The Abdus Salam
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Energy Agency

Workshop on "Physics for Renewable Energy"
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Crystalline Silicon Solar Cells

A. Goetzberger
Fraunhofer Institut for Solar Energy Systems
Germany

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Adolf Goetzberger

Fraunhofer-Institut für
Solare Energiesysteme ISE

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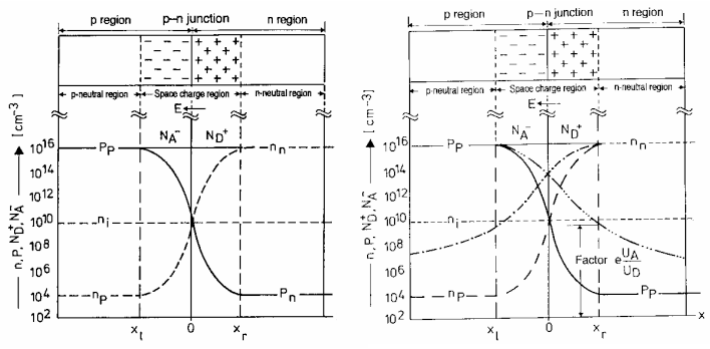
History of silicon solar cells

- 1839 first photovoltaic effect discovered by Edmond Becquerel
- 1904 physical explanation by Albert Einstein
- 1954 First silicon solar cell at Bell Laboratories by Chapin, Fuller and Pearson. 6% efficiency which was soon increased to 10%
- 1961 first fundamental theory by Shockley and Queisser based on detailed balance.
- 1991 first high efficiency silicon cell (?<20%) by M. Green.
- ……..
- ……..

Properties of silicon as a solar cell material

- Advantages
  - Unlimited supply of raw material
  - Well developed materials and device technology
  - Well developed understanding of physics
  - High solar cell efficiency
  - Well established long term solar cell stability
- Disadvantages
  - Low light absorption coefficient because of indirect band structure
  - Large thickness of material required
  - High cost of silicon wafers
  - At present shortage of solar grade silicon

Carrier distribution at pn junction



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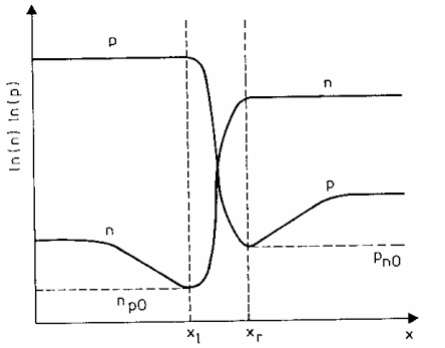
Diffusion gradients of minority carriers



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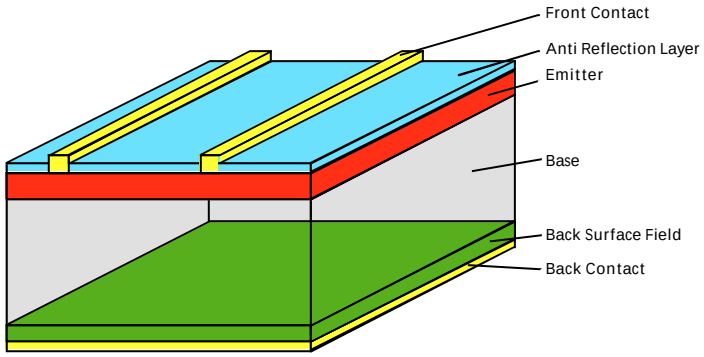

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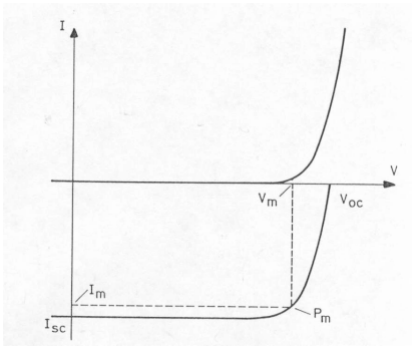
Solar cell characteristics



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Fundamental relations

$$I = I_0(\exp(V_A/V_T) - 1)$$

$$I = I_0(\exp(V_A/V_T) - 1) - I_L$$

$$Voc = V_T \ln(I_L / I_0 + 1)$$

I_0=Diode saturation current
V_A = Applied voltage
V_T = Therm. Voltage (const)
I_L = Light induced current

Efficiency $$\eta = \frac{I_m V_m}{P_{light}} = \frac{FFI_{sc}V_{oc}}{P_{light}}$$

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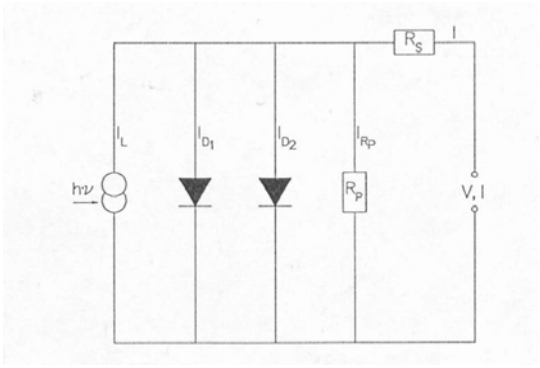
Equivalent circuit of solar cell



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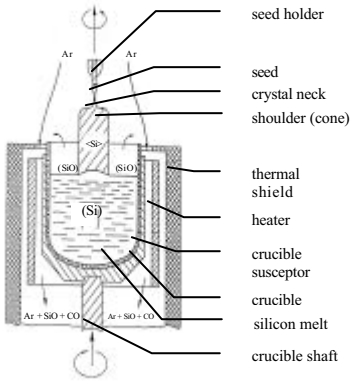
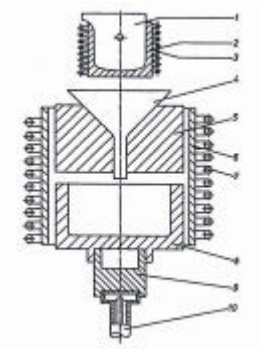
Crystal pulling apparatus



Si casting apparatus



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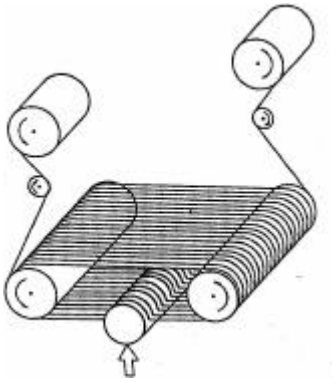
Multiple wire saw



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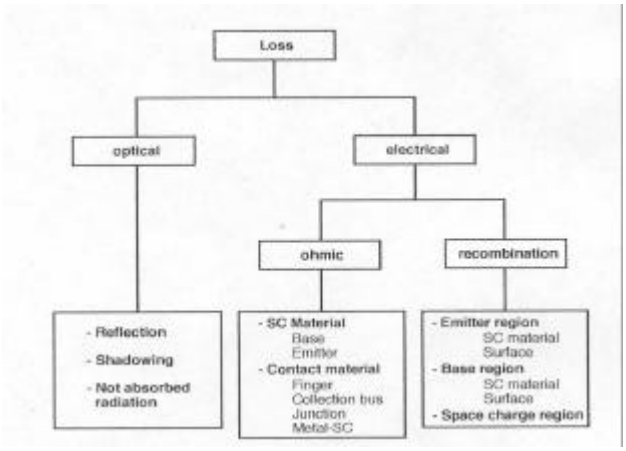

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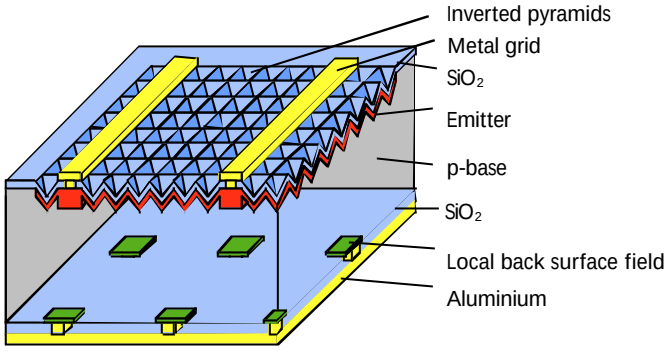
High efficiency solar cell



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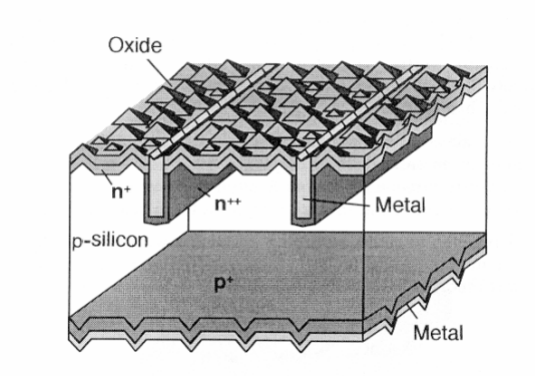
The buried contact solar cell



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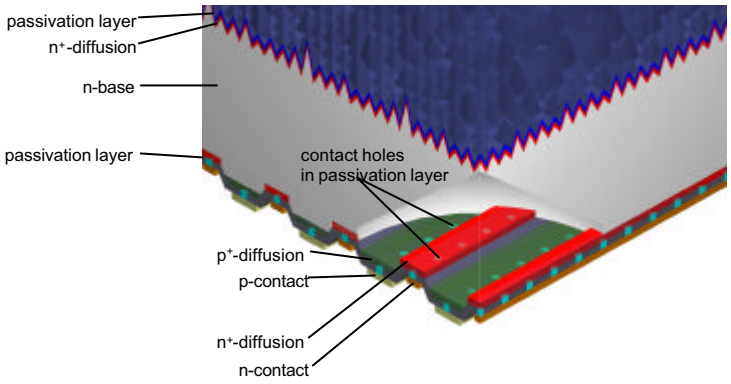
The point contact solar cell



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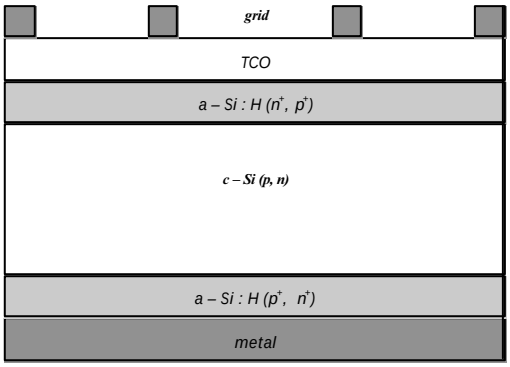
The hetero junction solar cell (HIT) by Sanyo



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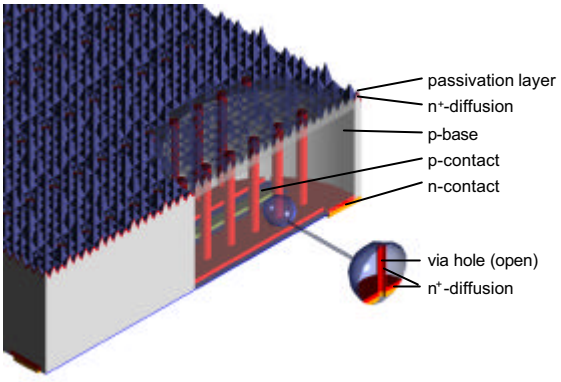
The emitter wrap through solar cell



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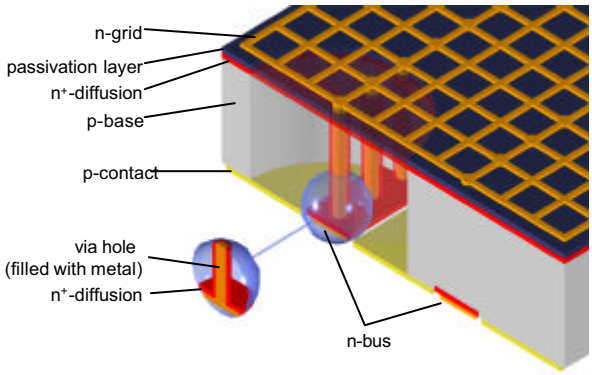
The metal wrap through cell



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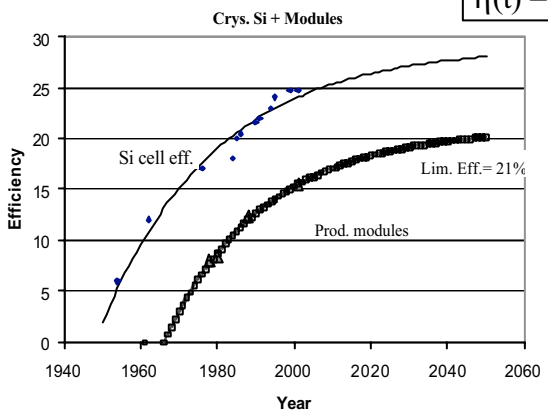
$$\eta(t) = \eta_L(1 - \exp((a_0\text{-}a)/c))$$



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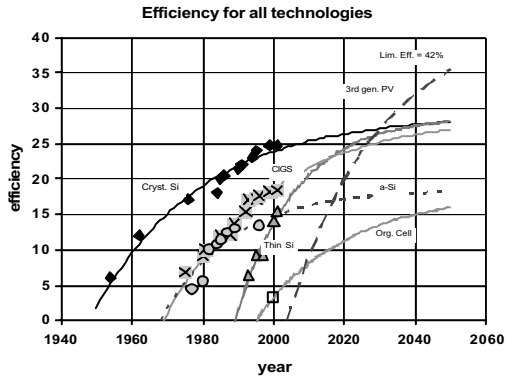
Long term efficiency development



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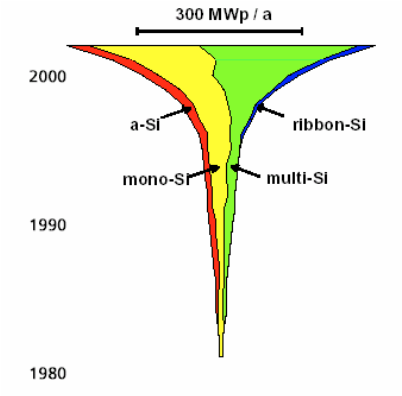
Market growth of solar cell technologies



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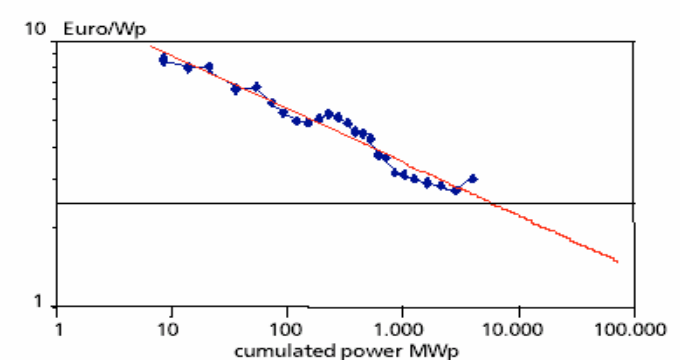
Learning curve for module prices



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Future developments

- Short term: Lower cost
  - Thinner wafers
  - Further enhancement of efficiency by adapting high efficiency techniques to production
  - New solar cell structures
- Long term
  - Crystalline thin film cells
  - Spectrum conversion to utilize solar spectrum more completely
- Crystalline silicon cells will dominate the market for a very long time

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