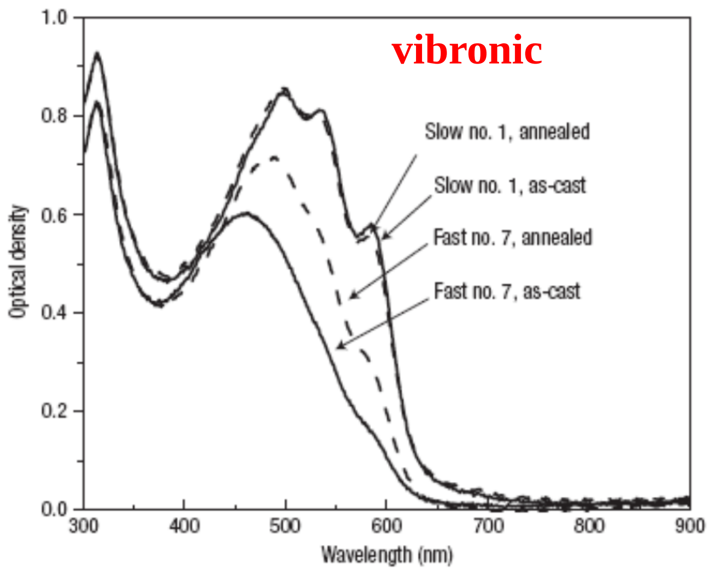
thermal anneal and solvent anneal



Y. Yang *Nat. Mater.* **2005**, *4*, 864



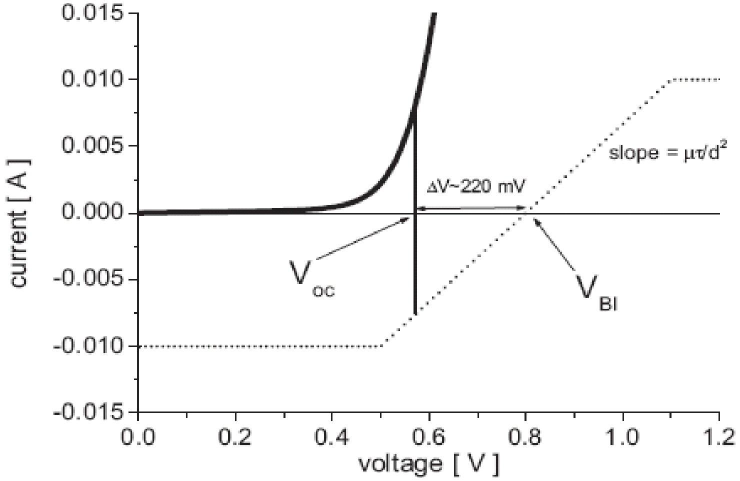
Immediately following the spin-coating, the films were either kept in covered petri dish for slow growth or were baked at 70 ˚C for ~30 s for fast growth.

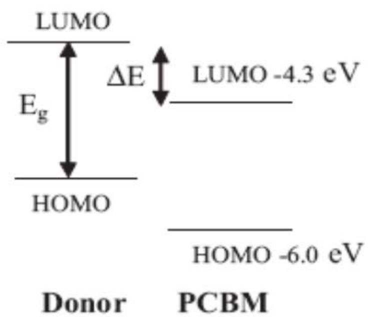


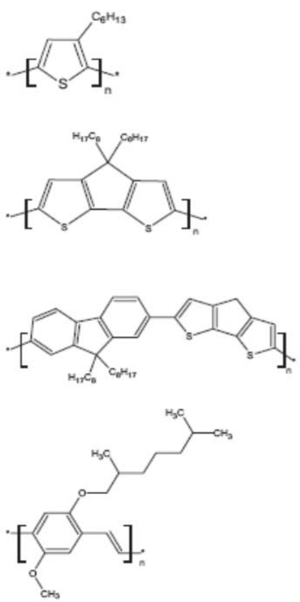
M. C. Scharber *Adv. Mater.* **2006**, *18*, 789

$$V_{oc} = (1/e)(|E^{Donor}HOMO| - |E^{PCBM}LUMO|) - 0.3\ V$$

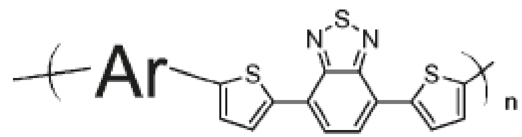
for bulk heterojunction cell

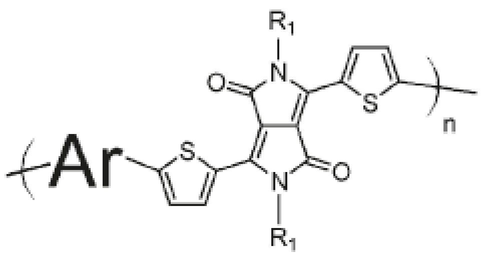


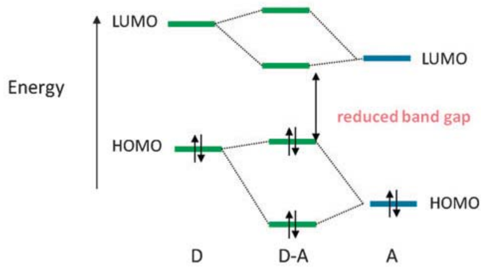




Processable Low-Bandgap Polymers

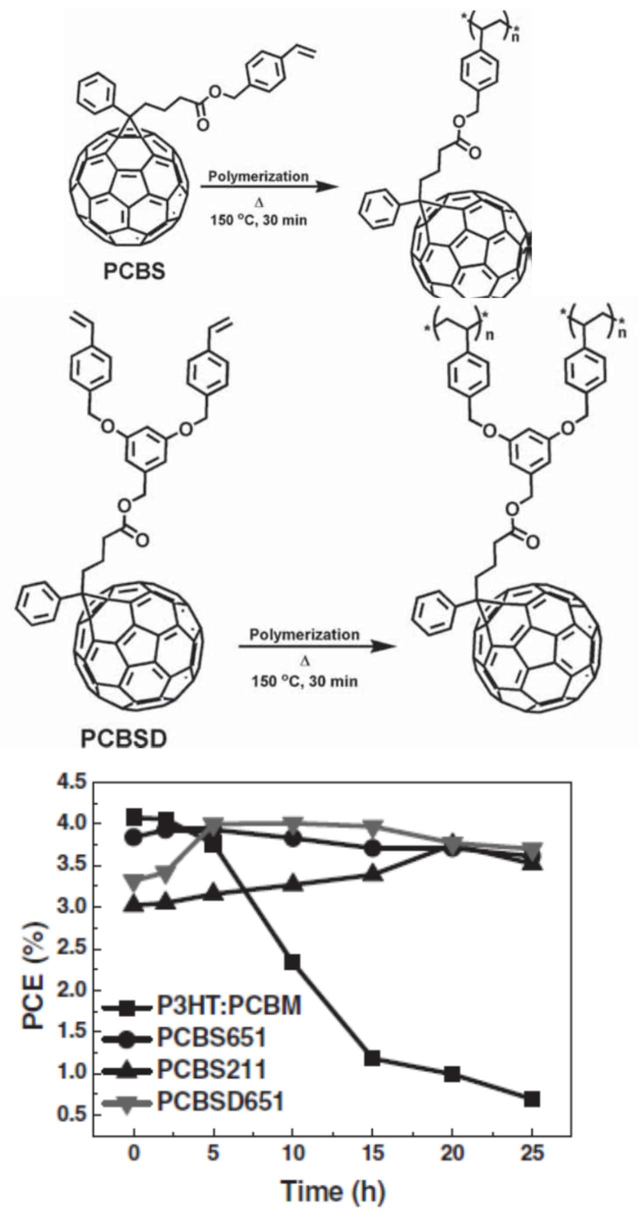


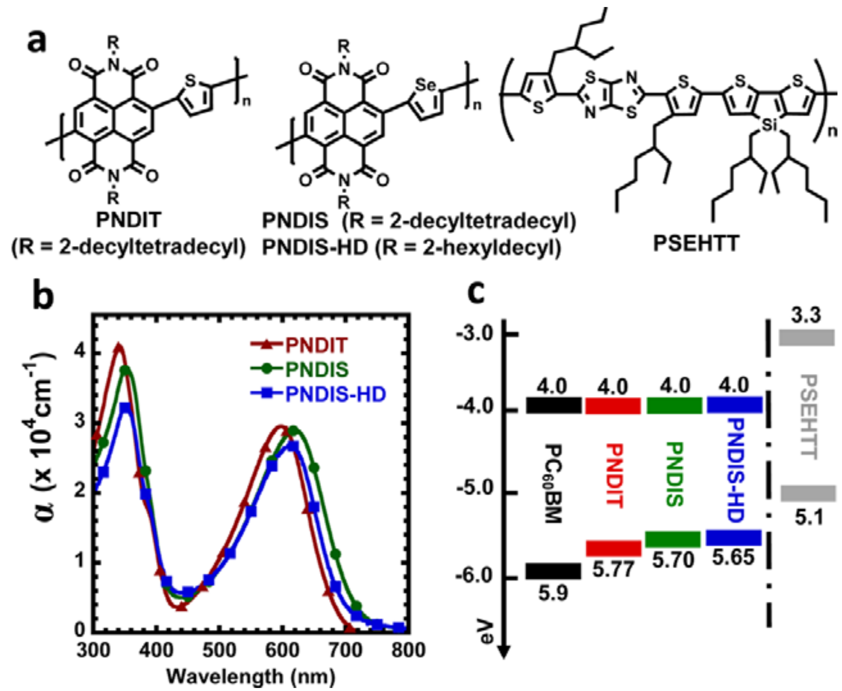




S. A. Jenekhe
J. Am. Chem. Soc.. **2013**, *135*, 14960

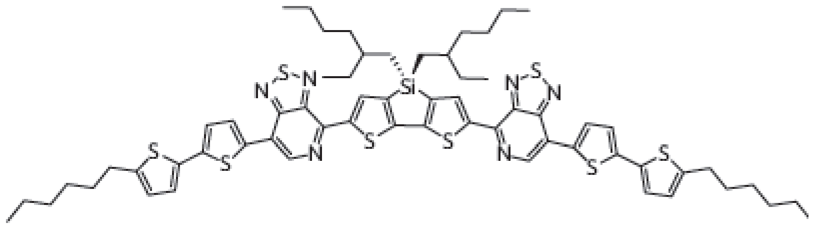
All Polymers



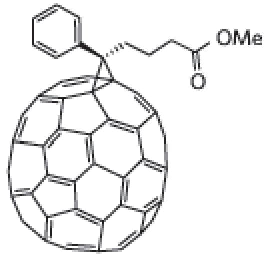


A. J. Heeger, G. C. Bazan *Nat. Mater.* **2012**, *11*, 44
Adv. Mater. **2013**, *25*, 2397

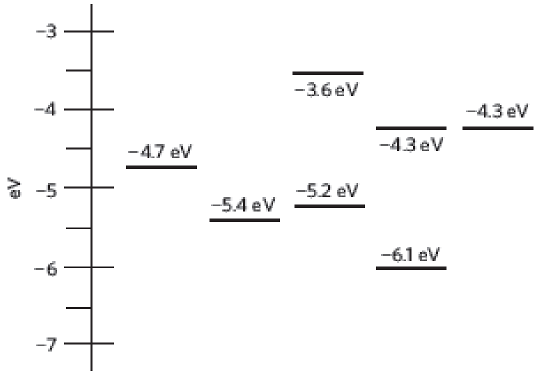
7.88%



DTS(PTTh$_2$)$_2$

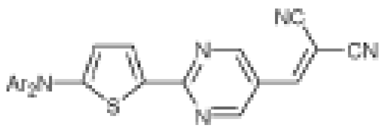


PC$_{70}$BM



ITO/MoO$_x$/DTS(PTTh$_2$)$_2$: PC$_{70}$BM/Al

K.-T. Wong *Chem. Commun.* **2012**, *48*, 1857

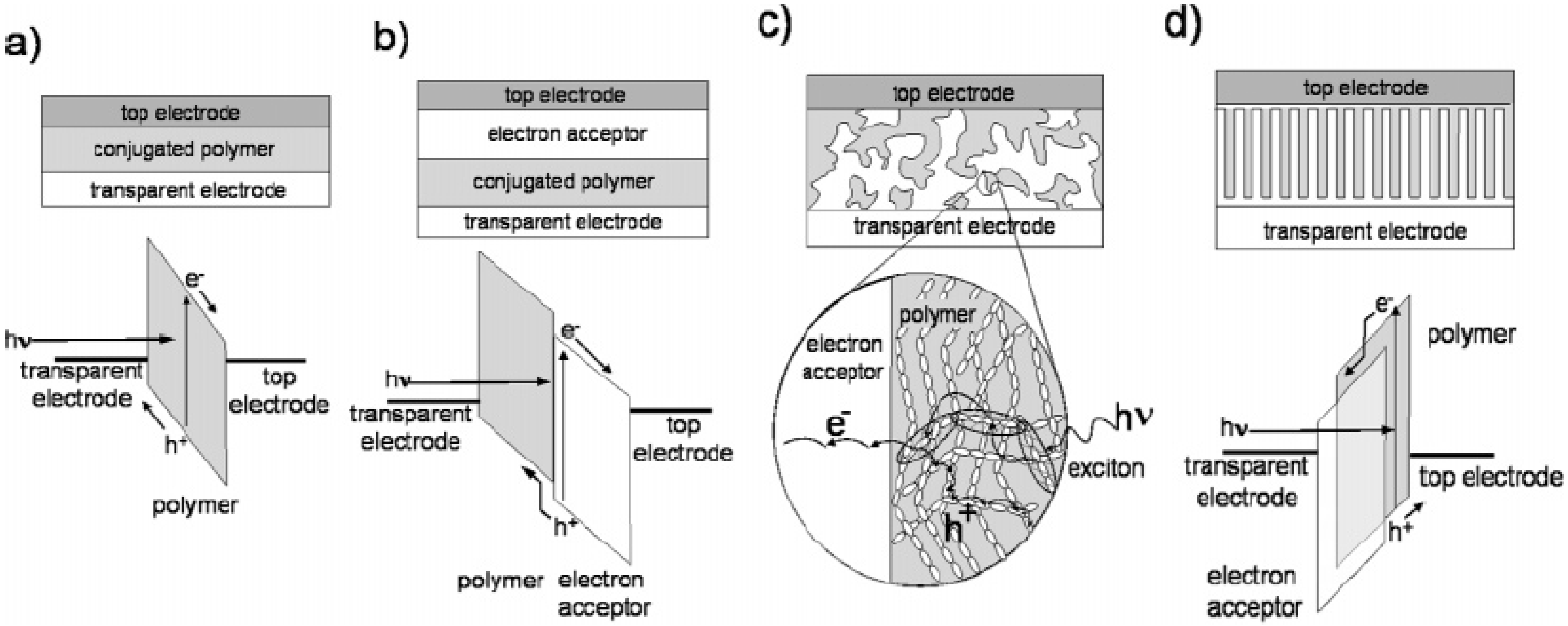


DTDCTP

ITO/MoO3/DTDCTP/DCDCTP: C60 (or C70)/C60 (or C70)/Ag

C60: 4.3%; C70: 6.4%

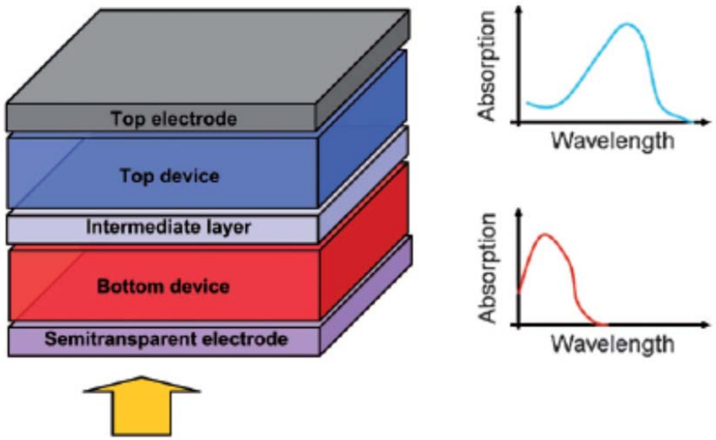
M. D. McGehee *Chem. Mater.* **2004**, *16*, 4533

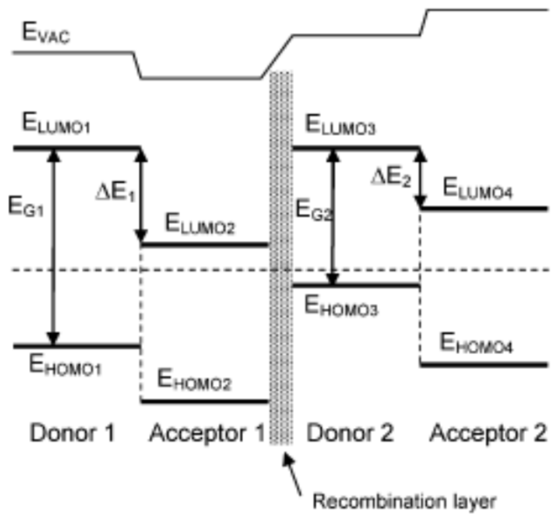


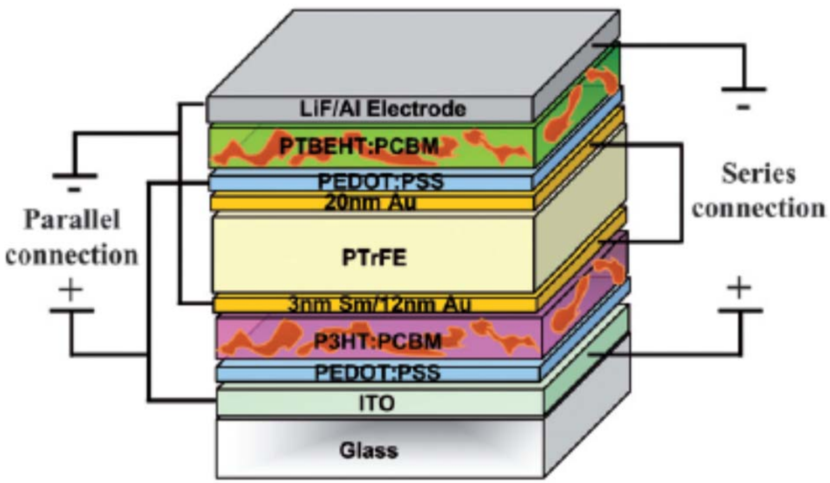
(a) singled-layer PV; (b) bilayered PV; (c) disordered bulk heterojunction (d) ordered bulk heterojunction

C. J. Brabec *Energy Environ. Sci.* **2009**, *2*, 347

Tandem Cells







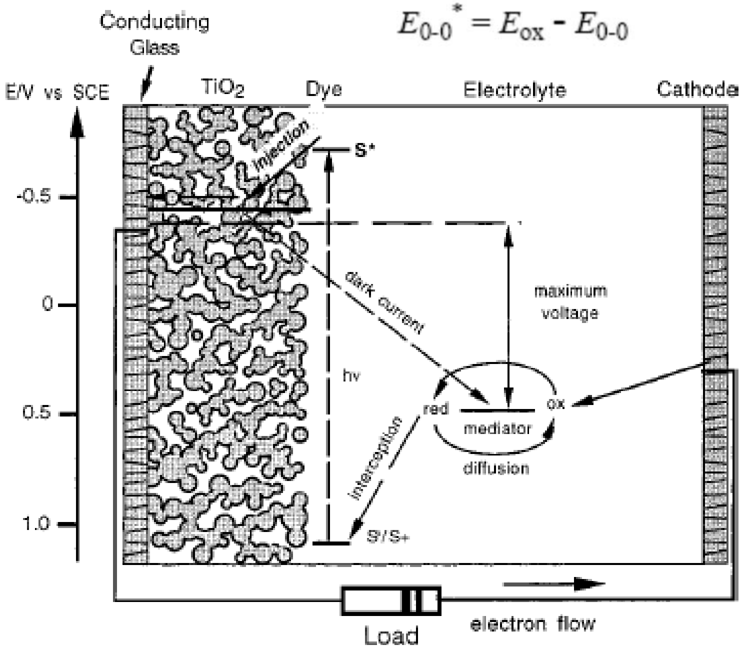
F. C. Krebs *Adv. Mater.* **2012**, *24*, 580

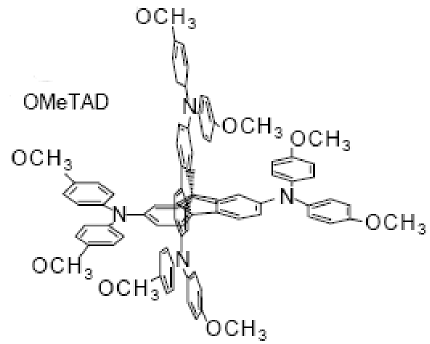
Stability of polymer Solar Cells

Dye-sensitized Heterojunction Solar Cell

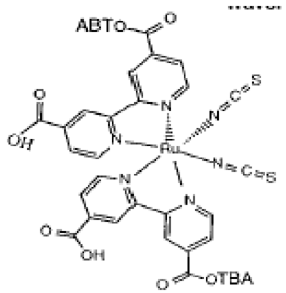
Michael Grätzel *Acc. Chem. Res.* **2000**, *33*, 269; *Nature* **1998**, *395*, 583

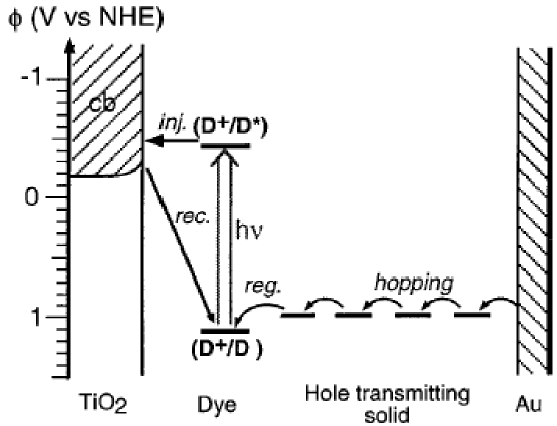
$$E_{0\text{-}0}^{*} = E_{ox} - E_{0\text{-}0}$$



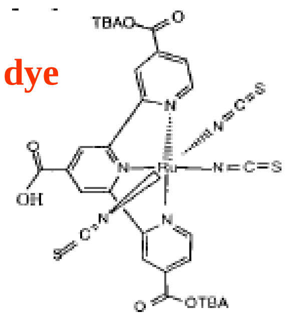


N719

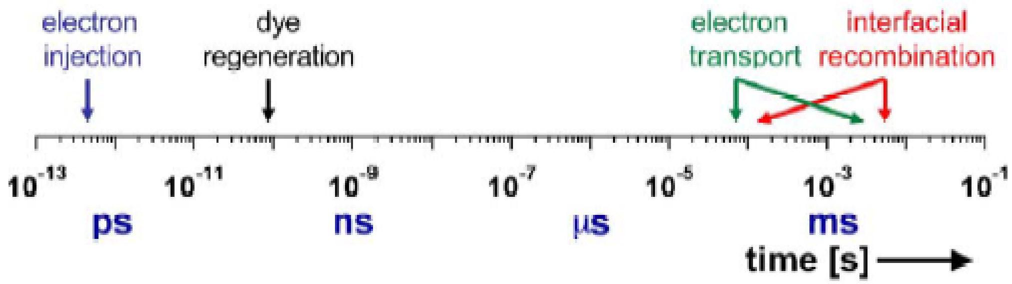




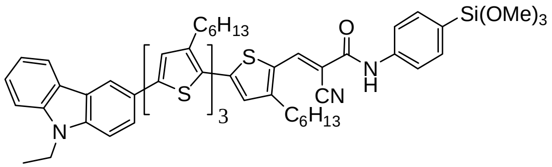
Black dye



Dynamic Competition

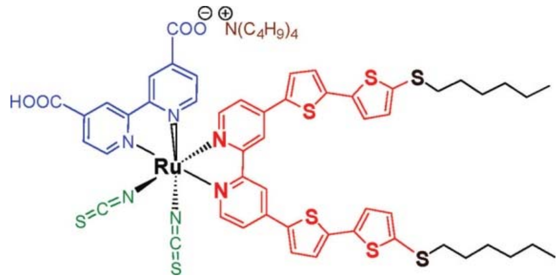


Hanaya, M..
CC **2015**, 51, 6315



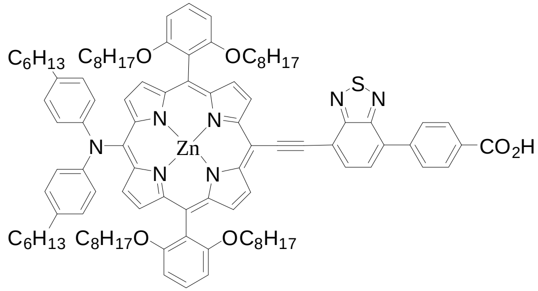
12.8%, >1.0 V ($Co^{II//III}$)

Wu, C.-G.; Grätzel, M.
ACS Nano **2009**, *3*, 3103



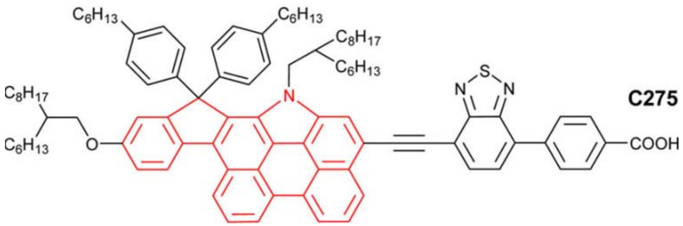
11.5`%, 743 mV, Z960

Yeh, C.-Y.; Grätzel, M.
ACIE **2014**, *53*, 2973



12.75%, 885 mV ($Co^{II//III}$)

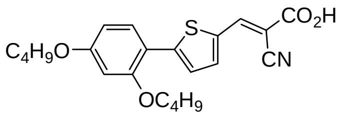
Wang, P.
JACS **2015**, 137, 3799

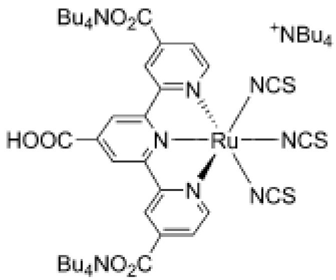


C275

12.5%, 956 mV ($Co^{II//III}$)

Han L.
Energy Environ. Sci. **2012**, *5*, 6077

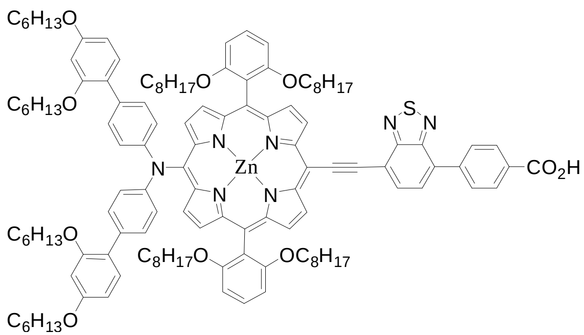




N749

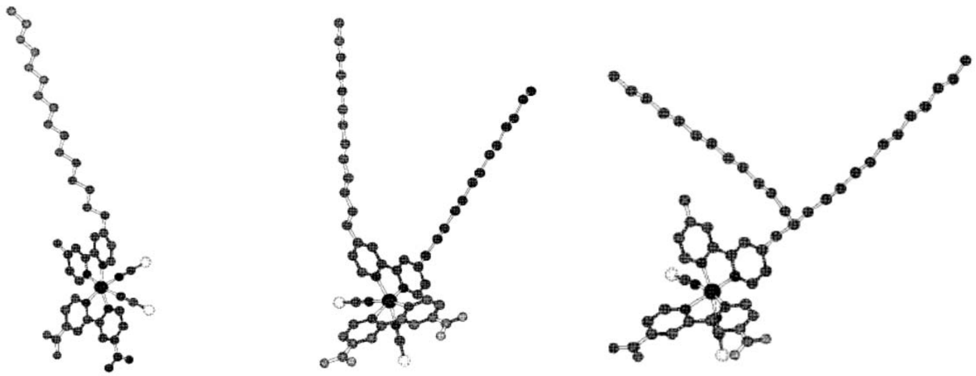
11.4%, 743 mV, I^-/I_3^-

Grätzel, M.
Nat. Chem. **2014**, *6*, 242



13%, 0.91 V ($Co^{II//III}$)

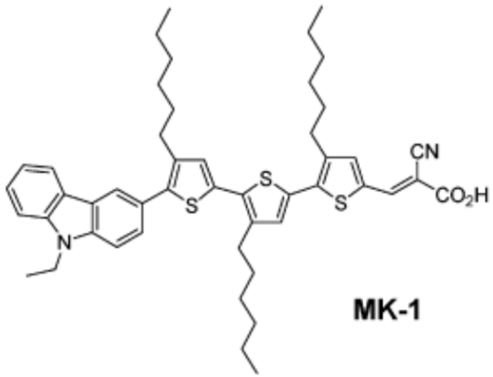
Langmuir **2002**, *18*, 952



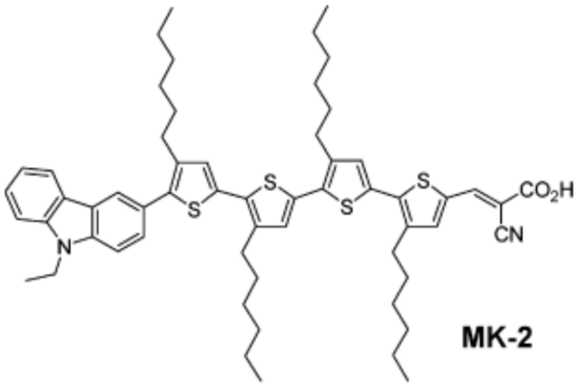
Complex **1** Complex **2** Complex **3**

complex	V_{oc}[g] (mV)	FF[h]
1	715	0.64
2	740	0.72
3	670	0.64
N3	640	0.65

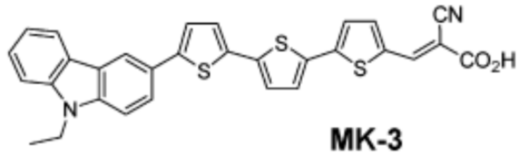
K. Hara *J. Am. Chem. Soc.* **2006**, *128*, 14256



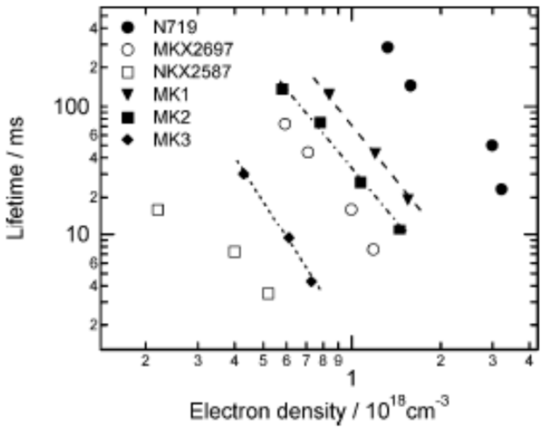
MK-1



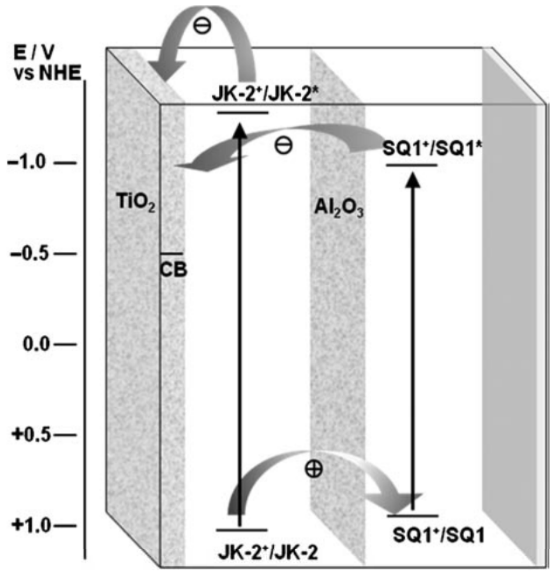
MK-2

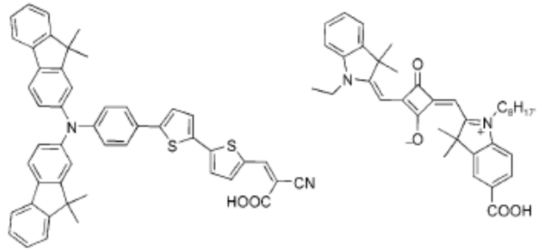


MK-3

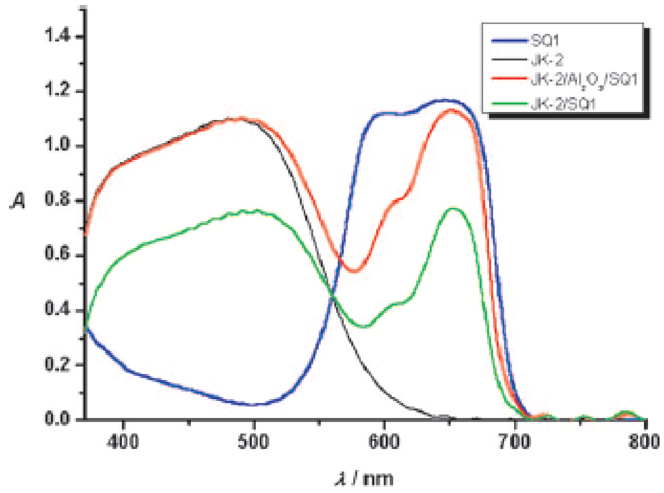


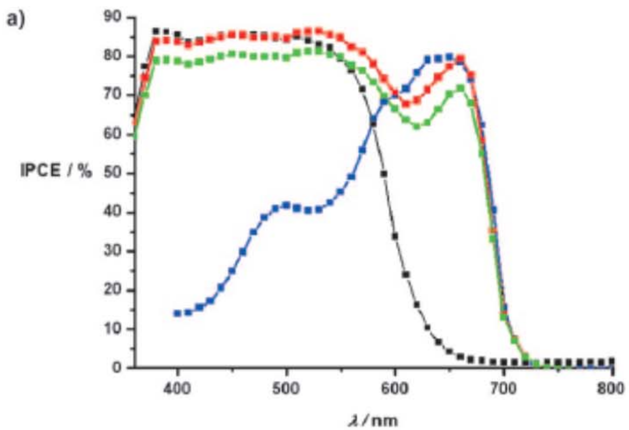
J. Ko, M. Gratzel *Angew. Chem. Int. Ed.* **2008**, *47*, 8259

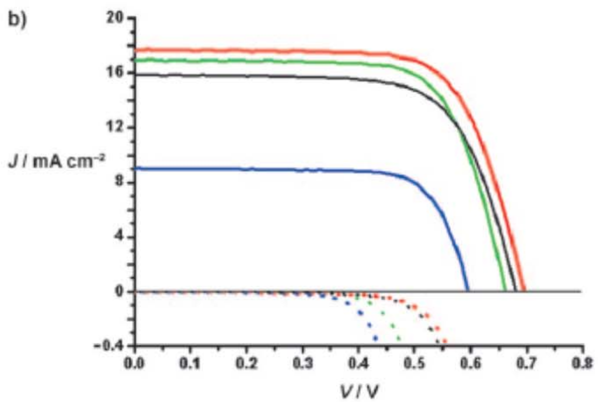




JK-2 SQ1





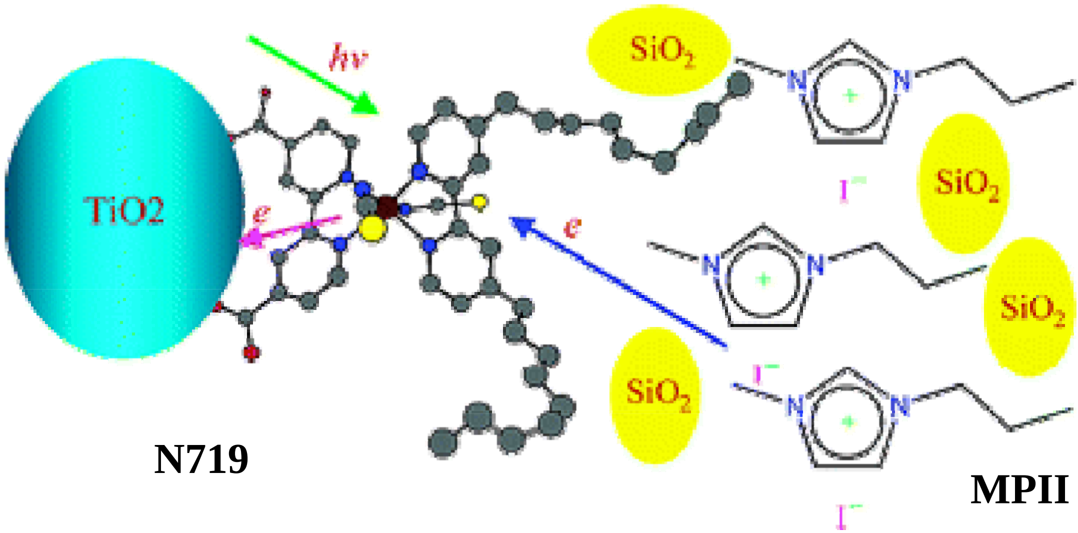


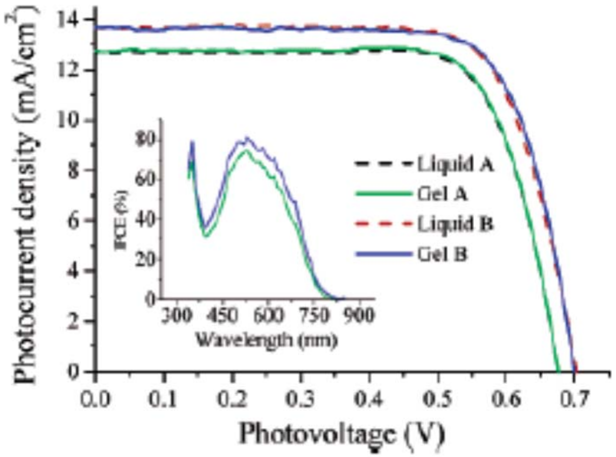
Recombination resistance:
SQ1 = 131.9 Ω
JK-2 = 64.8 Ω
JK-2/SQ1 = 52.6 Ω
JK-2/Al_2O_3/SQ1 = 52.0 Ω

Figure 2. a) IPCE spectra and b) *J*–*V* curve of **SQ** (blue line), **JK-2** (black line), **JK-2/SQ** (green line) and **JK-2/Al_2O_3/SQ** (red line). The dark-current–bias-potential relationship is shown as dotted curves.

Dye	J_{sc} [mAcm^{-2}]	V_{oc} [V]	FF	η [%]
JK-2	15.8	0.680	0.69	7.48
Al_2O_3/**JK-2**	13.7	0.740	0.76	7.80
SQ1	9.0	0.596	0.74	4.02
JK-2/SQ1	16.9	0.662	0.71	8.01
JK-2/Al_2O_3/SQ1	17.6	0.696	0.70	8.65

M. Gratzel *J. Am. Chem. Soc.* **2003**, *125*, 1166



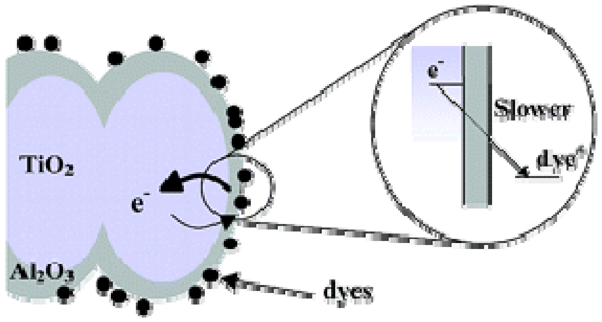


Liquid electrolytes A and B are composed of 0.5 M iodine and 0.45 M *N*-methyl-benzimidazole (NMBI) in either pure MPII or a mixture of MPII and 3-methoxypropionitrile (volume ratio: 13:7), respectively.

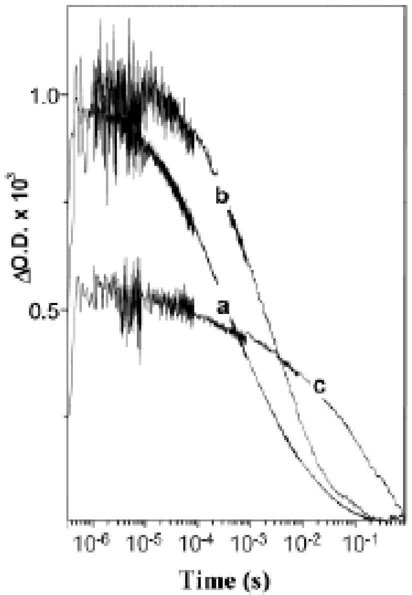
	η (%) at different light intensities				D_{app} (10^{-7} cm^2/s)	
electrolyte	0.1 sun	0.5 sun	1.0 sun	E_{eq} (mV)	I_3^-	I^-
liquid A	6.1	6.3	6.0	0	1.88	3.07
liquid B	7.0	7.2	7.0	26	8.21	14.1
gel A	6.3	6.4	6.1	0	1.89	3.09
gel B	6.9	7.1	7.0	26	8.21	13.9

apparent diffusion coefficient

J. R. Durrant *J. Am. Chem. Soc.* **2003**, *125*, 475



metal oxide	band-gap [eV]	E_{VB} [V vs SCE][b]	E_{CB} [V vs SCE][a]	Pzc (pH units)
SiO_2	8−8.9	+4.01	−4.48	2.1
ZrO_2	5.0	+3.75	−1.24	5.1
Al_2O_3	8.45−9.9	+3.85	−4.45	9.2
TiO_2	3.0−3.3	+2.73	−0.42	5.5

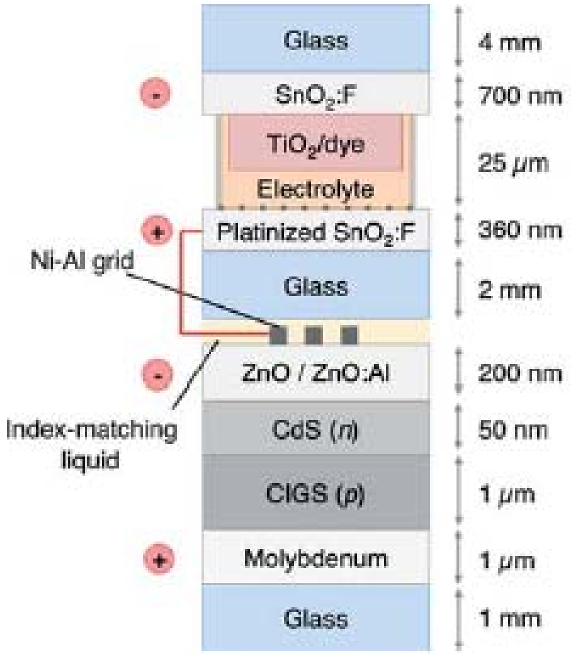


Current/Voltage Characteristics of Dye Sensitized Solar Cells Fabricated from Coated and Uncoated TiO_2 Films Sensitized with $RuL_2(NCS)_2$ and Obtained under AM1.5 Simulated Sunlight.

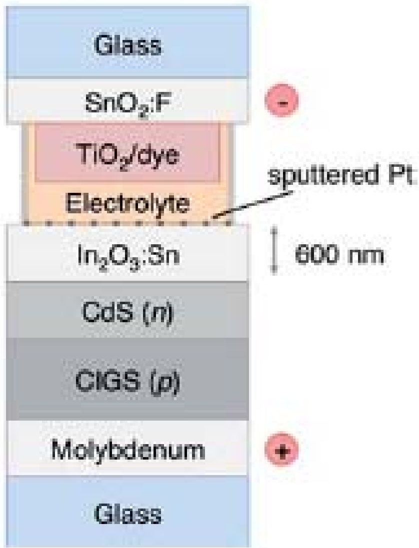
	h (%)[e]	V_{OC} (mV)	J_{SC} (mA/cm^2)	ff (%)
[a]TiO_2	3.7	735	9.1	55.1
[a]SiO_2/TiO_2	4.4	710	10.6	58.1
[a]Al_2O_3/TiO_2	5.6	760	12.1	61.1
[a,c]Al_2O_3/TiO_2	1.4	860	2.45	65.6
[a]ZrO_2/TiO_2	3.6	675	9.1	59.5
[d]TiO_2	2.0	710	5	54.4
[d]SiO_2/TiO_2	2.3	710	5.1	58.3
[d]Al_2O_3/TiO_2	2.5	760	5	65.4
[d]ZrO_2/TiO_2	2.0	710	5.1	51.6

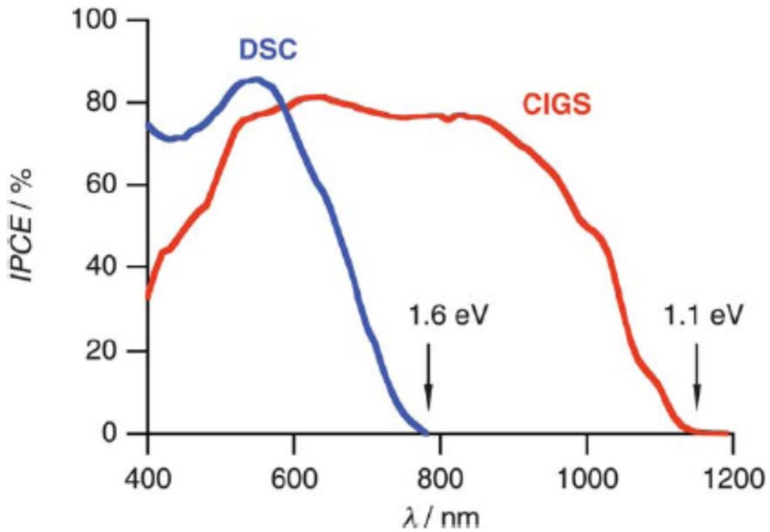
Transient absorption data monitoring photoinduced absorption of the dye cation following optical excitation of the dye $RuL_2(NCS)_2$ adsorbed on nanocrystalline TiO_2 films with (a) 0, (b) 1, and (c) 2 Al_2O_3 overlayer coatings.

M. Gratzel *Appl. Phys. Lett.* **2009**, *94*. 173508

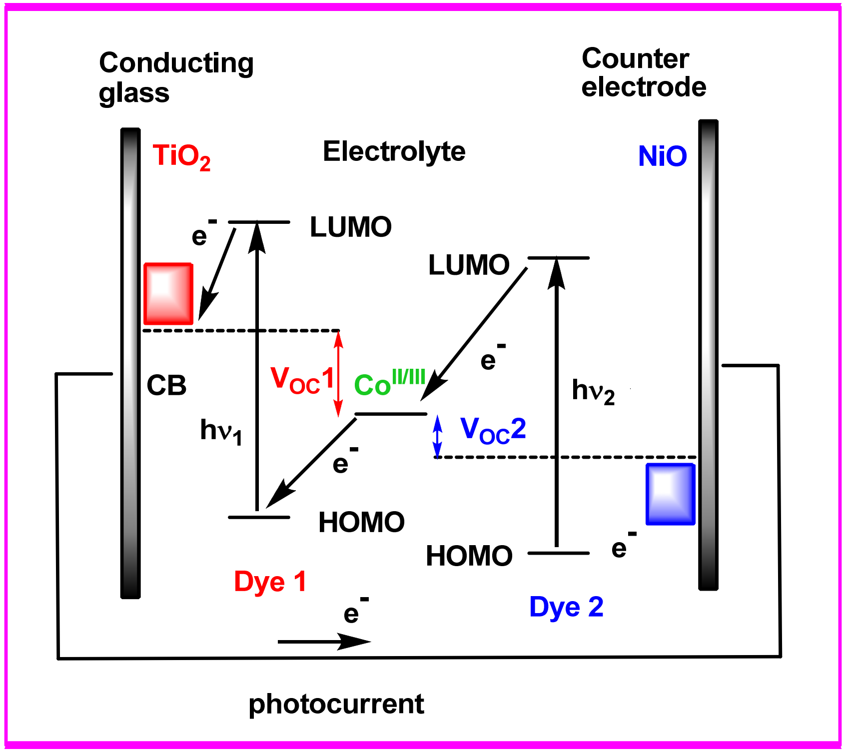


Schematic of the mechanically stacked (left) and monolithic (right) tandem device structure with a DSC top absorber and a CIGS bottom absorber.



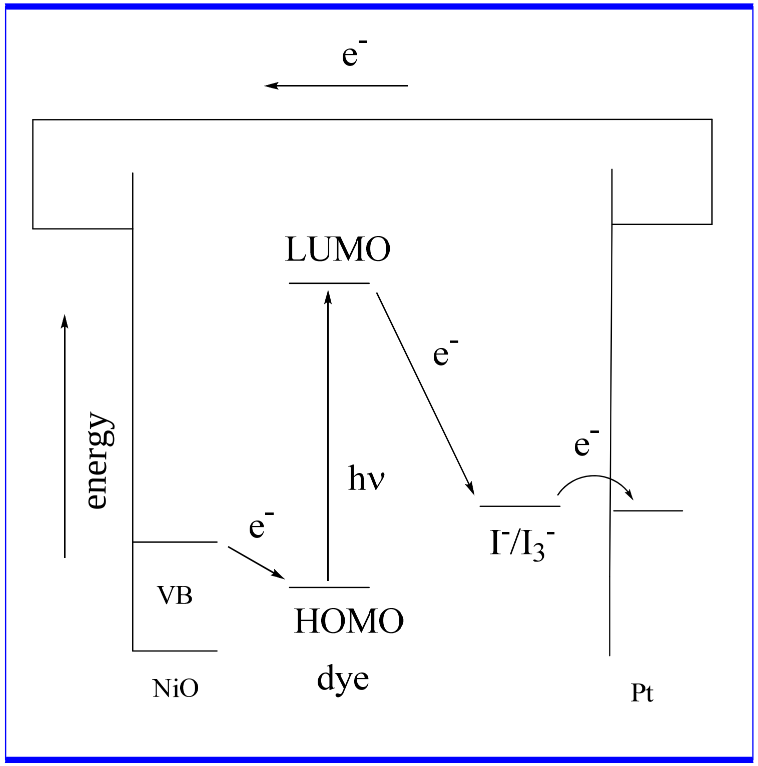


tandem cells



1. panchromatic dyes
2. $V_{OC} = V_{OC}1 + V_{OC}2$

p-type cells



1. low V_{OC}
2. low dye loading
3. fast charge recombination
4. low hole conductivity

O. M. Baker *Science* **2015**, *347*, 519

Single crystal $CH_3NH_3PbBr_3$
low trap density
carrier diffusion length ~17 μm
electron/hole mobility ~115 cm^2/V s

H. J. Snaith *Science* **2013**, *342*, 341

$CH_3NH_3PbBr_{3-x}Cl_x$
carrier diffusion length >1 μm
$CH_3NH_3PbI_3$
carrier diffusion length ~100 nm

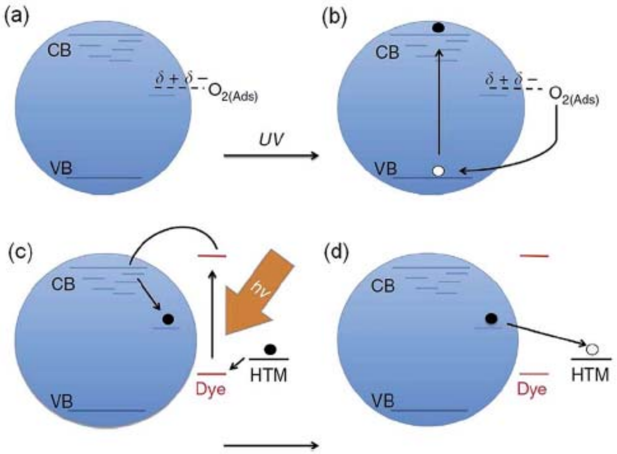
L. Wang *J. Mater. Chem. A* **2015**, *3*, 8970

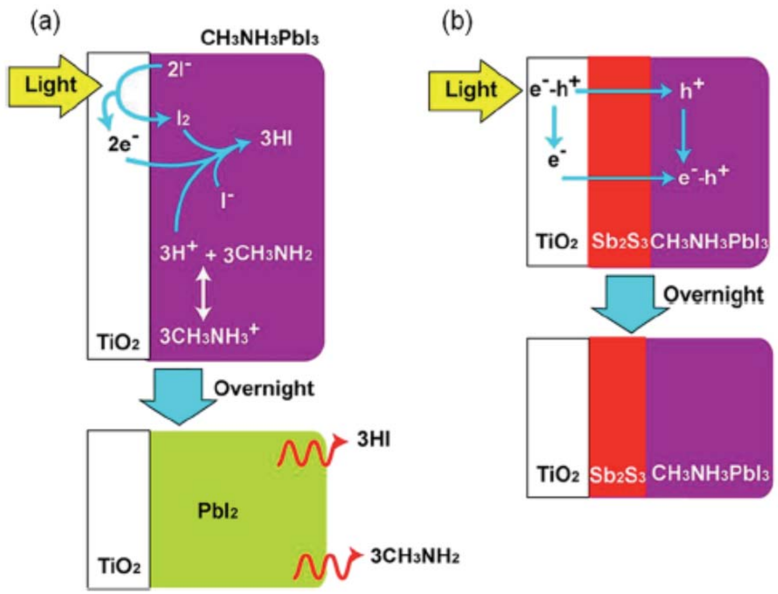
$$CH_3NH_3PbI_3\ (s) \leftrightarrow PbI_2\ (s) + CH_3NH_3I\ (aq) \quad (2a)$$

$$CH_3NH_3I\ (aq) \leftrightarrow CH_3NH_2\ (aq) + HI\ (aq) \quad (2b)$$

$$4HI\ (aq) + O_2\ (g) \leftrightarrow 2I_2\ (s) + 2H_2O\ (l) \quad (2c)$$

$$2HI\ (aq) \leftrightarrow H_2\ (g) + I_2\ (s) \quad (2d)$$





J. S. C. Loo *Energy Environ. Sci.* **2012**, *5*, 5902

Recent Advances in hybrid photocatalysts for solar fuel production