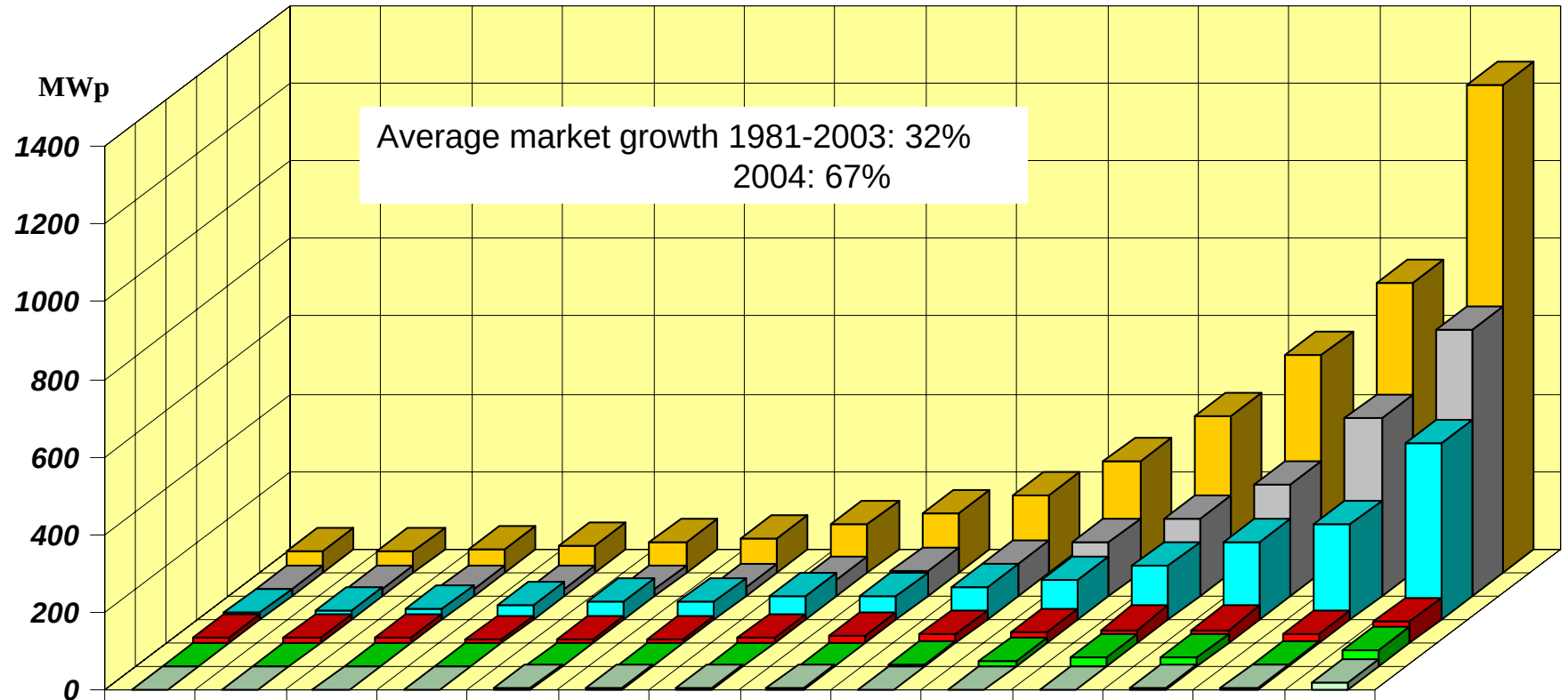
Production of PV cells



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
rest	1.0	1.0	1.0	2.0	4.0	6.0	6.0	7.0	0.7	3.6	2.8	5.0	7.0	19.0
ribbon Si	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	14.7	22.5	26.3	6.8	41.0
a-Si	14.0	15.0	13.0	11.0	9.0	12.0	15.0	19.0	24.8	27.0	35.8	35.8	25.8	55.2
mono c-Si	20.0	22.0	29.0	36.0	47.0	47.0	62.0	60.0	85.0	102.0	138.7	201.4	244.0	455.0
multi c-Si	21.0	20.0	18.0	21.0	20.0	24.0	43.0	67.0	84.5	140.0	201.6	288.7	459.8	687.0
Total	55.4	57.9	60.1	69.4	77.6	88.6	125.8	154.9	201.3	287.7	401.4	559.6	744.1	1256.8

Estimation money-market:

2004

3.5 € /Wp

~5000x10^6 €

Primary challenge of PV

Cost reduction of factor 5

to become competitive with conventional electricity

Today PV module price: 3.5-5.0 €/W_p **(W_p = Watt peak)**

Integral approach:

Reducing module costs

↓ raw materials & labor, investments

↑ efficiency, lifetime

Optimizing systems integration

↓ area and power related costs

Note: overall optimum ≠ highest efficiency

Thin-film solar cells

Advantages of thin film PV technologies:

- savings in material and energy consumption
- large area deposition
- monolithic integration
- energy pay back time
- implementation in building industry

Thin-film solar cells

Requirements:

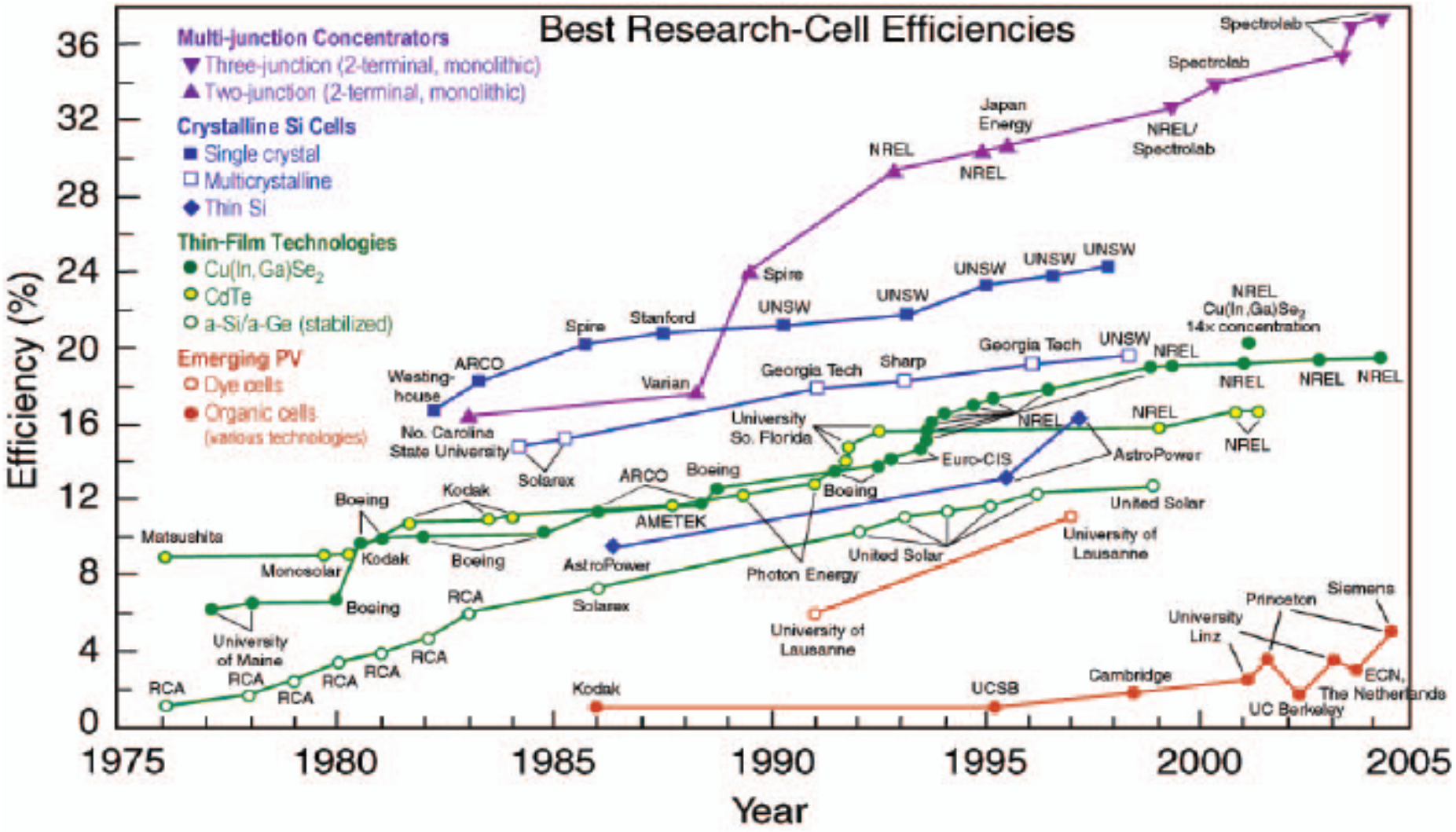
- long term stability (lifetime of 20 - 30 years)
- reliability
- availability of source materials
- cost effective
- no environmental hazards

Thin-film solar cells

Absorber materials less than a few µm thick:

- Silicon thin films (*a*-Si:H, *a*-SiGe:H, *µc*-Si:H, proto c-Si, poly c-Si:H)
- II-VI compounds (CdTe)
- II-IV-VI compounds ($CuInSe_2$, $CuInGaSe_2$)
- Thin film crystalline Si or GaAs (lift-off)
- Dye-sensitized nanocrystalline TiO_2 (nc-TiO_2)
- Fully organic solar cells

Laboratory cell performance



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Why thin-film solar cells?

Solar cell	Efficiency	Energy pay back time
c-Si	12 %	2.1 years
TF Si	6 %	1.4 years
$CuInSe_2$	10 %	1.25 years

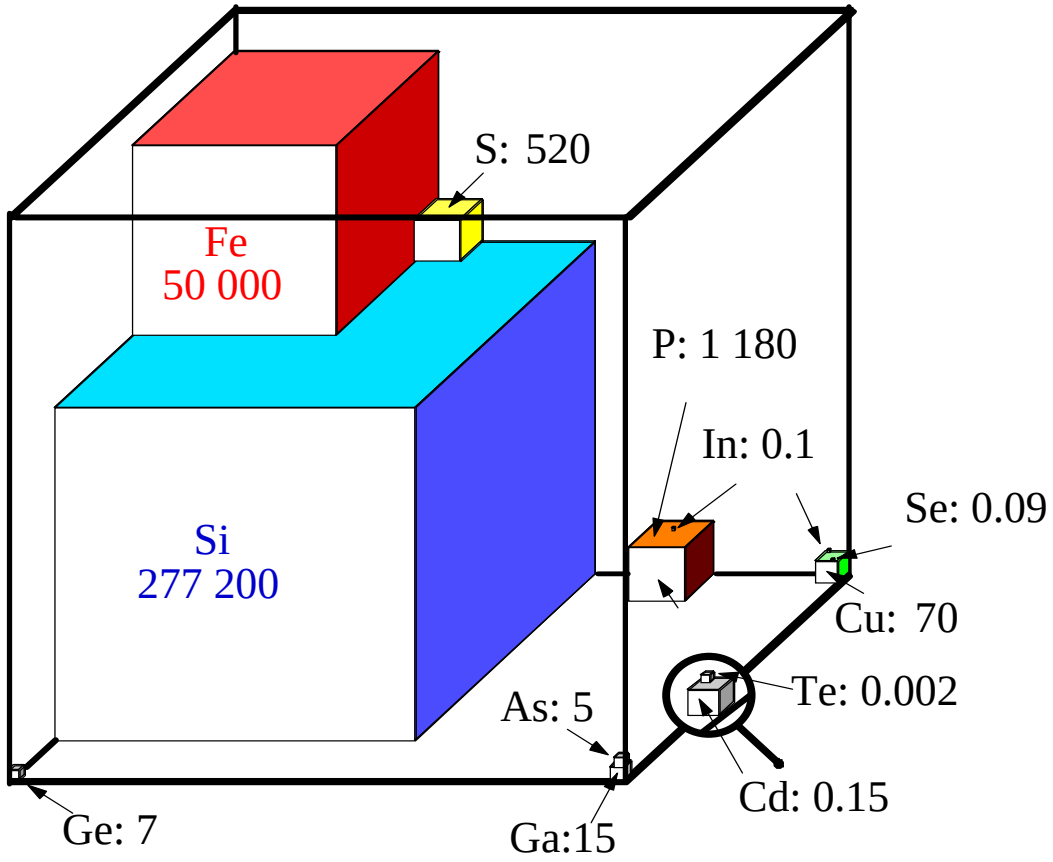
Palz and Zibetta

Annual insolation 1800 kWh/(m^2 year)

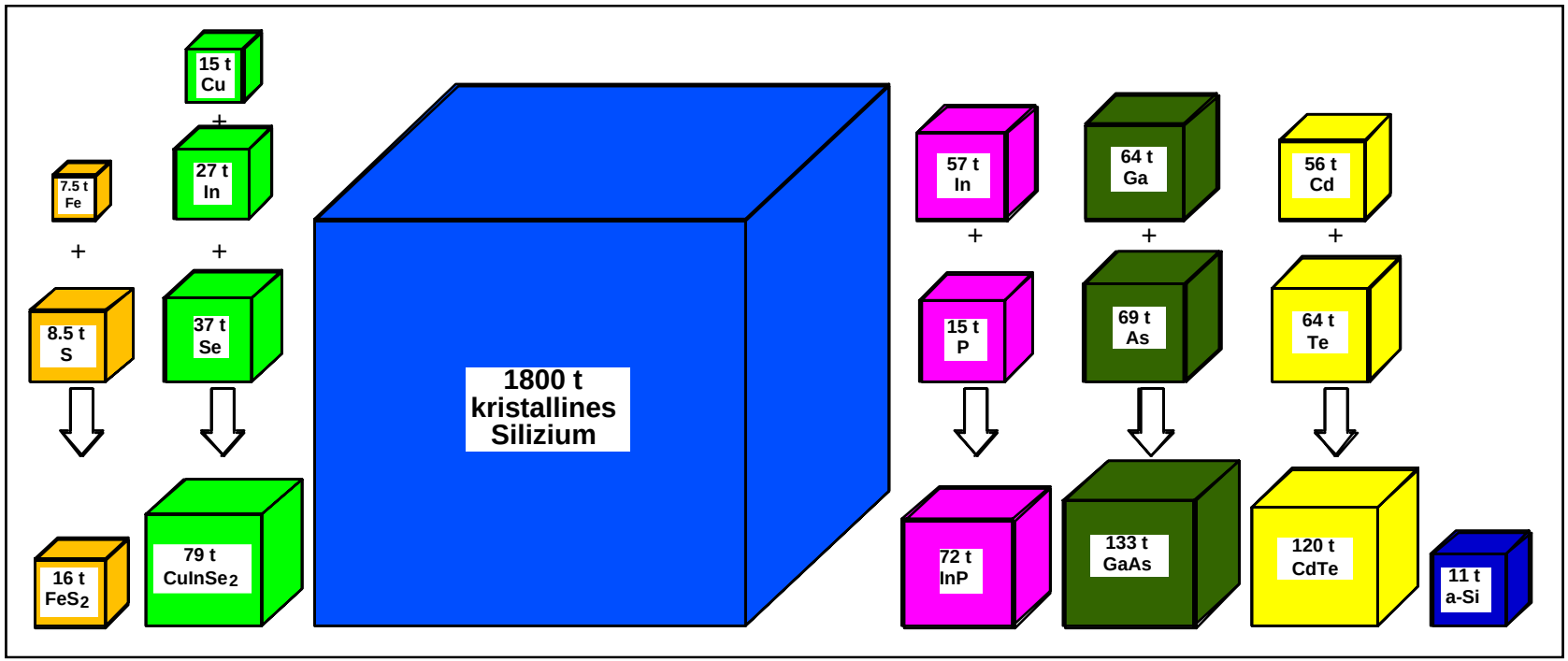
Energy pay back time: the time required for an energy conversion system or device to produce as much energy as is consumed for its production

Composition of the Earth

Total : 1 000 000

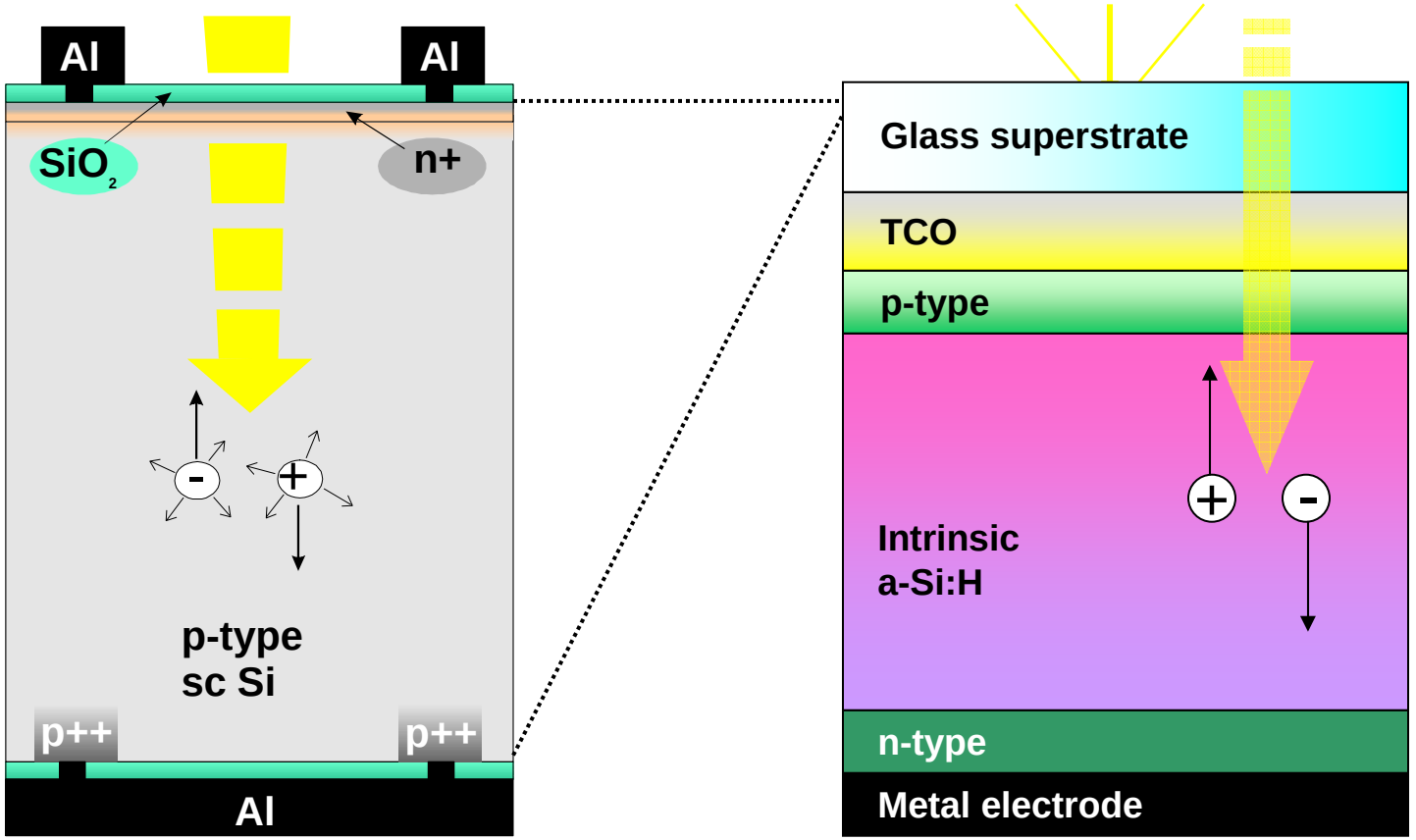


Material required for 1 MW_p



	16 t FeS_2	79 t $CuInSe_2$	1800 t c-Si	72 t InP	133 t GaAs	120 t CdTe	11 t a-Si
η(%)	3	12	20	20	20	10	10
d(µm)	0.1	2	150	3	5	2	0.5

Thin-film Si solar cells



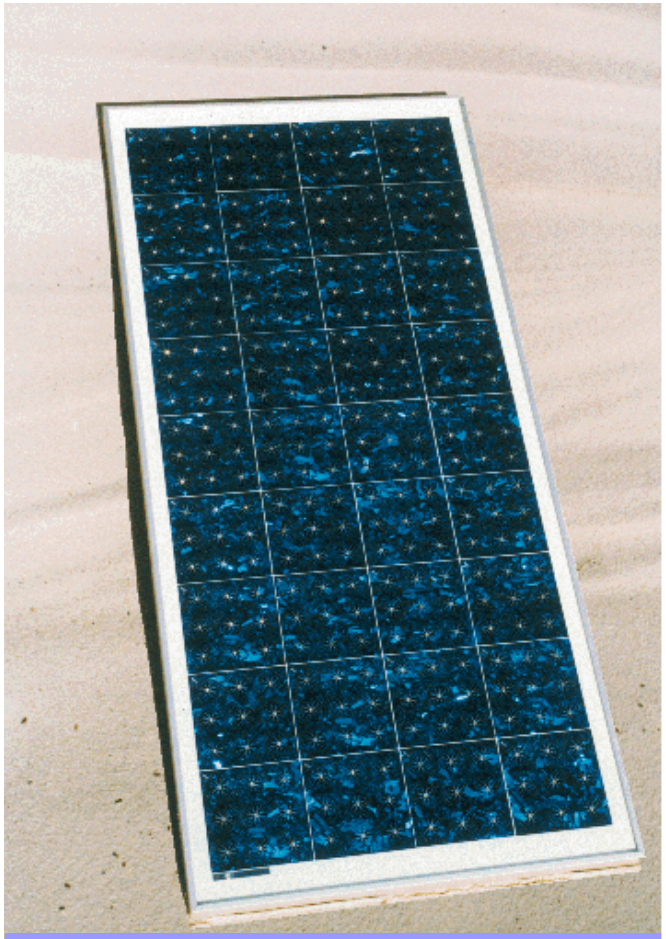
c-Si (200-300 µm)

a-Si:H (0.3-0.5 µm)

Why thin-film solar cells?

Solar cell	Si raw material	Present efficiency	Future efficiency	Peak Power	Peak Power
c-Si	1200-1500 g/m^2	14 %	16 %	160 W_p/m^2	0.13 W_p/g
TF Si	4-5 g/m^2	7 %	10 %	100 W_p/m^2	20 W_p/g

Why thin-film solar cells?



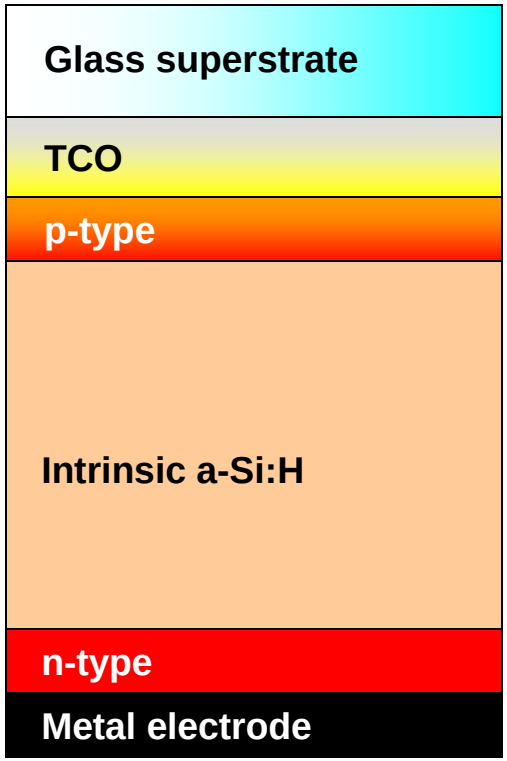
Rigid c-Si PV modules

Flexible *a*-Si:H PV modules

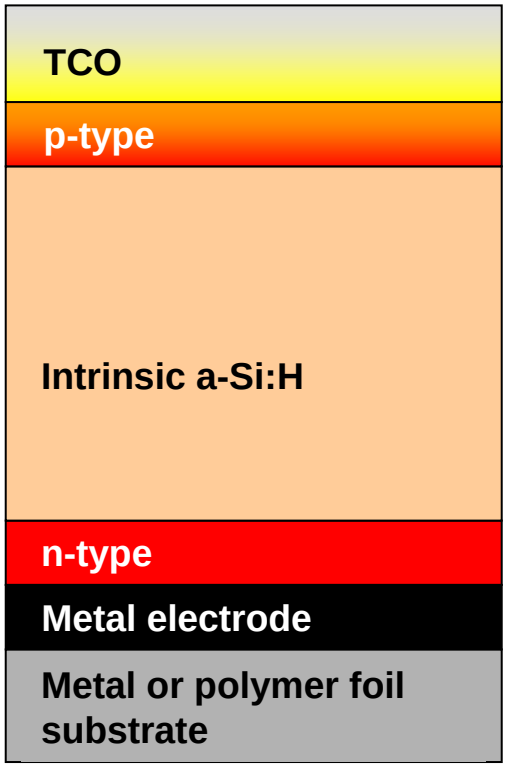
a-Si:H solar cells

Superstrate solar cell structure

(Light enters through carrier)



Substrate solar cell structure

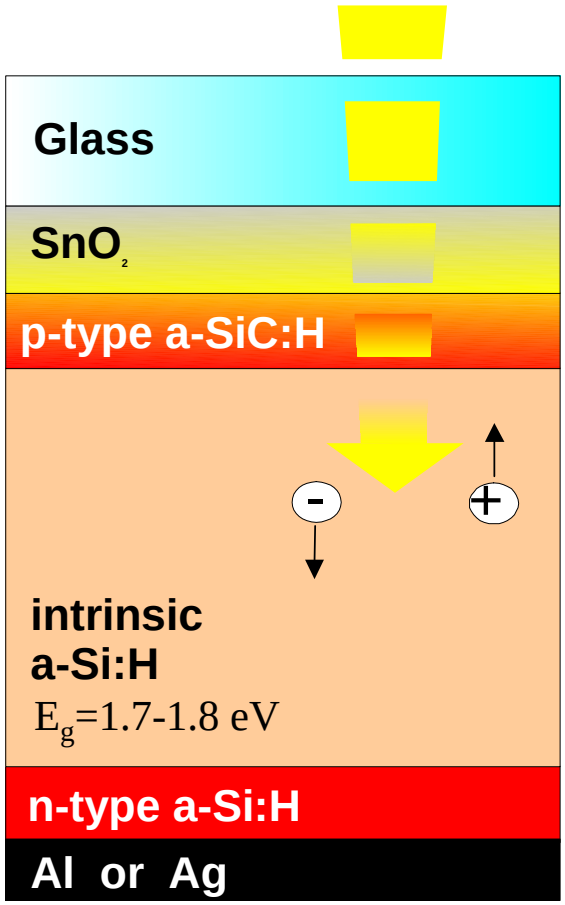


a-Si:H solar cells

+ First thin-film material to go commercial
+ Laboratory cell efficiency 13%, module 10%
+ Multi-junction cell capability

  (tandem or triple *pin* junctions a-Si/a-SiGe/µc-Si)
- Stabilized performance
- Deposition rate (rf PECVD 0.1-0.2 nm/s)

a-Si:H solar cells

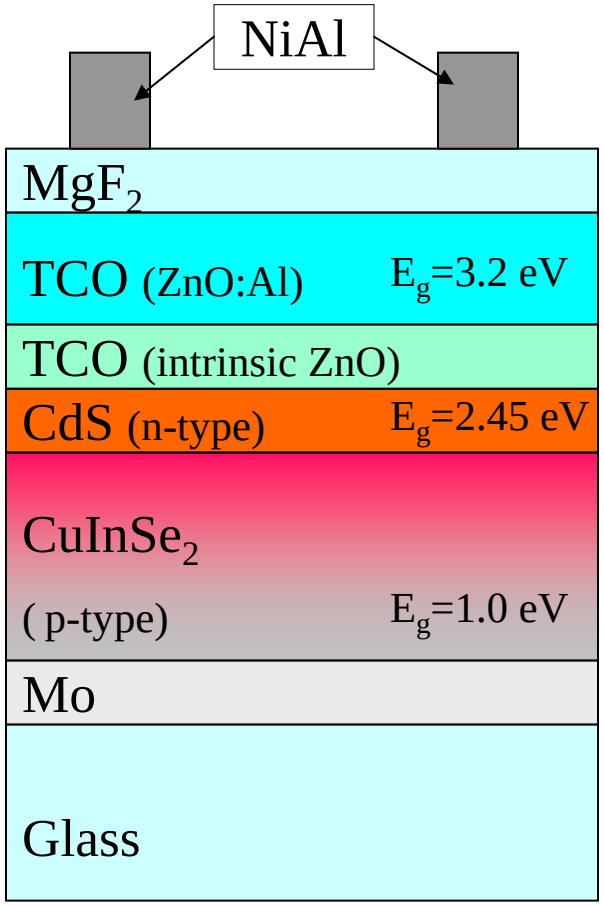


Active material:

- Amorphous silicon (*a*-Si:H)
- direct semiconductor
- band-gap variation (1.7-1.9 eV)
- thickness 0.3 microns

CIGS solar cells

Copper Indium Gallium Diselenide Cu (In, Ga) Se_2



Active material:

- alloy $Cu(In,Ga)(Se,S)_2$
- direct semiconductor
- positive role of Na
- band-gap variation
  (1.0 -1.7 eV)
- thickness 1 - 3 microns

CIGS solar cells

Copper Indium Gallium Diselenide Cu (In, Ga) Se_2

± Just introduced to the market

\+ Laboratory cell efficiency >19%

module 13-15%, minimodule 17%

\+ Single, graded-layer junction (low V_{oc})

\- Improve control over 5 to 6 elements that are applied in varying concentrations (Scale up)

\- Increase production yield

\- In and Ga availability (< 1000 MWp/yr)

CIGS solar cells

Copper Indium Gallium Diselenide Cu (In, Ga) Se_2

Production methods:

Vacuum methods:

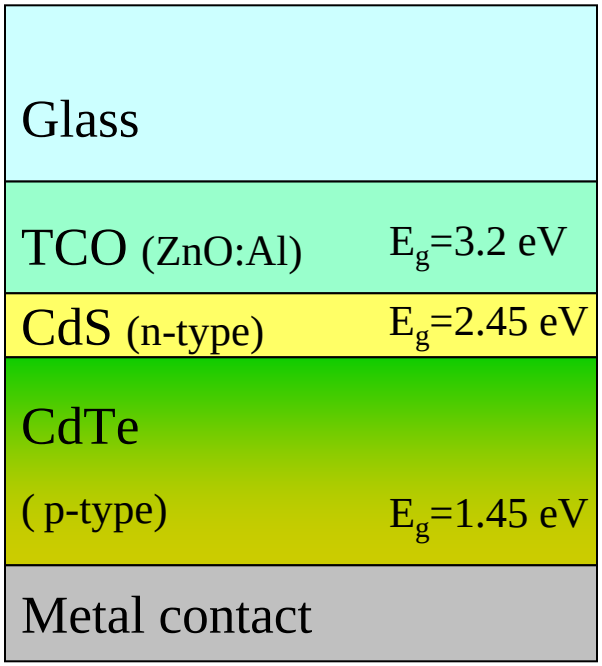
- Co-evaporation (Global Solar, Solibro)
- Sequential layer deposition (sputtering) (Shell Solar, Showa Shell)

Non-vacuum methods:

- Electrodeposition
- Nano powders, printing

CdTe solar cells

Cadmium Telluride



Active material:

- CdTe
- band-gap 1.45 eV
- thickness 1 - 3 microns

CdTe solar cells

Cadmium Telluride

± On the market (First Solar)

+ Laboratory cell efficiency 16%, module 11%

+ Atmospheric deposition possible

- Single junction (low V_{oc})

- Avoid extrinsic contact degradation

- Manufacturing involves cadmium

CdTe solar cells

Cadmium Telluride

Production methods:

- Close-space sublimation (Antec)
- Electro-deposition (BP Solar)
- Screen printing (Matsushita)
- Evaporation (Solar Cells Inc.)
- Spray deposition