Solar spectrum

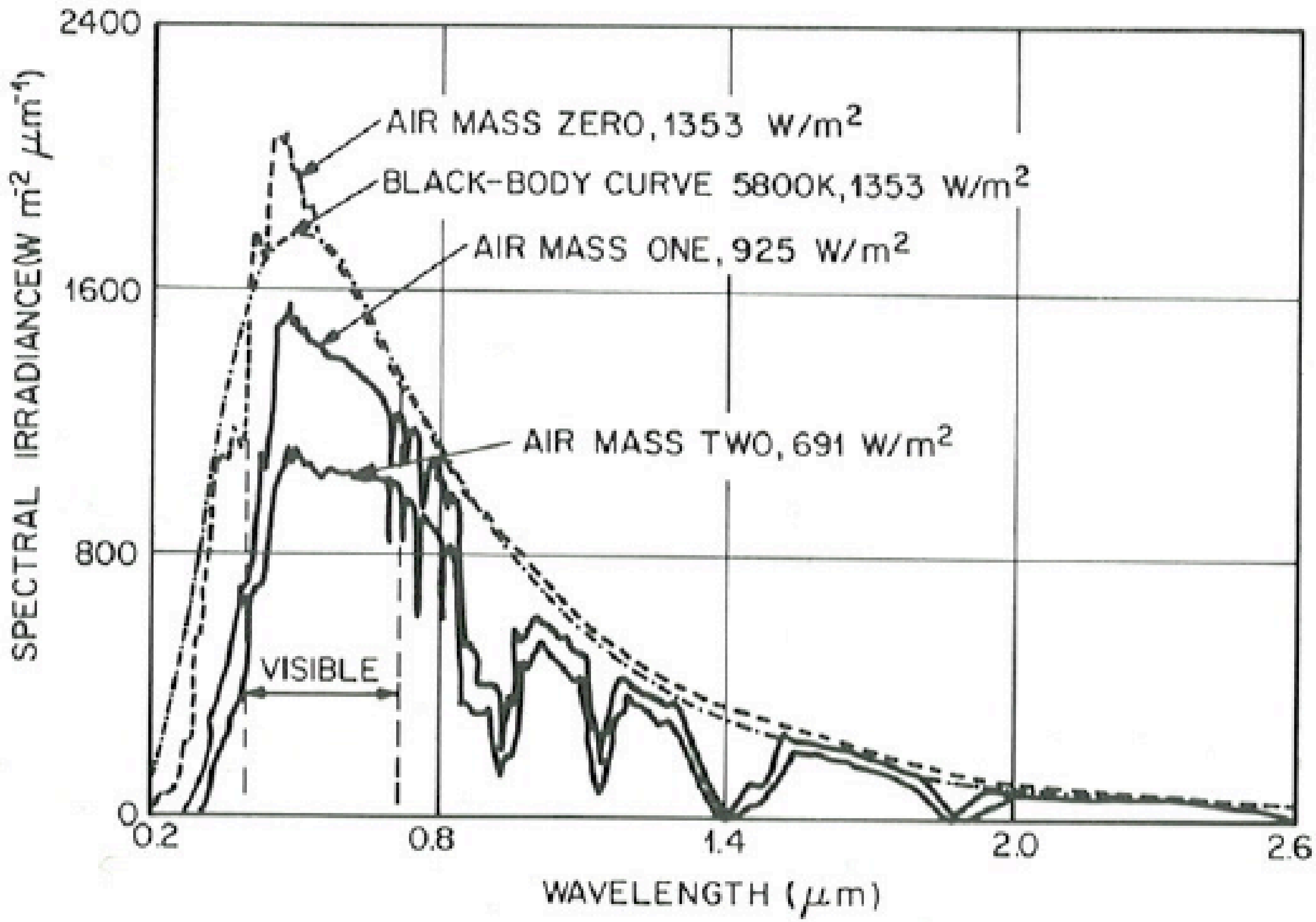


Fig. 1 Four curves related to solar spectral irradiance. (After Thekaekara, Ref. 10.)

Solar spectrum

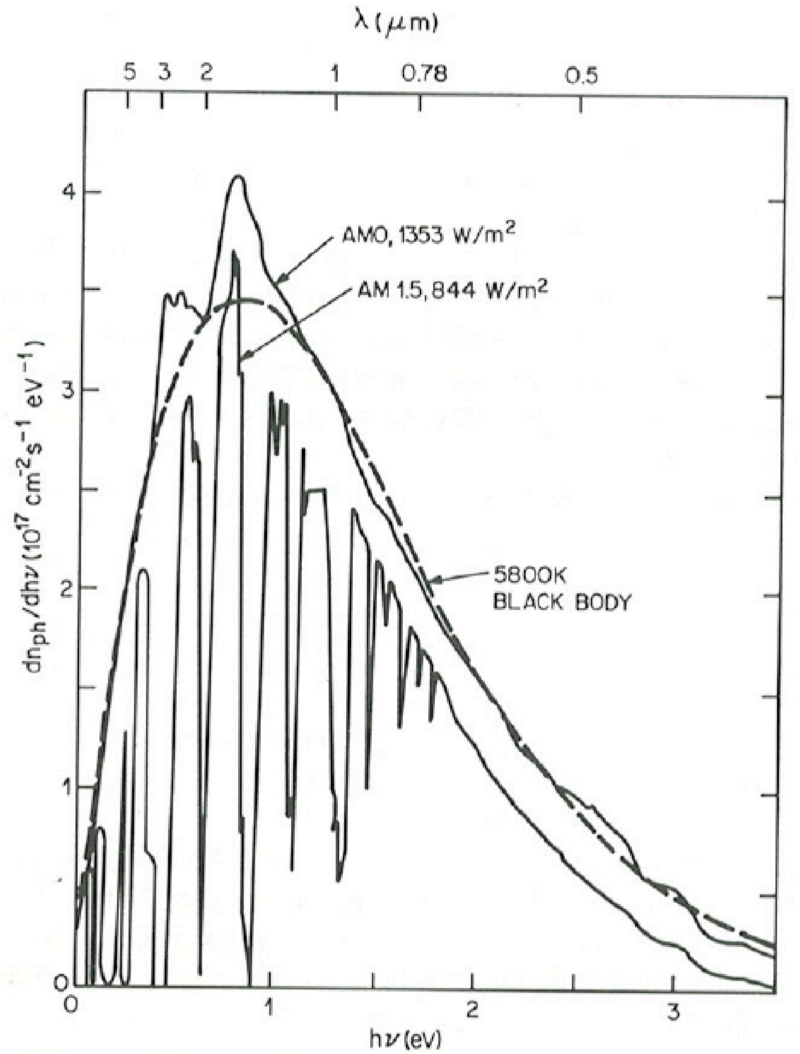


Fig. 2 Solar spectrum as a function of photon energy for AM0 and AM1.5 conditions. (After Henry, Ref. 11.)

Application to Solar cells

A solar cell is a pn junction with no voltage applied across the junction.
The solar cell converts photon power into electrical power and delivers this power to a load.

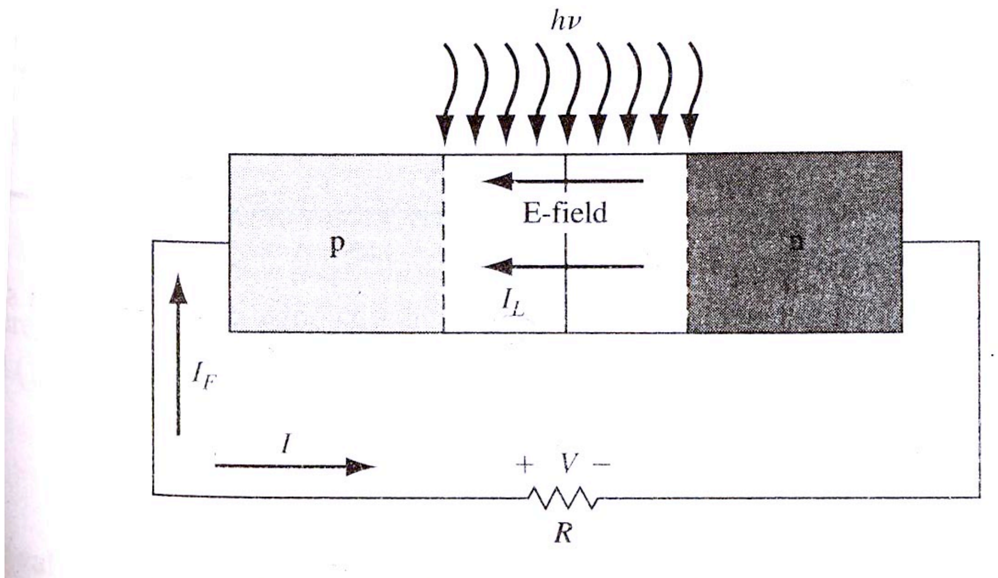
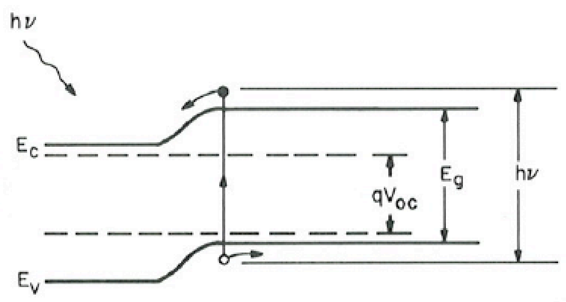


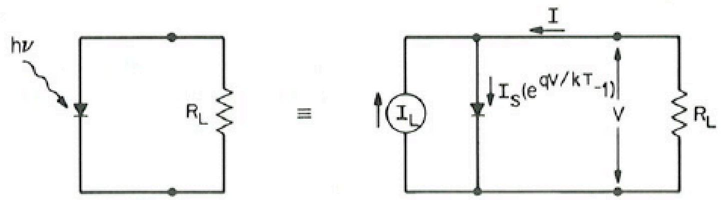
Figure 14.6 | A pn junction solar cell with resistive load.

Even with zero bias applied to the junction an electric field exists in the space charge region and therefore photon illumination can create electron-hole pairs producing a photocurrent I_L in the reverse-bias direction.
The forward-bias voltage produces a forward-bias current I_F.

Principle of working and equivalent circuit



(a)



(b)

Fig. 4 (*a*) Energy-band diagram of a *p-n* junction solar cell under solar irradiation. (*b*) Idealized equivalent circuit of a solar cell.

I-V characteristics

The net p-n junction current is:

$$I = I_L - I_F = I_L - I_s[\exp(\frac{eV}{kT}) - 1]$$

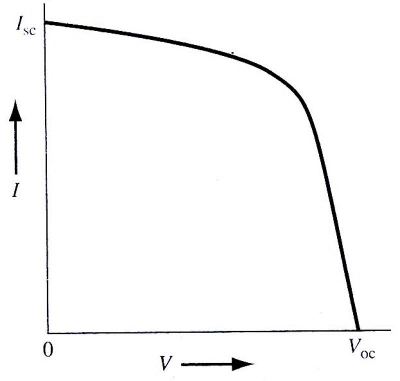


Figure 14.7 | *I–V* characteristics of a pn junction solar cell.

I_L is light generated current and I_F is the diode current in the absence of light.

There are two limiting cases of interest:

• Open-circuit condition R->∞. The net current is zero and the voltage produced is the open-circuit voltage (V_{oc})

$$I = 0 = I_L - I_F = I_L - I_s[\exp(\frac{eV_{oc}}{kT}) - 1]$$

$$V_{oc} = \frac{kT}{e}\ln(1 + \frac{I_L}{I_s})$$

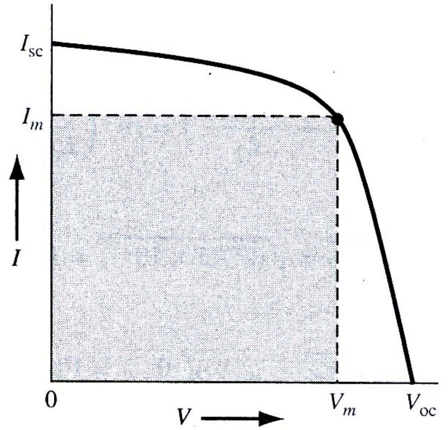


Figure 14.8 | Maximum power rectangle of the solar cell *I–V* characteristics.

• Short-circuit current R=0 V=0 => $I = I_{sc} = I_L$

Electrical Power

The power delivered to the load is:

$$P = I \cdot V = I_L \cdot V - I_s[\exp(\frac{eV}{kT}) - 1] \cdot V$$

The current and voltage which will deliver the maximum power is obtained by setting the derivative equal to zero dP/dV=0.

$$\frac{dP}{dV} = 0 = I_L \cdot - I_s[\exp(\frac{eV_m}{kT}) - 1] - I_s V_m (\frac{e}{kT}) \exp(\frac{eV_m}{kT})$$

Where V_m is the voltage that produces the maximum power and I_m is the current when $V=V_m$.

Solar radiation and conversion Efficiency

The conversion efficiency of a solar cell is defined as the ratio of output electrical power to incident optical power

$\eta_{conv}=P_m/P_{in}x100$

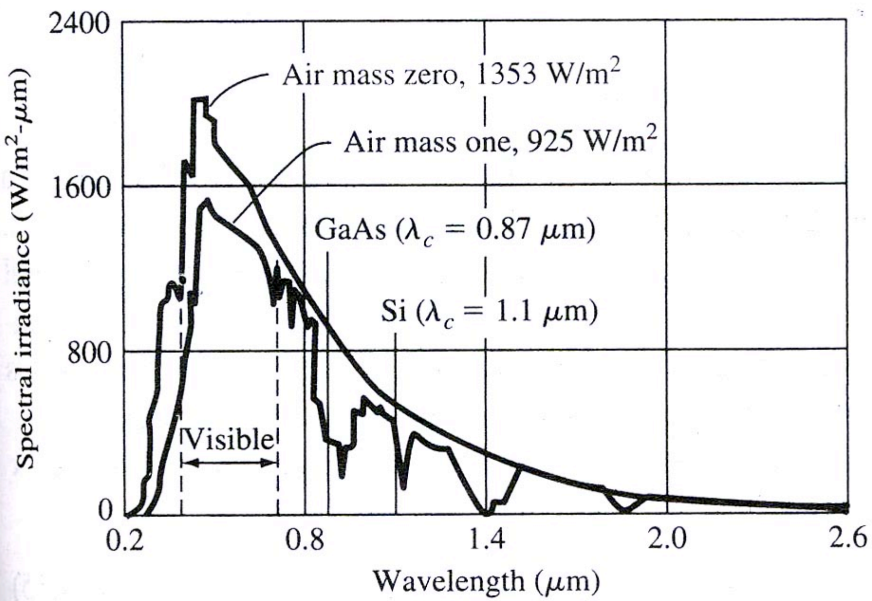


Figure 14.9 | Solar spectral irradiance.
(From Sze [16].)

Solar spectral irradiance (power per unit area per unit length)
AM0 solar spectrum outside the earth's atmosphere
AM1 solar spectrum at the earth's surface when the sun is at the zenith

GaAs vs Silicon solar cells

In solar cells it is important to note that photons with energy smaller than the bandgap will not produce any electron – hole pairs. Also photons with energy grater than the bandgap will produce electron and holes with the same energy (Eg) while the excess of energy is dissipated as heat.

The solar efficiency depends quite critically on how the semiconductor bandgap matches with the solar energy spectra.

The GaAs solar cells (more expensive) are used for space applications while Si (or amorphous silicon) are used for applications where cost is a key factor.

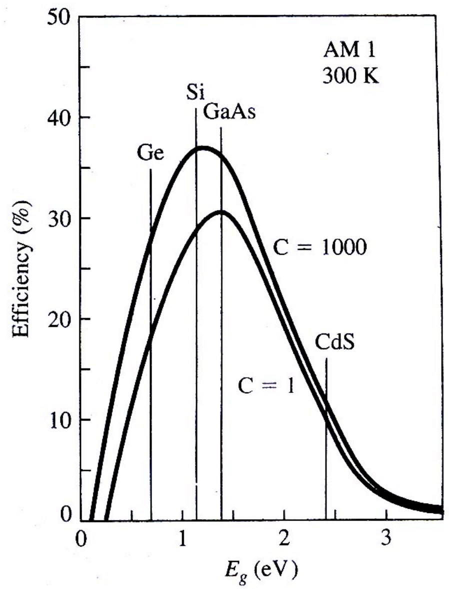


Figure 14.10 | Ideal solar cell efficiency at T = 300 K for C = 1 sun and for a C = 1000 sun concentration as a function of bandgap energy. *(From Sze [16].)*

Schematic representation p-n junction solar cell

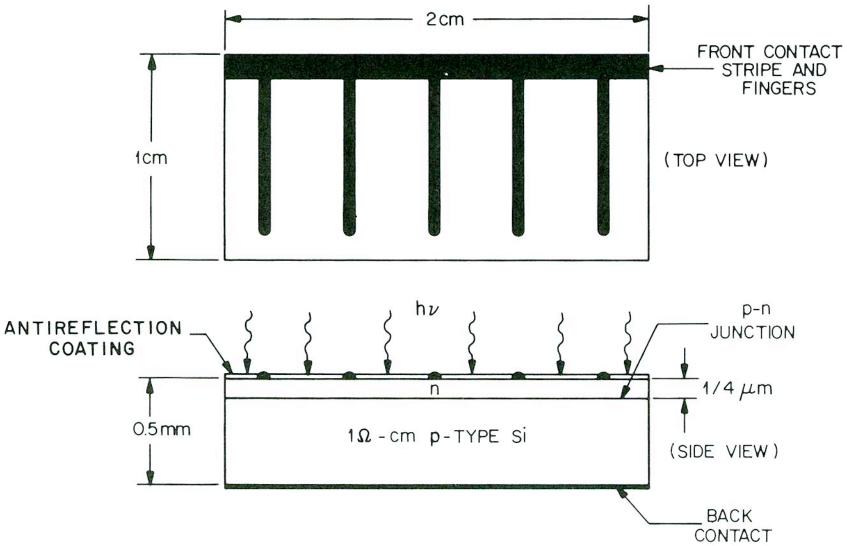
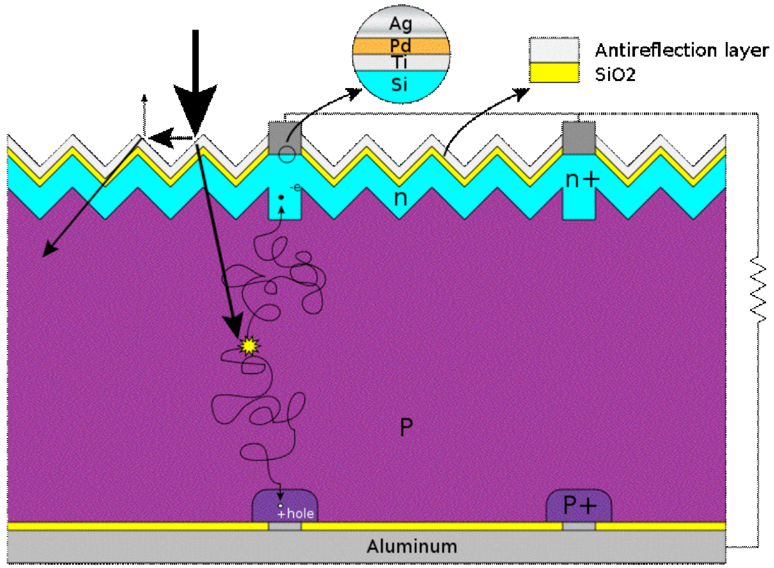
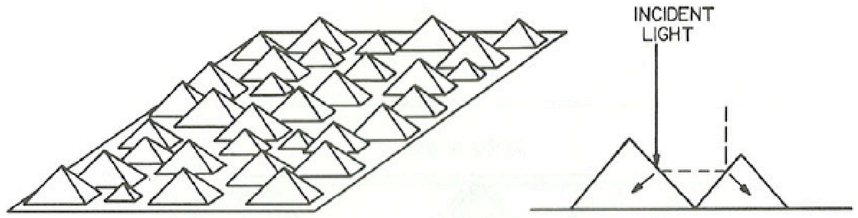


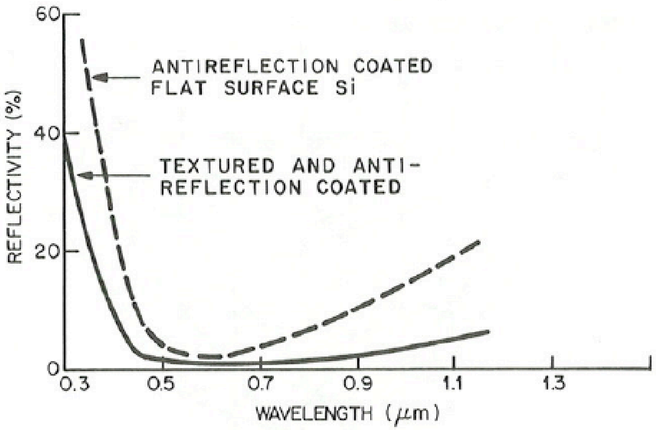
Fig. 9 Schematic representation of a silicon *p-n* junction solar cell.



Texturing the cell



(a)



(b)

Fig. 18 (*a*) Textured cell with pyramidal surfaces. (*b*) Reflectivity versus wavelength for a flat surface cell and a textured cell. (After Arndt et al., Ref. 23.)

Amorphous Silicon Solar cells

The atoms in a crystalline material are arranged in a perfect lattice and as a result is quite expensive to fabricate single crystal devices.

In contrast amorphous materials have an arrangement of atoms which is not perfect, but on a local scale the atoms still have the same number of nearest and second neighbor atoms as a perfect crystal.

Amorphous silicon films are deposited by chemical vapor deposition techniques and can be deposited on almost any substrate which makes them very inexpensive and versatile.

Electron properties of amorphous silicon

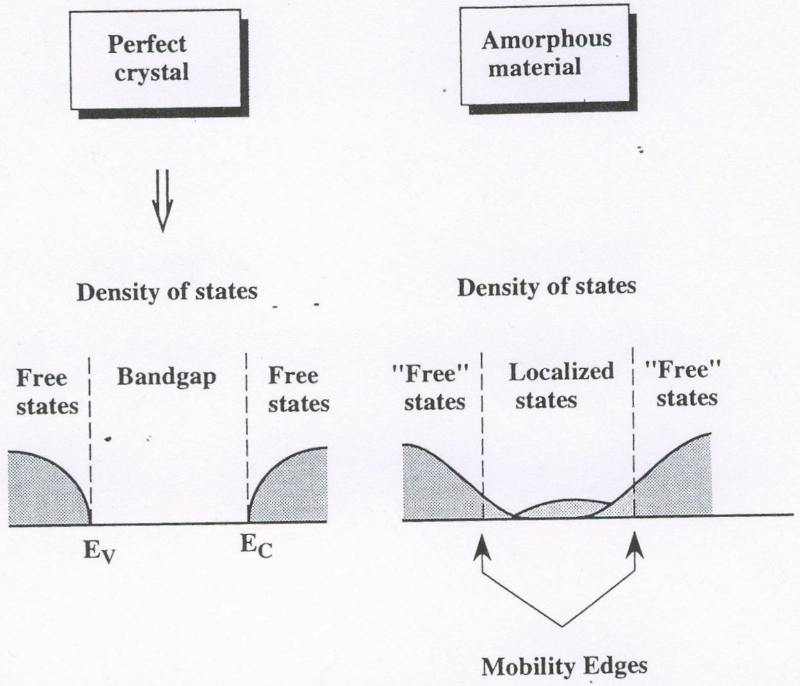


Figure 7.11: A schematic of the effect of disorder in an amorphous material on the density of states. A comparison is shown for the perfect crystal and an amorphous material. Mobility edges represent effective bandedges in the amorphous material.

The point in energy where the transition occurs is called the mobility edge. This mobility edge define an effective bandgap for a-Si film (1.6 eV).

a-Si films

An important aspect of a-Si is that the vertical k selection rule which produces low absorption in crystalline (indirect) Si no longer applies. This is because the k-selection rule is applicable strictly in perfect crystals (electronic states have the plane wave exp(ikr) form).
As a result a-Si can have very high absorption coefficient and one needs a very thin film 1μm) to absorb the solar energy.

Heterojunctions can be used for solar cells. The use of more one bandgap can improve the conversion efficiency. The technology is, of course, expensive and is used only in space applications where efficiency is very important.

Best research cell efficiencies