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## **Workshop on "Physics for Renewable Energy" October 17 - 29, 2005**

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### **Crystalline Silicon Solar Cells**

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# Crystalline Silicon Solar Cells

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Solare Energiesysteme ISE

Workshop on Physics for  
'RENEWABLE ENERGY'  
October 17 - 29, 2005  
Miramare-Trieste, Italy

ISE Workshop 2005



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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.
- .....
- .....

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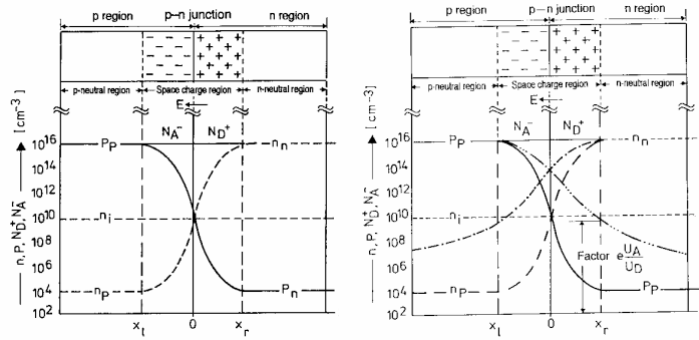
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## Properties of silicon as a solar cell material

- 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

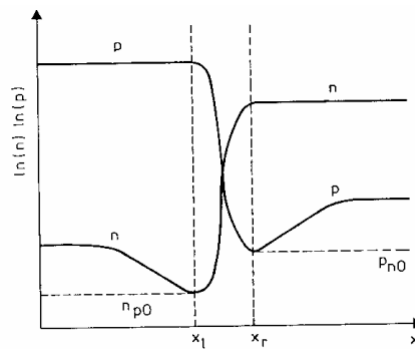
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## Carrier distribution at pn junction

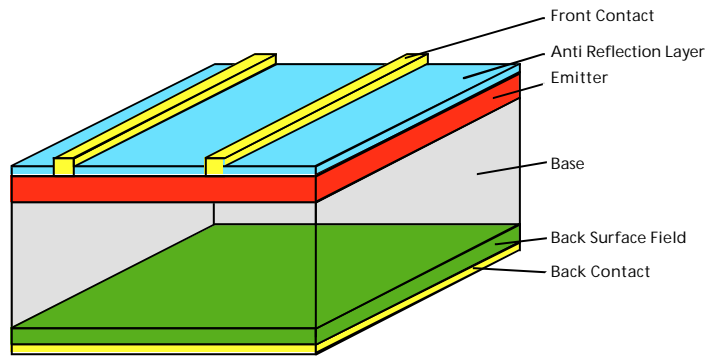


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## Diffusion gradients of minority carriers

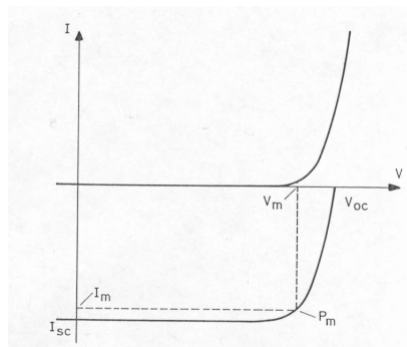


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## Solar cell characteristics



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## Fundamental relations

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

$I_0$  = Diode saturation current

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

$V_A$  = Applied voltage

$V_T$  = Therm. Voltage (const)

$I_L$  = Light induced current

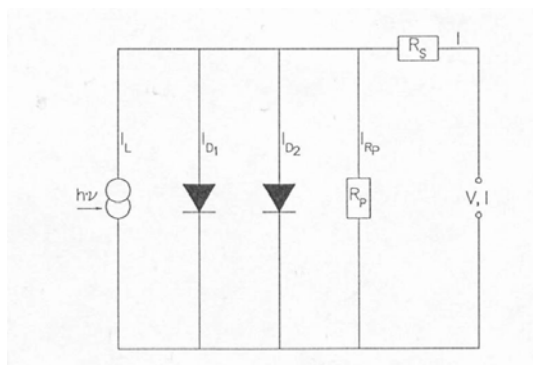
$$V_{oc} = V_T \ln(I_L / I_0 + 1)$$

$$\text{Efficiency } \eta = \frac{I_m V_m}{P_{light}} = \frac{FF I_{sc} V_{oc}}{P_{light}}$$

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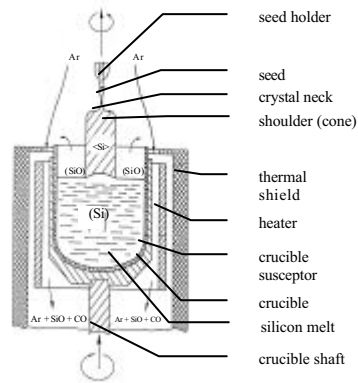
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## Equivalent circuit of solar cell



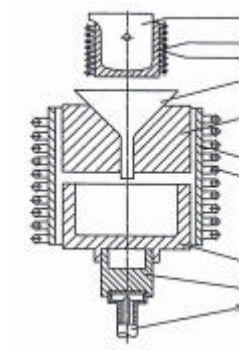
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## Crystal pulling apparatus

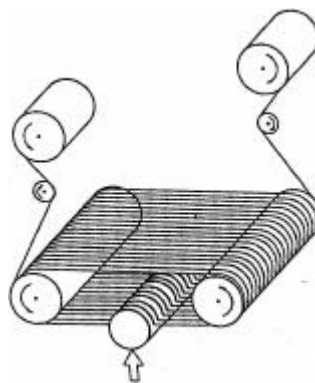


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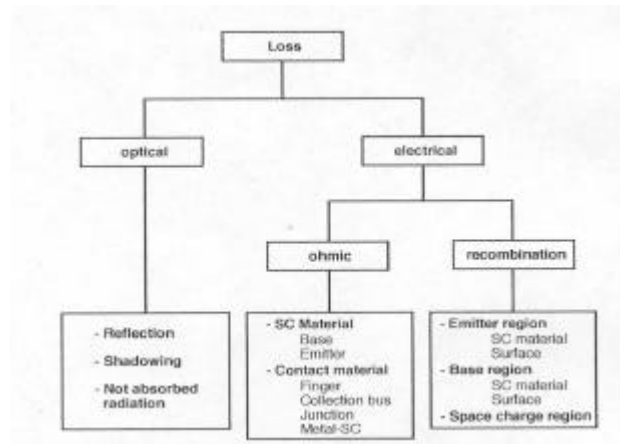
## Si casting apparatus



## Multiple wire saw

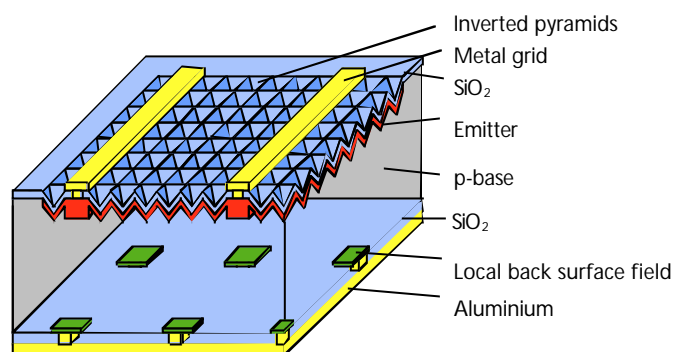


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## High efficiency solar cell

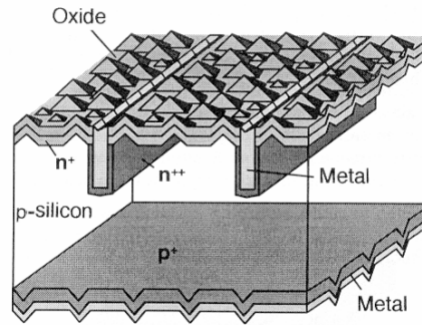


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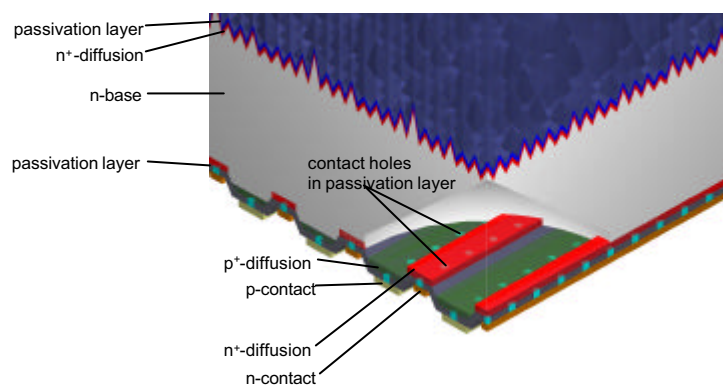
## The buried contact solar cell



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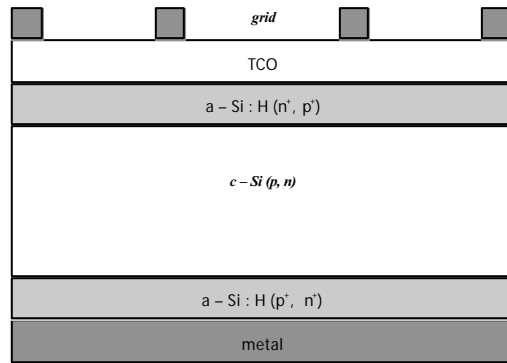
## The point contact solar cell



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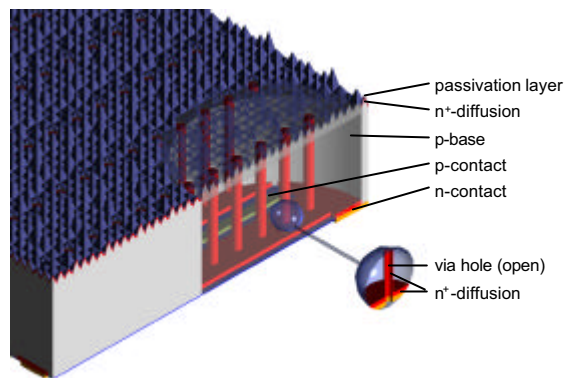
## The hetero junction solar cell (HIT) by Sanyo



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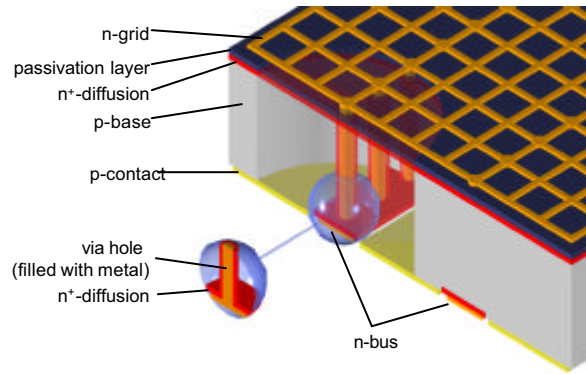
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## The emitter wrap through solar cell

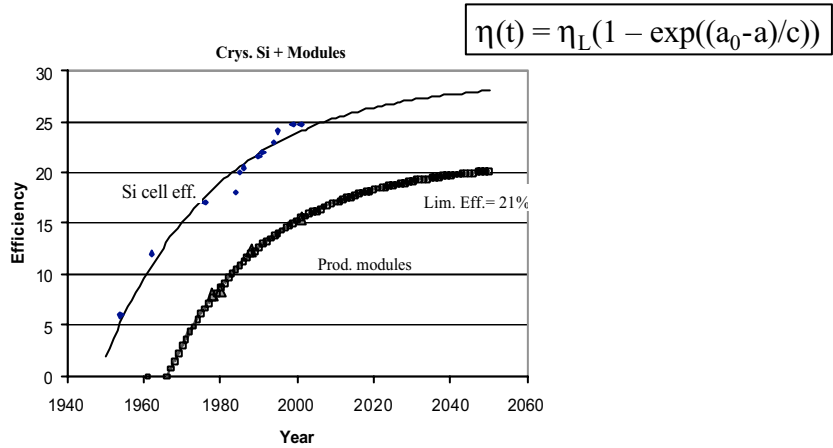


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## The metal wrap through cell

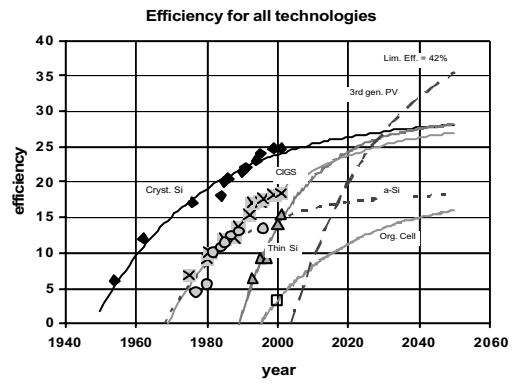


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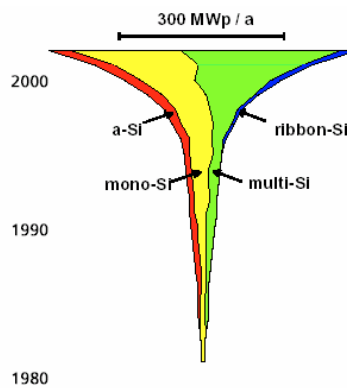
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## Long term efficiency development



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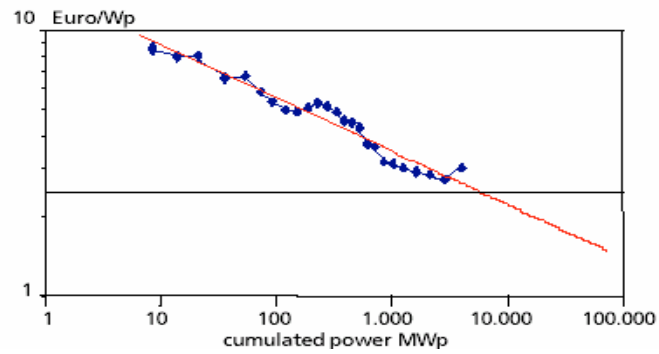
## Market growth of solar cell technologies



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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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