Photovoltaic and Photoelectrochemical Solar Cells

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History

- **Photovoltaic** (Solid State) solar cells, such as conventional SINGLE CRYSTAL or POLYCRYSTALIN Solar Cells, were discovered by Chapin, Fuller and Pearson, researchers at AT&T Bell Labs in 1954.
  - **p-n junction is formed between two solid layers.**
- **Photoelectrochemical** (Liquid) solar cell was discovered by Becquerel in 1839.
  - -illuminating sliver of semiconductor in a liquid can generate small but perceptible voltages.
  - Then again in 1976
    - **p-n junction is formed between a solid and a liquid layer.**

The Sun's Radiative Energy Output

- Enormous energy output….. About 4 x 10^{20} J/sec
  - Remember……

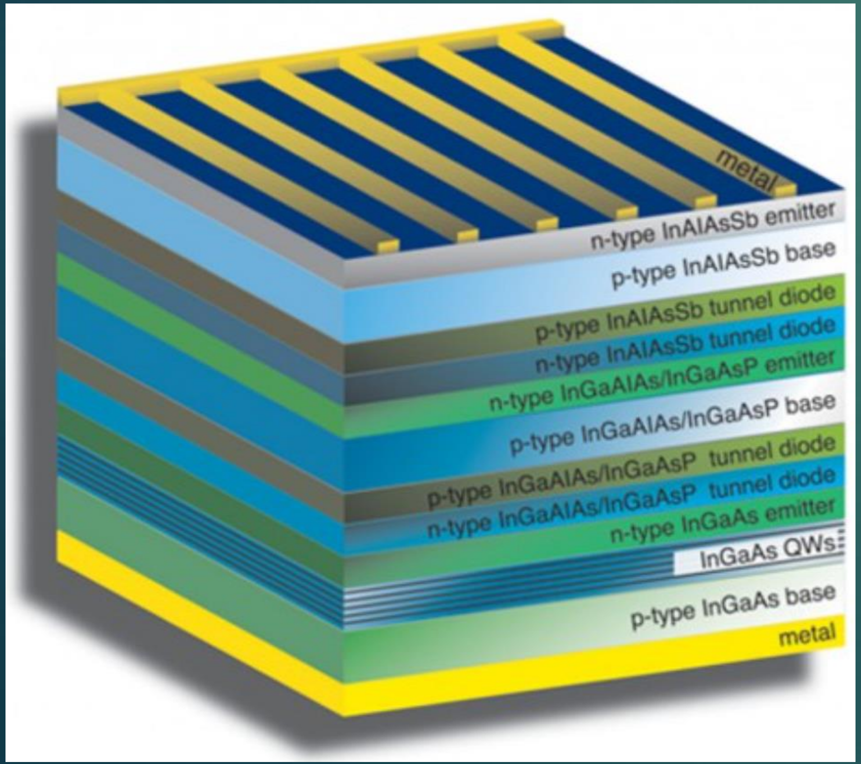
    1 Joule = N . m = kg.m^2/s^2 …………. 6 x 10^{11} kg/sec of H_2 is converted to He

  - Output is electromagnetic radiation in the UV, IR and Radio Spectral Region
  - Earth gets 925 W/m^2 on a sunny day at noon
- AT THIS RATE THE SUN IS EXPECTED TO LAST AROUND 5 BILLION YEARS before becoming a small white dwarf.
- Trivia: In 1.1 billion years from now, the Sun will be 10% brighter than it is today.

  In 3.5 billion years from now, the Sun will be 40% brighter than it is today. At this time Earth will look like todays Venus.

Present Day PV Cells

- Silicon based with a band gap of 1.1V
- Polycrystalline Si with around 18-20% efficiency.



←Best case are the multilayered PV cells with about 30-35% efficiency but too costly.

Solar Concentrator improves efficiency→

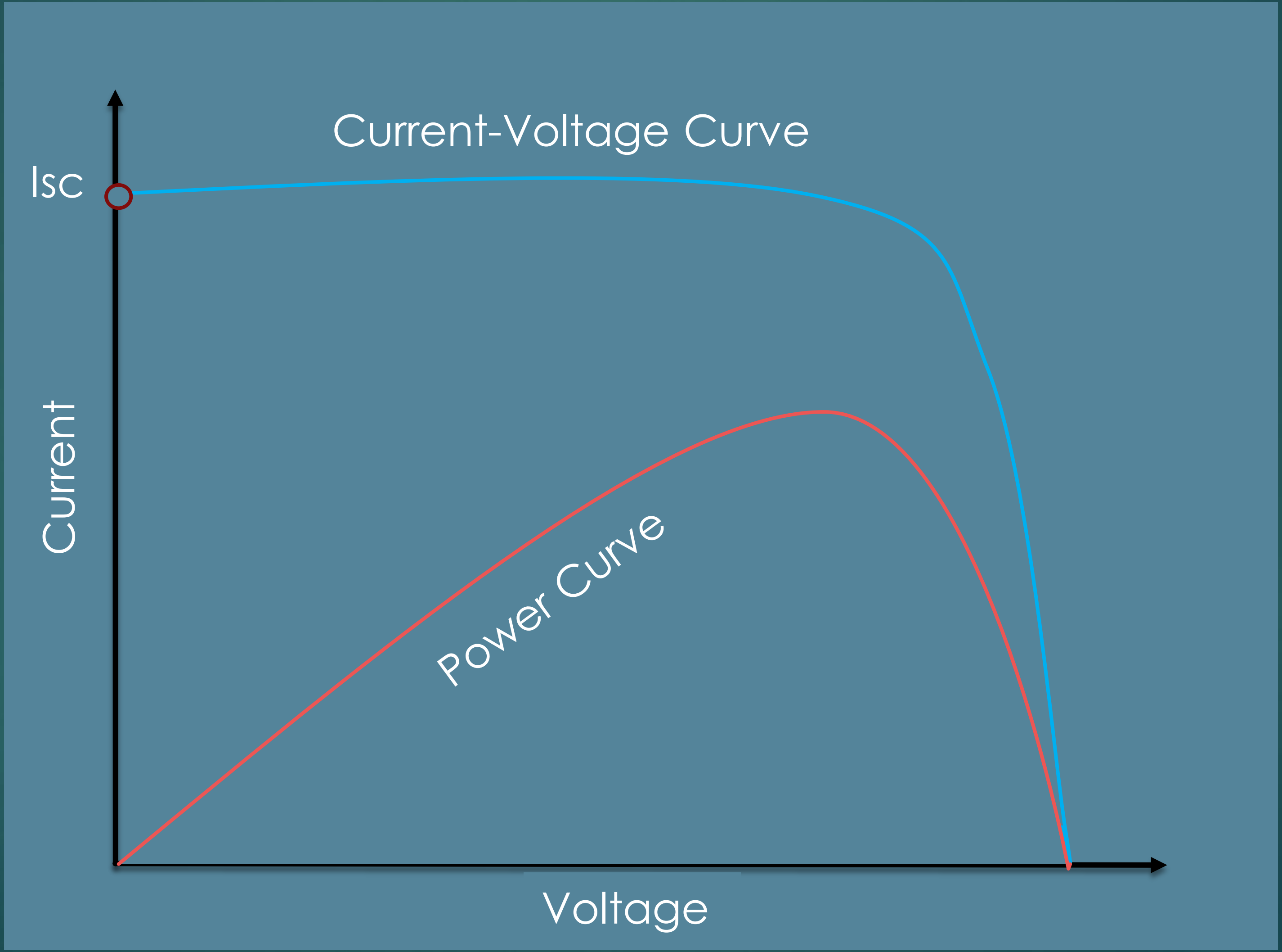
Solar Cells

- Group IV
- Group III/IV
- Group II/VI

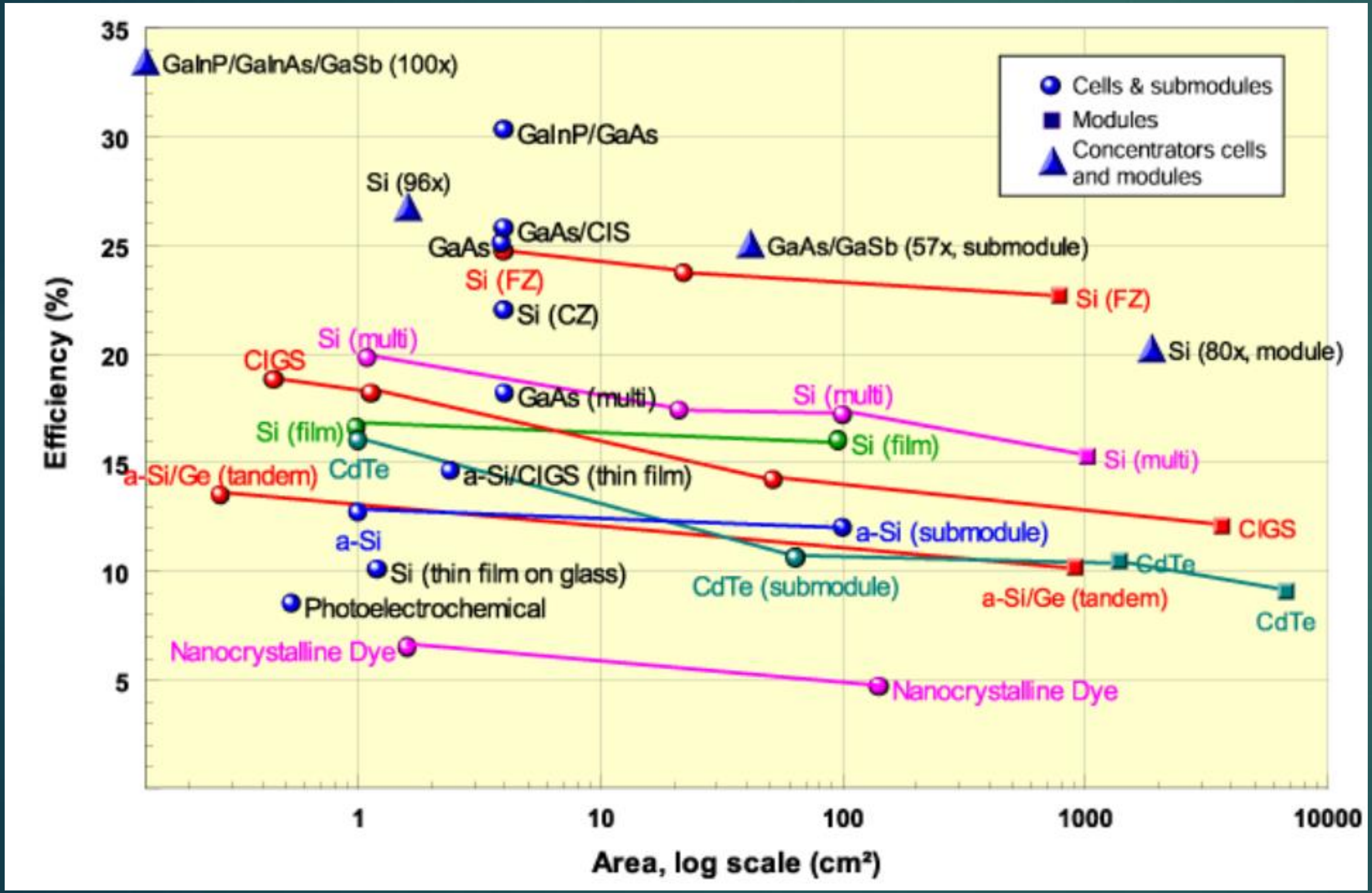
IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
							2 He 4.003
		5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.183
		13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.909	36 Kr 83.80
47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.904	54 Xe 131.30
79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po (210)	85 At (210)	86 Rn (222)

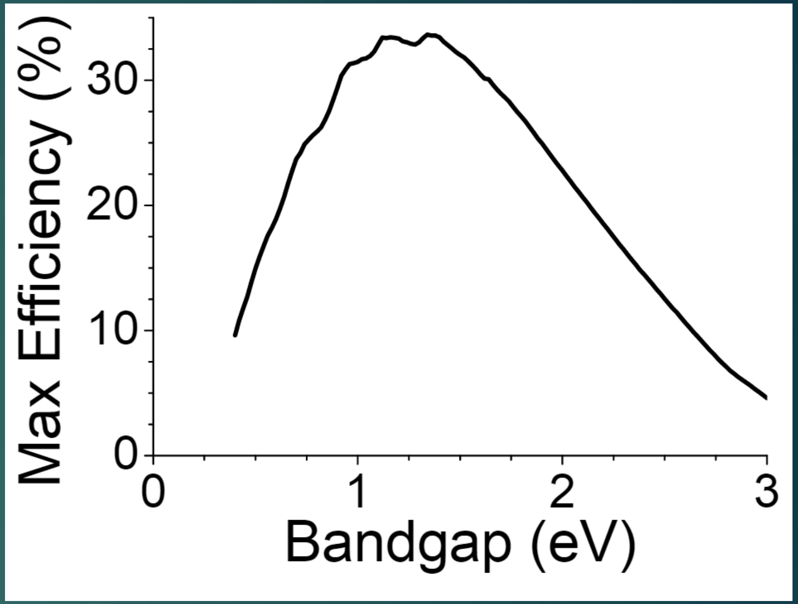
- n-type semiconductor has extra free electrons
- p-type semiconductor is lacking free electrons

Solar Cell Characterization – "IV Curve"



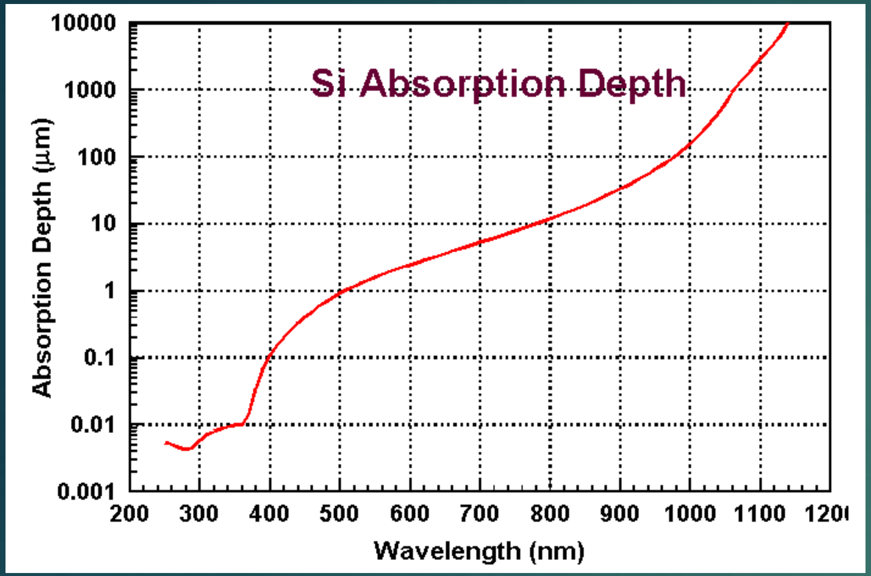
2015: Where EFFICIENCIES stand today



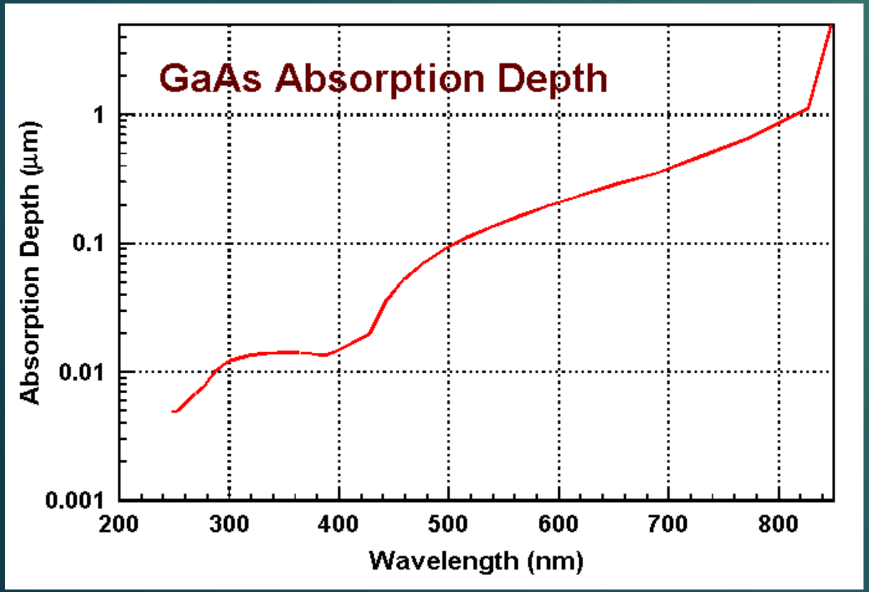


Shockley-Queisser Limit (for single p-n junction cell): Semiconductors with band gap between 1 and 1.5eV, or near-infrared light, show to have the highest efficiency.

Band Gap + Photonic Absorption Depth



Band gap 1.11 eV (at 300 K)



Band gap 1.43 eV (at 300 K)

Semiconductor Band Gaps

Material	Energy gap (eV)	
	0K	300K
Si	1.17	1.11
Ge	0.74	0.66
InSb	0.23	0.17
InAs	0.43	0.36
InP	1.42	1.27
GaP	2.32	2.25
GaAs	1.52	1.43
GaSb	0.81	0.68
CdSe	1.84	1.74
CdTe	1.61	1.44
ZnO	3.44	3.2
ZnS	3.91	3.6

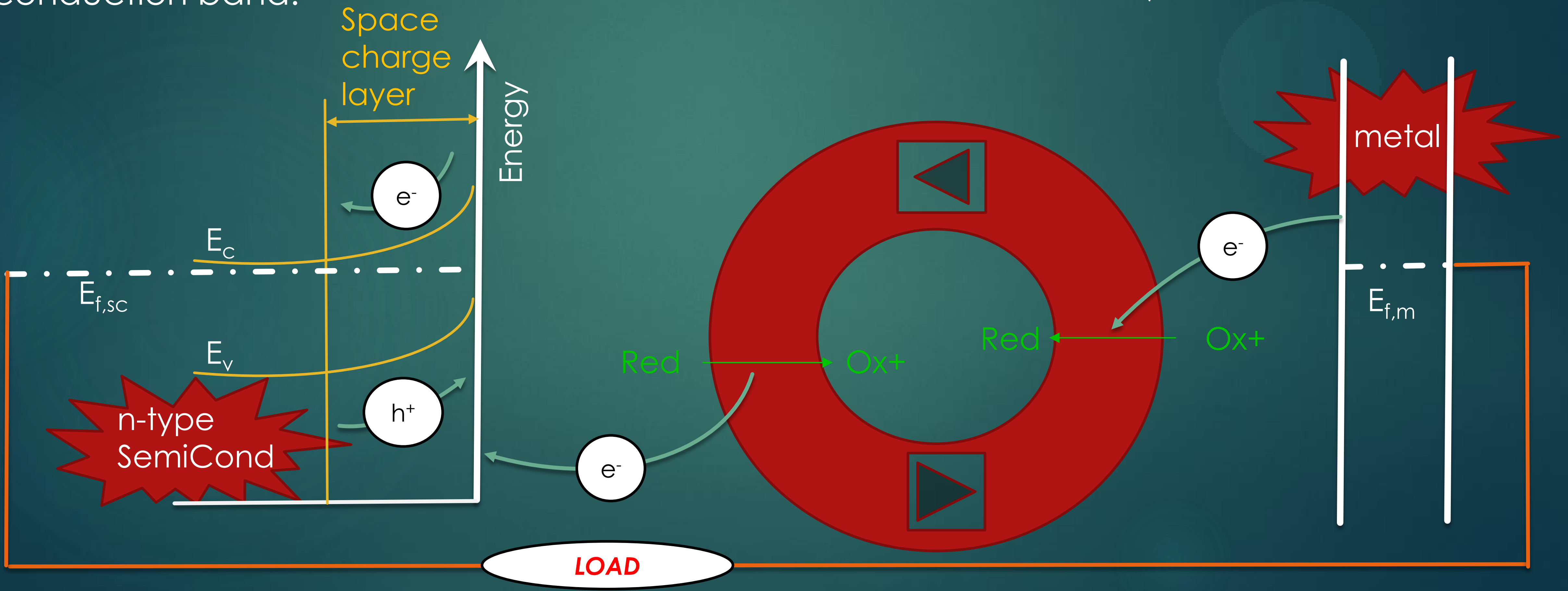
Photoelectrochemical Solar Cell

- DO NOT exist on a commercial scale.
- Aqueous based electrolytes are problematic to use. TOO MUCH PARASITIC REACTIONS TAKE PLACE.
- Excellent approach to evaluate the semiconductors photo response.

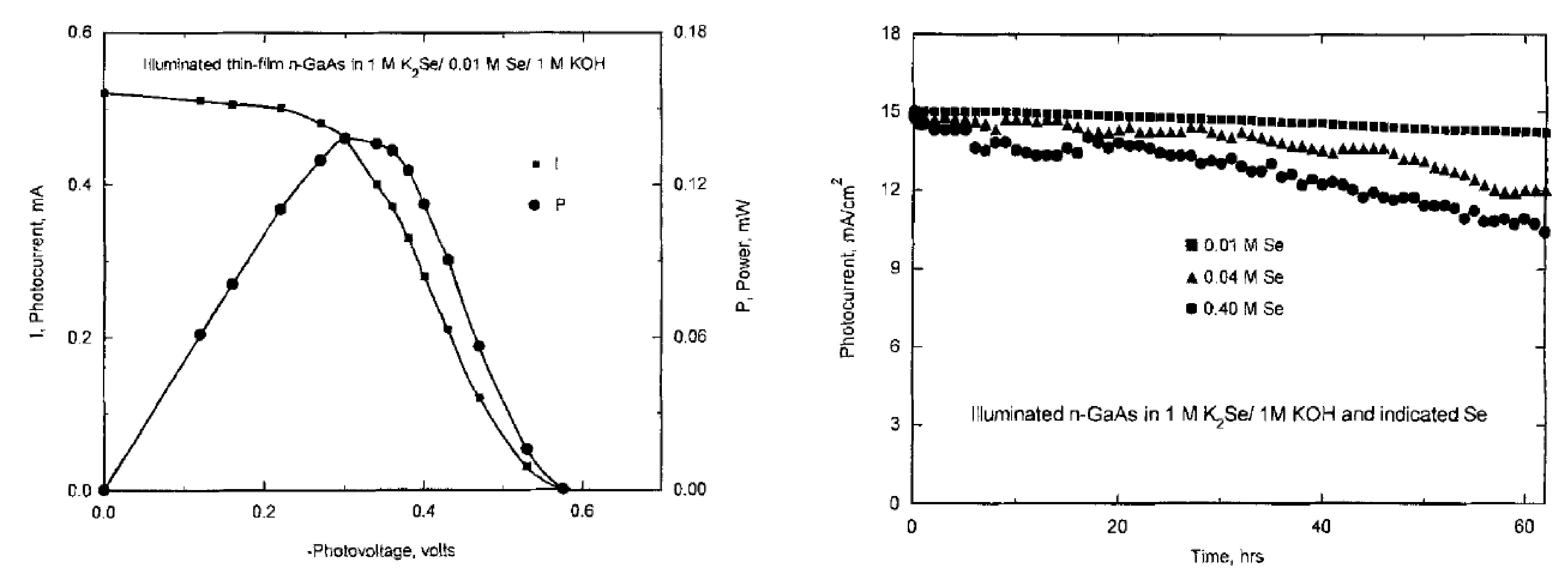
Schematic Energy Diagram in a Photoelectrochemical Solar Cell

- In an n-type semiconductor introduction of electron donors move the Fermi Level ($E_{f,sc}$) toward the conduction band.

f,sc = Fermi level of semicond
c = conduction band
v= valence band
F,m = Fermi level of metal

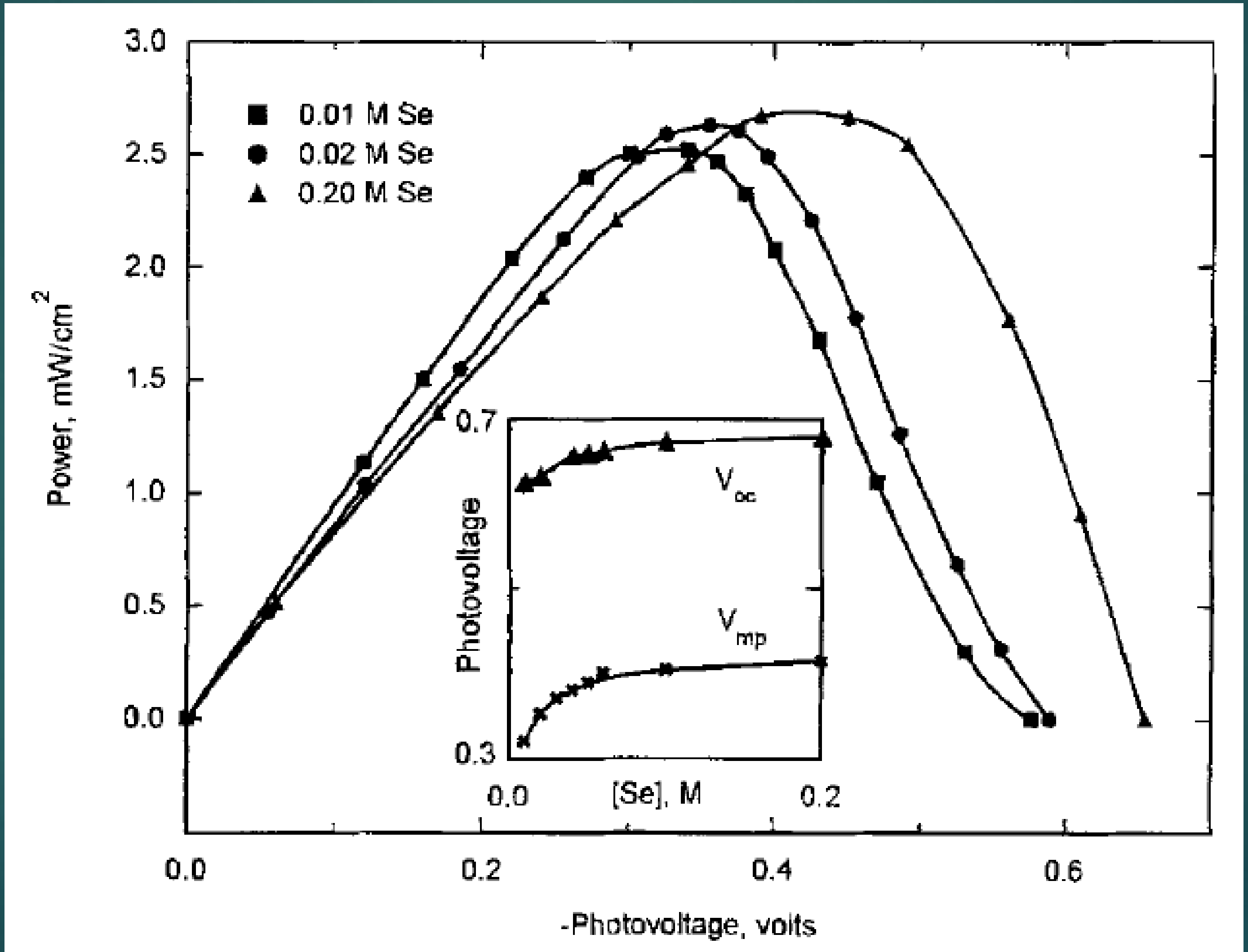


Example of Measured PEC IV curve and Current Density – GaAs in polyselenide



REF: Forouzan et al. J. Electrochem. Soc., Vol. 142, No. 5, 1995, 100, 1539-1545.

Power density as a function of electrolyte concentration.



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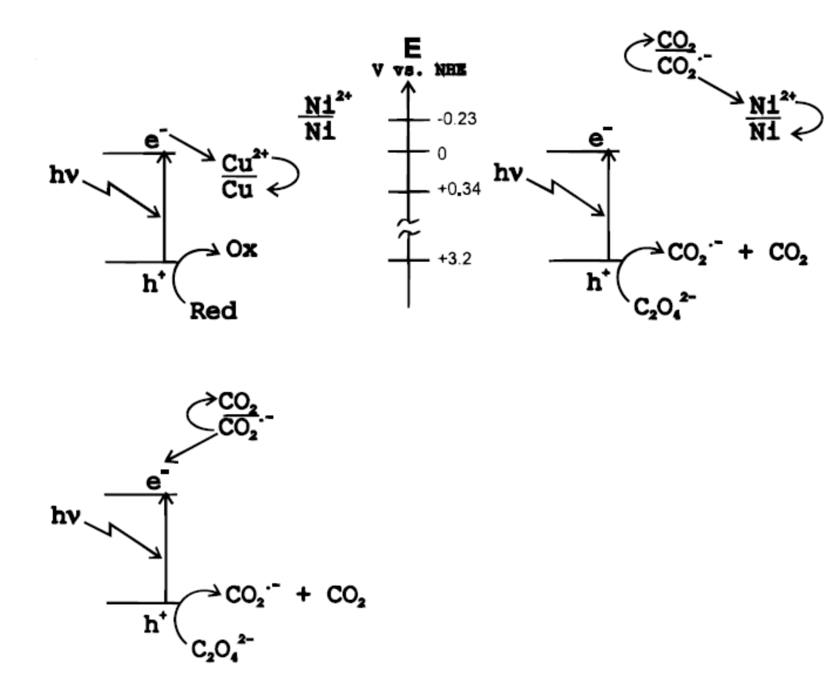
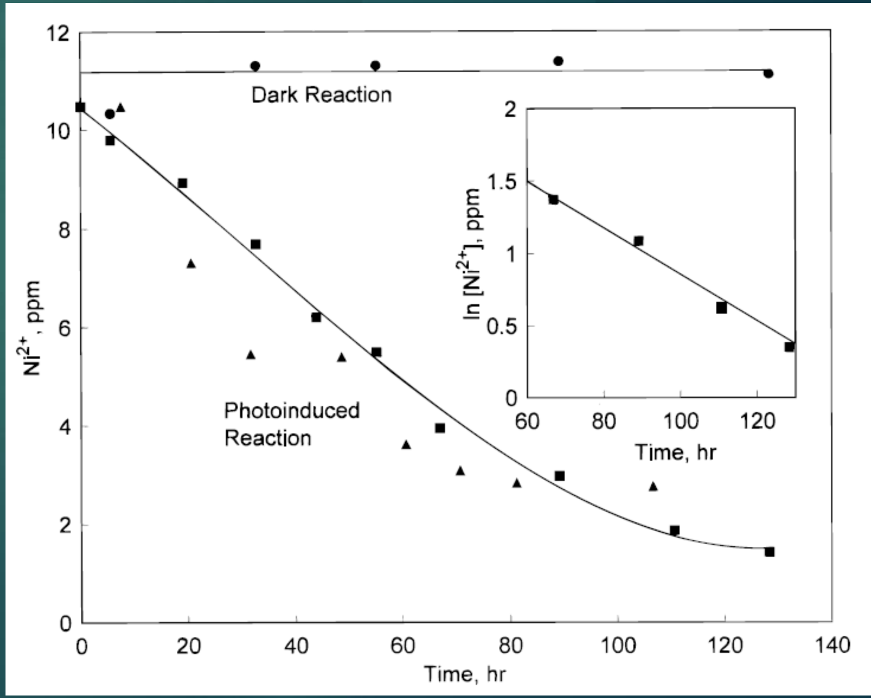
Other usage for PEC

- Although PEC may never become a mainstream method for the conversion of solar energy to electrical energy but there are other uses for it.
  - For example……
    - Reduction of heavy metals from remote water sources. May even be useful for the military to decontaminate local water sources from harmful metallic contaminants.



If electron generated at surface of the semiconductor is not energetic enough to reduce the species then one can use an intermediate….. in this case an oxalate radical



REF: Forouzan et al. J. Phys. Chem. 1996, 100, 18123-18127

Conclusion

- Theoretical calculations show a maximum solar to electric conversion efficiency of about 33% for a single junction PV cell.
- Most suitable semiconductors for conversion of solar radiation have a band gap between 1.1 and 1.5 eV.
- Single crystal based PV cells show highest efficiencies but are too expensive and takes a long time to produce. The alternative is polycrystaline semiconductors.
- Si is the second most abundant element on the earth therefore cheaper than all other elements to use. Better alternative is GaAs.
- Industry needs to lower the cost of PV panels. Presently each decently efficient medium size good quality panel runs about $500-800 each.