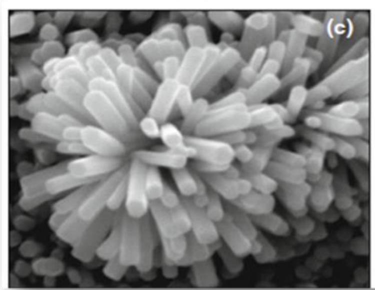
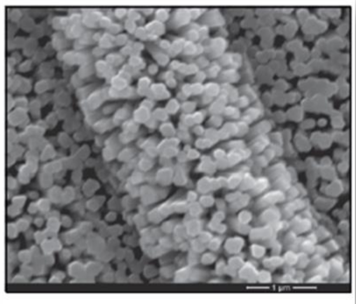
Advanced Nano materials for solar cell applications





Dhayalan Velauthapillai, HIB

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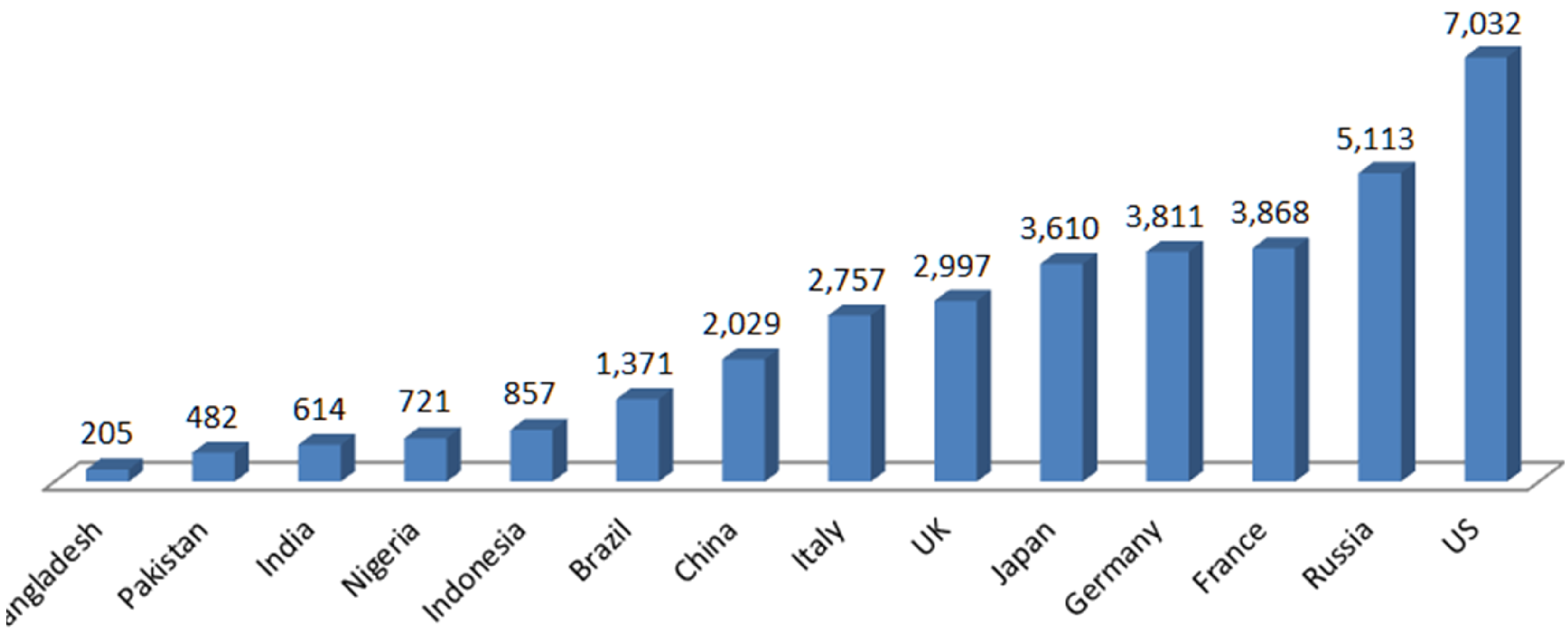
World Meteorological Organization's statement

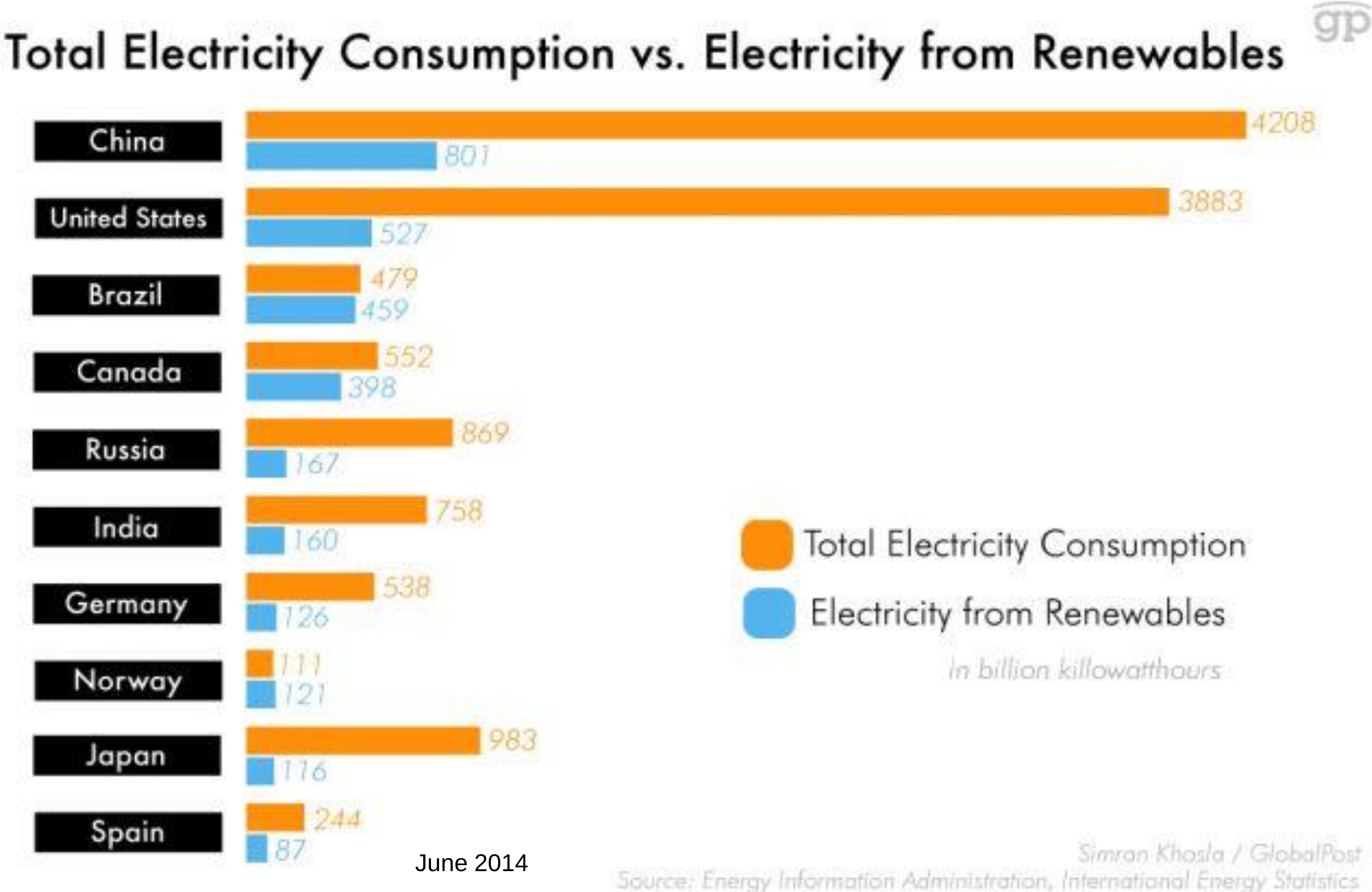
Nov. 2014

- 2014 on track to being among hottest on record
- The global average air temperature over land and sea surface for January to October was about 0.57° Centigrade (1.03 Fahrenheit) above the average of 14.00°C (57.2 °F) for the 1961-1990 reference period
- Lima Talks - goal is to reduce greenhouse gas emissions to limit the global temperature increase to 2 degrees Celsius above current levels

Energy Use per Capita

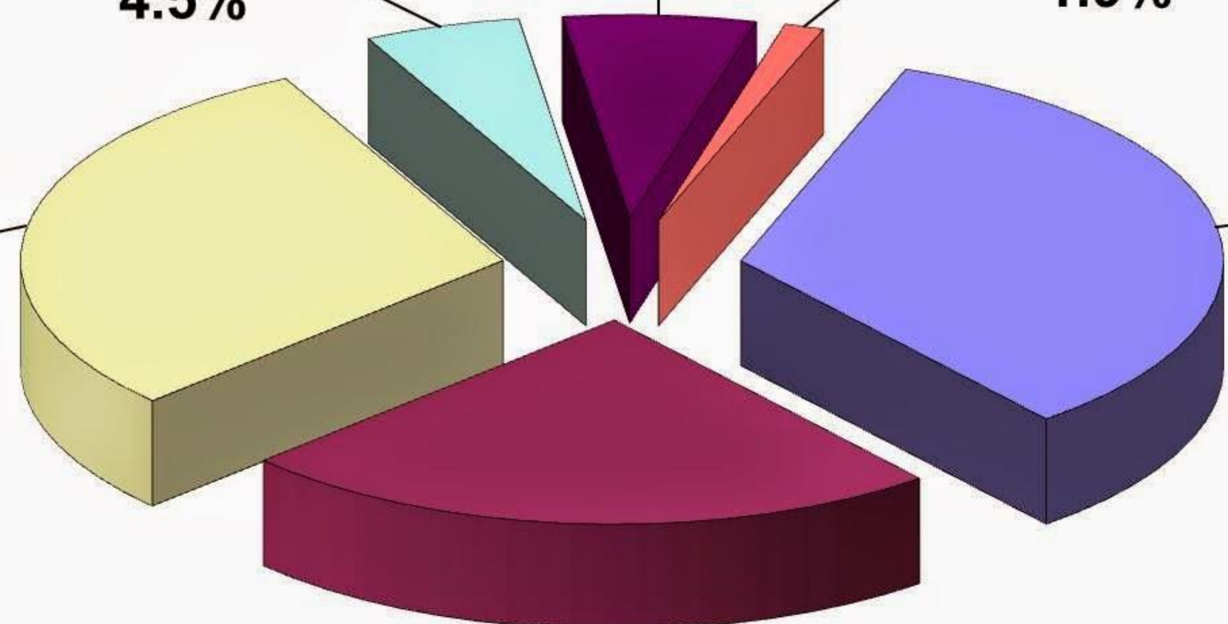


The World Bank : Kilograms of oil equivalent (2011)
http://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capita


Total Electricity Consumption vs. Electricity from Renewables
China
4208
801
United States
3883
527
Brazil
479
459
Canada
552
398
Russia
869
167
India
758
160
Germany
538
126
Norway
111
121
Japan
983
116
Spain
244
87
Total Electricity Consumption
Electricity from Renewables
In billion killowatthours
Simran Khosla / GlobalPost
Source: Energy Information Administration, International Energy Statistics

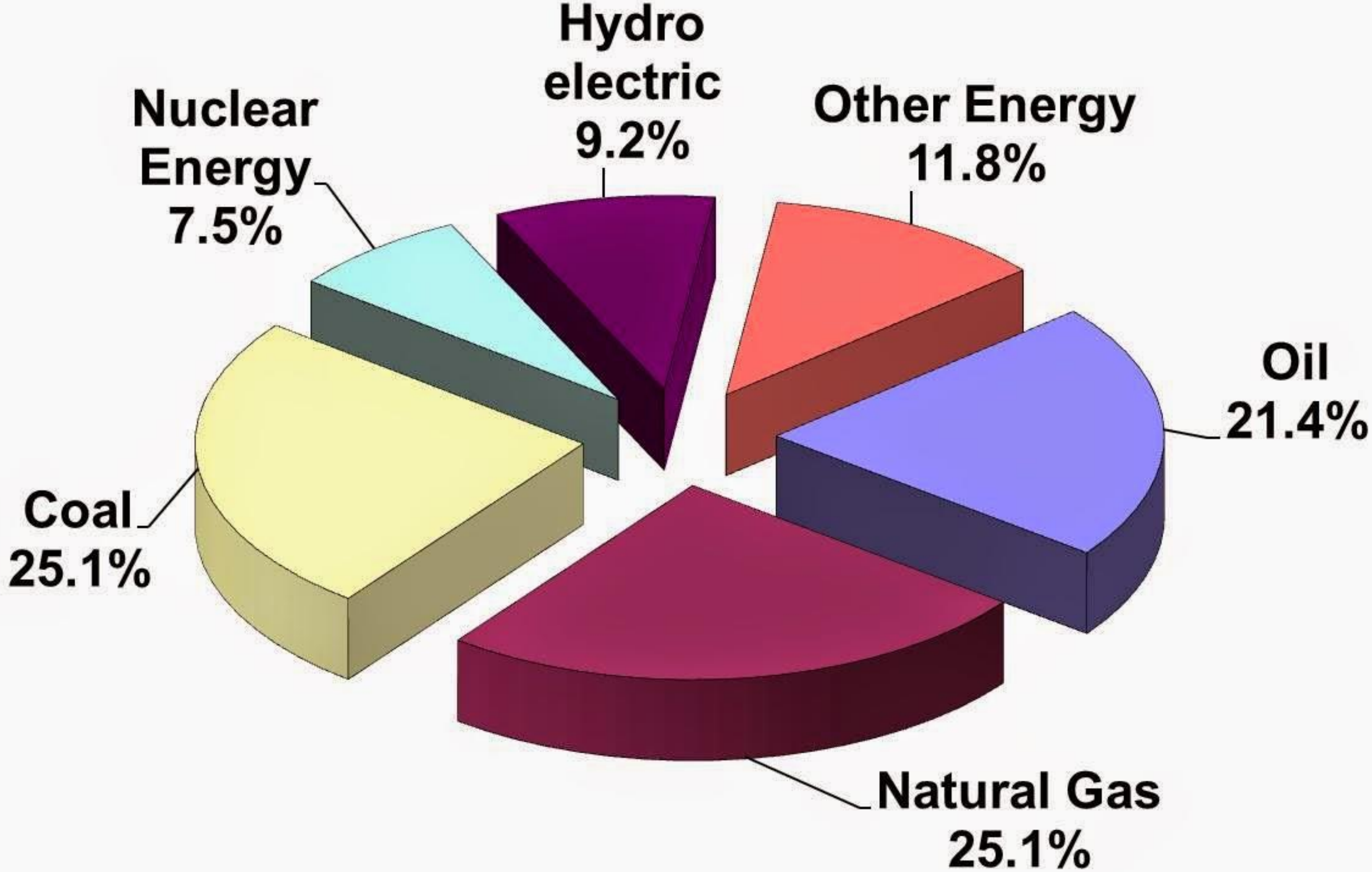
June 2014

World Energy Consumption By Fuel 2012



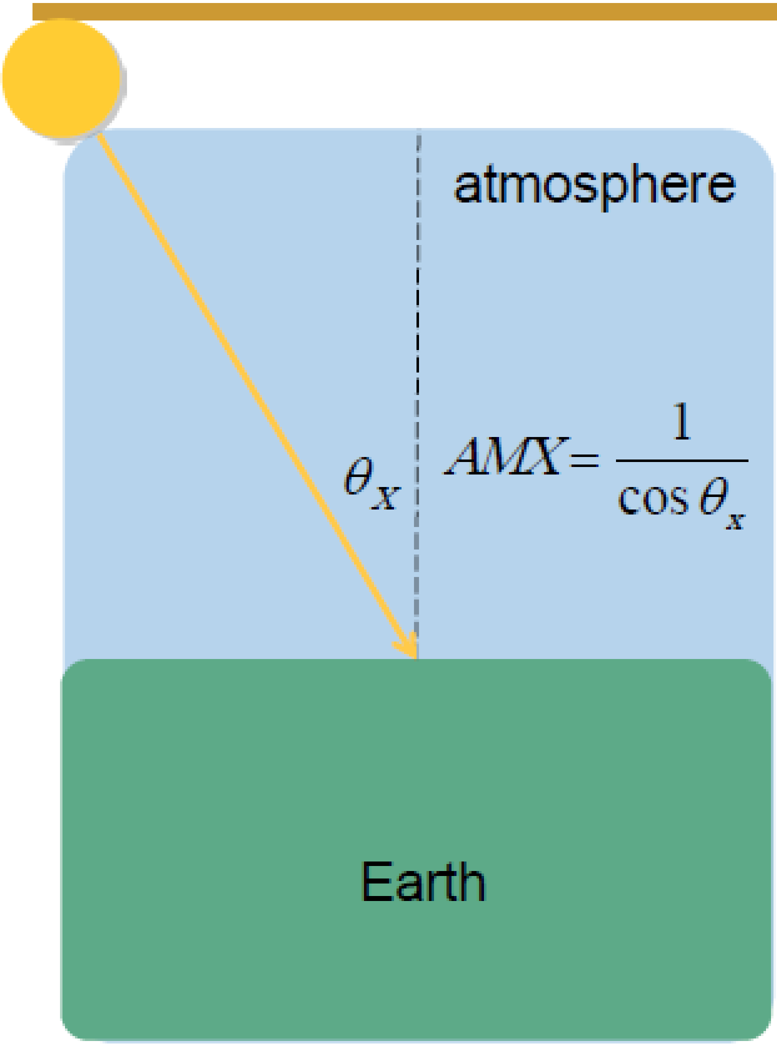
Source: The Cultural Economist
Data from BP

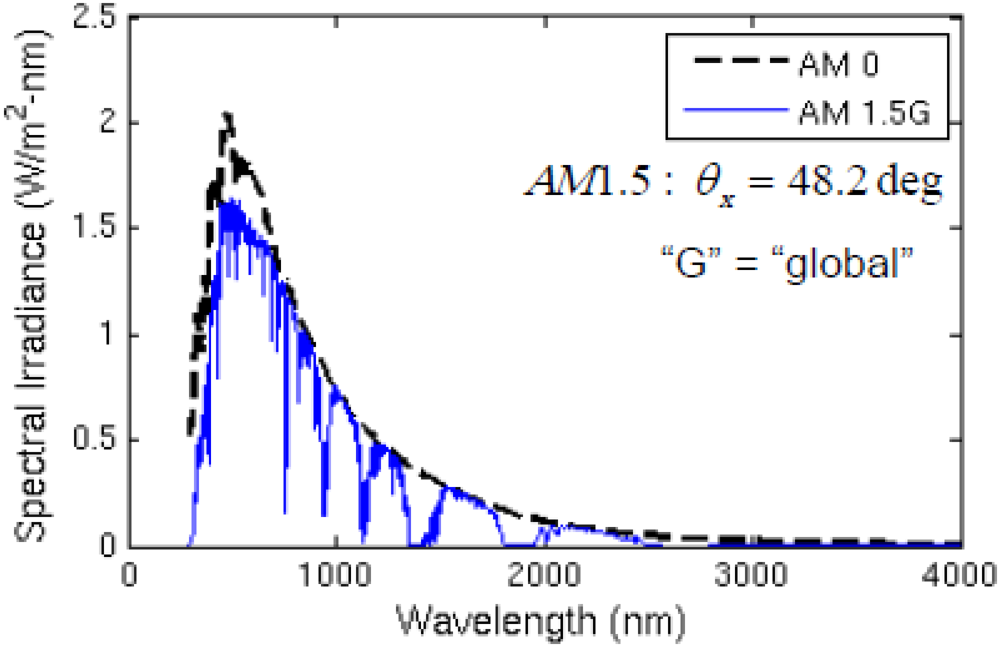
Adjusted World Energy Consumption By Fuel 2050



Source: The Cultural Economist

solar spectrum (terrestrial)

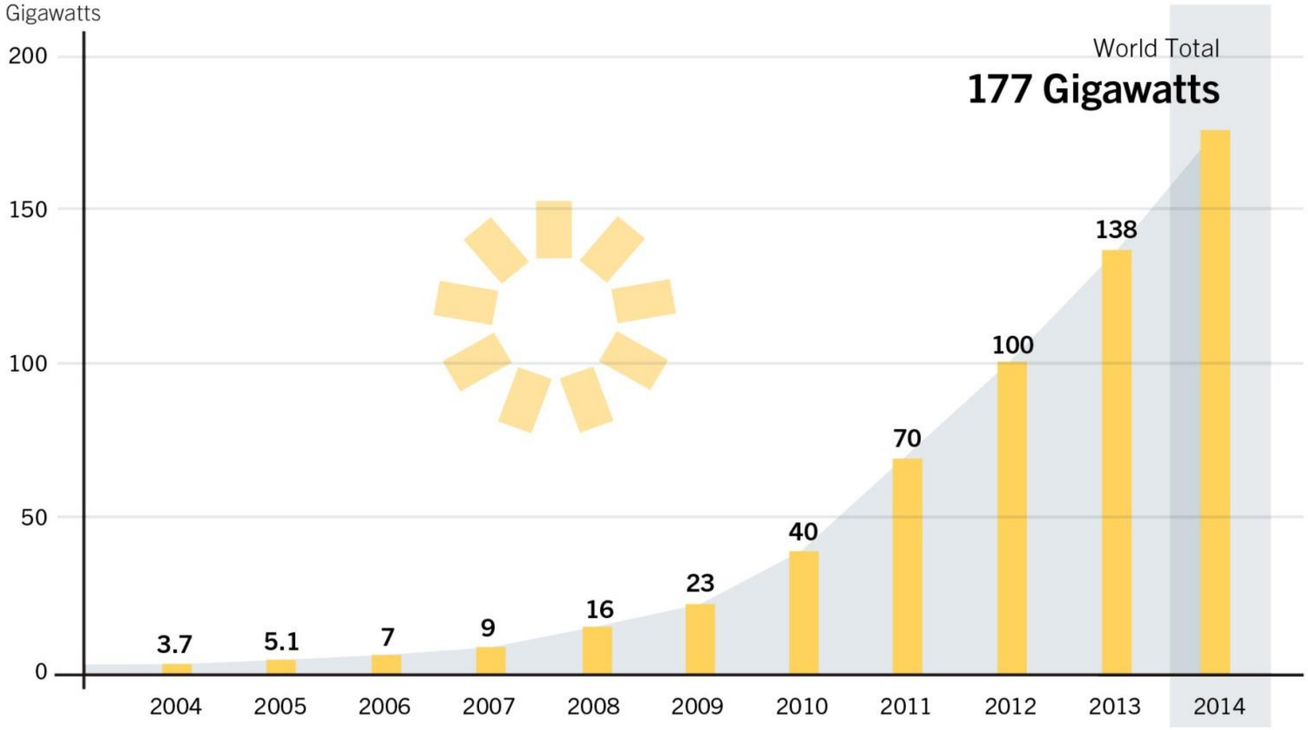




Integrated power = 100 mW/cm^2)

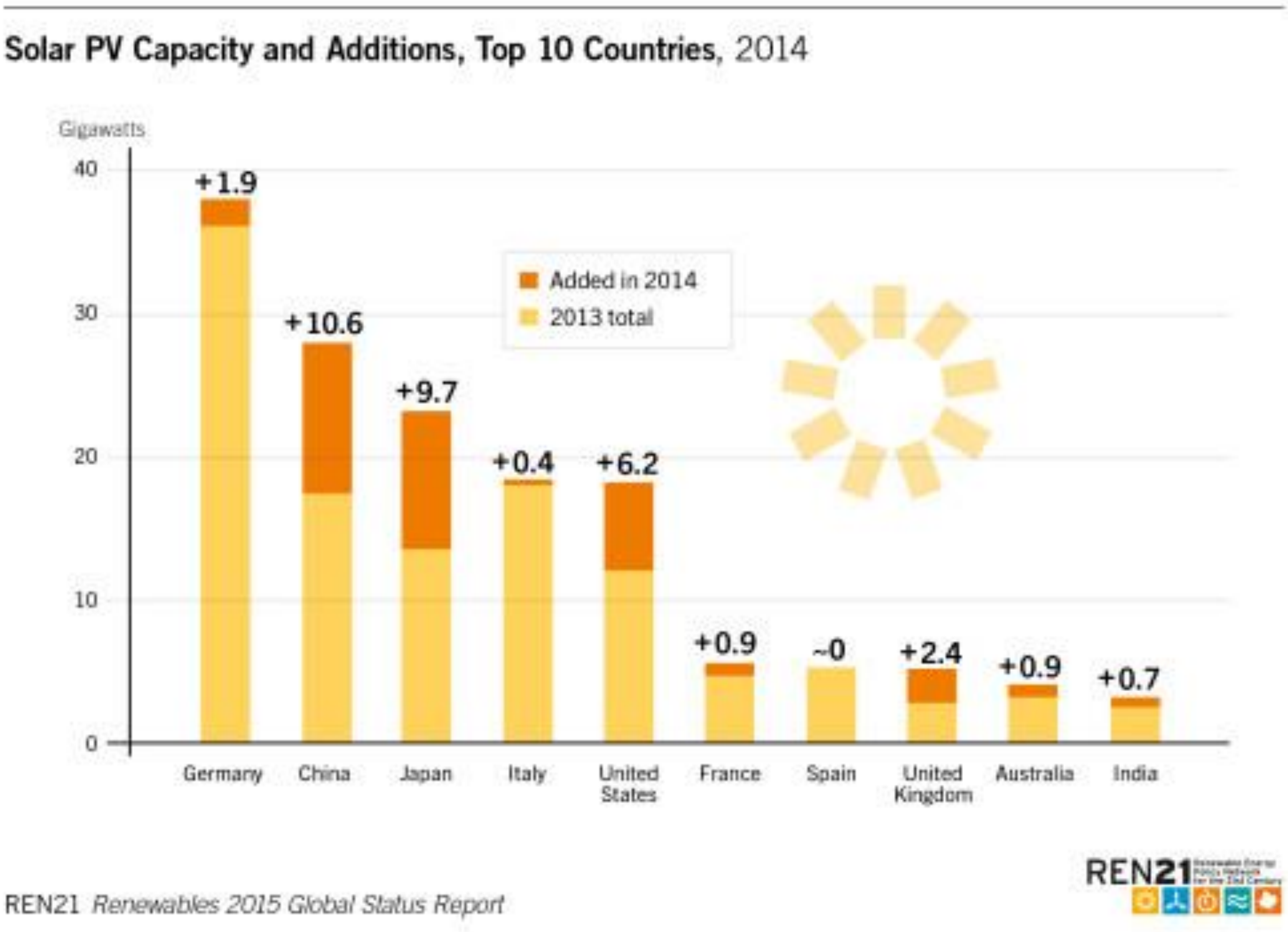
http://en.wikipedia.org/wiki/Air_mass_(solar_energy)

Solar PV Global Capacity, 2004–2014

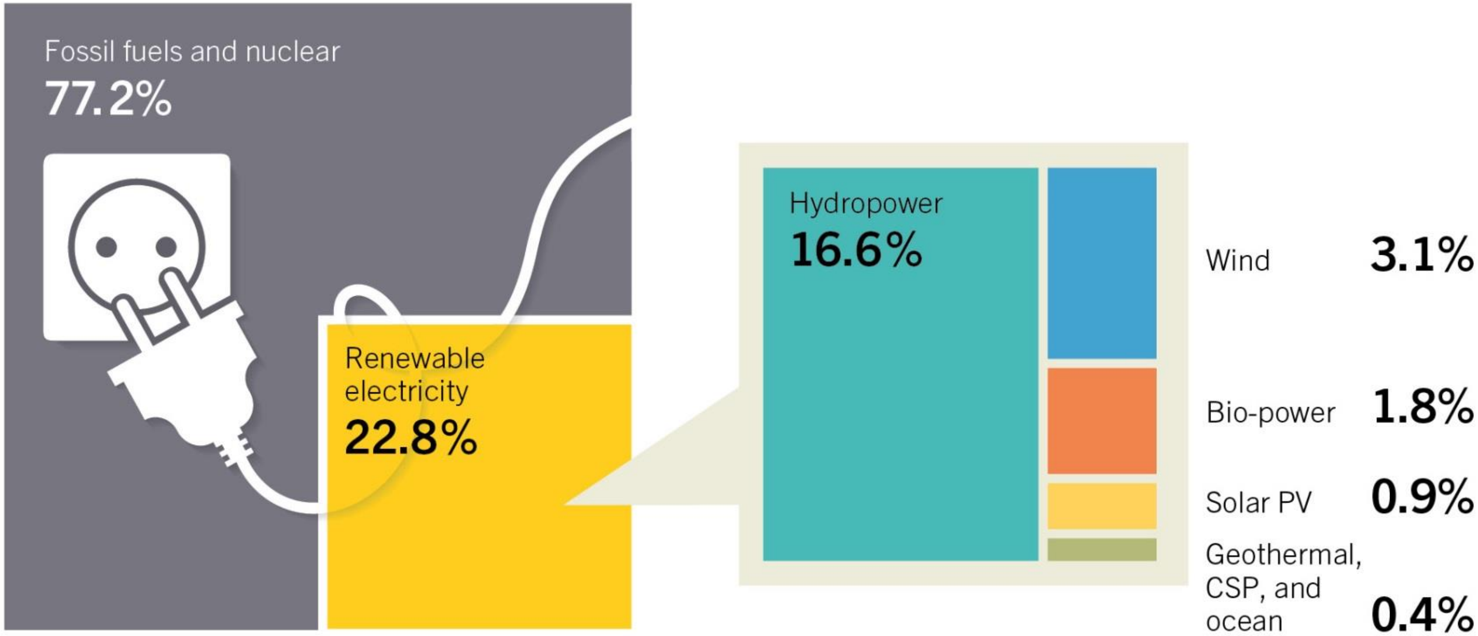


REN21 *Renewables 2015 Global Status Report*

HØGSKOLEN I BERGEN



Estimated Renewable Energy Share of Global Electricity Production, End-2014



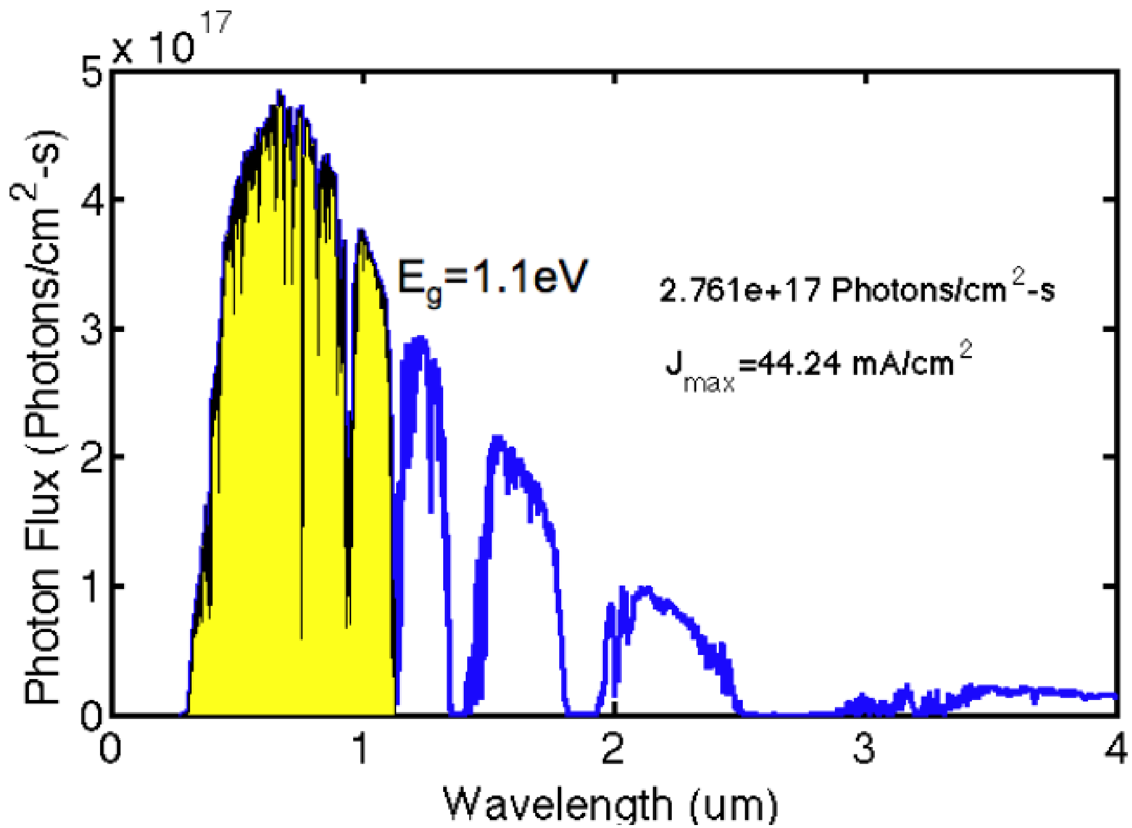
Based on renewable generating capacity in operation at year-end 2014.

REN21 *Renewables 2015 Global Status Report*

REN21 Renewable Energy Policy Network for the 21st Century

how many photons can be absorbed?

Example: Silicon E_g = 1.1eV. Only photons with a wavelength smaller than 1.1 μm will be absorbed.



solar spectrum (AM1.5G)

Lundstrom, 2011

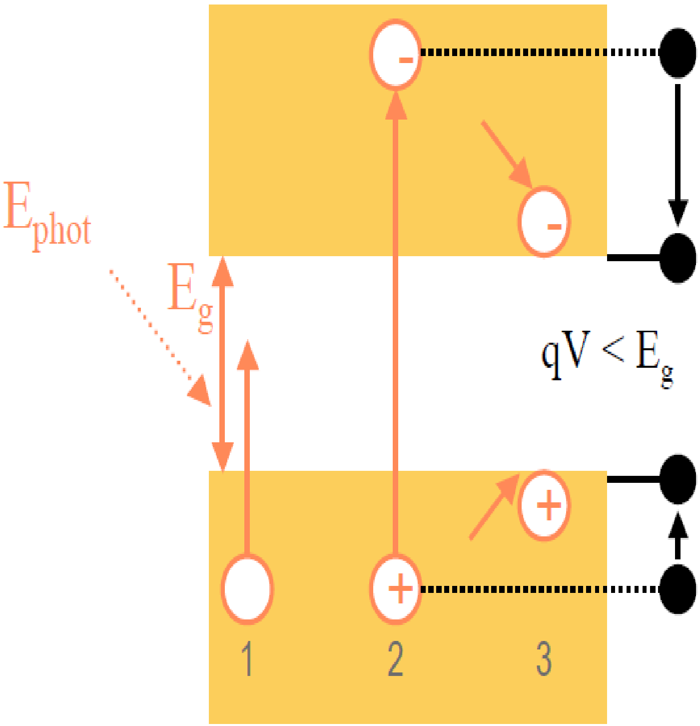
Solar Cell – Basics

The operation of a photovoltaic (PV) cell requires 3 basic attributes:

1. The absorption of light, generating either electron-hole pairs or excitons.
2. The separation of charge carriers of opposite types.
3. The separate extraction of those carriers to an external circuit.

The trouble with homo-junction solar cells

- Only photons with sufficient energy can excite e^- across the band gap E_g
- Insufficiently energetic photons with $E_{phot} < E_g$ will not contribute to the photocurrent generation
- Photons with $E_{phot} > E_g$ will initially generate energetic excited charge carriers
- Any energy in excess of E_g will be wasted heating up the solar cell through thermalization



Marstein et al, IFE

- Upper limit of homo junction is 33%

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Thermalization ($E > E_g$)	47%
Transmission ($E < E_g$)	18.5%
Recombination	1.5%
Remaining efficiency	33%
Total	100%

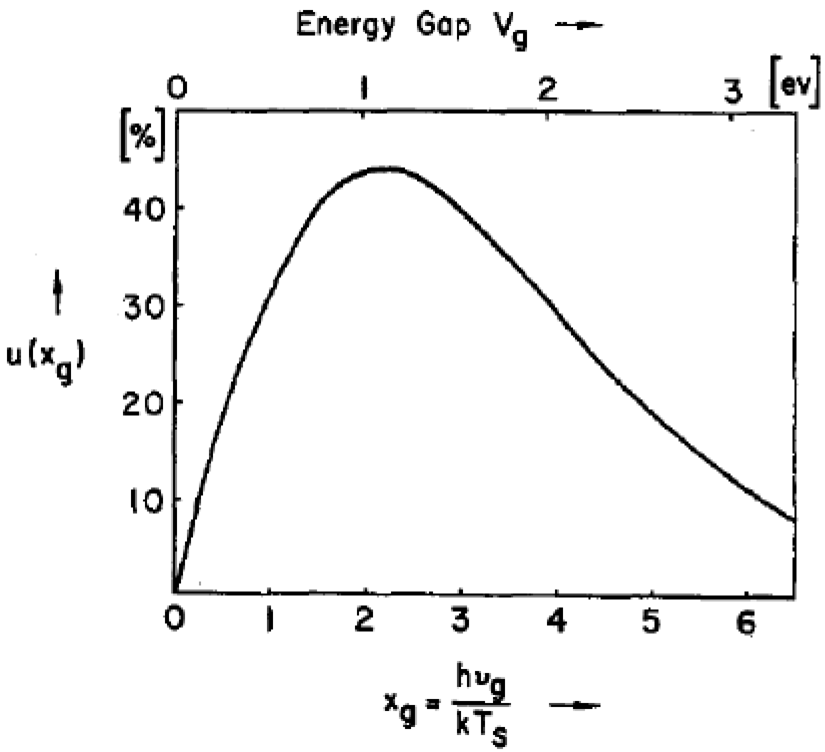
M.C. Beard et al., Nano Letters 7 (2007) p 2506

Shockley-Queisser Limit

1) Smaller bandgaps give higher short circuit current

2) Larger bandgaps give higher open-circuit voltage

3) For the given solar spectrum, an optimum bandgap exists.



W. Shockley, and H. J. Queisser, "Detailed Balance Limit of Efficiency of p-n Junction Solar Cells", *J. Appl. Phys.*, **32**, 510, 1961.

- Historical Developments –

- 1839: Photovoltaic effect was first recognized by French physicist Alexandre-Edmond Becquerel.

- 1883: First solar cell was built by Charles Fritts, who coated the semiconductor selenium with an extremely thin layer of gold to form the junctions (1% efficient).

- 1946: Russell Ohl patented the modern solar cell

- 1954: Modern age of solar power technology arrives – Bell Laboratories, experimenting with semiconductors, accidentally found that silicon doped with certain impurities was very sensitive to light.

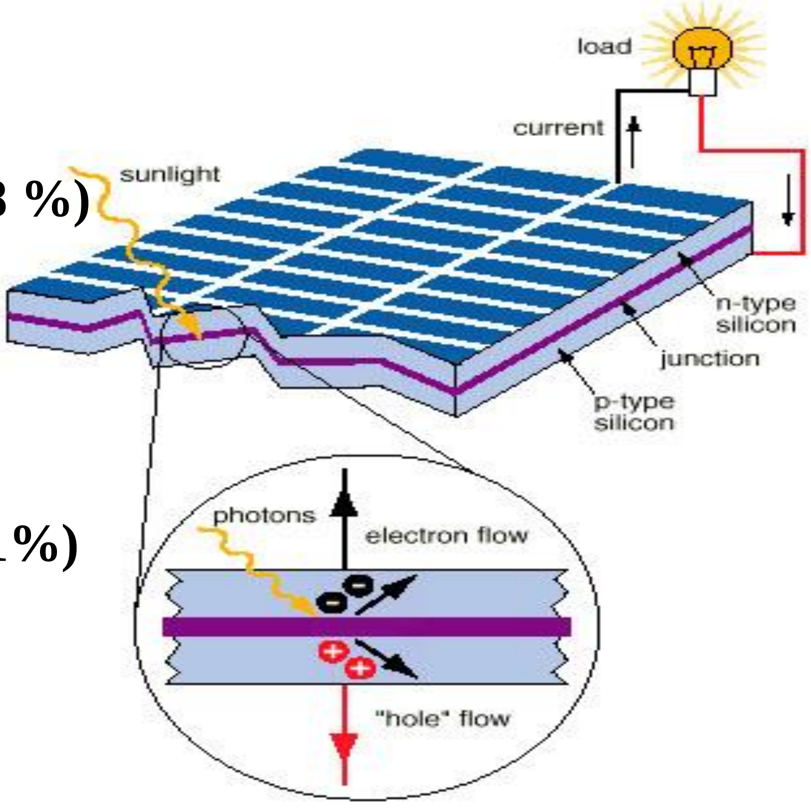
DIFFERENT GENERATION OF SOLAR CELLS

(1) First generation – Silicon solar cells

Silicon

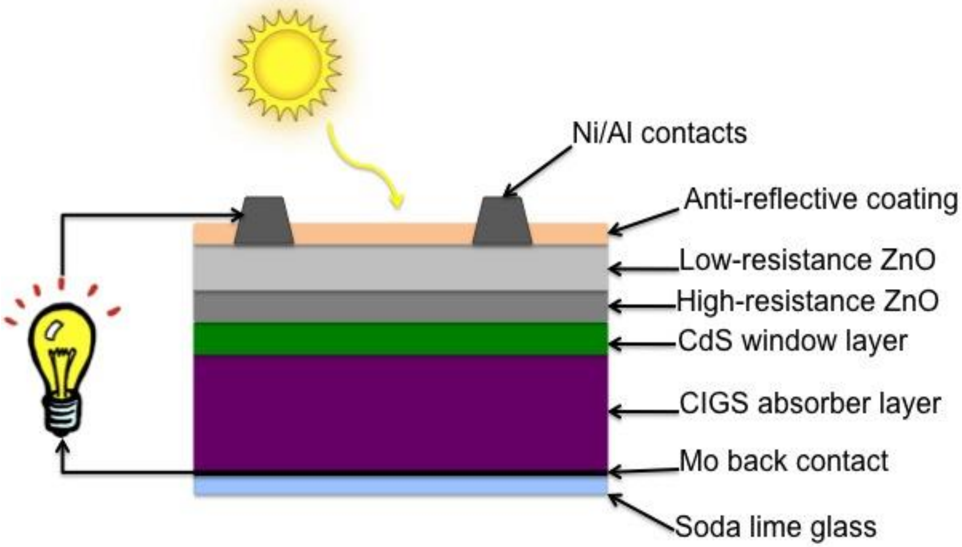
Single crystalline silicon (28 %)

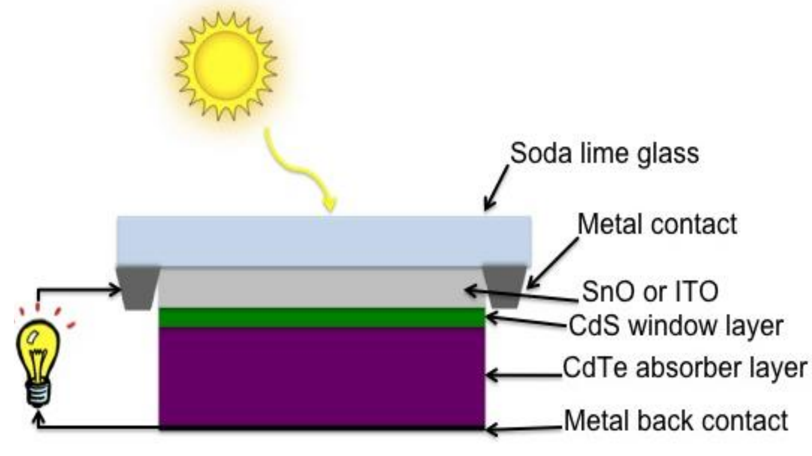
Multicrystalline silicon (21%)

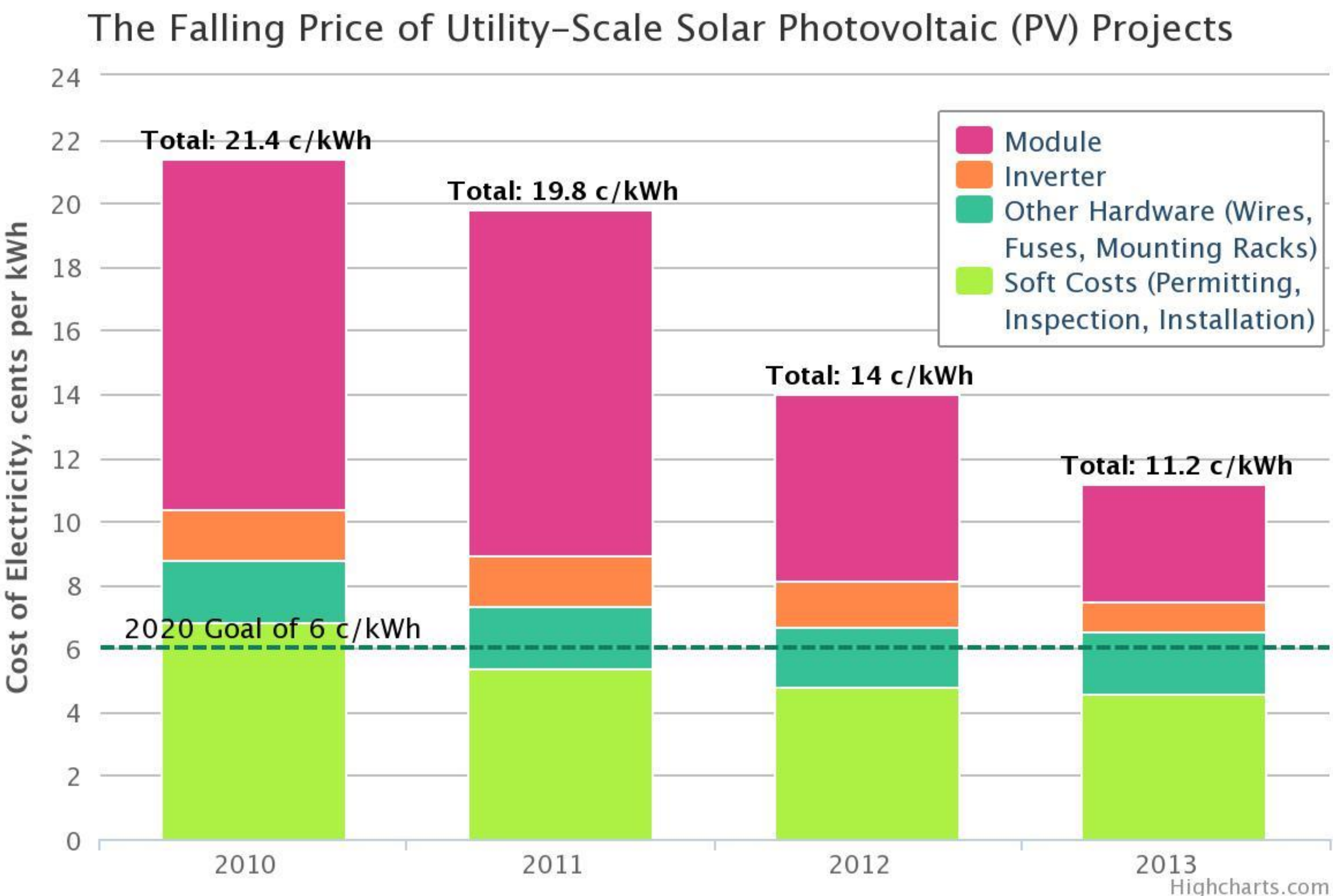


(2) Second generation – Thin film solar cells

Thin film solar cells →
- Amorphous silicon (16 %)
- Copper indium gallium diselenide (CIGS) (20 %)
- Cadmium Telluride (CdTe) (17 %)





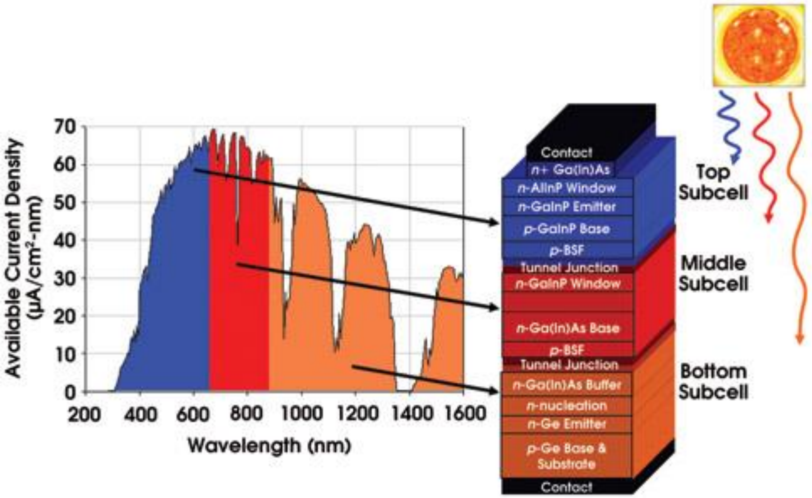


http://www1.eere.energy.gov/solar/

(3) Third generation solar cells

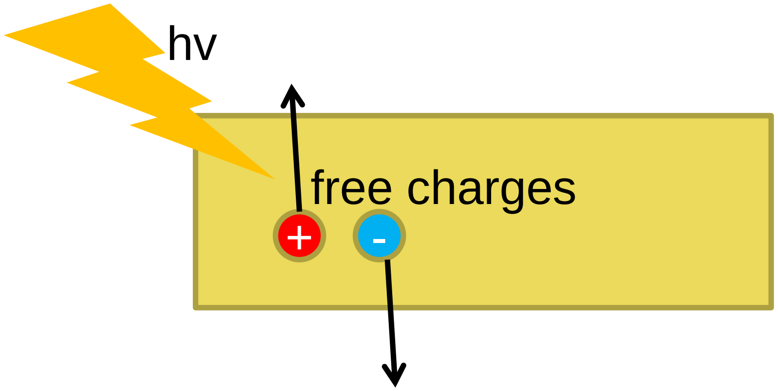
Third generation solar cells →

- **Multijunction solar cells**
- **Dye sensitized solar cells**
- **Quantum dot sensitized solar cells**
- **Organic or polymer solar cells**

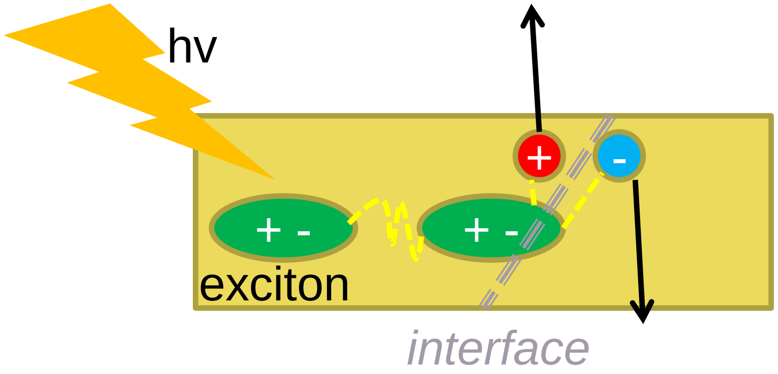


A multijunction solar cell composed of multiple layers of various semiconductor materials can convert more than 40 percent of incoming sunlight into usable electricity – Photonics Spectra

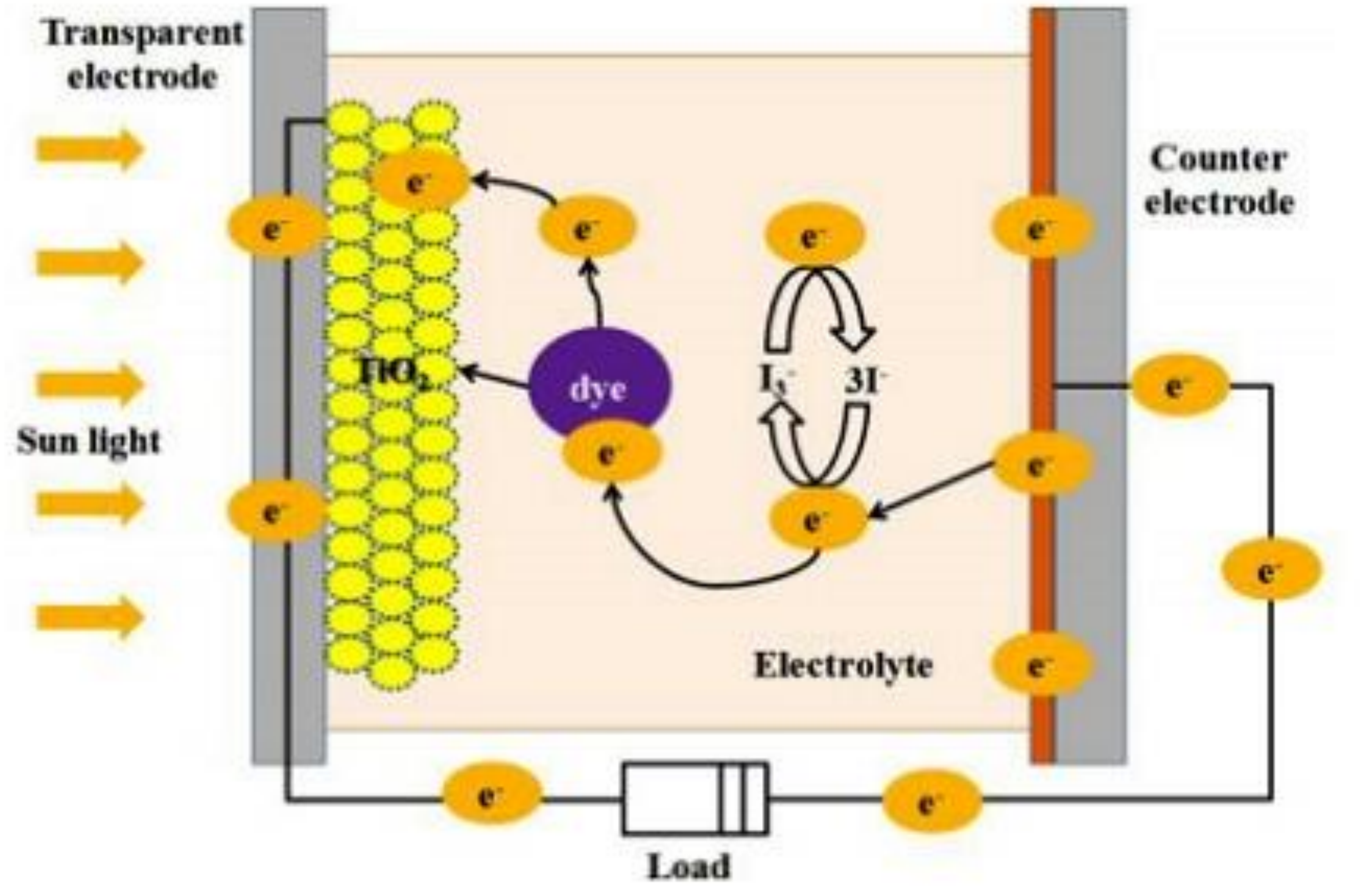
Conventional Solar Cell
(p-n junction Si)



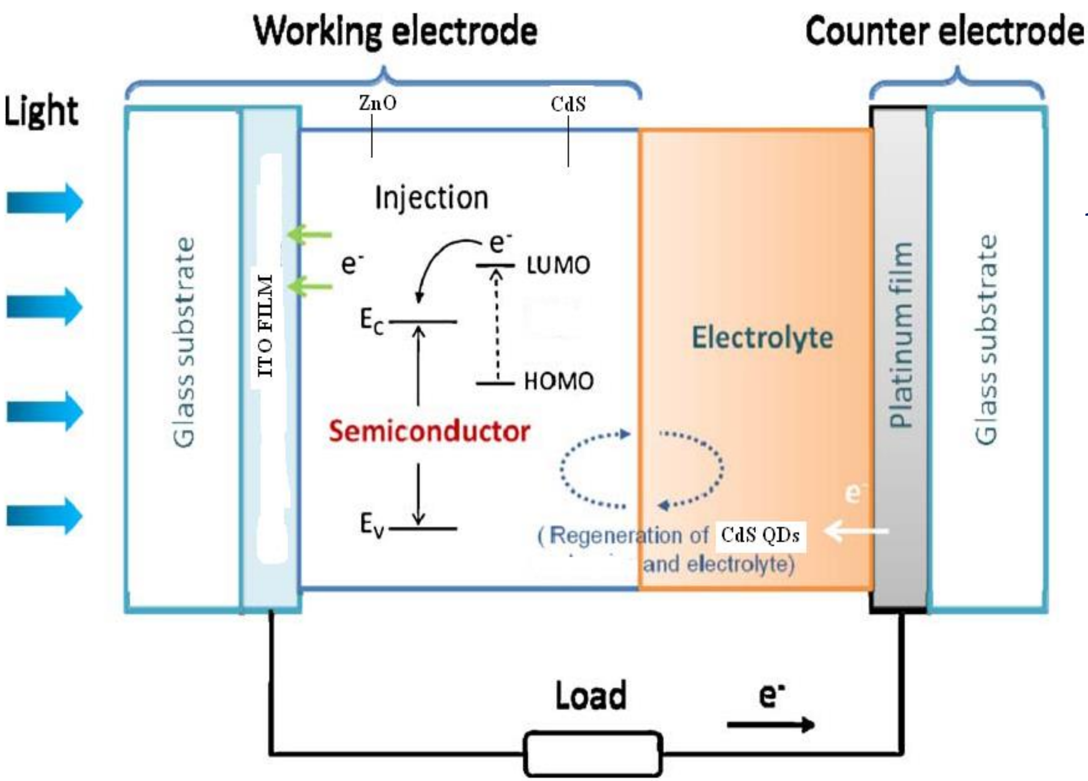
Excitonic Solar Cell
(DSSC, OPV)



a) Schematic diagram of dye-sensitized solar cells



(b) Quantum dot sensitized solar cells



Advantages – adjustable band gap,

high extinction coefficients,

flexible substrate,

low cost of materials,

better stability,

and long life time.

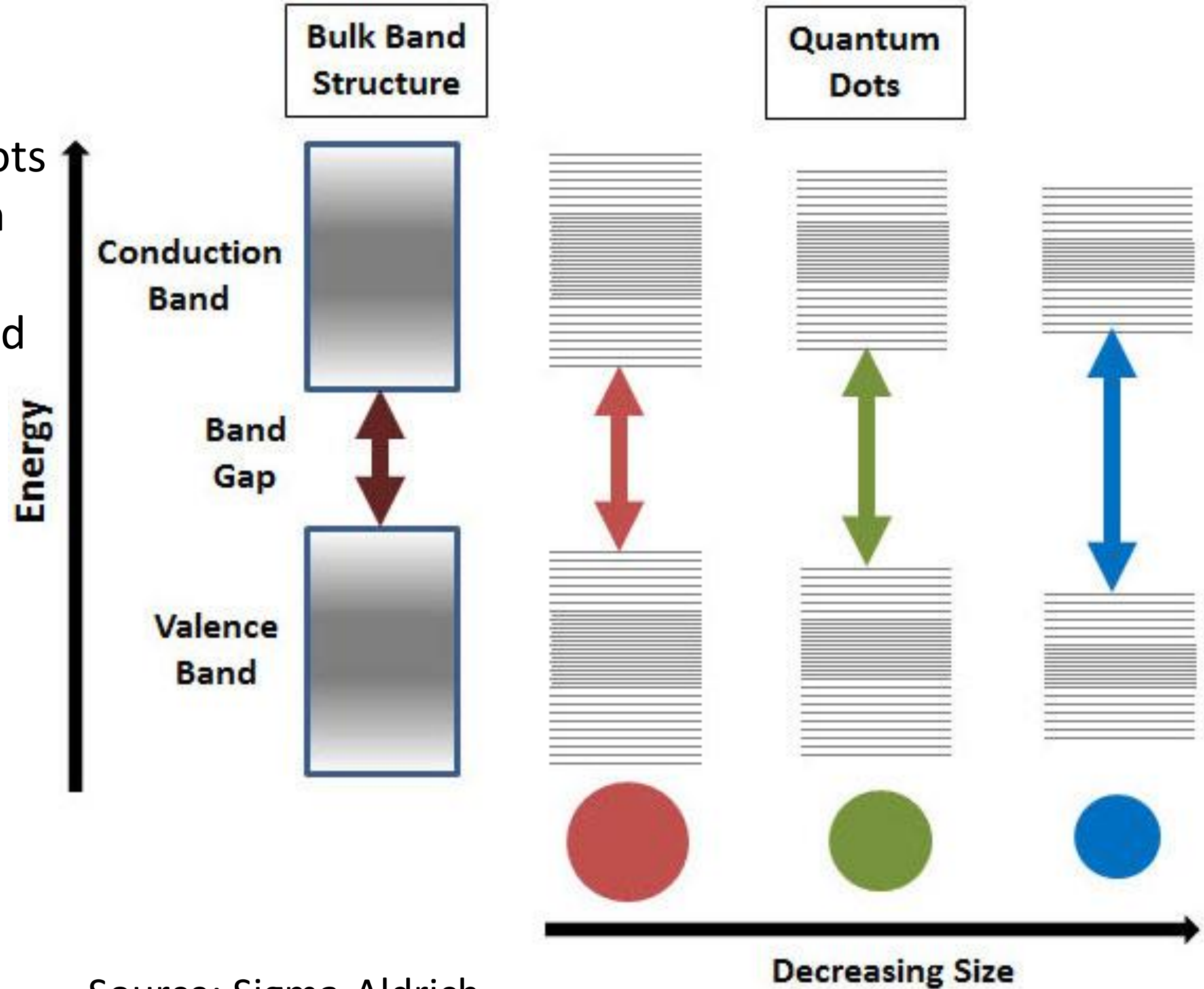
Schematic diagram of quantum dot sensitized solar cells

HOMO-highest occupied molecular orbital

LUMO-lowest unoccupied molecular orbital

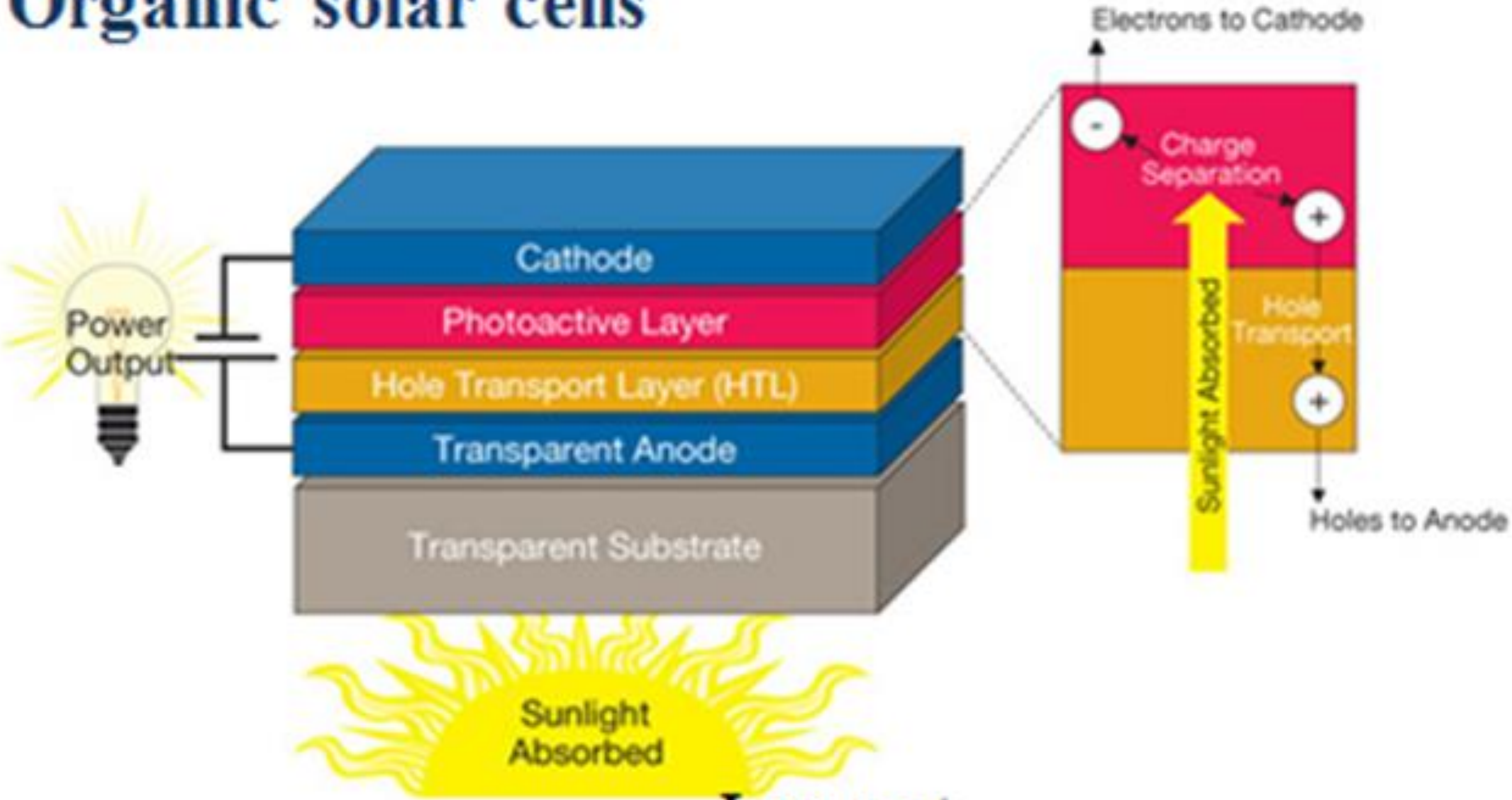
Quantum Confinement effect

Splitting of energy levels in quantum dots due to the quantum confinement effect, semiconductor band gap increases with decrease in size of the nanocrystal.



Source: Sigma-Aldrich

(c) Organic solar cells

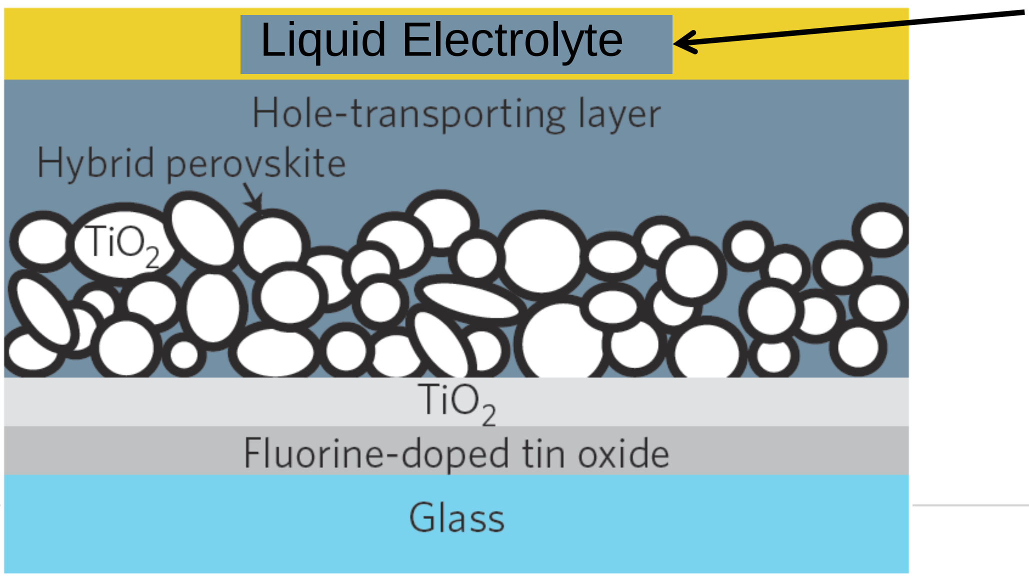


Advantages →

- Low cost
- Light weight
- Easy to fabrication
- Flexible, semi-transparent, etc.,

d) Perovskite Solar Cells

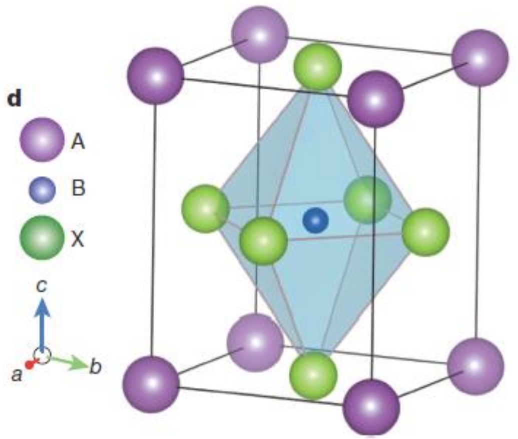
- Dyes do not absorb all the incident light, reducing DSSC efficiency.
- In 2009, Miyasaka (Toin U. of Yokohama, Japan) turns to perovskite as possible replacement of the dye and achieved 3.8% efficiency.
- Problem: Liquid electrolyte dissolved away the perovskite within minutes.

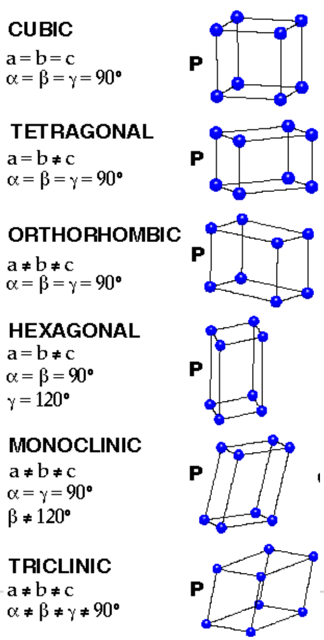


0.15 M LiI and 0.075 M I_2 in methoxyacetonitrile

JACS. 2009, 131, 6050.

CH_3NH_3PbX – Perovskite ABX_3





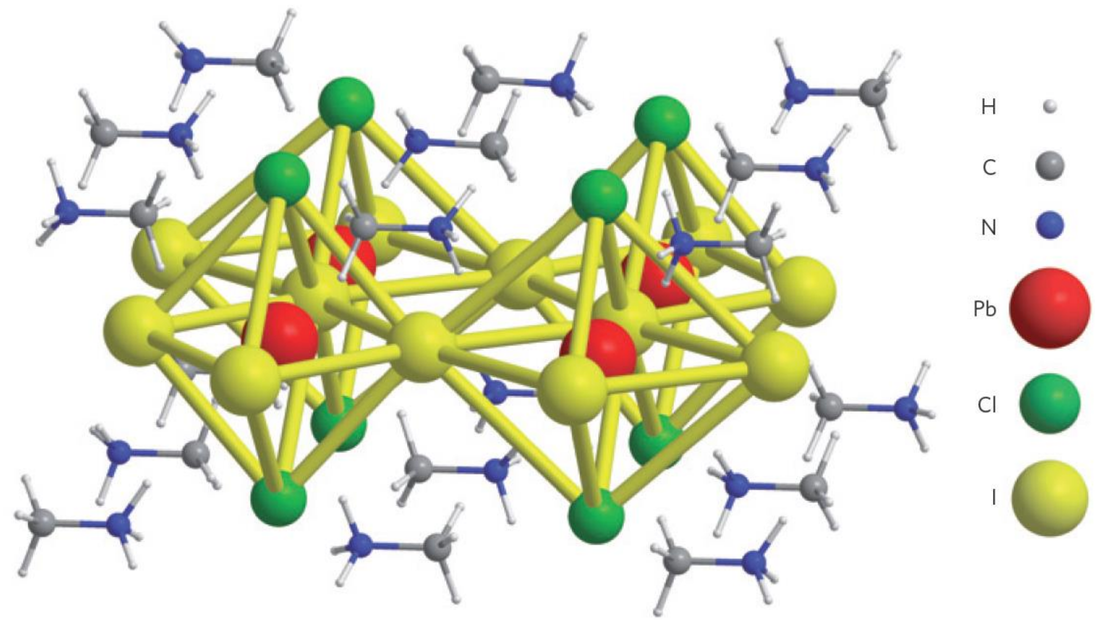


Figure 1 | Crystal structure. Possible structure of the hybrid perovskite $CH_3NH_3PbI_{3-x}Cl_x$. At present, crystallographic data on the precise position of the organic ligands are not available.

Phase Transition ($CH_3NH_3PbI_3$):

Orthorhombic → Tetragonal → Cubic

162 K 327 K (54 C)

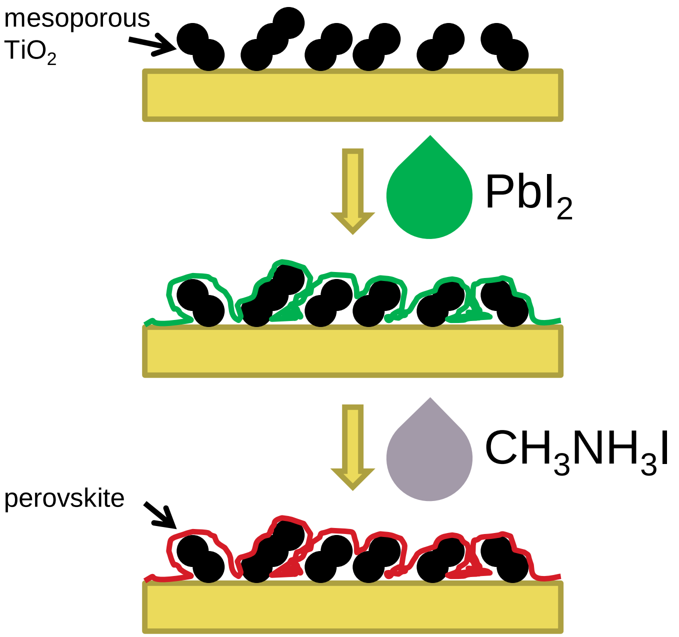
The organic ligand is disordered in Tetragonal and Cubic phase.

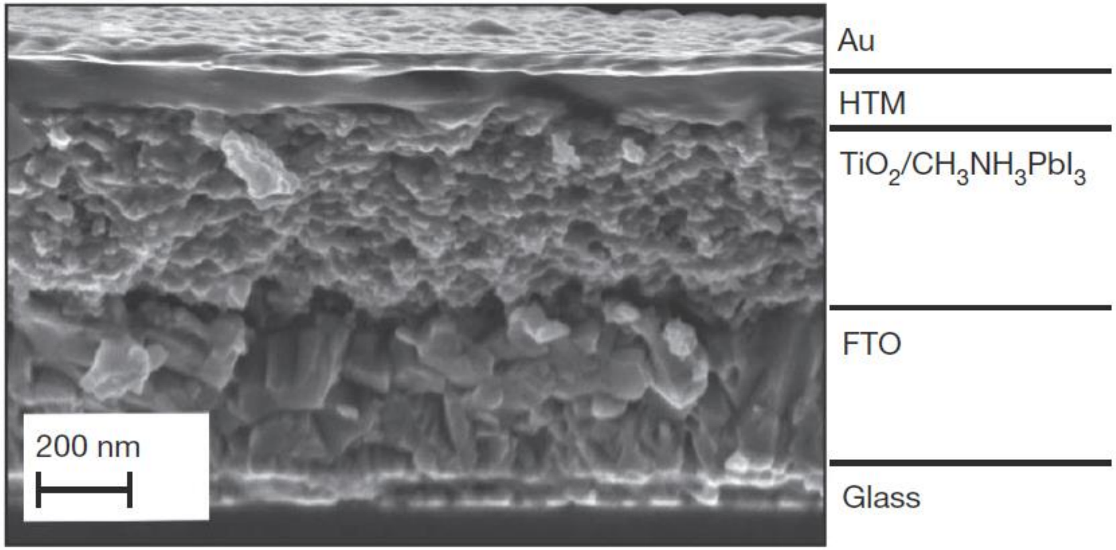
Nature. 2013, 12, 1087

J. Mater. Chem. A, 2013, 1, 15628

DSSC with Perovskite

2013, Grätzel sticks with the TiO_2 structure and tinkered with the deposition step.





Efficiency: 15%

Nature. 2013, 499, 316

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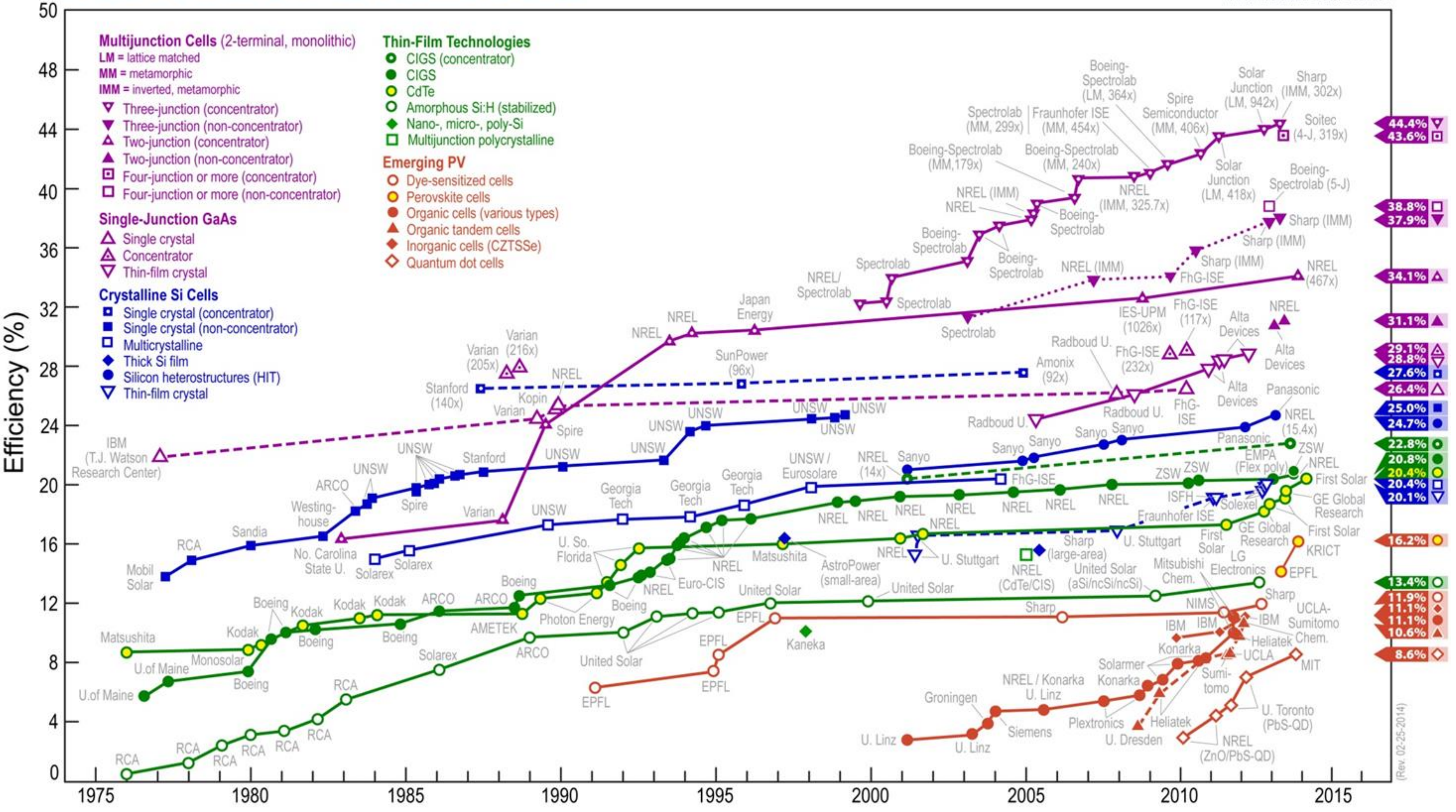
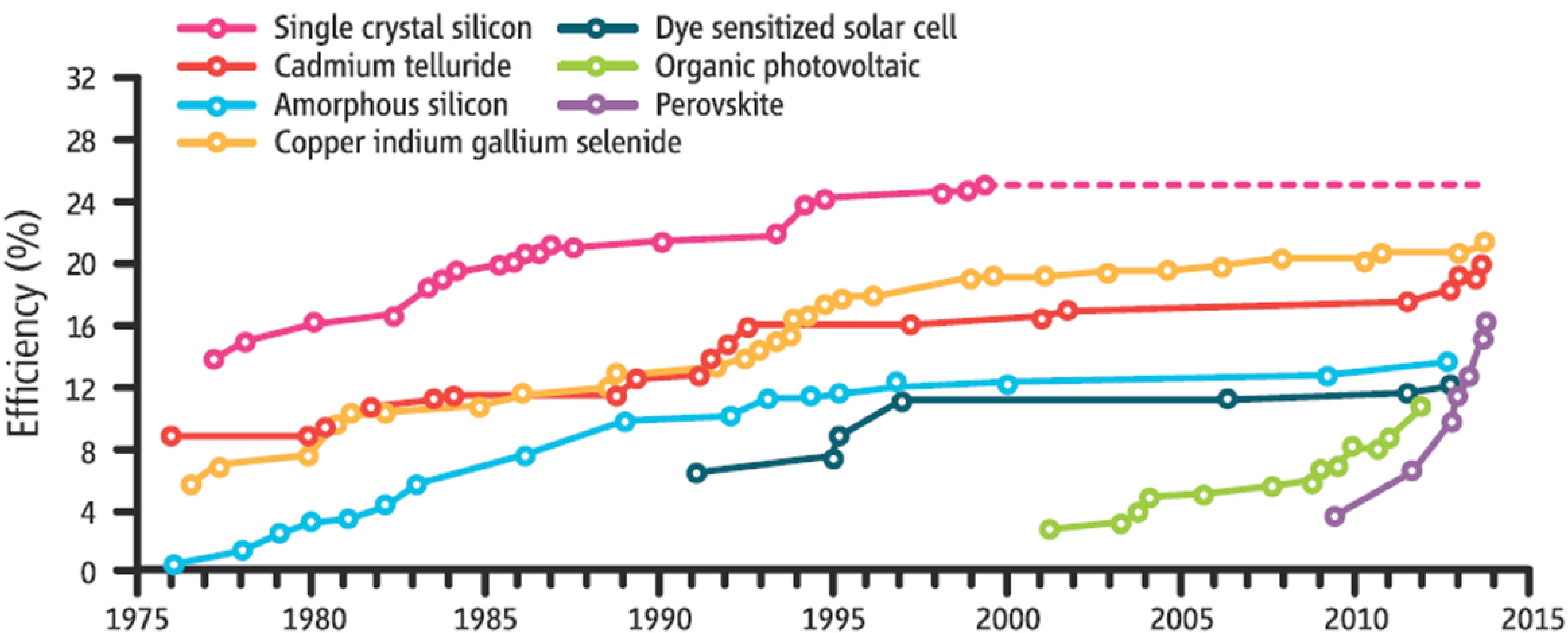
Best Research-Cell Efficiencies

NREL

NATIONAL RENEWABLE ENERGY LABORATORY



Best Research-Cell Efficiencies



Solar cell	Highest reported efficiency (%)
Silicon (single crystal, single cell)	27.6 ±1.0
CIGS (thin film, single cell)	20.3 ±0.6
CdTe (thin film, single cell)	16.7 ±0.5
Dye-sensitized (single cell)	11.2 ±0.3
Organic polymer (single cell)	9.2 ±0.3
Perovskite	15.0±0.3
InGaP/GaAs/InGaAs (tandem cell)	42.3 ±2.5

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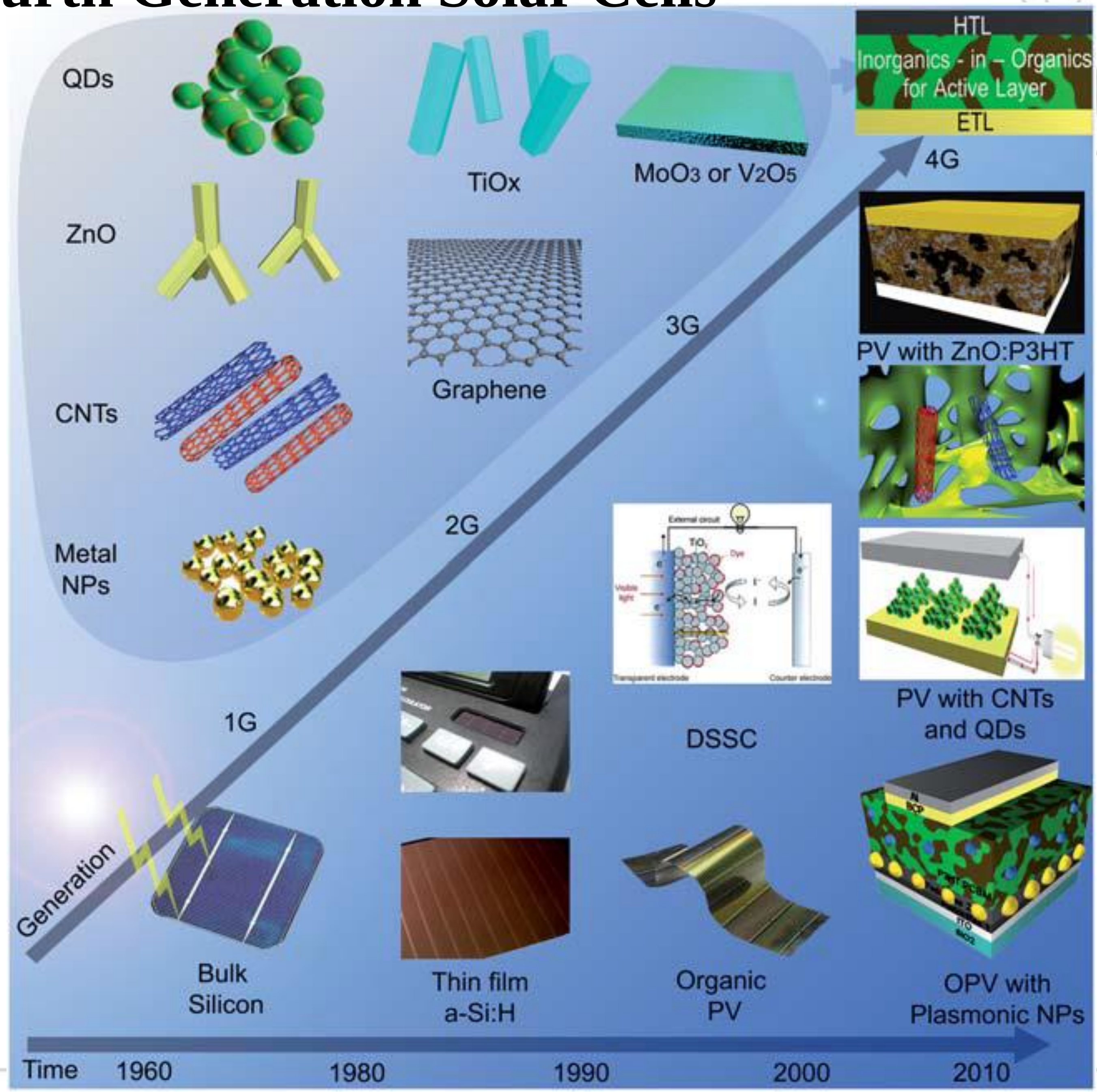
Fourth Generation Solar Cells

Timeline
1G to 4G

Nanoscale,
2013, 5,
8411–8427



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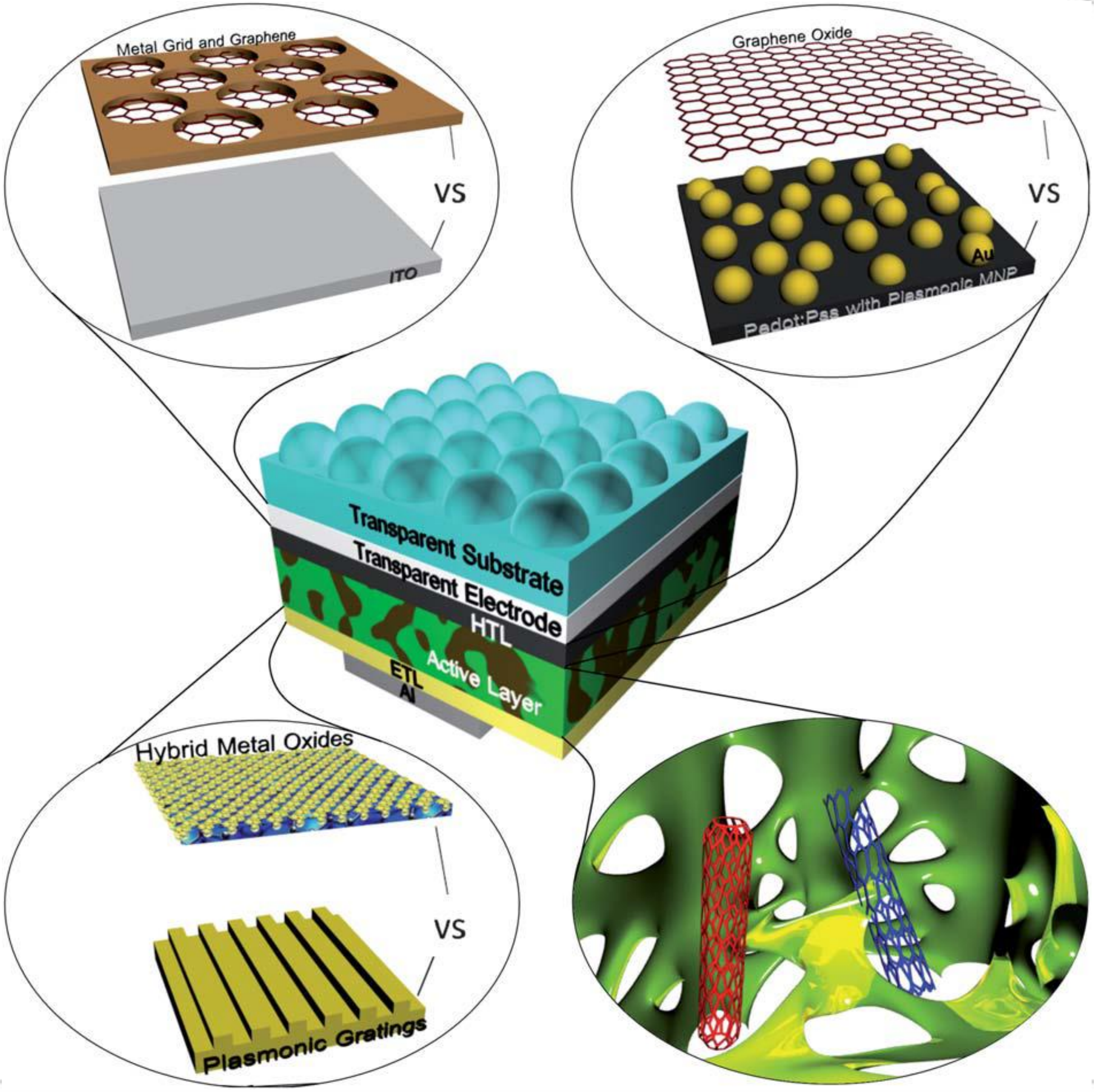
Fourth Generation Solar cells

Hybrid - inorganic crystals within a polymer matrix

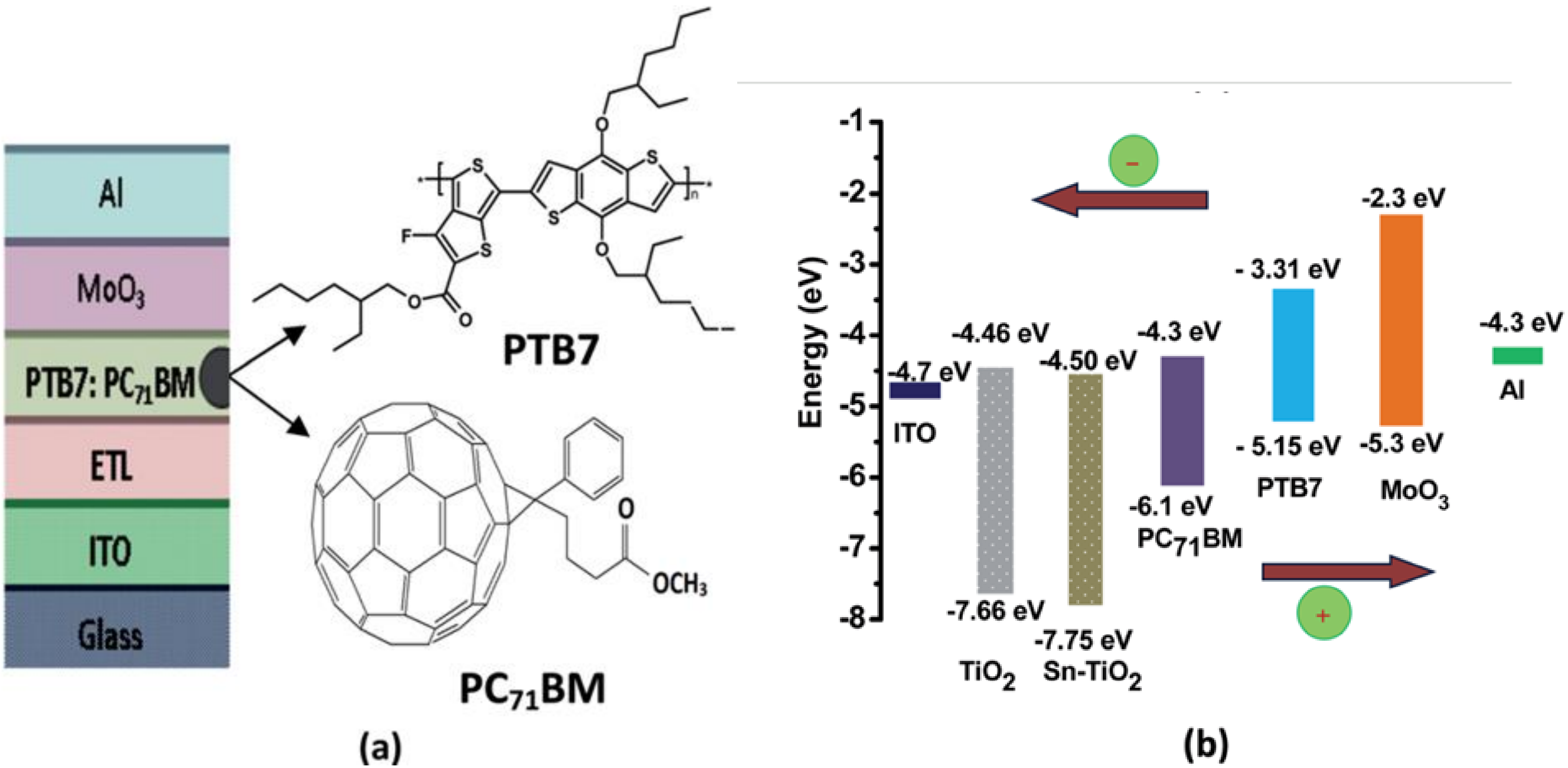
Nanoscale,
2013, 5,
8411–8427



Organic Solar Cells – Future Applications

Courtesy - SNE Research

DOPED TiO_2/PTB7:PC_{71}BM BASED INVERTED POLYMER SOLAR CELLS



J. Mater.Chem. 2014, 2, 11426

Journal of
Materials Chemistry C

RSCPublishing

PAPER

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High performance inverted organic solar cells with solution processed Ga-doped ZnO as an interfacial electron transport layer†

Cite this: *J. Mater. Chem. C*, 2013, **1**, 8161

M. Thambidurai,‡*[a] Jun Young Kim,‡[a] Jiyun Song,[a] Youngjun Ko,[a] Hyung-jun Song,[a] Chan-mo Kang,[a] N. Muthukumarasamy,[b] Dhayalan Velauthapillai[c] and Changhee Lee*[a]

Received 21st August 2013
Accepted 18th October 2013

DOI: 10.1039/c3tc31650e

www.rsc.org/MaterialsC

We demonstrate solution-processed Ga-doped ZnO incorporated as an interfacial electron transport layer into inverted organic solar cells with active layers comprising either PCDTBT or PTB7 mixed with $PC_{71}BM$. The 5.03 at% Ga-doped ZnO showed the best efficiencies of 5.56% and 7.34% for PCDTBT and PTB7 polymers respectively.

DOPED TiO_2/PTB7:PC_{71}BM BASED INVERTED POLYMER SOLAR CELLS

Journal of Materials Chemistry A

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
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Cite this: J. Mater. Chem. A, 2014, 2, 11426

Enhanced power conversion efficiency of inverted organic solar cells by using solution processed Sn-doped TiO_2 as an electron transport layer†

M. Thambidurai,‡*[a] Jun Young Kim,‡[a] Hyung-jun Song,[a] Youngjun Ko,[a] N. Muthukumarasamy,[b] Dhayalan Velauthapillai,[c] Victor W. Bergmann,[d] Stefan A. L. Weber[d] and Changhee Lee*[a]

Received 29th January 2014
Accepted 28th April 2014

DOI: 10.1039/c4ta00531g

www.rsc.org/MaterialsA

We have investigated the photovoltaic properties of inverted solar cells comprising a bulk heterojunction film of thieno[3,4-*b*]-thiophene/benzodithiophene (PTB7) and [6,6]-phenyl-C_{71}-butyric acid methyl ester ($PC_{71}BM$), sandwiched between indium tin oxide (ITO)/Sn-doped TiO_2 front and MoO_3/aluminum back electrodes. The inverted organic solar cell (IOSC) fabricated with a Sn-doped TiO_2 film showed a significantly greater power conversion efficiency of 7.59%, compared to that of the TiO_2 film (6.70%). Further studies confirm that the improved morphology and electrical properties of the Sn-doped TiO_2 film result in reduced shunt loss and interfacial charge recombination and hence enhanced photovoltaic performance.

Nanoscale

COMMUNICATION

View Article Online
View Journal | View Issue

Cite this: *Nanoscale*, 2014, **6**, 8585

Received 21st May 2014
Accepted 2nd June 2014

DOI: 10.1039/c4nr02780a

www.rsc.org/nanoscale

High-efficiency inverted organic solar cells with polyethylene oxide-modified Zn-doped TiO_2 as an interfacial electron transport layer†

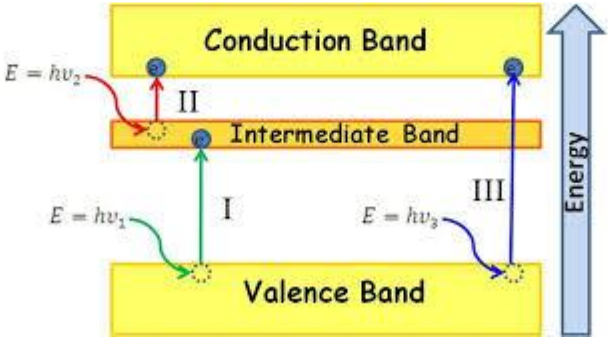
M. Thambidurai,‡*[a] Jun Young Kim,‡[a] Youngjun Ko,[a] Hyung-jun Song,[a] Hyeonwoo Shin,[a] Jiyun Song,[a] Yeonkyung Lee,[a] N. Muthukumarasamy,[b] Dhayalan Velauthapillai[c] and Changhee Lee*[a]

High efficiency inverted organic solar cells are fabricated using the PTB7:$PC_{71}BM$ polymer by incorporating Zn-doped TiO_2 (ZTO) and 0.05 wt% PEO:ZTO as interfacial electron transport layers. The 0.05 wt% PEO-modified ZTO device shows a significantly increased power conversion efficiency (PCE) of 8.10%, compared to that of the ZTO (7.67%) device.

Ongoing solar cell research

Eksperimental:

- ❑ Dye Sensitized Solar Cells (DSSC)
- ❑ Quantum Dots Sensitized Solar Cells (QDSSC)
- ❑ CZTS based Solar Cells
- ❑ Organic Solar Cells (OSC)
- ❑ Perovskite Solar Cells - *initial stages*



Computational:

- ❖ Simulation study on nano structures for solar cell applications
- ❖ Simulation study on Intermediate Bandgap Solar Cells