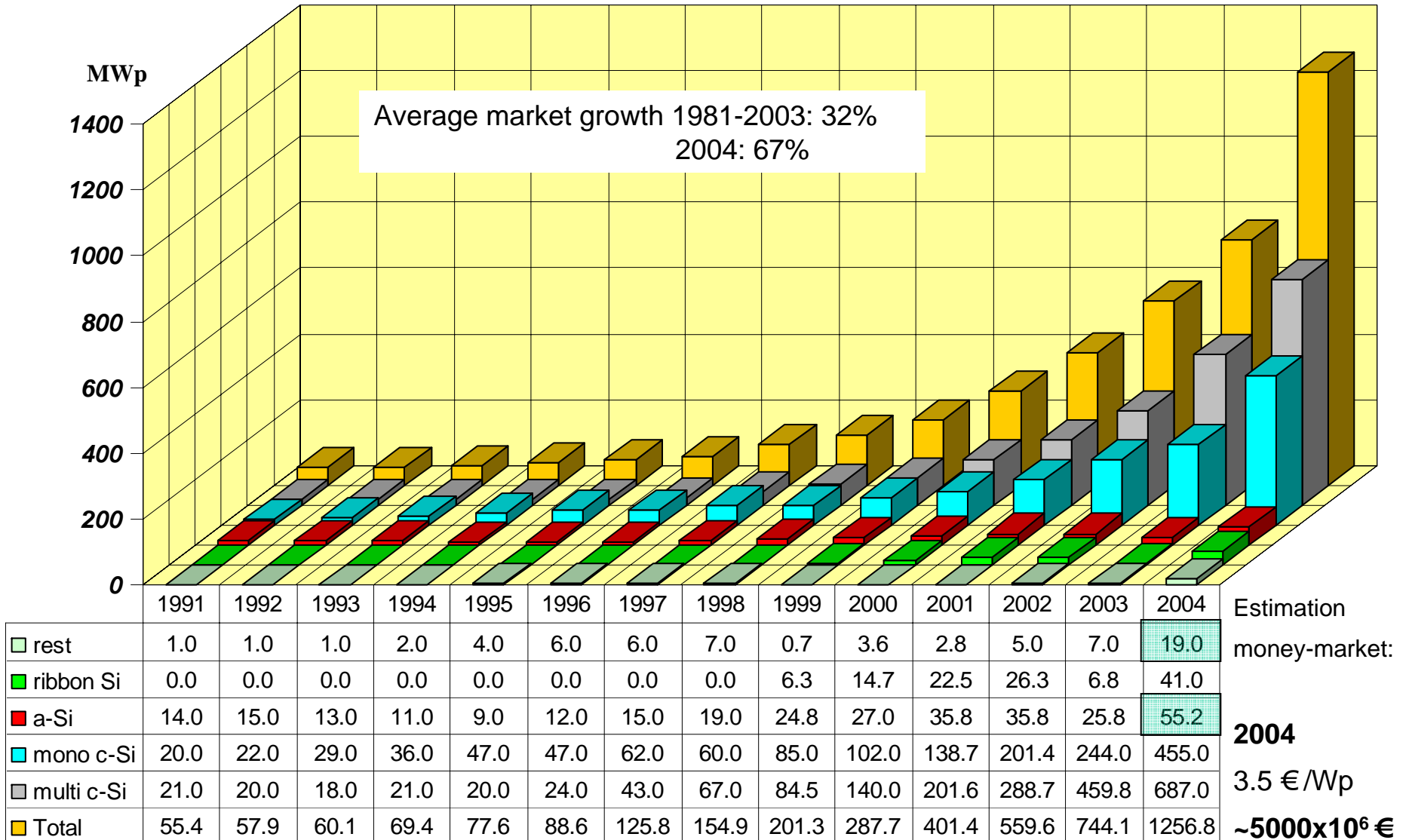


Production of PV cells



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:

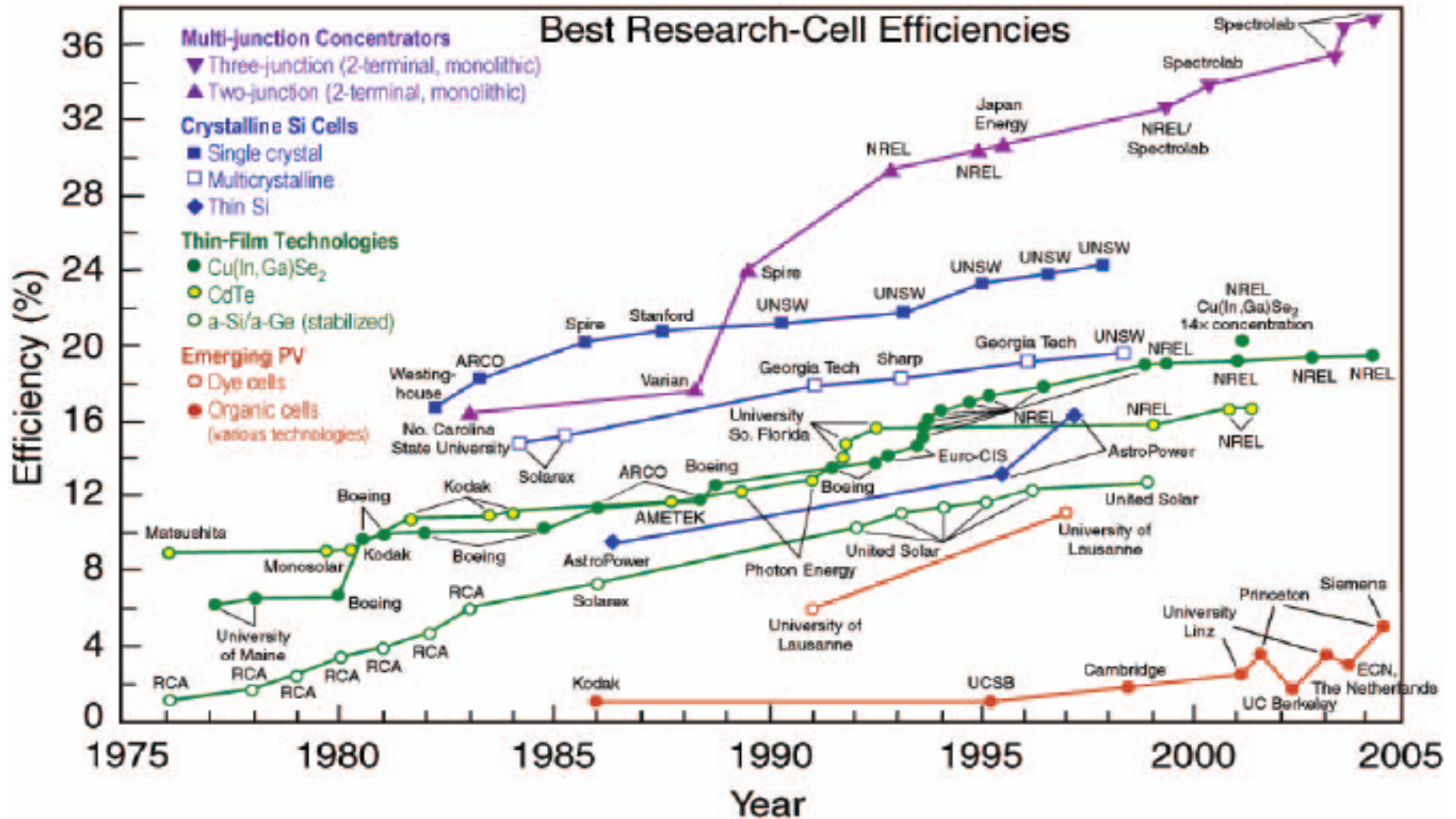
- long term stability (lifetime of 20 - 30 years)
- reliability
- availability of source materials
- cost effective
- no environmental hazards

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



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

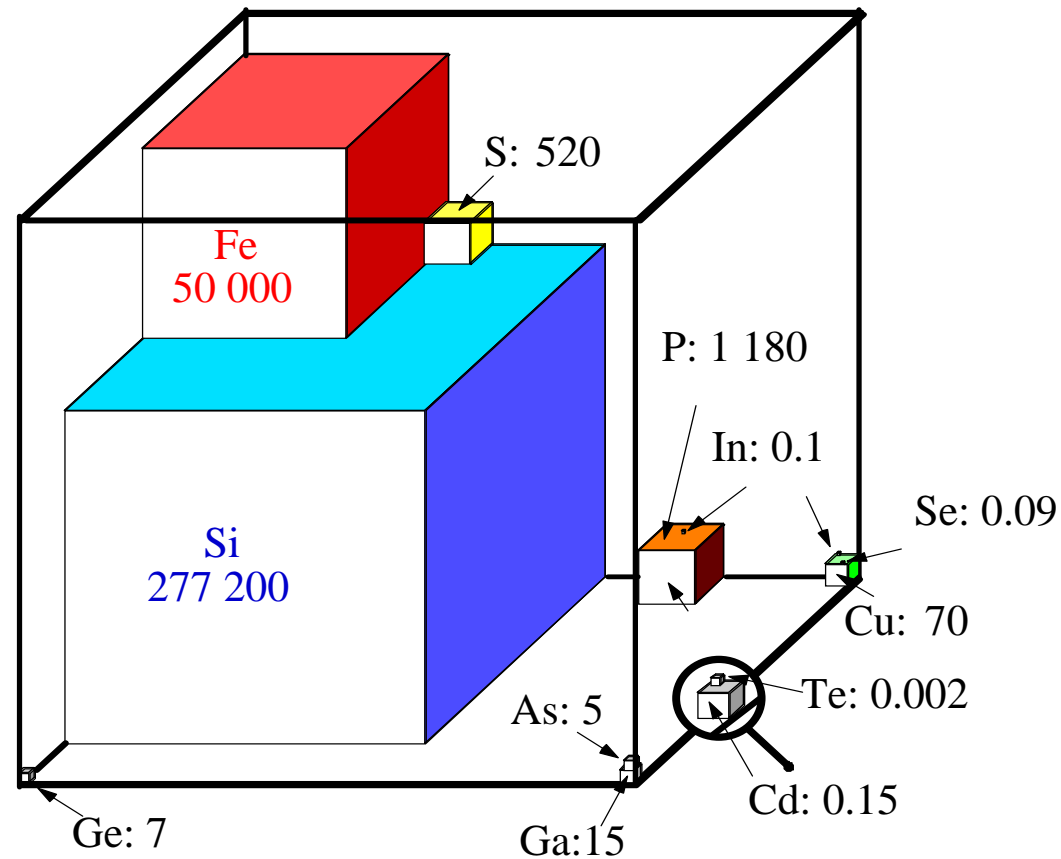
Palz and Zibetta

Annual insolation 1800 kWh/(m² year)

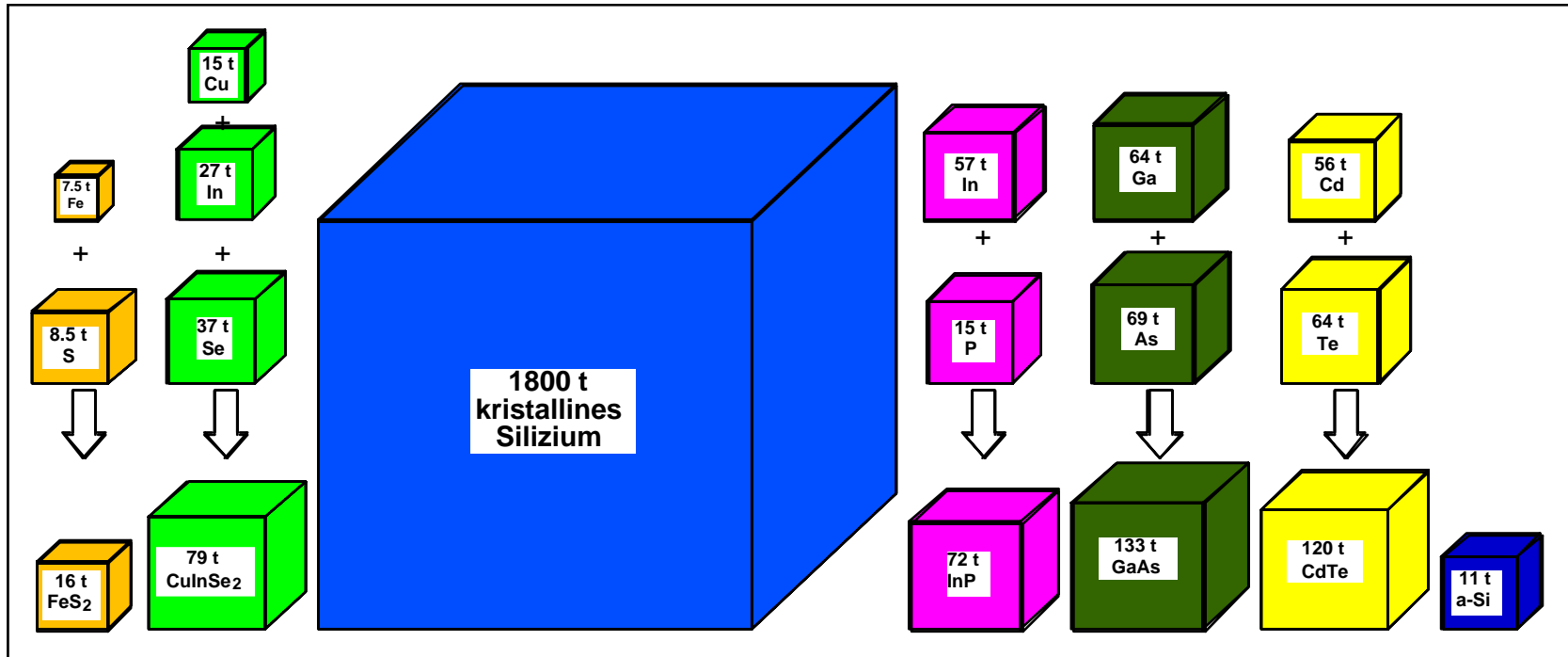
Energy pay back time: the time required for an energy conversion system or device to produce as much energy as is consumed for its production

Composition of the Earth

Total : 1 000 000

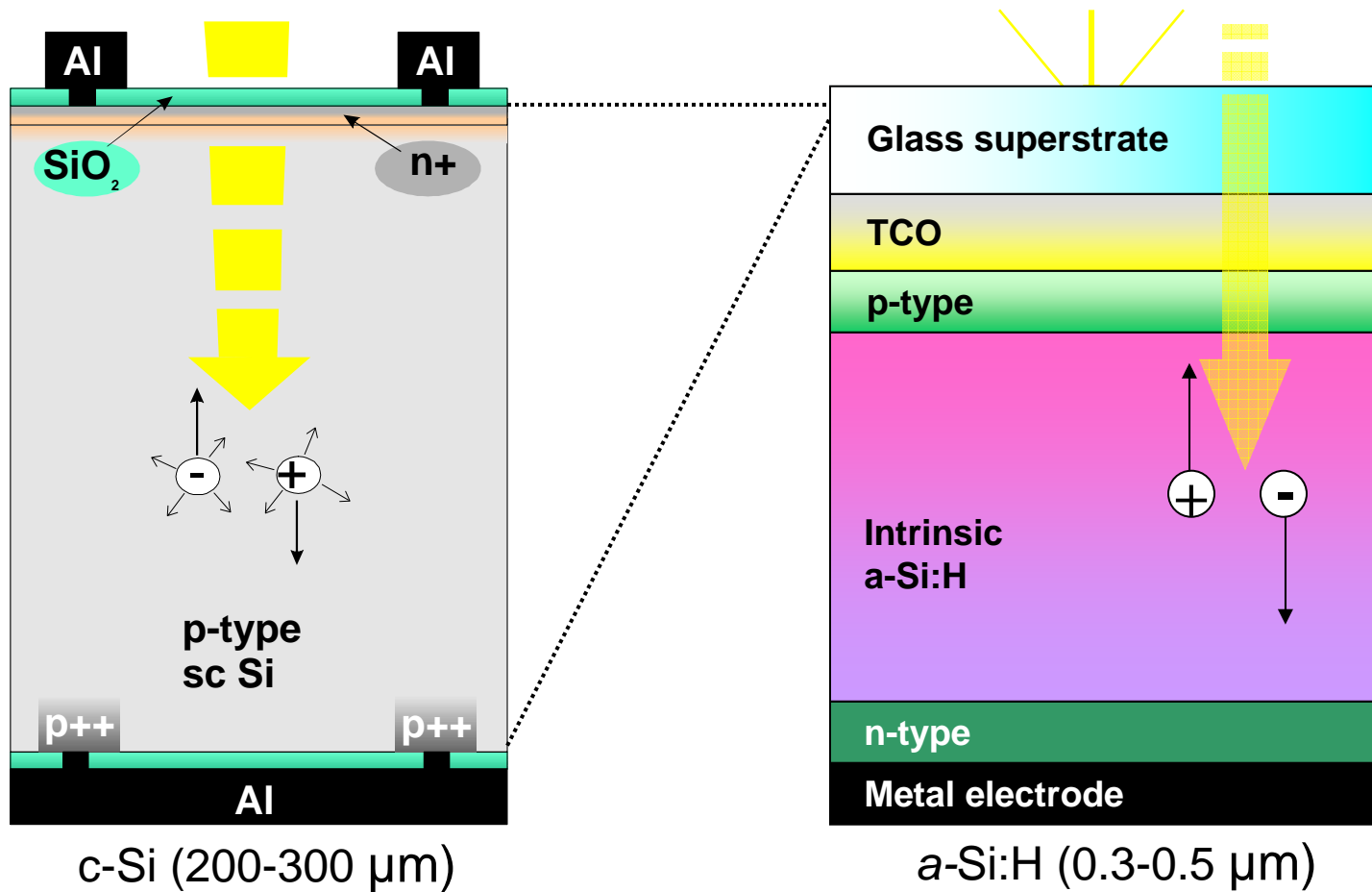


Material required for 1 MW_p



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

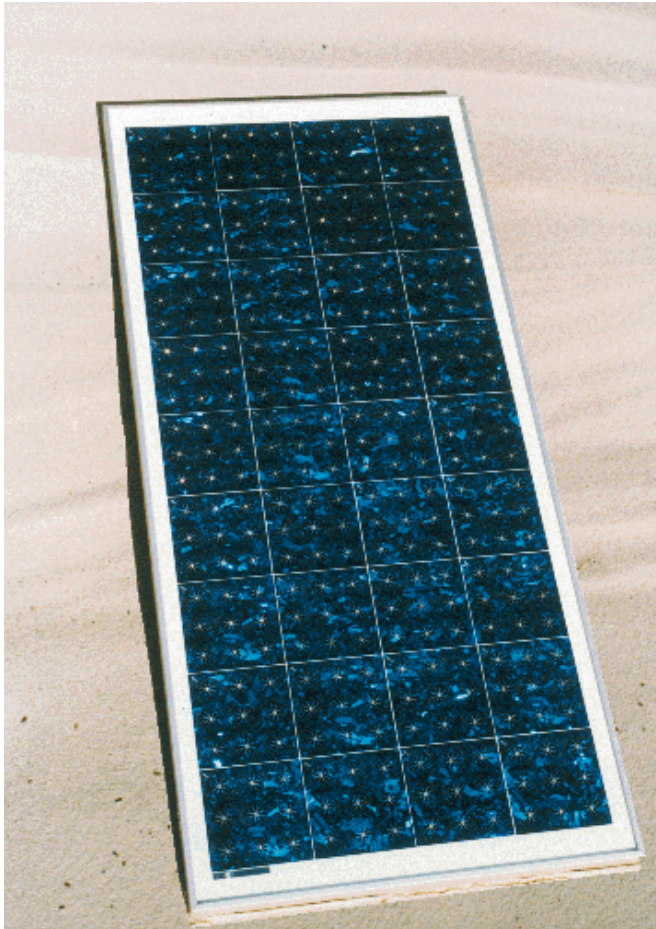
Thin-film Si solar cells



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

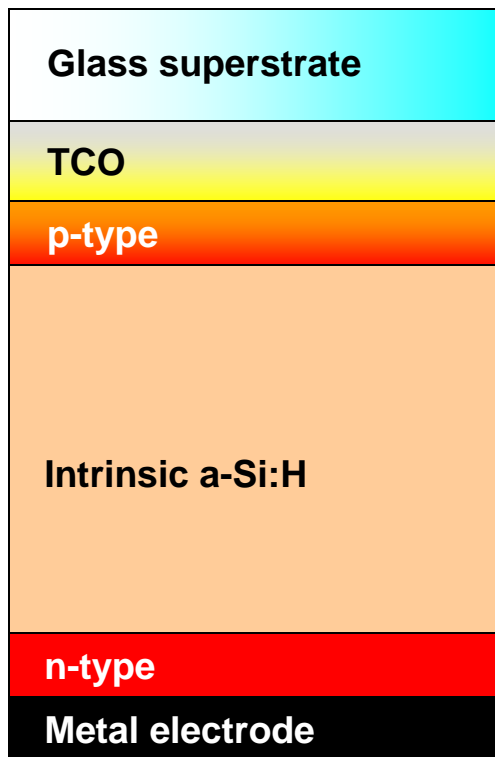


Flexible *a*-Si:H PV modules

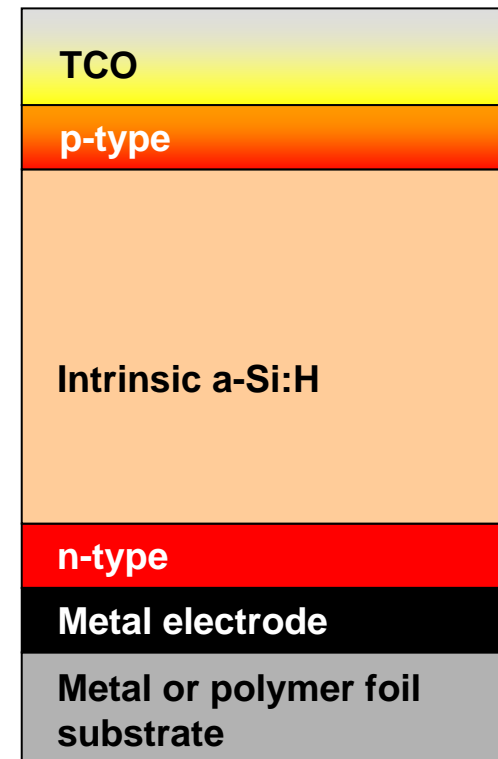
a-Si:H solar cells

Superstrate solar cell structure

(Light enters through carrier)



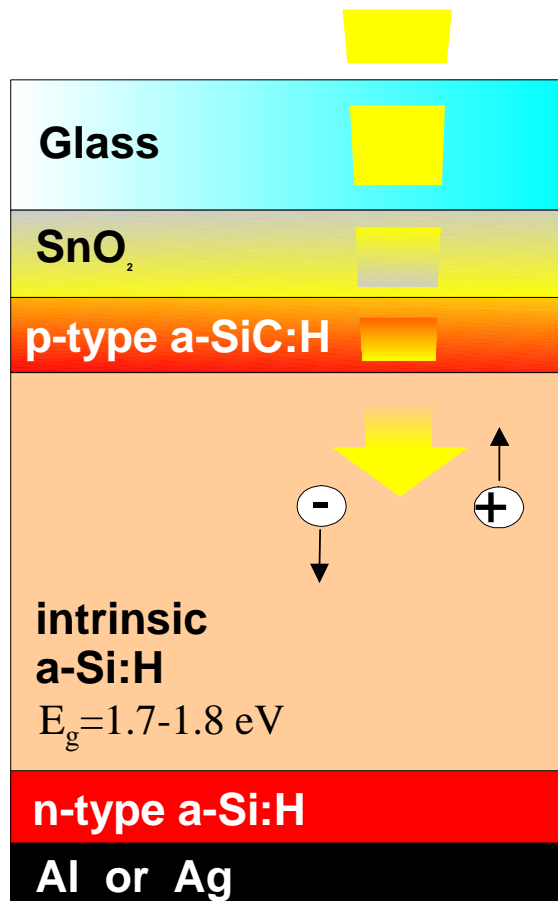
Substrate solar cell structure



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/ μ c-Si)
- Stabilized performance
- Deposition rate (rf PECVD 0.1-0.2 nm/s)

a-Si:H solar cells

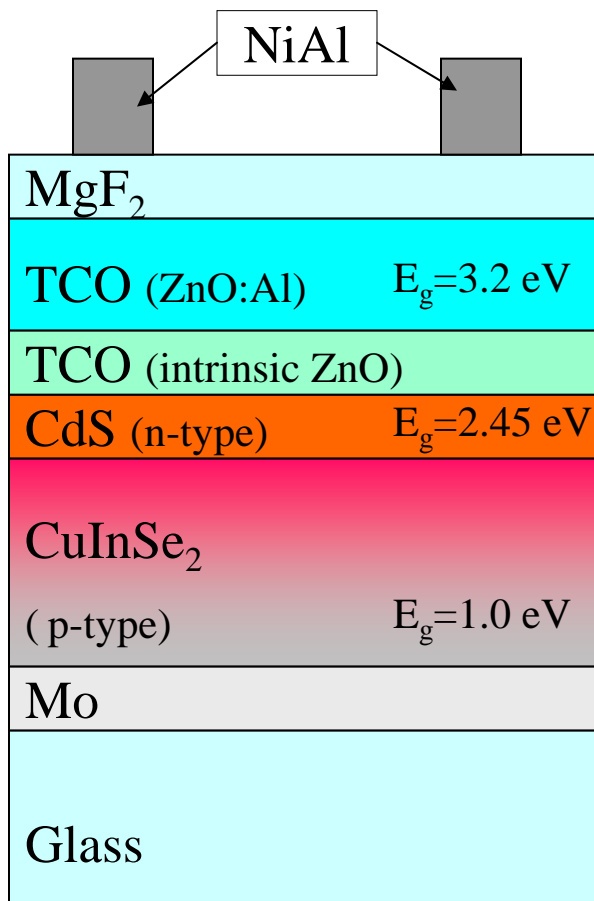


Active material:

- 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) Se₂



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) Se₂

- ± 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) Se₂

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

Glass	
TCO (ZnO:Al)	$E_g=3.2$ eV
CdS (n-type)	$E_g=2.45$ eV
CdTe (p-type)	$E_g=1.45$ eV
Metal contact	

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