Solar Cells

“Solar revolution" is the idea that one day we will all use free electricity from the sun.

On a bright, sunny day, the sun shines approximately 1,000 watts of energy per square meter of the planet's surface.
Solar Cells

The solar cells are also referred to as “photovoltaic cells” because their operation is based on a photovoltaic effect.

Early history

- 1839 - Alexandre Becquerel observes the photoelectric effect via an electrode in a conductive solution exposed to light.
- 1873 - Willoughby Smith finds that selenium is photoconductive.
- 1904 - Albert Einstein publishes a paper on the photoelectric effect.
- 1950s - Bell Labs produce solar cells for space activities.
- 1954 - AT&T exhibits solar cells with 6% efficiency. The New York Times forecasts that solar cells will eventually lead to a source of "limitless energy of the sun".
History (continued)

• 1960 - Hoffman Electronics creates a 14% efficient solar cell.

• 1967 - *Soyuz 1* is the first manned spacecraft to be powered by solar cells

The spacecraft crashed during its return to Earth. One of the reasons: the left solar panel deployment failure
History (continued)

• 1977 - World production of solar cells exceeds 500 kW.

• 1985 - 20% efficient silicon cell are created by the Centre for Photovoltaic Engineering at the University of New South Wales.

• 1991 - President George H. W. Bush directs the U.S. Department of Energy to establish the National Renewable Energy Laboratory.

• 1994 - NREL develops a GaInP/GaAs solar cell to exceed 30% conversion efficiency.

• 2005 - Solar cells in modules can convert around 17% of visible incidental radiant energy to electrical energy.

• 2006 - Estimated yearly solar cell production reached 1868 megawatts. Worldwide polysilicon production grows from 31,000 tons in 2005 to 36,000 tons in 2006.
Solar cell operation and usage

1. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.

2. Electrons are knocked loose from their atoms, allowing them to flow through the material to produce electricity. The complementary holes (positive charges) that are also created flow in the direction opposite of the electrons in a silicon solar panel.

3. An array of solar panels converts solar energy into a usable amount of direct current (DC) electricity.

4. The DC current enters an inverter.

5. The inverter turns DC electricity into 120 or 230-volt AC (alternating current) electricity needed for home appliances.
Solar spectrum
Solar spectrum
Semiconductors can convert the photons directly into electrons and holes

(a) \[ h\nu = \varepsilon_g \]

(b) \[ h\nu < \varepsilon_g \]

(c) \[ n = 2 \]
Can photoconductors be used as solar cells?

- No voltage generated
- No current at zero external bias; \( P_{\text{dis}} = V \times I > 0 \)
- Photoconductor can't be used as an energy source
Can photodiodes be used as solar cells?

- The light generates the electron-hole pairs
- The built-in voltage separates the e-h pairs, i.e. stores the energy
- Photodiode can be used as an energy source
Junction (pin or Schottky) photodiode as a solar cell

The photocurrent

\[ I_{Ph} = q \eta_{ext} P_{inc} / (h\nu) \]

is not a function of external bias. The photocurrent is a reverse current.

Therefore, the total current \( I_T = I_d - I_{Ph} \), (\( I_d \) is the dark current):

\[ I = I_S \left[ \exp\left(\frac{qV}{kT}\right) - 1 \right] - I_{Ph} \]
The difference between the photodiode and the junction solar cell:

1) Normally there is no external bias applied to the solar cell.
2) The charge of photo-carriers partly compensate the built-in voltage.
3) Unlike photodiodes, the speed of response is not important; instead the collection of all the photo-carriers is critical
If the junction is illuminated by photons with \( hv > \varepsilon_G \), the electron-hole pairs are created with a generation rate \( G \) (cm\(^{-3}\)×sec\(^{-1}\)).

The number of holes created per second within a diffusion length \( L_h \) on the n-side is \( A \times L_h \times G \), where \( A \) is the area of the diode.

The number of electrons created per second within a diffusion length on the p-side is \( A \times L_e \times G \).

The total photo-generated current is given by

\[
I_{ph} = qAG(L_h + L_e)
\]
Solar cell photocurrent

The photocurrent current is directed from the n-side to the p-side and is opposed to the main (forward) diode current from the p-side to the n-side.

Therefore, for the illuminated diode,

\[ I = I_S \left[ \exp\left(\frac{qV}{kT}\right) - 1 \right] - I_{ph} \]

Where

\[ I_S = qAG\left(\frac{L_h}{\tau_h} p_{N0} + \frac{L_e}{\tau_e} n_{P0}\right) \]

\[ I_{ph} = qAG\left(L_h + L_e\right) \]

Note that, in contrast to photodetectors, the diffusion current is accounted for in the total current; different dynamics of drift (within the depletion region) and diffusion (outside the depletion region) currents are neglected.
Photodiode I-V curves and equivalent circuit

\[ I = I_S \left[ \exp\left(\frac{qV}{kT}\right) - 1 \right] - I_{ph} \]

\[ I_{ph} = qAG(L_h + L_e) \]