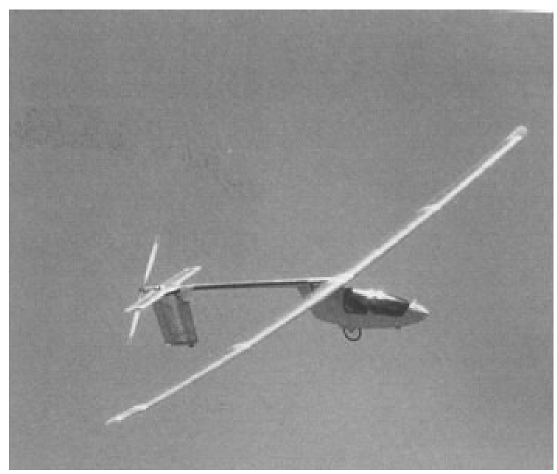
SOLAR CELLS

LECTURE 4

Prof. John David



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Lecture notes :
Either at http://www.shef.ac.uk/webct/ or
http://hercules.shef.ac.uk/eee/teach/resources/MEC316/MEC316.html

Limitations of Solar Cells

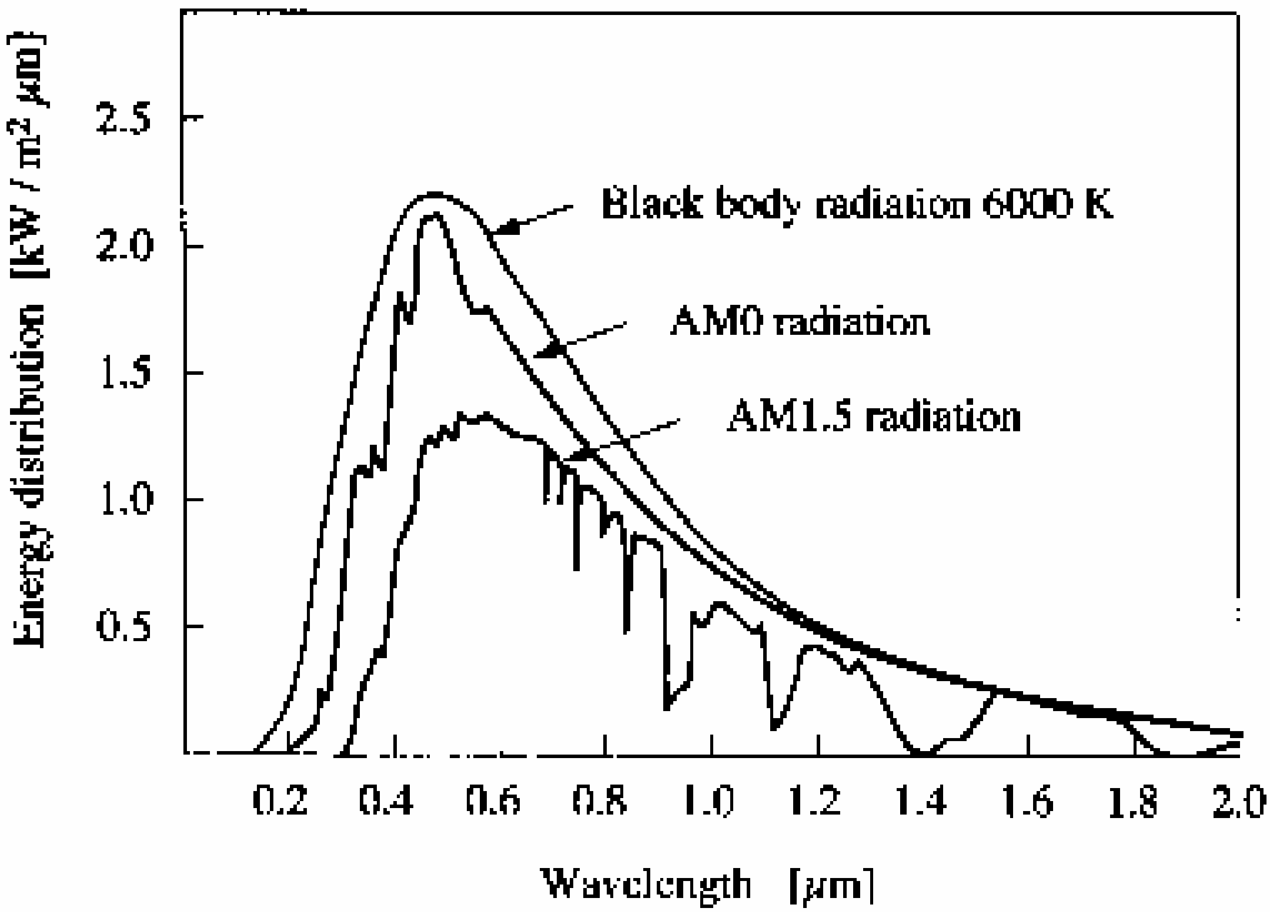
News in brief

Lights going out on bus shelters

SOLAR powered lighting in Dronfield bus shelters is to be scrapped because there is too little winter sunlight to keep the bulbs lit.

Dronfield Town Council has decided to replace the lighting after a series of complaints that shelters were left unlit.

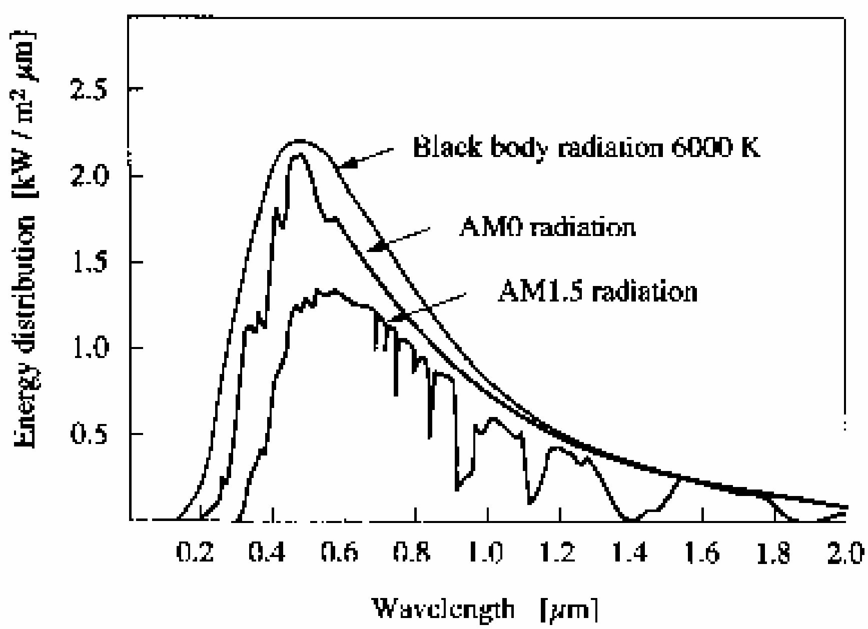
Solar Radiation



The spectral distribution of solar energy measured outside the Earth's atmosphere (AM0) is essentially constant and similar to that of a black body at 6000K. The deviations are due to absorption effects in the solar atmosphere.

At the Earth's surface light absorption by gases such as water vapour, ozone and carbon monoxide, as well as scattering by molecules, aerosols and dust particles attenuate the light by at least 30%. This attenuation varies significantly with atmospheric conditions.

Solar Radiation



AM0 is the spectral distribution of solar radiation measured outside the Earth's atmosphere. (1.353kW/m^2)

AM1 is the spectral distribution of solar radiation measured at the Earth's surface when the Sun is overhead. (Normalised to 0.925kW/m^2)

AM1.5 is the spectral distribution of solar radiation measured at the Earth's surface when the Sun is at 45^o elevation. (Normalised to 0.844kW/m^2)

The mean daily global irradiation in hot Meditteranean countries is in the range 3.2 - 5.2 kW/m^2

Making Efficient Solar Cells

Although Gallium Arsenide (GaAs) can be used to make solar cells which are more efficient than silicon solar cells, it is much more expensive than silicon.

It is therefore used in space applications, where cost is not the major factor, or it is used in concentrator cells.

For an amorphous silicon solar cell with an area of $2cm^2$, a typical efficiency, η, is 12%. Such a cell can deliver 10mW of power at a voltage of 0.6V.

Solar cells made by thin film deposition techniques such as sputtering, electro-plating or spray coating have efficiencies of around 5%, but are much cheaper to make.

Efficiency of Different Types of Solar Cells

Single Crystal Silicon	24.7%
Polycrystalline silicon	19.8%
Amorphous silicon	12.7%
Single Crystal Gallium Arsenide	25.1%
Polycrystalline Gallium Arsenide	18.2%
$CuInGaSe_2$	18.4%
GaInP/GaAs 2-junction	30.3%
GaInP/GaAs/Ge 3-junction	28.7%

All above measured at AM1.5 ($1000 W\text{-}m^{-2}$) at 25C. Quoted September 2001

Spectrolab July 2003

GaInP/InGaAs/Ge 3-junction	36.9%

Optimisation of Solar Cell Efficiency, η

The efficiency, η, depends on V_{max} and I_L.

V_{max} is determined by the band gap, E_g, of the semiconductor and therefore depends on the semiconductor material used.

I_L depends on the number of minority carriers reaching the p-n junction. This depends on how many minority carriers can reach the p-n junction, which in turn depends on the diffusion length of minority electrons and holes. The bigger the diffusion length is, the more carriers can be collected at the junction.

Solar Cells Arrays

In order to generate significant electrical power, it is necessary to have a large array of solar cells with both -

Parallel connection to increase current capacity

Series connection to increase voltage capability

Batteries are normally required to store power for later use

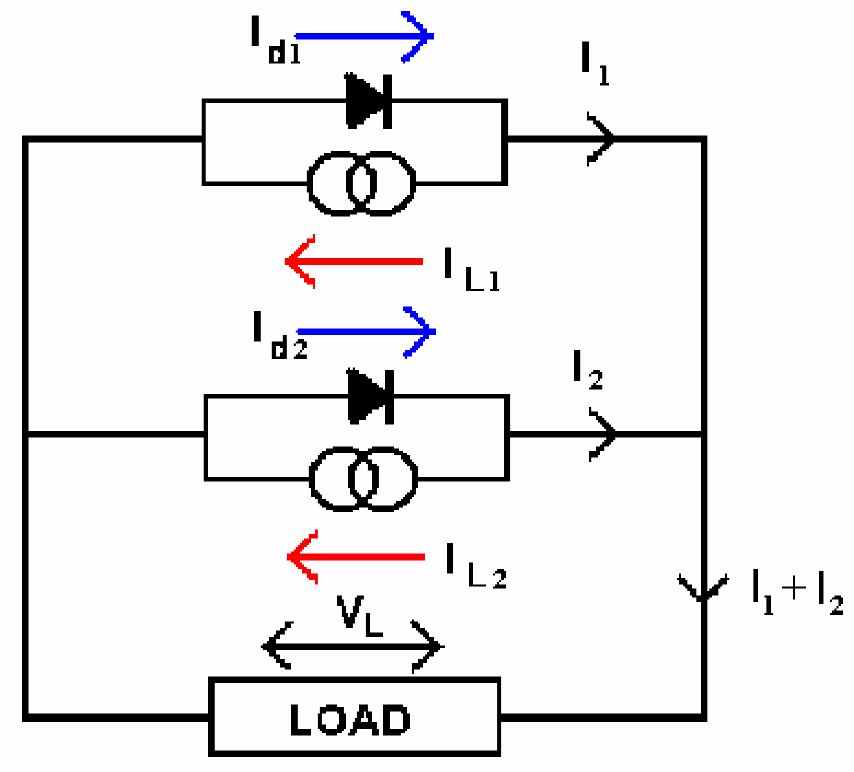
A regulator is required to prevent overcharging of the batteries

A blocking diode is needed so that at dark times the batteries do not discharge through the solar panels

An inverter is normally required to convert the DC power to AC power

It is possible to use the GRID for storage and supply. 2-way metering allows solar energy to be supplied to the grid

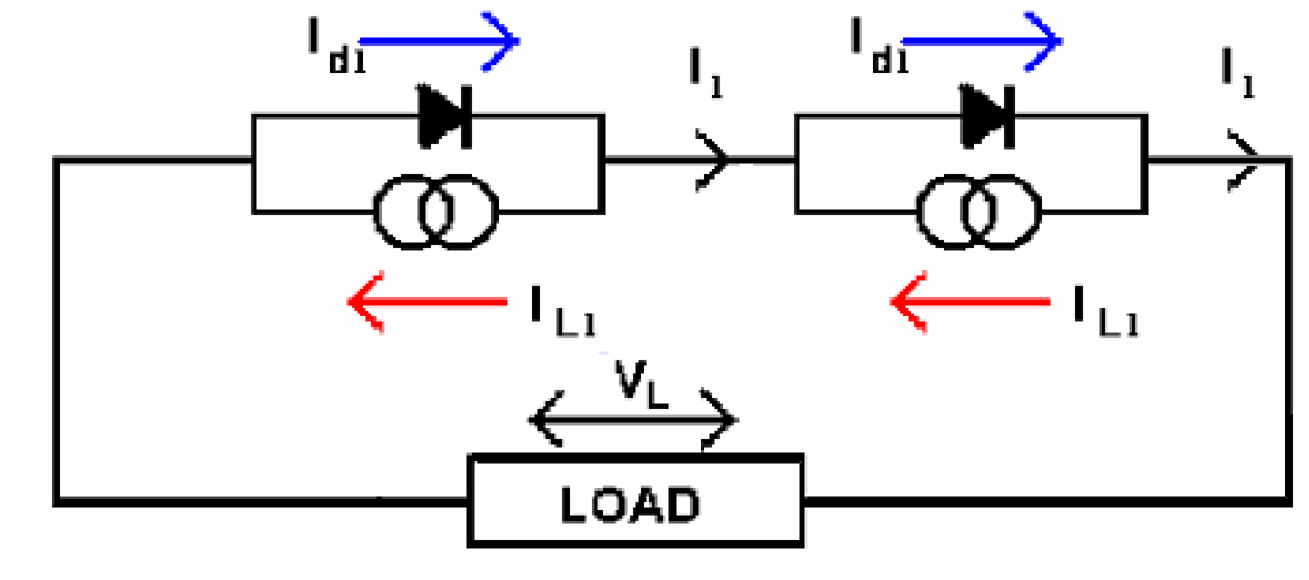
Solar Cells in Parallel



$$I = I_{01}\left[\exp\left(\frac{eV}{kT}\right) - 1\right] - I_{L1} + I_{02}\left[\exp\left(\frac{eV}{kT}\right) - 1\right] - I_{L2}$$

$$I = \left[I_{01} + I_{02}\right]\left[\exp\left(\frac{eV}{kT}\right) - 1\right] - \left(I_{L1} + I_{L2}\right)$$

Solar Cells in Series



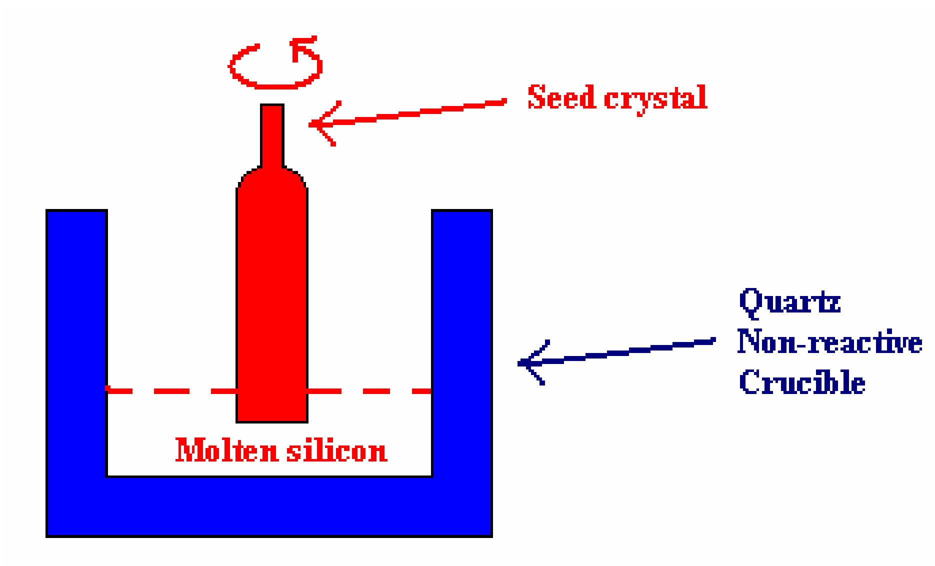
When two solar cells are placed in series-

The current is limited by the cell generating the smaller current

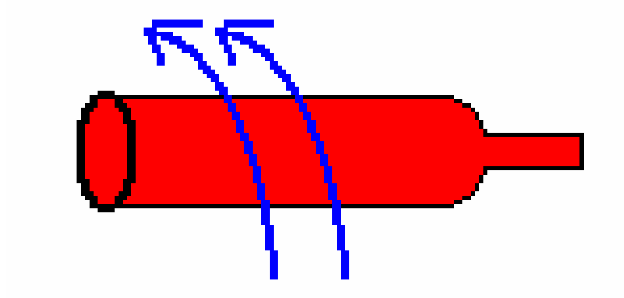
The voltage is the sum of the two solar cell voltages.

Solar cells from Crystalline Silicon

Crystalline silicon is still widely used for solar cells.
Silicon is traditionally grown as ingots -

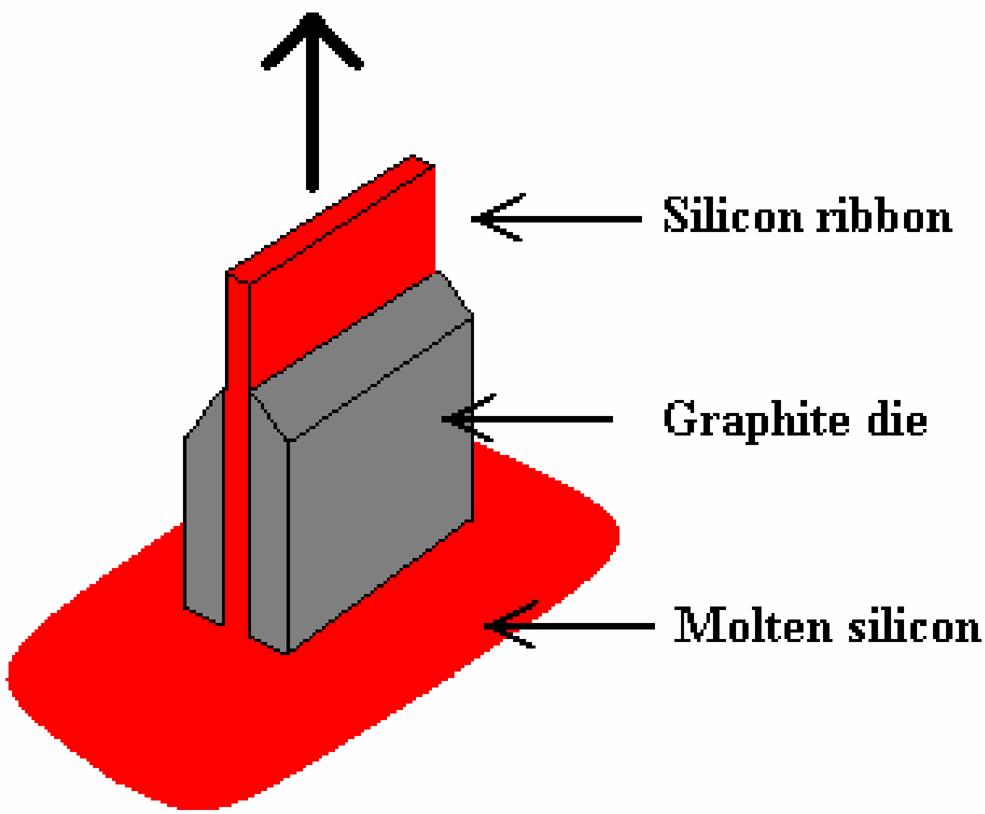


This is an expensive process, requiring a lot of energy. It is also wasteful since the ingots have to be sawn into wafers, which typically looses about 50% of the ingot



Solar Cells from Ribbon and Sheet Growth

Since ingot growth is expensive and wasteful of material, ribbon and sheet growth of thin material has been tried as an alternative -



This technique produces poly-crystalline material with grain boundaries between crystals, impurities from the die and rough surface quality, giving quite poor efficiency solar cells

Solar Cells from Thin Film Deposition

Much effort has gone into studying alternative, cheap techniques for film deposition such as evaporation, sputtering, electro-plating and even spray on techniques.

These techniques generally give poorer quality solar cells, but with significant cost savings. The cost saving is partly because of the reduction in the cost of providing the actual photovoltaic layer, but also savings from simpler processing.

THIN FILM CRYSTALLINE

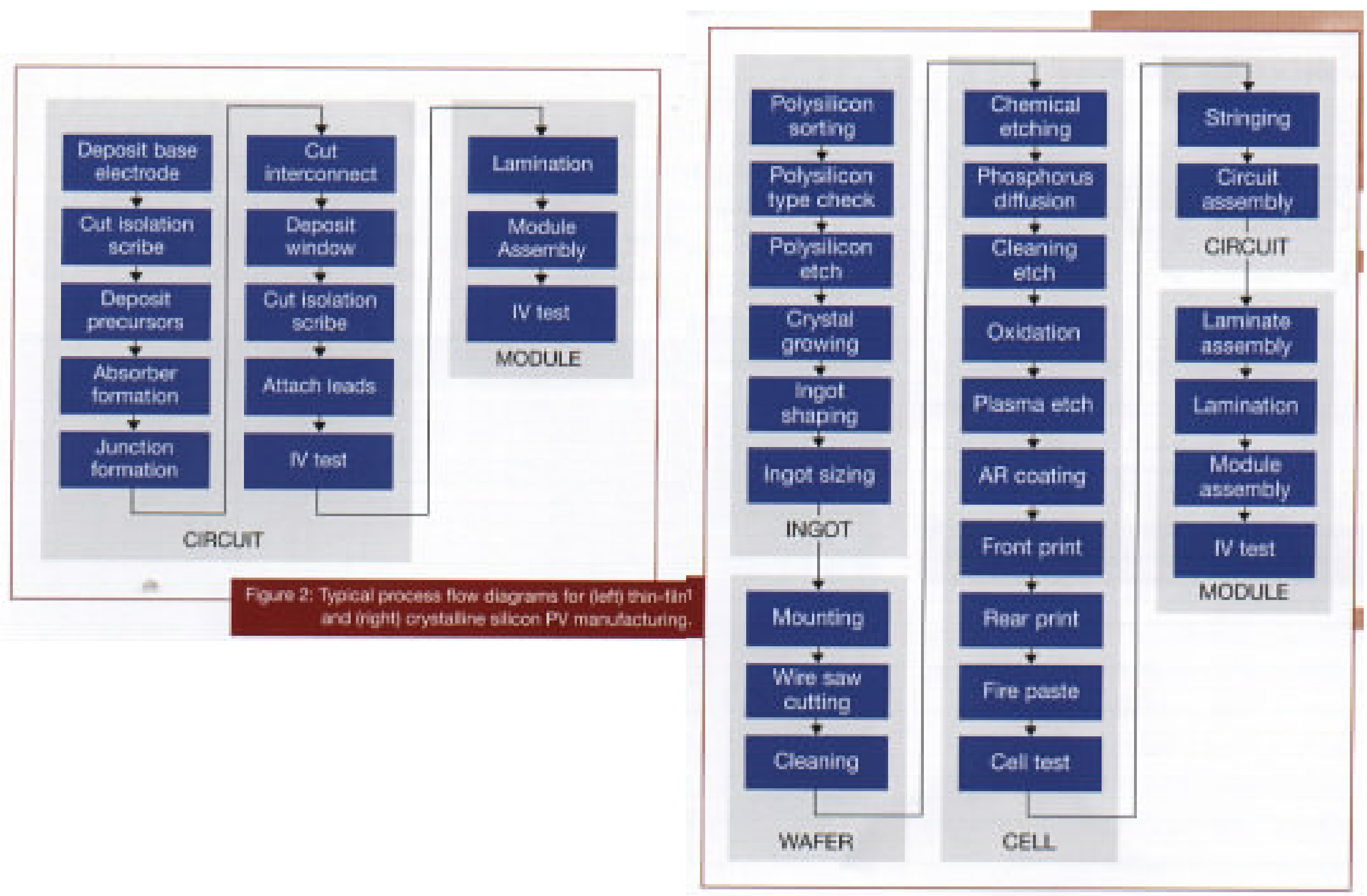
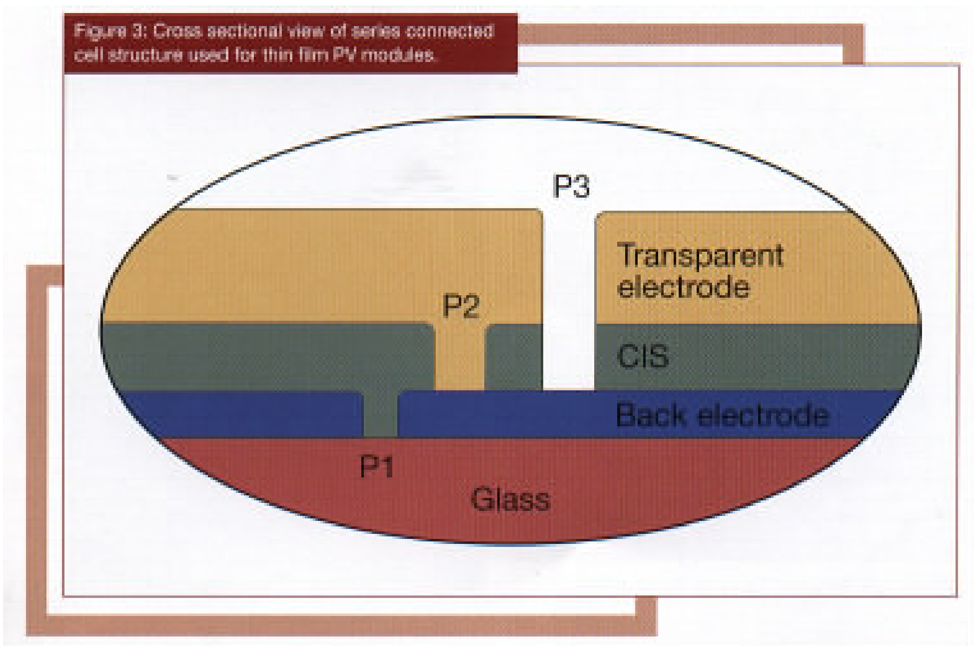


Figure 2: Typical process flow diagrams for (left) thin-film and (right) crystalline silicon PV manufacturing.

Solar Cells from Thin Film Deposition

The pictures below shows a schematic and a photograph of an array of thin film solar cells made from Copper Indium Diselenide. The fabrication process automatically connects adjacent cells in series



Multi-junction Solar Cells

The bandgap of the semiconductor material used in a solar cell determines the energy of photons that can be detected, according to the equation

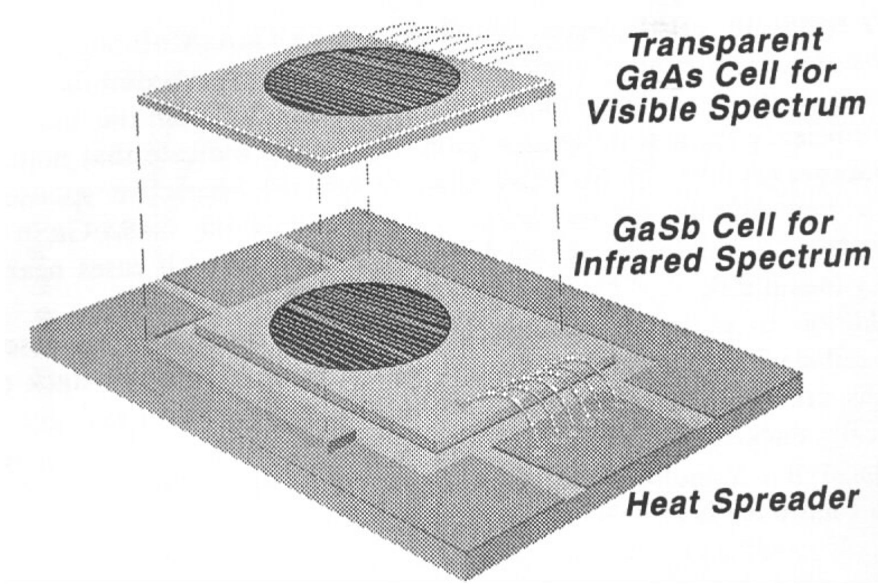
$$\lambda_{max} = hc / E_g = 1.24 / E_g(\text{in eV})$$

If the energy of the photon is significantly higher than the bandgap, then the conversion of light to electricity becomes inefficient, since generally the photon still only generates one electron-hole pair and the extra energy is generated as heat in the solar cell. To circumvent this problem, multi-junction solar cells are used so that two or three semiconductors are used to absorb different parts of the solar spectrum. The cells are deposited on top of each other with the highest band gap material at the surface, since this will be transparent to the lower energy photons that will be absorbed in the lower bandgap material which is beneath the higher bandgap material

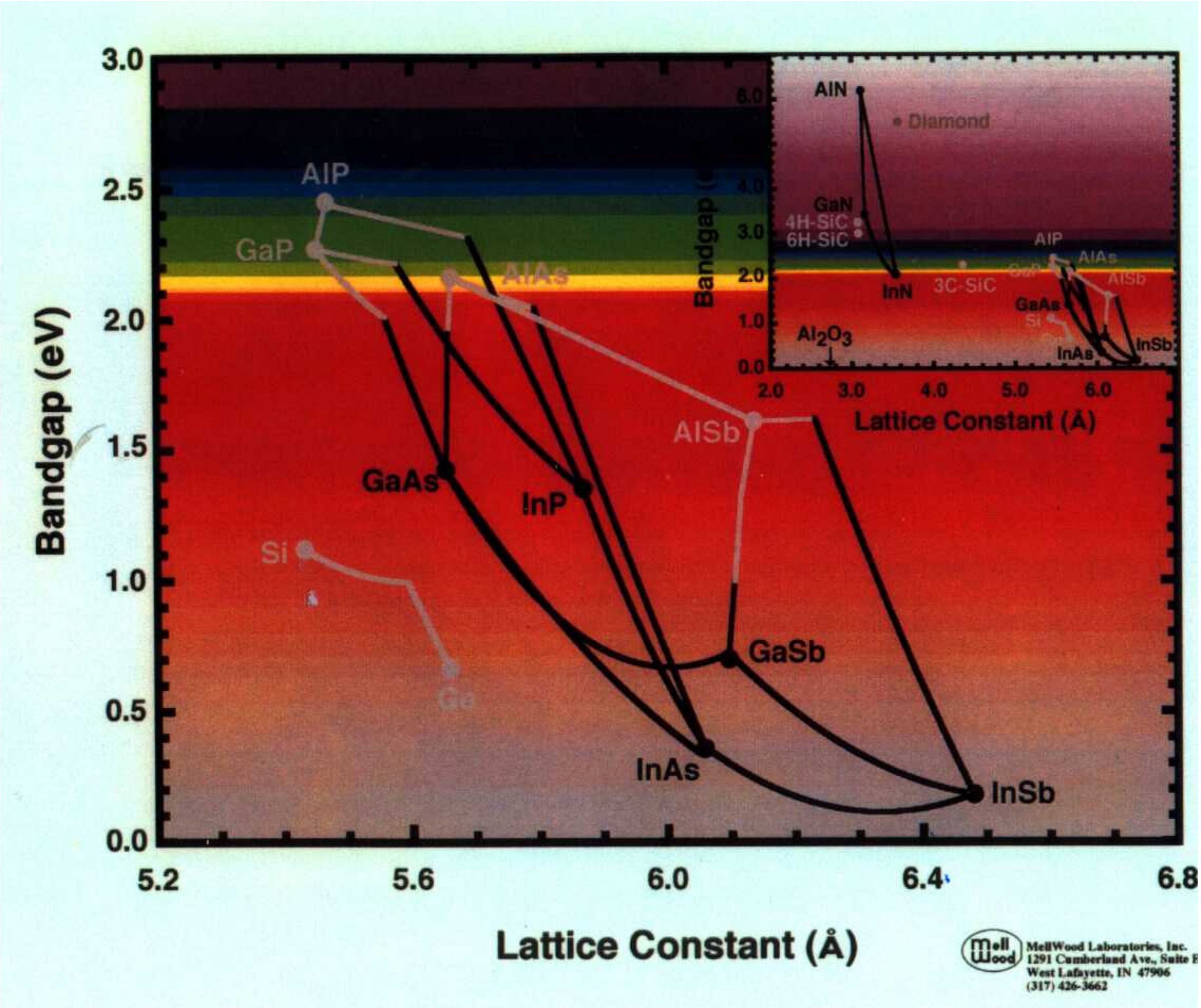
Multi-junction Solar Cells

The upper diagram shows a two junction monolithic GaInP/GaAs solar cell, while the lower picture shows a mechanically stacked GaAs/GaSb dual cell

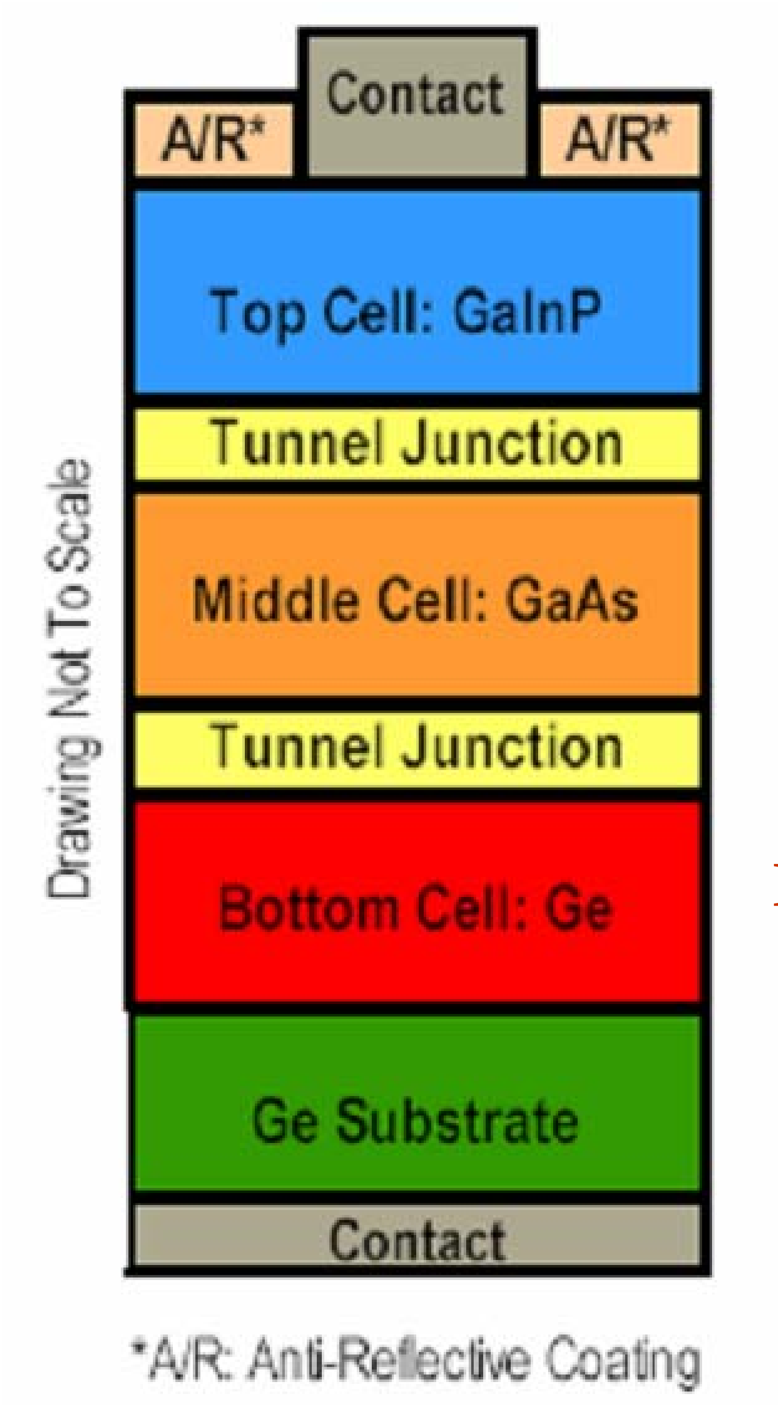
MgF_2	0.12μm	Anti-reflection Coatings
ZnS	0.065μm	
n-AlInP	0.04μm	Upper Solar Cell
n-GaInP	0.1μm	
p-GaInP	0.8μm	
p+GaAs	0.02μm	Tunnel Diode
n+GaAs	0.02μm	
n-AlGaAs	0.2μm	Lower Solar Cell
n-GaAs	0.1μm	
p-GaAs	3.5μm	
P+GaAs	100μm	Substrate



Bandgap Energy for different Semiconductors as a function of Lattice Spacing



Multi-junction Solar Cells



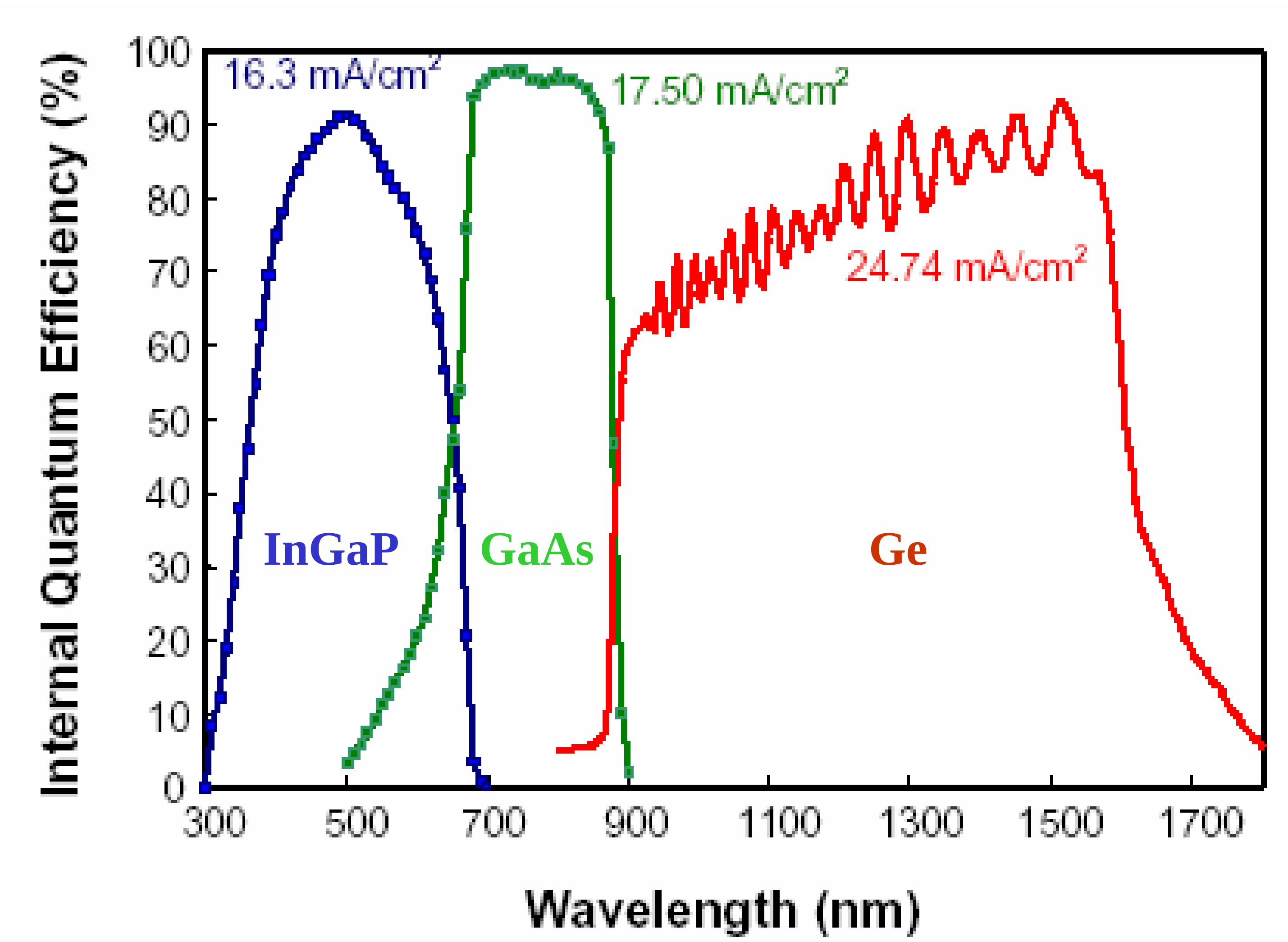
Band Gap 1.89eV (0.66μm)

Band Gap 1.42eV (0.873μm)

Band Gap 0.67eV (1.85μm)

Schematic of Spectrolab Triple-junction Solar Cell for Space Applications

Multi-junction Solar Cells



Wavelength Range Coverage of the individual junctions of a Triple-junction Solar Cell

Multi-junction Solar Cells

N.H. Karam et al. / Solar Energy Materials & Solar Cells 66 (2001) 453–466

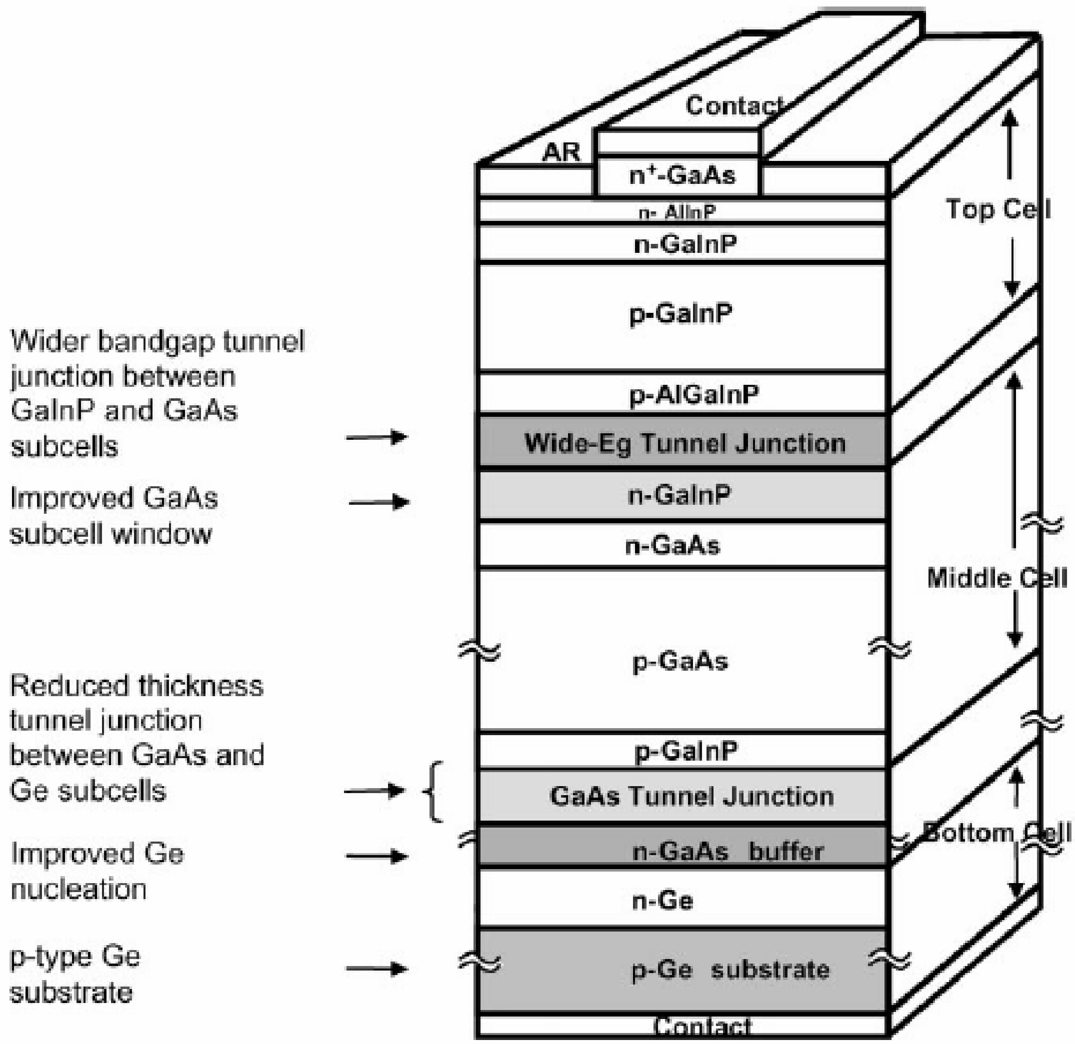


Fig. 3. Improved regions in the semiconductor device structure of triple-junction solar cells.

Multi-junction Solar Cells

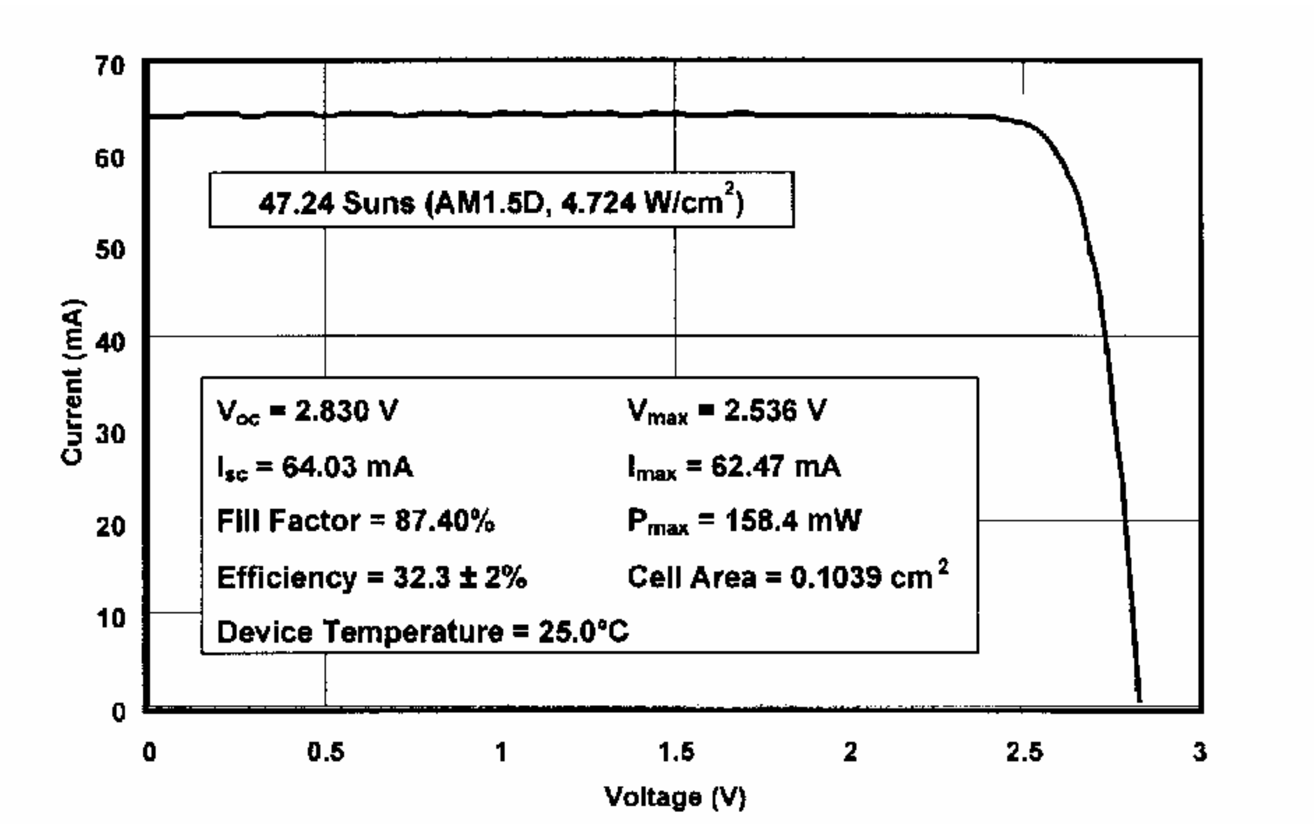
Semiconductors should be chosen to optimally cover the wavelength range of the incident light. If they are to be grown epitaxially, then the semiconductors need similar lattice spacings. The highest band gap materials should be at the top.

•Because all the solar cells are p-n junctions, there are inevitably unwanted n-p junctions between the cells. By making these unwanted junctions very highly doped ($n^{++}p^{++}$), the barrier is very thin and electrons and holes can tunnel through the junction (tunnel junction). The material in the tunnel junction should have a high band gap to minimise light absorption.

•The current through the multi-junction cell is limited by the junction generating the lowest current, so the junctions have to be designed to generate similar currents from the light which illuminates them. This is achieved by careful choice of semiconductors and optimisation of the depletion width of the solar cells to adjust the amount of absorption in each pn junction.

•Crystalline multi-junction solar cells are expensive to make, so are only used in space applications, or in concentrator systems.

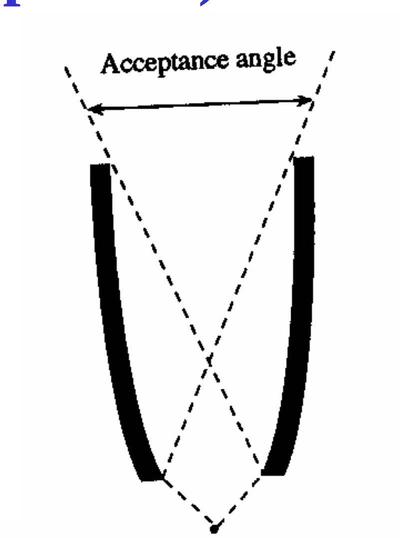
Multi-junction Solar Cells



I-V characteristic of multi-junction solar cell illuminated with concentrated light of 47.23 suns

Concentrator Solar Cells

Concentrator cells are quite small cells which have sunlight from a large area focussed onto them, either by mirrors (top picture) or by lenses (bottom picture)



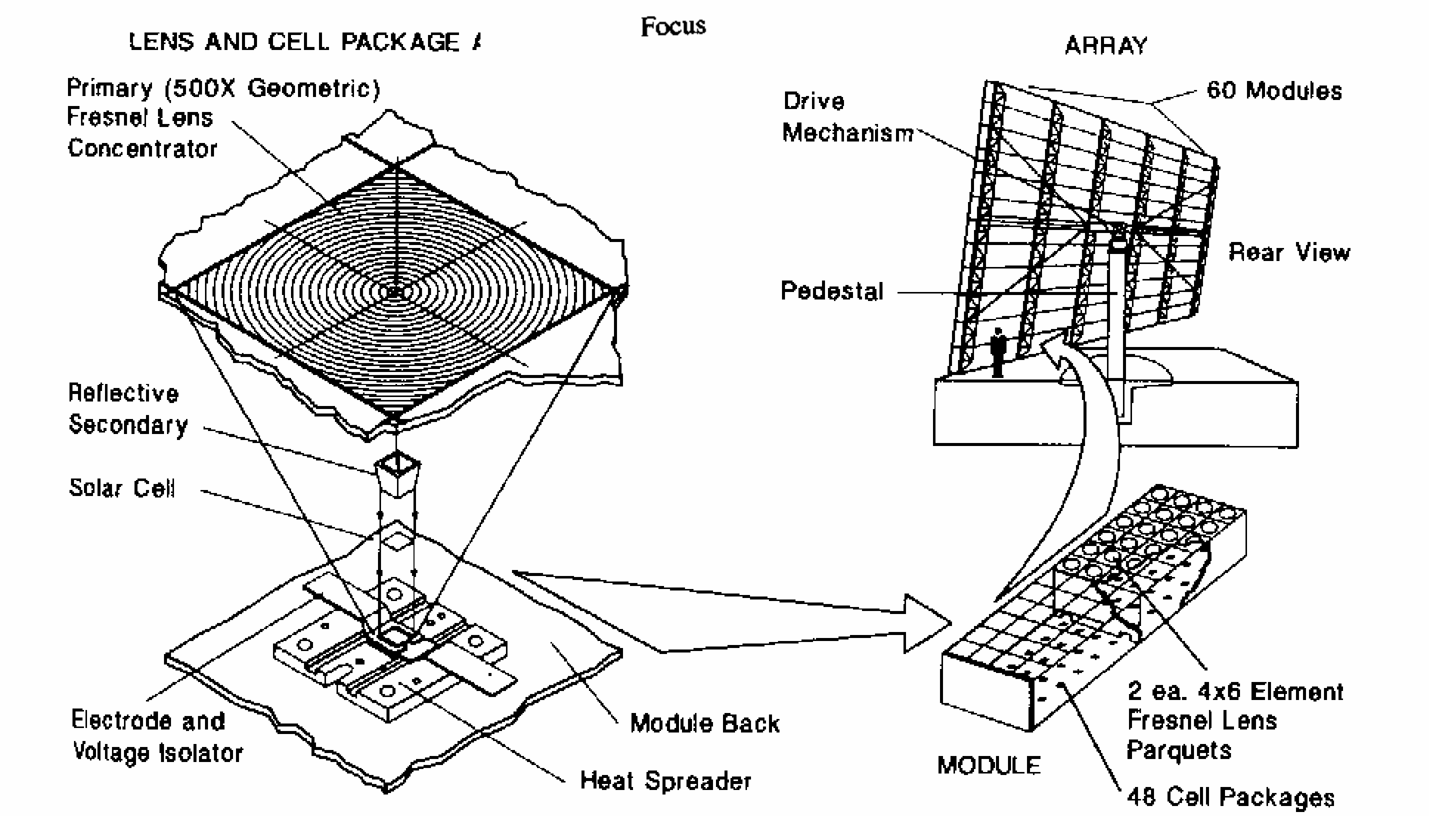


FIGURE 11.1 Components of a Fresnel lens concentration PV system. SOURCE: McNaughton and Richman (1992a, p. 2–3).

Improvements in Solar Cell System Performance

There is constant research to improve the performance and cost of solar cells systems. Solar cells will only be used for domestic power supply when they can generate electricity at a cost which is competitive with other generation techniques.

This will only be achieved when inexpensive fabrication techniques can be used to manufacture solar cells with reasonable efficiencies and long operational lifetimes.

Further research is also needed to improve methods of power storage and ways of interfacing solar power to the national grid.

The solar cell industry is currently growing at over 15% per annum and is projected to grow at 20-25% for the next 20 to 30 years.

Cost of Installing and Running Solar Cell Systems

The cost of installing a solar cell system is generally quoted in terms of dollars per watt peak, ie how much it will cost to install the system for each watt of power it will generate under optimum conditions.

Depending on the projected lifetime of the system, along with many other factors, a unit cost for each kW hour of electricity can then be generated.

Average system costs in 1995 and 2000 were $7-15 and $5-12 per peak watt respectively, with a required cost of $3-4 per peak watt to make them economically viable.

Concentrator systems have recently been proposed with a system cost of $1.50 per peak watt and an average electrical cost in southern Europe of $0.058/kWhr, which is competitive with the lowest utility costs. The southern UK cost would be $0.13/kWhr, which would require subsidy to make it viable.

(YEB is currently 6.51p/kWhr or $0.096/kWhr)

Problems with Solar Generation

HIGH COST (though steadily decreasing)

DC - AC CONVERSION REQUIRED

LIMITED MAXIMUM VOLTAGE OUTPUT

LARGE AREAS NEEDED FOR BIG ARRAYS

POWER STORAGE PROBLEMS

PAYBACK TIME > 10 YEARS

MAJOR DETERIORATION OVER 10 YEARS

SOLAR CELLS

END OF LECTURE 4

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 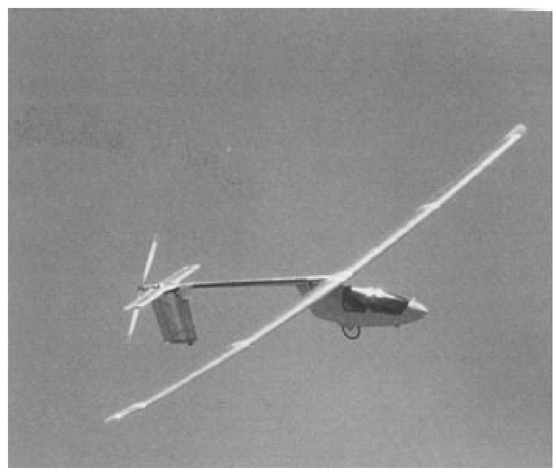

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