Crystalline Silicon Solar Cells

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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

Diffusion gradients of minority carriers
Solar cell characteristics

[Diagram showing the structure of a solar cell with labels for Front Contact, Anti Reflection Layer, Emitter, Base, Back Surface Field, and Back Contact.]
**Fundamental relations**

\[
I = I_0 ( \exp \left( \frac{V_A}{V_T} \right) - 1 ) \\
I = I_0 ( \exp \left( \frac{V_A}{V_T} \right) - 1 ) - I_L \\
V_{oc} = V_T \ln \left( \frac{I_L}{I_0} + 1 \right)
\]

Efficiency \( \eta = \frac{I_m V_{m}}{P_{light}} = \frac{FFI_{sc} V_{oc}}{P_{light}} \)

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

**Equivalent circuit of solar cell**
Crystal pulling apparatus

- seed holder
- seed
- crystal neck
- shoulder (cone)
- thermal shield
- heater
- crucible
- susceptor
- crucible
- silicon melt
- crucible shaft

Si casting apparatus

Multiple wire saw
High efficiency solar cell

- Inverted pyramids
- Metal grid
- $\text{SO}_2$
- Emitter
- p-base
- $\text{SO}_2$
- Local back surface field
- Aluminium
The buried contact solar cell

The point contact solar cell

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The hetero junction solar cell (HIT) by Sanyo

![Diagram of a hetero junction solar cell (HIT) by Sanyo]

The emitter wrap through solar cell

![Diagram of the emitter wrap through solar cell]
The metal wrap through cell

\[ \eta(t) = \eta_L (1 - \exp((a_0-a)/c)) \]
Long term efficiency development

Market growth of solar cell technologies
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**