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Conventional Solar Cells

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Chapter 2

CONVENTIONAL SOLAR CELLS

2.1 Silicon Solar Cell

Silicon is still most favoured candidate for terrestrial as well as space solar cells in view of its well understood technology, abundant availability of the starting material (SiO$_2$) and the non-toxic nature. This is inspite of the low efficiency obtained in these solar cells. It is possible to prepare a single crystal silicon of high purity with a high degree of structural perfection. Due to these obvious reasons, silicon solar cells have been dominating the scene for many decades.

In the past, the p-n cells consisted of 10 ohm cm boron-doped wafer, diffused on one side to a depth of 0.2-0.5 Micrometer with phosphorus ($n^+$-$p$ structure) contacted with Ti-Pd-Ag or Ti-Ag solder, and covered with 670 to 800 Å of SiO. These p-n cells are able to convert 11.5 per cent of AMO and 14 per cent of AM I sunlight into useful power. This solar cell design was a compromise between AMO efficiency and radiation tolerance. Cells made with lower resistivity boron-doped substrates yielded higher efficiencies initially but degraded under high energy particle radiations at a faster rate.
Several significant breakthroughs in Si cells have occurred in recent years. The first of these was the discovery by Wysocki and coworkers that p+n cells doped with Li in the base exhibited greatly improved radiation tolerance compared to other cells because of their ability to recover after the damage has occurred. Lithium doped cells with AMO efficiencies of 13.8 per cent have been reported. Cells with enhanced response at blue and ultraviolet wavelengths have been produced with AMO efficiencies of 15.5 per cent; the same cells also exhibited improved radiation tolerance as compared to the conventional Si cells.

The third significant development in the field of silicon homojunction

![Figure 2.1 Silicon Solar Cell Construction and working](image)
solar cells was the idea of back surface field solar cells that the open
circuit voltage could be improved considerably (0.6V) diffusing a
heavily doped region at the back contact the thickness of Si wafer used
in solar cell production is now of the order of 250-300 Micrometer.
Theoretically and experimentally, it has been shown that 100 μm thick
cell with a back surface field yields an efficiency as high as, or even
higher than the conventional n+p cell.

Silicon had been mainly used in homojunction solar cells, but recent
observations show that it has an equal potential for other structures also,
viz., Schottky barriers, MIS and SIS cells and in several heterojunctions
such as Si-CdS, Si-GaAs etc. The standard single crystal silicon solar
cells are made on Czochralski grown silicon, though silicon grown by
other cost effective techniques has been developed and used. These
include the dendritic web grown (WEB), EFG ribbon, and float zone
which are compatible with the cost goal for photovoltaic modules of
efficiencies 12-13 per cent, 10 percent and 10-11 per cent respectively.
Cells with improved blue sensitivity and higher current densities have
been designed by etching the diffused layer to remove a surface region
having high recombination rate. The frequency factor and open circuit
voltage improve while the photocurrent decreases with increasing
doping level in the base; the net result of these complicating factors is
that the efficiency improves somewhat with decreasing base resistivity.
An Investigation of Efficiency Factors of Nanostructured Dye-Sensitized Solar Cells

Over the past ten years, open-circuit voltage has gradually risen from 600 mV to 660 mV level. A second major frontier that the silicon solar cell is exploring concerns the performance of cell with base resistivity above 50 ohm cm. These cells have the potential for increased radiation resistance due to decreased boron concentration. The search for increased cell voltage in Si has led to sufficient understanding so that a cell can be designed which is capable of achieving the limit efficiency.

2.2 Polycrystalline Silicon Solar Cell

Several methods for obtaining polycrystalline silicon for solar cells have been developed. These methods either result in sheet growth or ingot growth. For sheet-growth, edge defined film, fed process capillary action shaping technique, dendritic web ribbon process etc. are employed. Till now ribbon of 10 cm width and a thickness of 150 micron have been grown at a rate of 4 cm min. Polycrystalline silicon can also be produced by casting whereby molten silicon is poured into a crucible and the silicon solidifies in a controlled manner. Recently directional solidification of silicon in crucible has also been investigated and very large grain polycrystalline silicon ingots have been grown. In contrast to single crystal, polycrystalline silicon is composed of a conglomerate of individual crystals (grains) separated by boundaries.
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To make solar cells more cost effective for terrestrial applications and to bring down the cost attention is now being diverted for using polycrystalline Si substrates because of the following advantages:

(i) Polycrystalline growth requires less stringent conditions as compared to those for single crystal, leading to high speed growth.

(ii) Shaped crystal growth, the geometry and thickness of which are more amenable to absorbing incident light as compared to conventional silicon wafers.

(iii) Shaped crystal growth also obviates the need for conventional sawing and surface preparation, thereby significantly lowering the substrate cost.

![Figure 2.2 Polycrystalline Silicon Solar Panel](image)

Inherently, polycrystalline Si has significantly different properties from its single crystal counterpart. The major electronic loss mechanisms are associated with lattice mismatch at grain boundaries due to dangling bonds among the atoms. This defect region is modeled as a two
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dimensional plane with a certain energy distribution of localized states. These states may act as segregation sites for impurity atoms, thus reducing the concentration of impurity atoms in the bulk of crystal; or in the equilibrium condition these defect states fill with majority carriers, as required by the internal chemical potential, and a grain boundary space charge region is established to preserve charge neutrality.

2.3 Amorphous Silicon Solar Cell

Amorphous silicon is emerging as a very promising material for solar energy conversion, although with great efforts it has yielded solar cells with low efficiencies of the order of 10 per cent. Amorphous silicon has the following major benefits:

(i) the manufacturing process is inherently cheaper, and

(ii) the quantity of silicon required for solar cell fabrication is quite low as compared to that for single or polycrystalline silicon.

P-N junction amorphous silicon solar cells are produced by the glow discharge decomposition of silicon. Analysis shows that the presence of monoatomic hydrogen in amorphous silicon reduces the density of states within the forbidden gap and allows to dope it. Doping concentration is controlled by the presence of small quantities of gases containing the desired dopant during the glow discharge decomposition. Glow discharge deposited amorphous silicon has resulted in good quality
photovoltaic solar cells. Recent work has yielded 10 per cent efficiency on \(2\text{cm}^2\) area cell.

**Figure 2.3** Amorphous Silicon Solar Cell

Amorphous silicon is represented as a-Si. The Lifetime of amorphous cells is shorter than the lifetime of crystalline cells. Amorphous cells have current density of up to 15 mA/cm², and the voltage of the cell without connected load of 0.8 V, which is more compared to crystalline cells. Their spectral response reaches maximum at the wavelengths of blue light therefore, the ideal light source for amorphous solar cells is fluorescent lamp. The most serious problem associated with the amorphous silicon solar cells is that these degrade in their performance very rapidly with time, even after being sealed hermetically.
2.4 Cadmium Sulphide / Cadmium Telluride Solar Cell

The development history of cadmium sulphide solar cell is as old as that of p-n junction solar cell that was made for the first time in 1954. From this material, heterojunction solar cells Cds/CuS are fabricated. Since these cells are thin film solar cells, their production methods are amenable to mass fabrication. Therefore, in the beginning it was felt that cadmium sulphide solar cells would provide economic feasibility, since their unit cost is very low as compared to the other material solar cells. Later on, two main limitations, i.e., low efficiency and less stability, of the cadmium sulphide solar cell as compared to silicon solar cell decreased the formers importance in the photovoltaics. For terrestrial applications, the best CdS solar cell showed 10 per cent conversion efficiency at AM I condition against the theoretical calculated efficiency of 15 per cent.

The CdS/Cu₂S cell is made by spraying CdS onto a glass substrate and then dipping it in copper. Prior to this spray, the glass is coated with a conducting layer of indium tin oxide for current collection. Such fabricated CdS cells show lower efficiencies than the conventional evaporated ones. To increase the stability of these cells a 100 Å thick copper film is deposited on Cu₂S, which also enhances short circuit current. It is followed by heat treatment of the cell film at 160°C for 15
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minutes in air forming a Cu₂O layer at the surface, resulting in low surface recombination velocity for the charge carriers. Efforts are being made to replace CdS by Cd-Zn-S to improve the lattice and electron affinity matches, resulting in an increase in $V_{oc}$ from 0.5 to 0.7 volts and efficiency up to 15 per cent. Attempts have been made to replace Cu₂S by Cd-Te, Cu-In-Se₂ direct band gap semiconductors giving further rise in efficiency of the cell. These materials have high absorption coefficient and are more stable against environmental changes.

Cadmium sulphide solar cells degrade in ambient air rapidly; however, when protected from moisture and oxygen and properly electrically loaded, it is expected that the lifetime of these cells may increase up to 15 years or more. Severe degradation of these cells have been observed due to the presence of water vapour illuminated at higher temperatures and load voltage exceeding 0.33 V. A decrease in short circuit current occurs with the presence of water vapour leaving the open circuit voltage and fill factor of the cell almost unaffected. Decrease in short circuit current is due to the additional traps created by water vapours, which lower the collection efficiency. In addition to this, when CdS solar cell is illuminated and operated at a load voltage greater than or equal to 0.33V, degradation in cell performance occurs. Open circuit voltage and fill factor are affected drastically, while the short circuit current remains unaffected. Degradation due to moisture can be
avoided by hermetic encapsulation of the device and forced water cooling at higher temperatures. Stability is achieved by evaporating a 100 Å layer of copper onto the Cu$_2$S surface followed by heat treatment.

2.5 Gallium Arsenide Solar Cell

The gallium arsenide solar cell held promise first as a higher efficiency device and later as a device, which is more favourable for high temperature applications, especially for space applications. Gallium arsenide is suitable for use in high-efficiency solar cells for several reasons:

- The GaAs band gap is 1.43 eV, nearly ideal for single-junction solar cells.
Gallium arsenide has a high absorptivity and requires a cell only a few microns thick to absorb sunlight. (Crystalline silicon requires a cell 100 microns or more in thickness.)

Unlike silicon cells, GaAs cells are relatively insensitive to heat. (Cell temperatures are often quite high, especially for concentrator applications.)

Alloys made from gallium arsenide using aluminum, phosphorus, antimony, or indium have characteristics complementary to those of gallium arsenide, allowing great flexibility in high-efficiency cell design.

Gallium arsenide is very resistant to radiation damage. This, along with its high efficiency, makes GaAs very desirable for space applications.

In the beginning, the development of gallium arsenide solar cell was hindered by different cell design concepts to be utilized for making an efficient solar cell and the high price of raw material due to limited resources of gallium. Since the advent of light emitting diodes in the commercial market the demand of GaAs increased tremendously. The demand was further boosted up by the use of GaAs in semiconductor injection lasers. All this ultimately led to a well-developed technology for GaAs.
GaAs is a direct gap material with a steep absorption edge at 1.4 micron that is, it has high absorption coefficient over the entire solar spectrum above 1.4 micron. In the case of GaAs, surface losses are much more drastic than for silicon because sunlight is absorbed and carriers are created much closer to the surface. Virtually all the carriers generated by sunlight are generated in the first 3 micron of the GaAs from the surface. For this reason, high recombination velocity and low lifetime of minority carriers usually result in severe losses. This makes the properties of the top side of the junction much more important.

Figure 2.5 GaAs Solar Cell Driven Car

The high recombination velocity reduces short circuit current by lowering the collection efficiency, and can even lower the open circuit voltage and fill factor by increasing the forward dark current. These high surface losses can be partly overcome by making the junction depth small as in silicon solar cells, or by establishing an aiding electric field at the surface. It is difficult to incorporate a drift field in the diffused
region and therefore, an alternative method for overcoming the surface recombination problem is to grow a very thin, transparent alloy layer of Ga$_{1-x}$Al$_x$As on the surface of the gallium arsenide junction. The Ga$_{1-x}$Al$_x$As matches the lattice of GaAs very closely which results in low recombination velocity. GaAs solar cell basically have p-n or n$^+$ p$^+$ structure to the similar to the silicon solar cell structure. A p-n junction is obtained by diffusing Zn into n type GaAs single crystal. An efficiency of 22 percent at AMI condition has been reported for fabricating n$^+$pp$^+$ solar cell from GaAs.

2.6 Tandem Solar Cell

Generally solar cell have low efficiency and high cost. To reduce cost and to achieve greater efficiency we need a cell, which is called tandem solar cell. Tandem solar cell is an array of p-N junctions to utilize the most part of the solar cell in descending order of band gap. By this process we get effective conversion of high energy photons into electrical power. It light is not absorbed by high band gap material is absorbed by low band gap material. In this methods (structure) current increased, and therefore, efficiency increased. The maximum efficiency of single junction solar cells based on silicon is located in the range of 25 %.
The tandem concept utilising high-quality inorganic semiconductor materials with different bandgaps already allows solar energy conversion efficiencies of far above 35%, significantly more than theoretically possible in an ideal single layer solar cell. Therefore, tandem solar cells are developed since over a decade and with inorganic active materials, this structure is already advanced and technologically implemented (e.g. satellite power supply). Recently, connected stacked cells made of evaporated small molecules reached remarkable results. All of them are based on serial connections with thin metal layers as recombination centers. Recently, Hiramoto, Suezaki and Yokoyama published a paper in which they claimed the doubling of the voltage of a normal cell by evaporating two small molecule cells on top of each other, connected in series by a 10 nm gold layer. The currents of these cells were very low, but doubled voltages were reached. In 2002, Yakimov and Forrest described a drastically enhanced efficiency of evaporated cells stacked in series by using copper-phtalocyanine(CuPc)
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And 3,4,9,10-perylenetetracarboxylicbis-benzimidazole (PTCBI) connected by a 0.5 nm silver layer as recombination center. The efficiency was 2.5%.

To achieve effective conversion of high-energy photons electric power, GaAs on GaAs cell is fabricated with minimized interconnection of a p-n junction cell with wider band gap ($E_g$). By this process, we get high efficiency of lattice matching with GaAs and applicability to tandem cells using wide gap material ($\text{Al}_x\text{Ga}_{1-x}\text{As}$).