PHOTOVOLTAICS

Direct Conversion of Sunlight to Electricity

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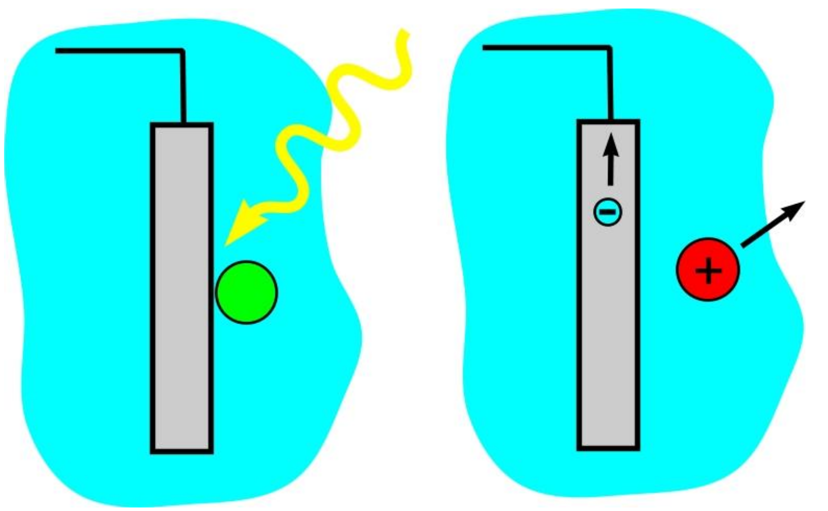
Photovoltaic effect
Early (simple) solar cells: 1839 –
Heterojunction solar cells: 1946 –
- principle of operation
- commercial solar cells and modules

Distributed junction solar cells
State of the Art?

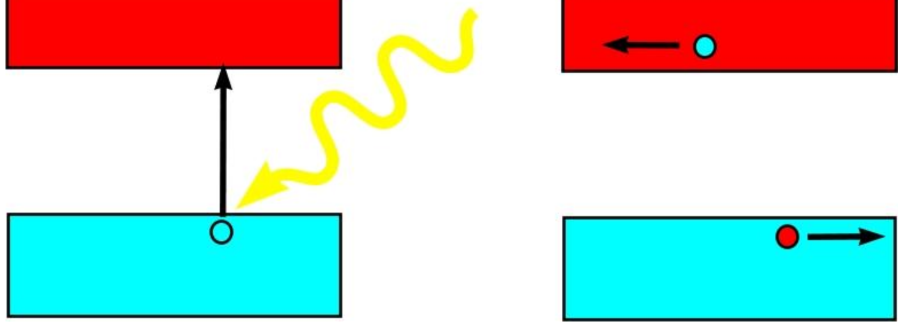
PHOTOVOLTAIC EFFECT

Light generates free charges

Photochemical
Edmond Becquerel,
Comptes Rendus **9**, 561 – 567 (1839)



electrons and ions



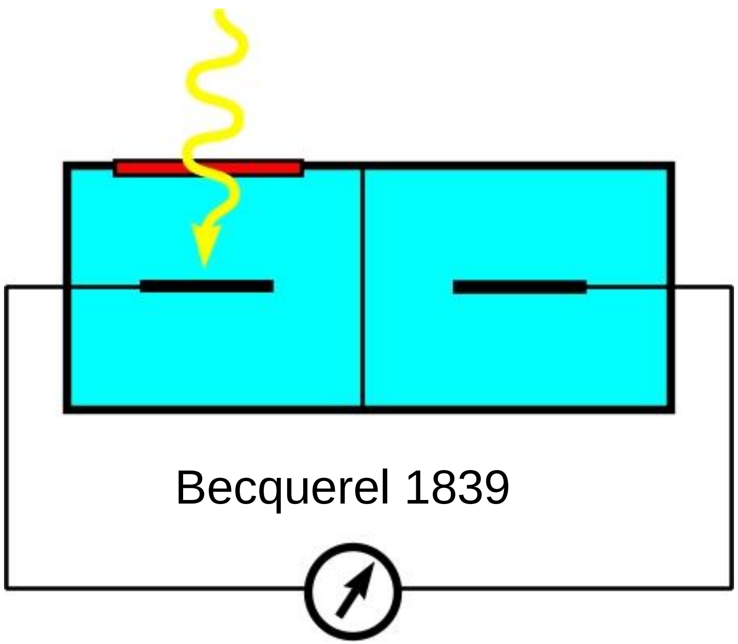
Solid State
W.G. Adams & R.E. Day,
Proc Roy Soc Lond **25**, 113 -117 (1876)

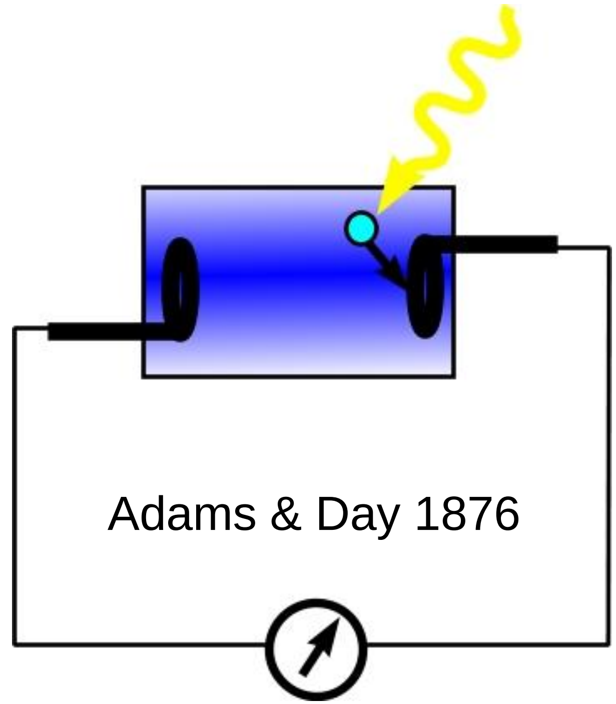
electrons and holes

SIMPLE SOLAR CELLS

(photoresistors)

Single homogeneous material between two contacts
Diffusion/drift of charge to one electrode gives current
Voltage is low

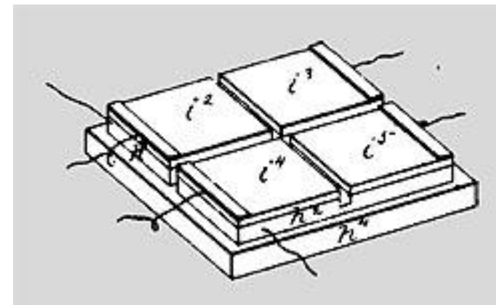




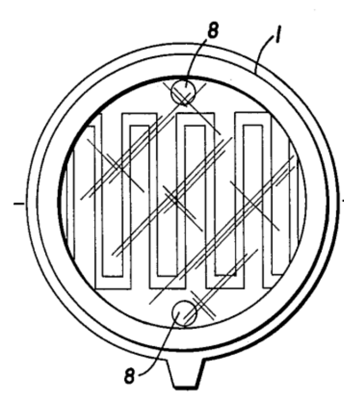
illuminated electrode is cathode

SIMPLE SOLAR CELLS

(photoconductors)



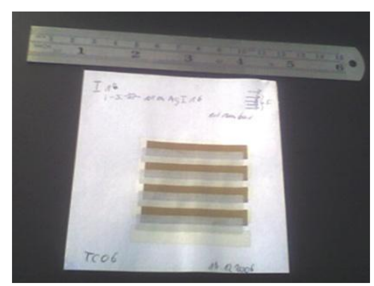
First thin film solar cell Charles Fritts 1882
Selenium with thin gold leaf front electrode,
(transparent to green light)
tin plated back electrode
Am J. Sci **26,** 465 – 482 (1883)

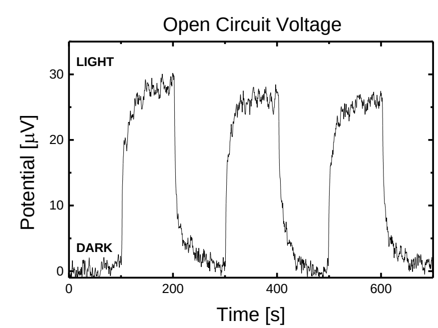


PV discovered in Fritts cell by W. Siemens
Sitzungsber. Preuss. Akad.Wiss zu Berlin
1885 (I), 147-148

Screen printed CdS, CdSe Y. T Sivhonen &
S.G. Parker 1963, (Texas Instruments)
US 3208022 (1965)

First fully printed silicon cell 2008



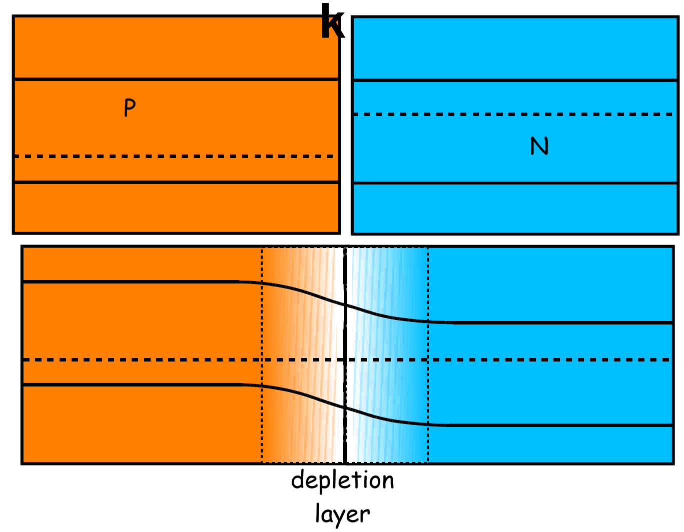


HETEROJUNCTION SOLAR CELLS

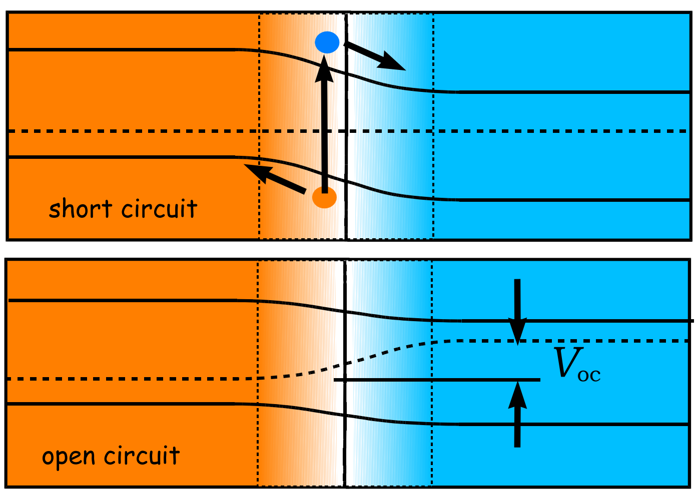
(photodiodes)

Inbuilt electric field
Anode and Cathode given by diode direction

dark



light



electrons & holes produced in the junction
electrons pulled to n-type layer
holes puled to p-type layer

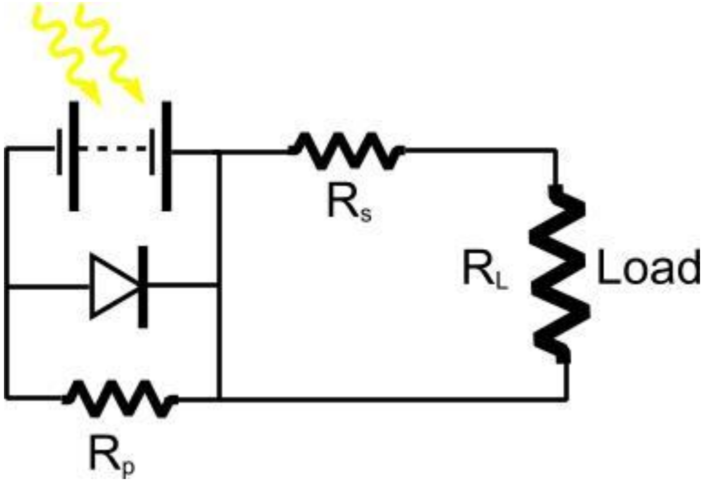
Short circuit current j_{sc} is from n to p
Open circuit : charge collection gives V_{oc}

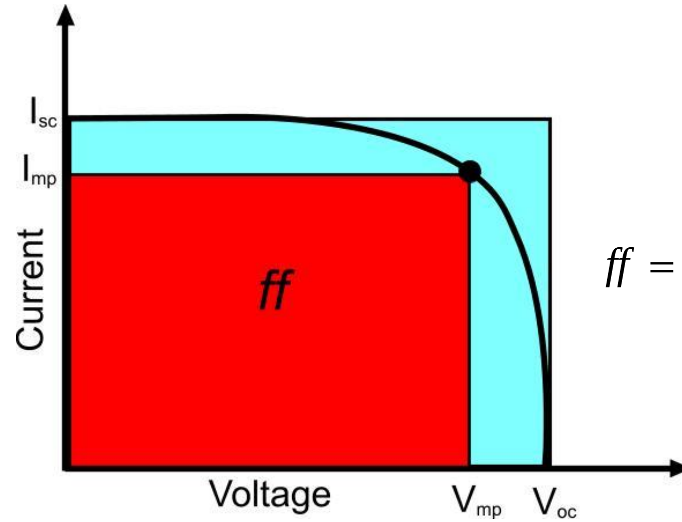
$$j = j_0 \left(e^{eV/kT} - 1 \right) - j_{SC}$$

$$V_{OC} = \frac{kT}{e} \ln\left(1 + \frac{j_{SC}}{j_0}\right)$$

HETEROJUNCTION SOLAR CELLS

Equivalent circuit





$$ff = \frac{I_{mp}V_{mp}}{I_{sc}V_{oc}}$$

Quantum Efficiency (QE) = number charge carriers/number of photons
Internal quantum efficiency (IQE): only absorbed photons
External quantum efficiency (EQE): all photons hitting the cell

Cell efficiency η: maximum electrical power out/ radiant energy in
Module efficiency: useful power out/radiant energy in

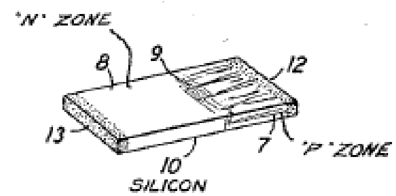
$$\eta = \frac{I_{mp}V_{mp}}{EA} = ff\,\frac{I_{sc}V_{oc}}{EA}$$

Standard test conditions (IEC 6125)
1kW/m^2 25 ^{0}C AM1.5 sunlight spectrum
1 cm^2 cell

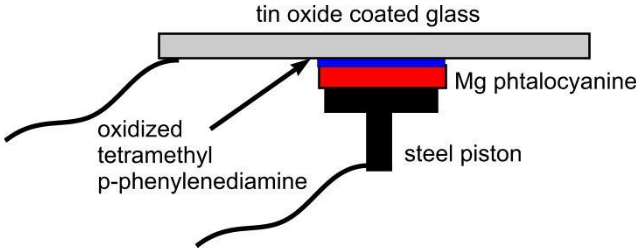
HETEROJUNCTION SOLAR CELLS

Silicon pn junction cell (Bell Labs) 1941
R.S. Ohls, US Patent 2402662 (1946)

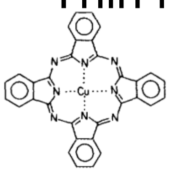
FIG. 2



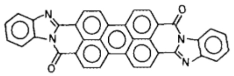
First organic PV (OPV) cell
D. Kearns & M, Calvin,
J Chem. Phys 29, 950-951 (1958)



GaAS solar cells 1970
Thin film a-Si:H (RCA 1976)



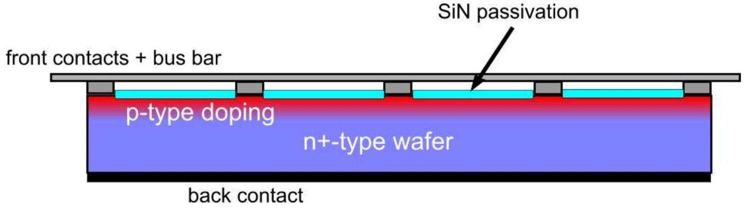
CuPc



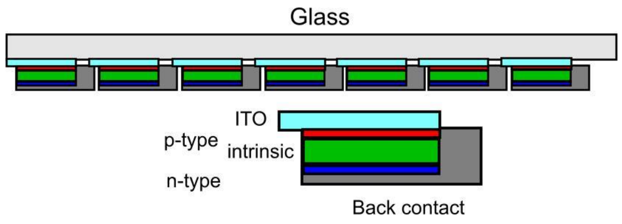
PV

Thin film OPV, C.W. Tang, Appl Phys Lett 42, 183 – 185 (1985)

Modern commercial solar cells



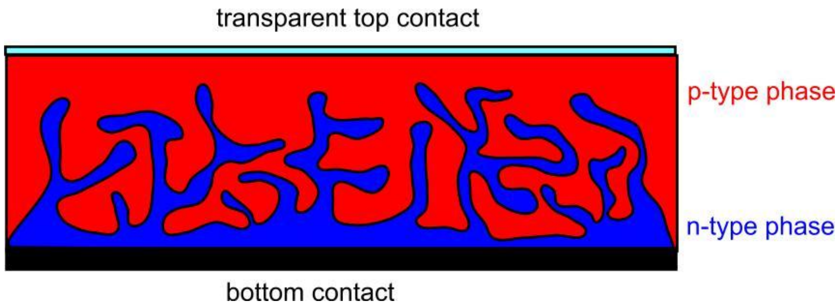
Crystalline



Thin film

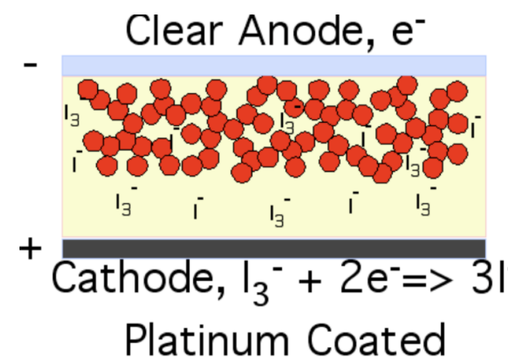
Other geometries include tandem cells and graded junctions

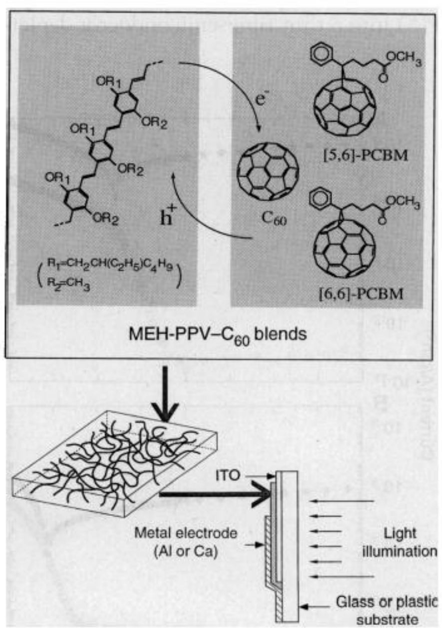
DISTRIBUTED JUNCTION SOLAR CELLS



Only one layer of mixed material
More light reaches the junction
Larger junction
shorter distance for charge to travel

Dye Sensitised Solar Cell (Photochemical)
B. O'Regan & **M. Grätzel**, Nature **353**, 737-740 (1991)

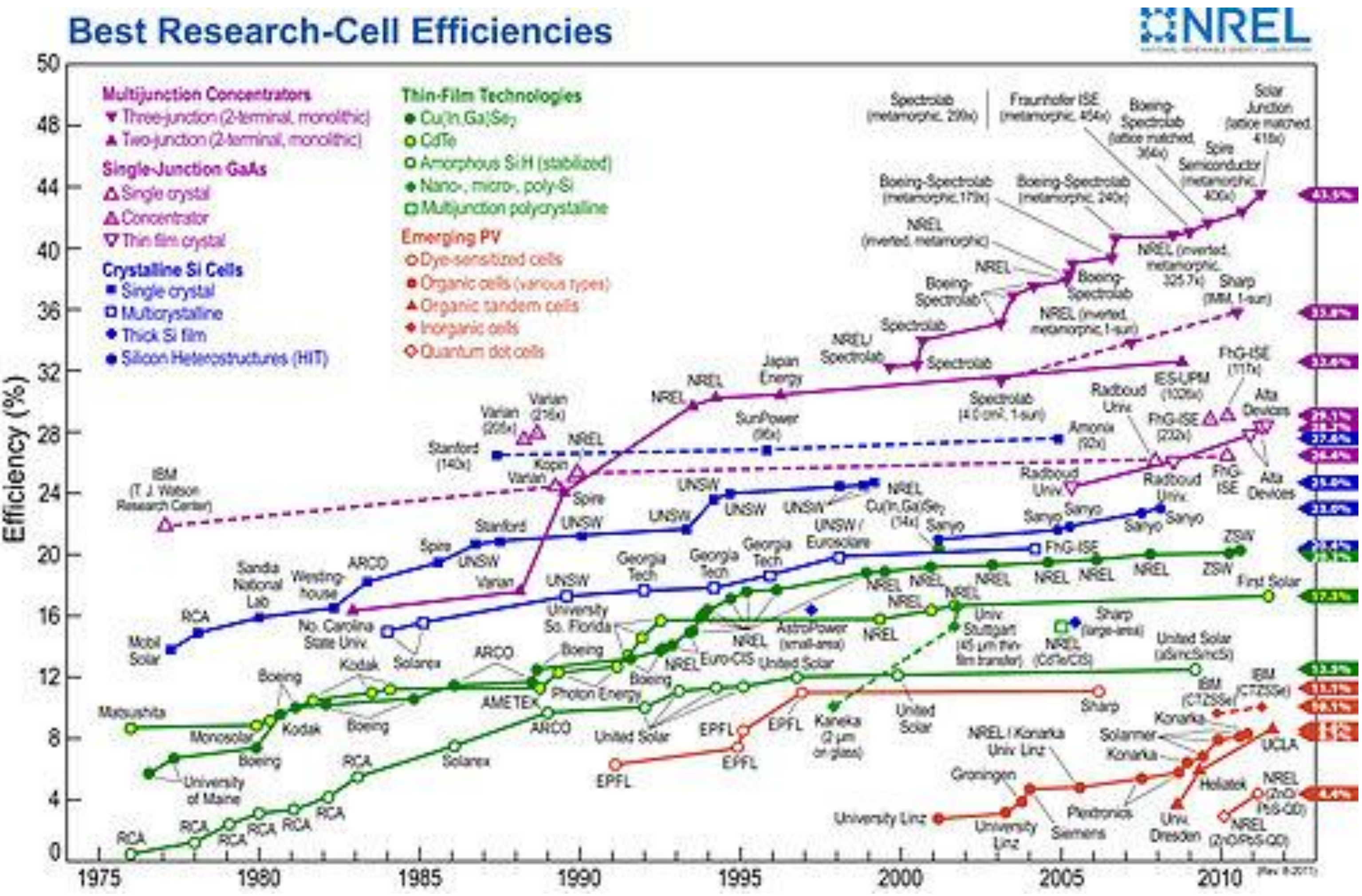




Polymer – fullerine blends (OPV)
G. Yu, J. Gao, J.C. Humelen, F. Wudl, and **A.J. Heeger**

Alan Heeger & Michael
Grätzel are founders of
Konarka

STATE OF THE ART?



2010/10/07
NREL/Spire
42.3%

Other factors to discuss:
Industrial scalbility
price per Wp
cost per kWh

Are they green?

2010/10/07 NREL Spire 42.3% triple junction tandem cell.

Different technologies: c-si, thin film, OPV, photochemical,