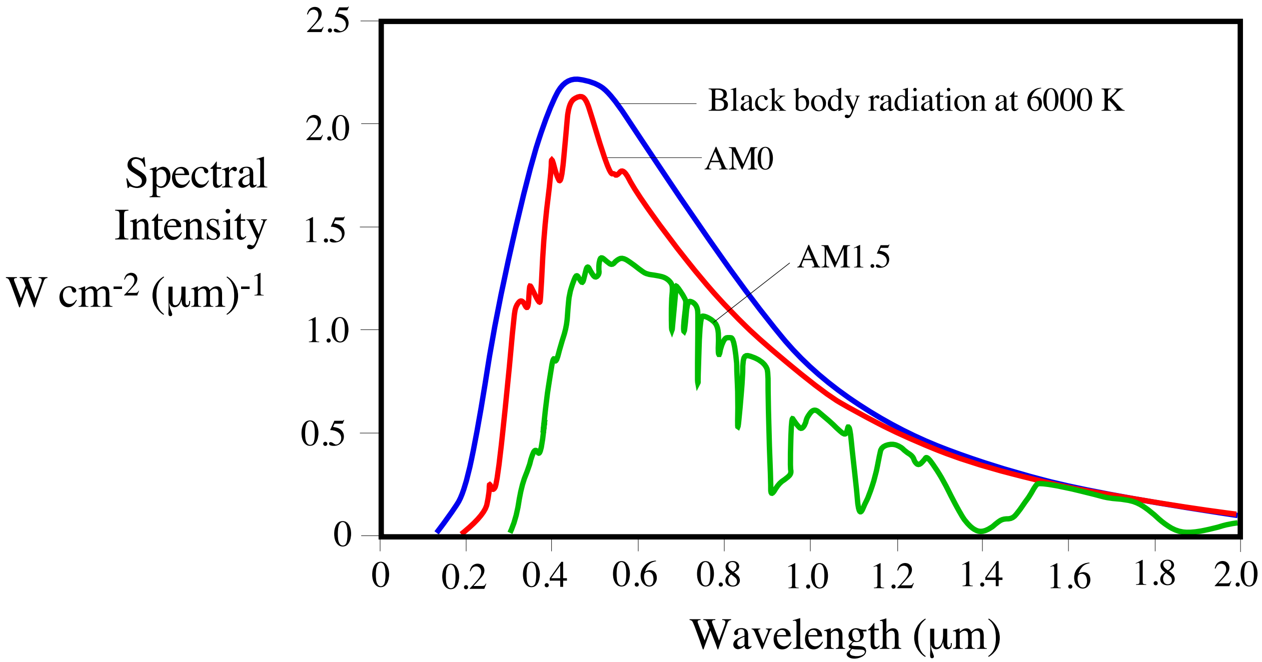
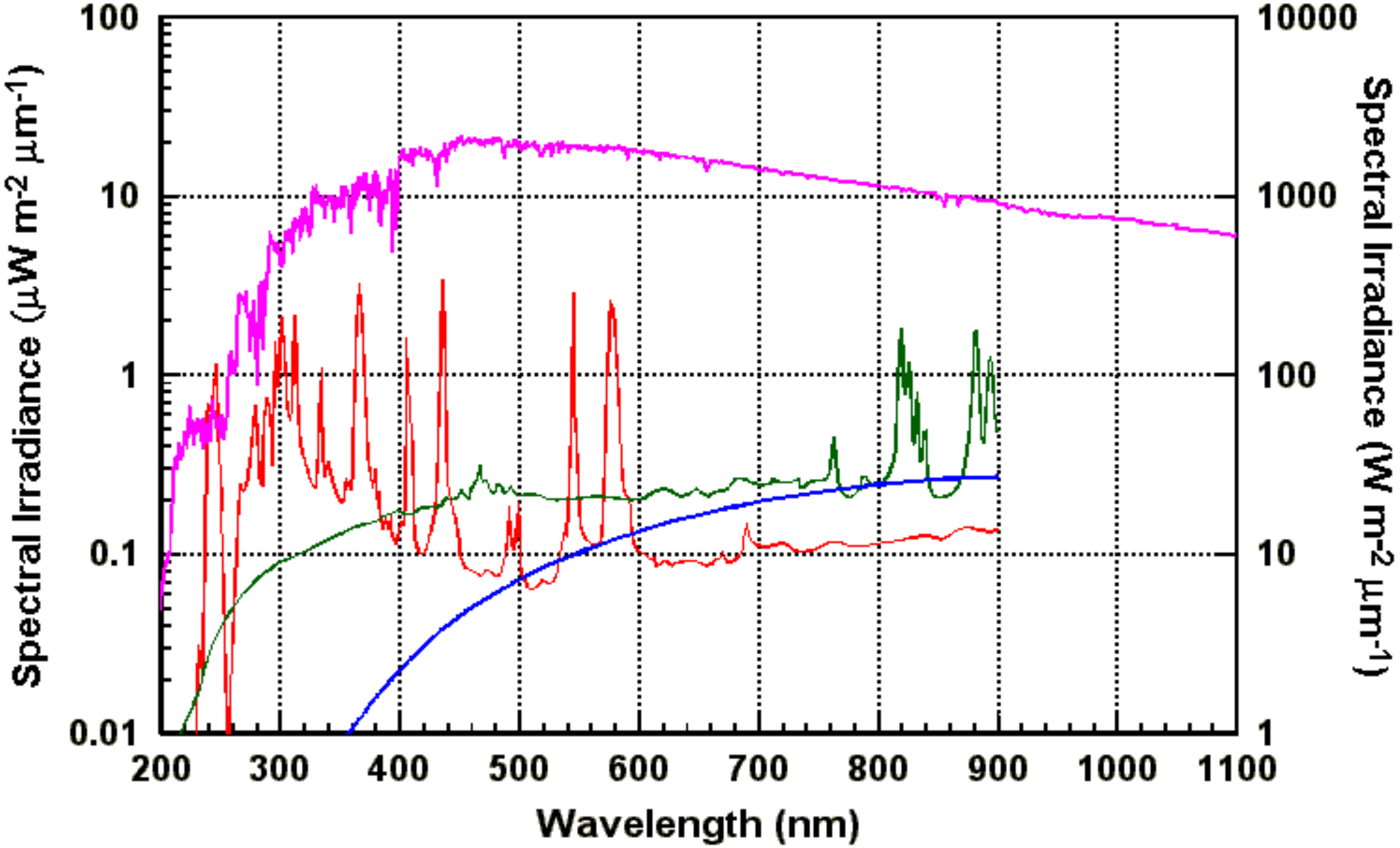
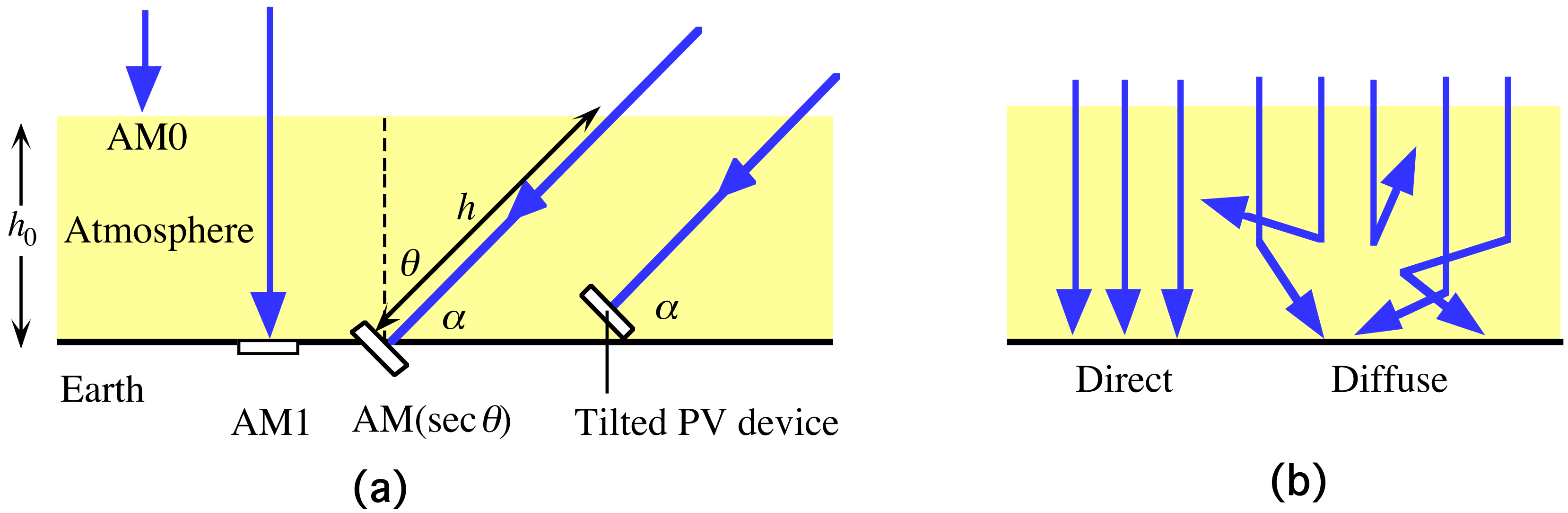


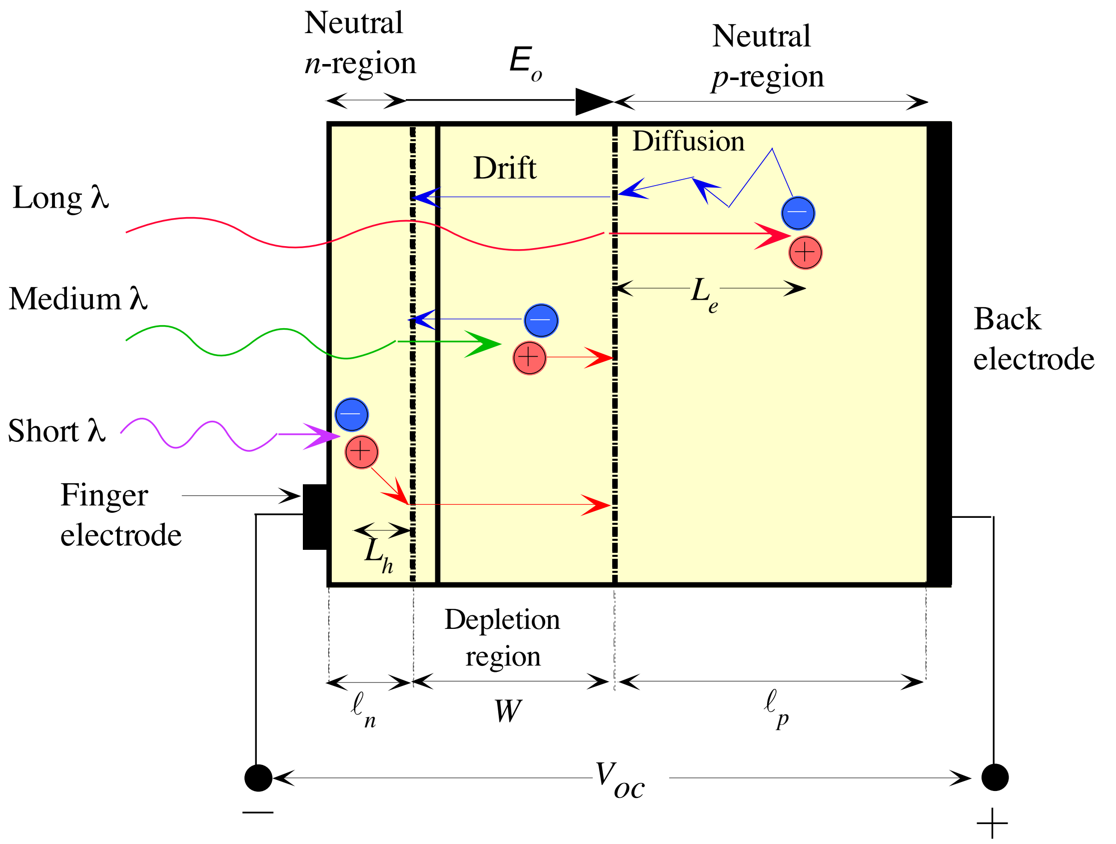
The spectrum of the solar energy represented as spectral intensity (I_λ) vs wavelength above the earth's atmosphere (AM0 radiation) and at the earth's surface (AM1.5 radiation). Black body radiation at 6000 K is shown for comparison (After H.J. Möller, *Semiconductors for Solar Cells*, Artech House Press, Boston, 1993, p.10)



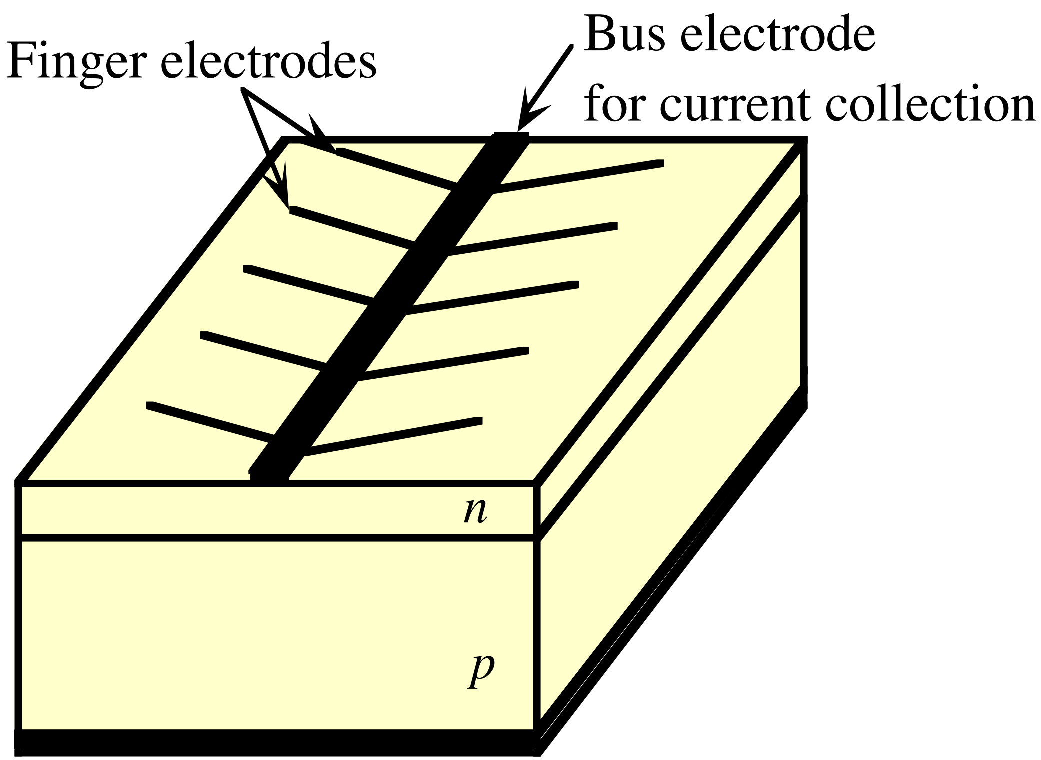
- The spectral irradiance of xenon (green), halogen (blue) and mercury (red) light bulbs (left axis) are compared to the spectral irradiance from the sun (purple, which corresponds to the right axis).



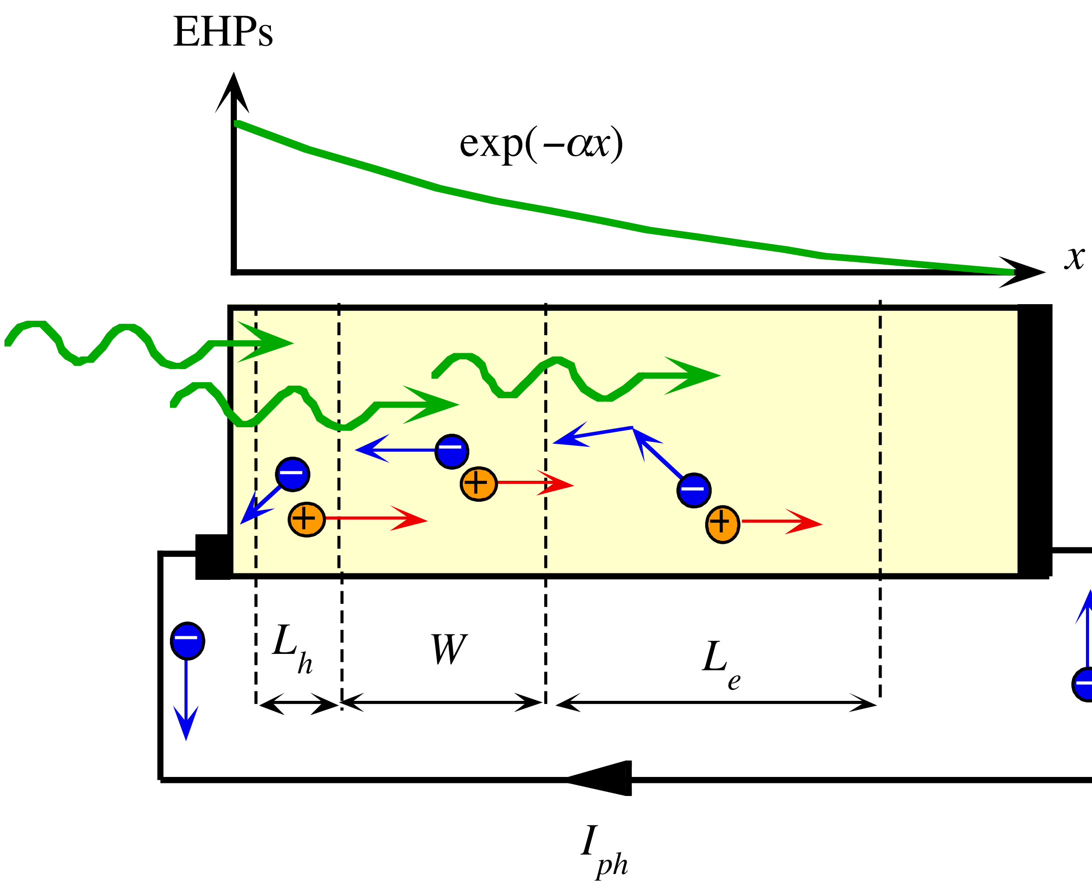
(a) Illustration of the effect of the angle of incidence θ on the ray path length and the definitions of AM0, AM1 and AM(secθ). The angle α between the sun beam and the horizon is the solar latitude (b) Scattering reduces the intensity and gives rise to a diffused radiation



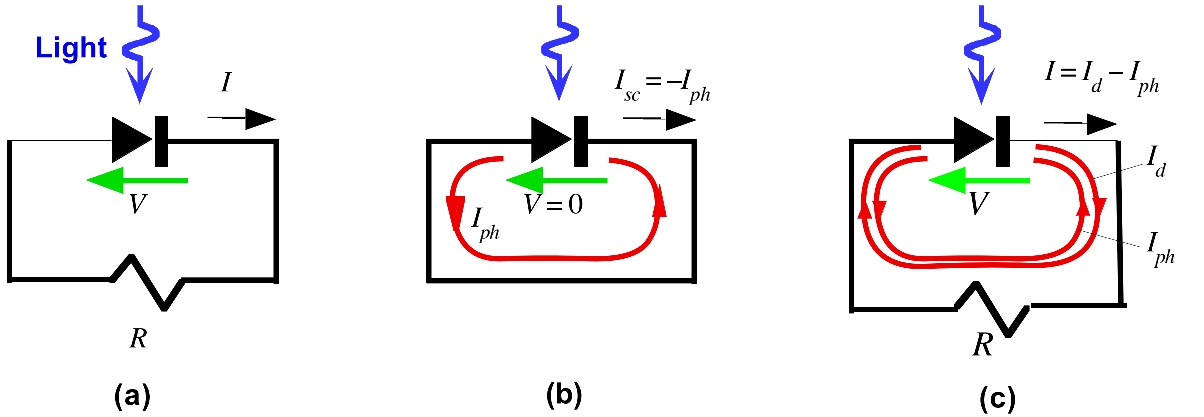
The principle of operation of the solar cell (exaggerated features to highlight principles)



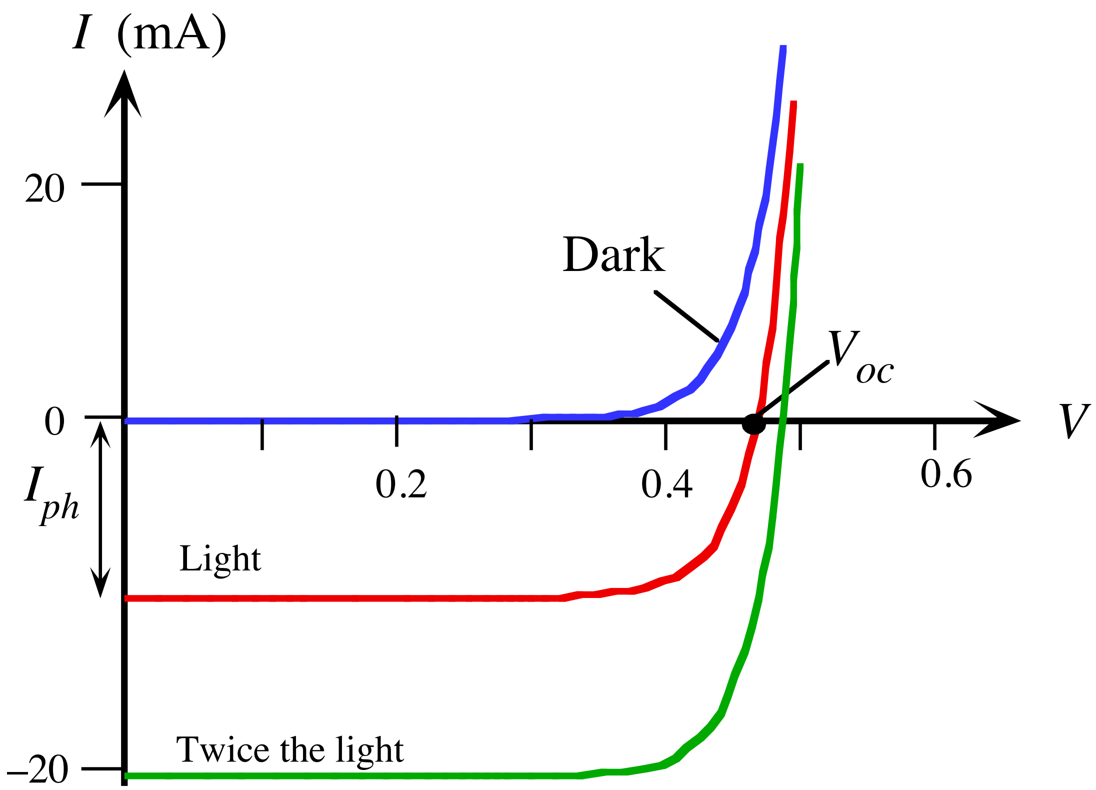
Finger electrodes on the surface of a solar cell reduce the series resistance



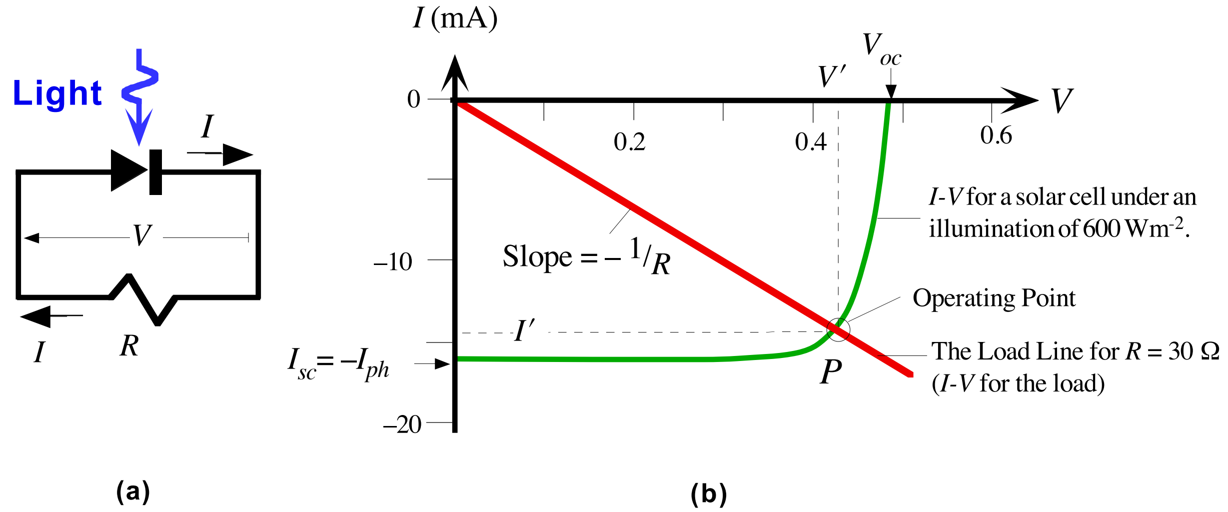
Photogenerated carriers within the volume $L_h + W + L_e$ give rise to a photocurrent I_{ph}. The variation in the photegenerated EHP concentration with distance is also shown where α is th absorption coefficient at the wavelength of interest.



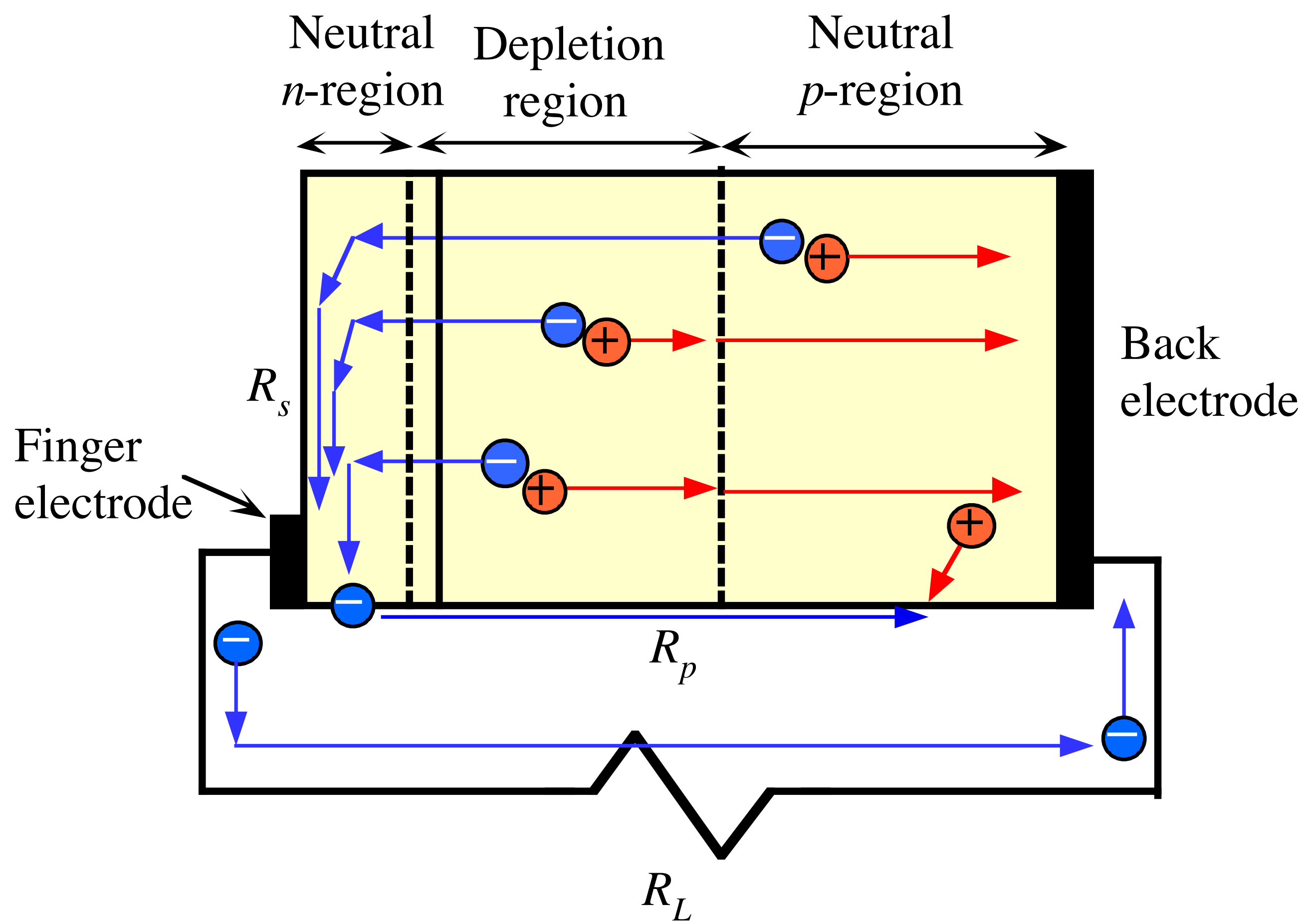
(a) The solar cell connected to an external load R and the convention for the definitions of positive voltage and positive current. (b) The solar cell in short circuit. The current is the photocurrent, I_{ph}. (c) The solar cell driving an external load R. There is a voltage V and current I in the circuit.



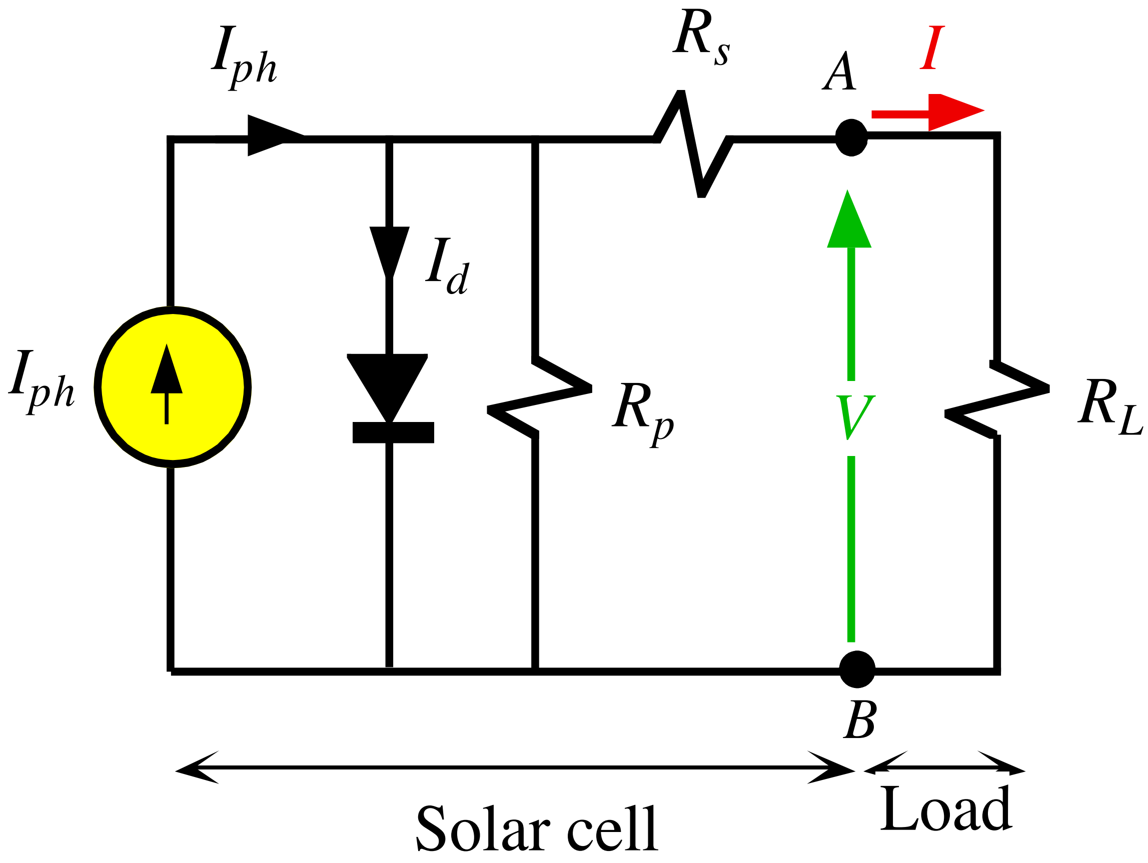
Typical *I-V* characteristics of a Si solar cell. The short circuit current is I_{ph} and the open circuit voltage is V_{oc}. The *I-V* curves for positive current requires an external bias voltage. Photovoltaic operation is always in the negative current region.



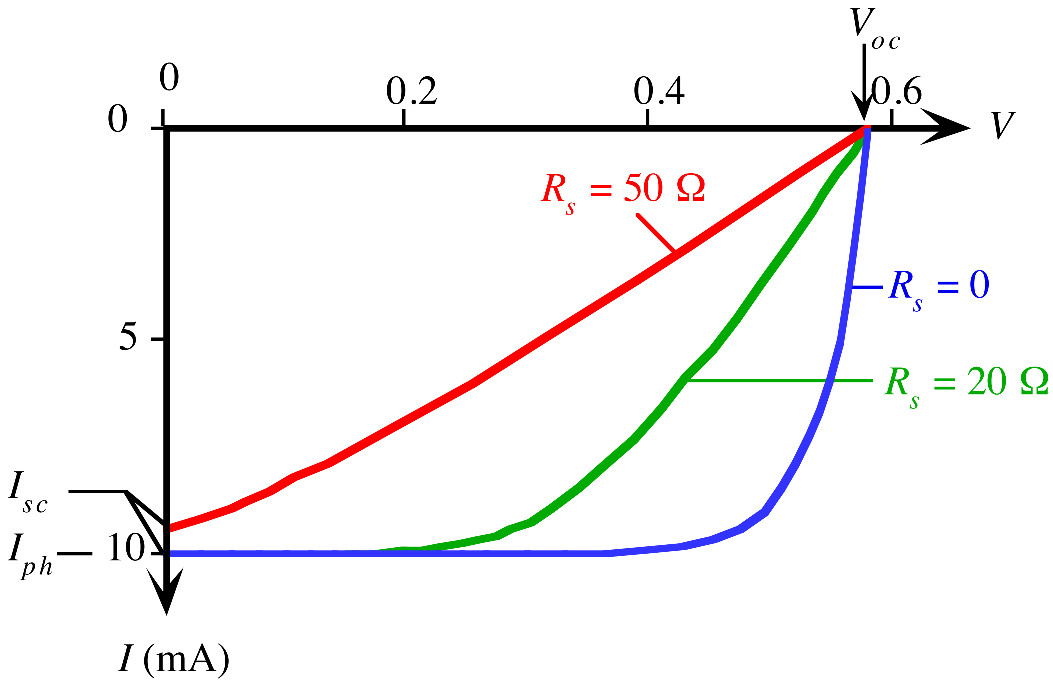
(a) When a solar cell drives a load R, R has the same voltage as the solar cell but the current through it is in the opposite direction to the convention that current flows from high to low potential. (b) The current I' and voltage V' in the circuit of (a) can be found from a load line construction. Point P is the operating point (I', V'). The load line is for $R = 30\ \Omega$.



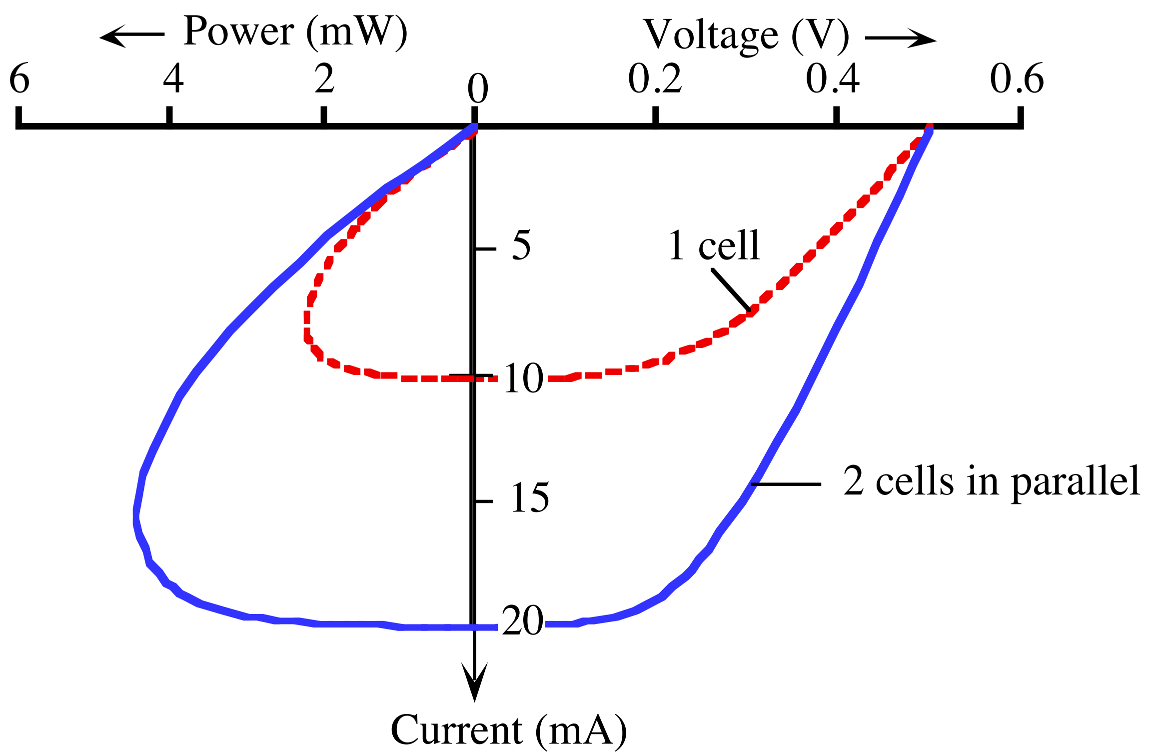
Series and shunt resistances and various fates of photegenerated EHPs.



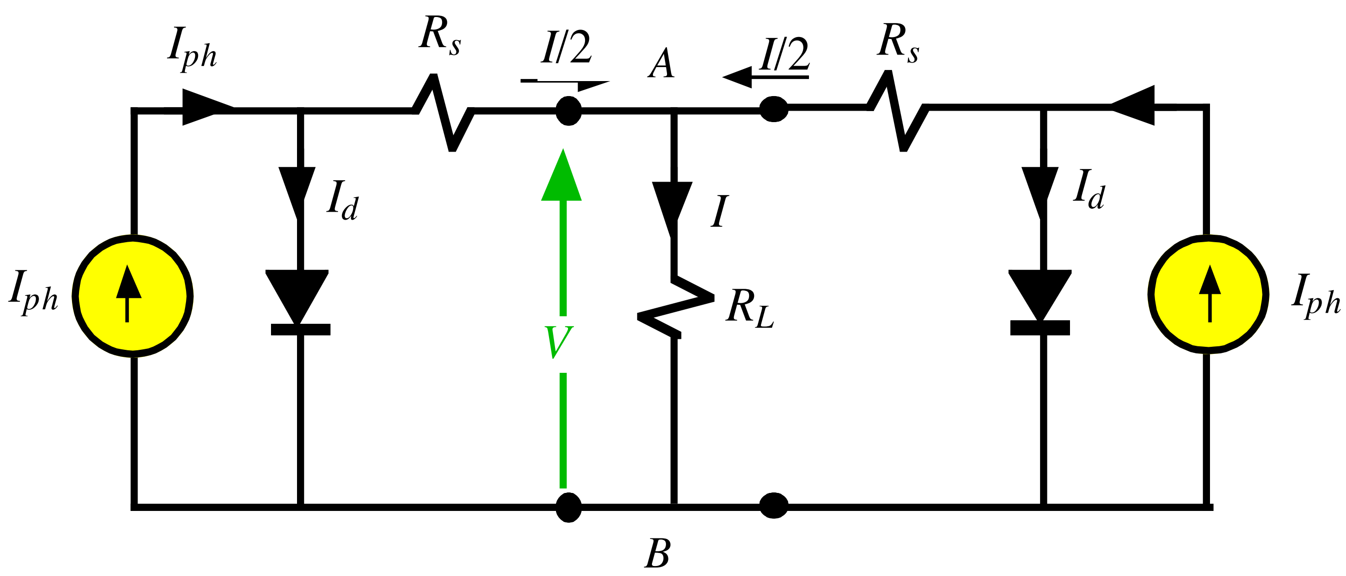
The equivalent circuit of a solar cell



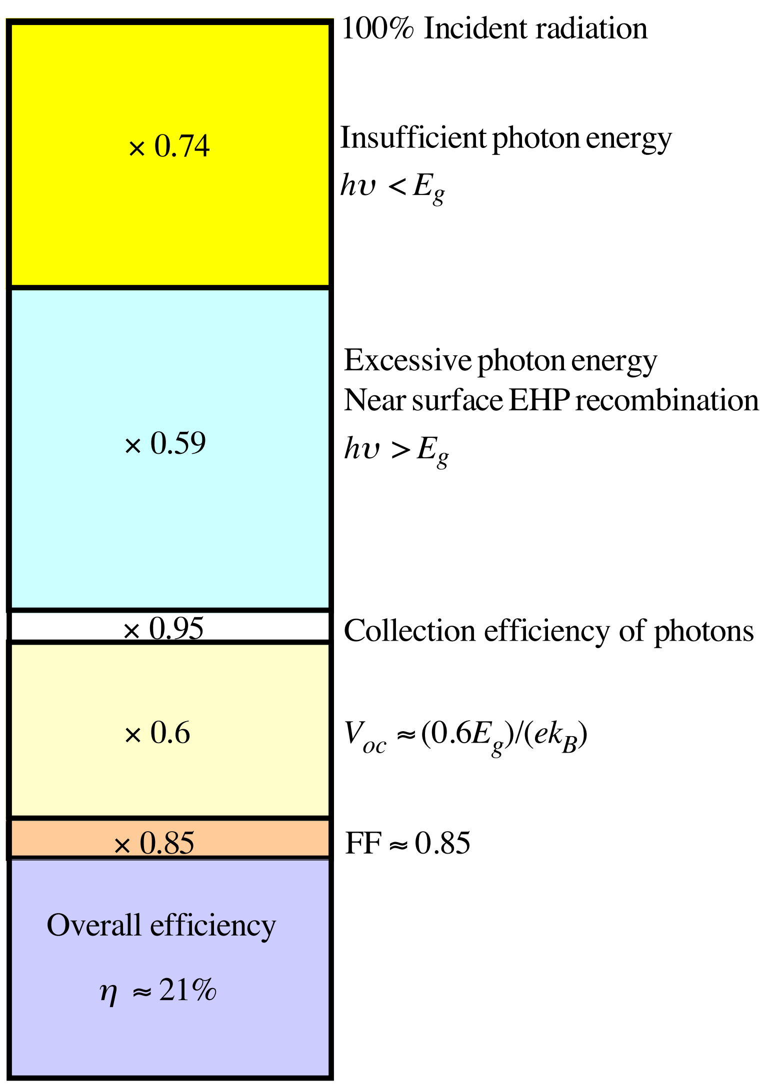
The series resistance broadens the I-V curve and reduces the maximum available power and hence the overall efficiency of the solar cell. The example is a Si solar cell with $n \approx 1.5$ and $I_o \approx 3 \times 10^{-6}$ mA. Illumination is such that the photocurrent $I_{ph} = 10$ mA.



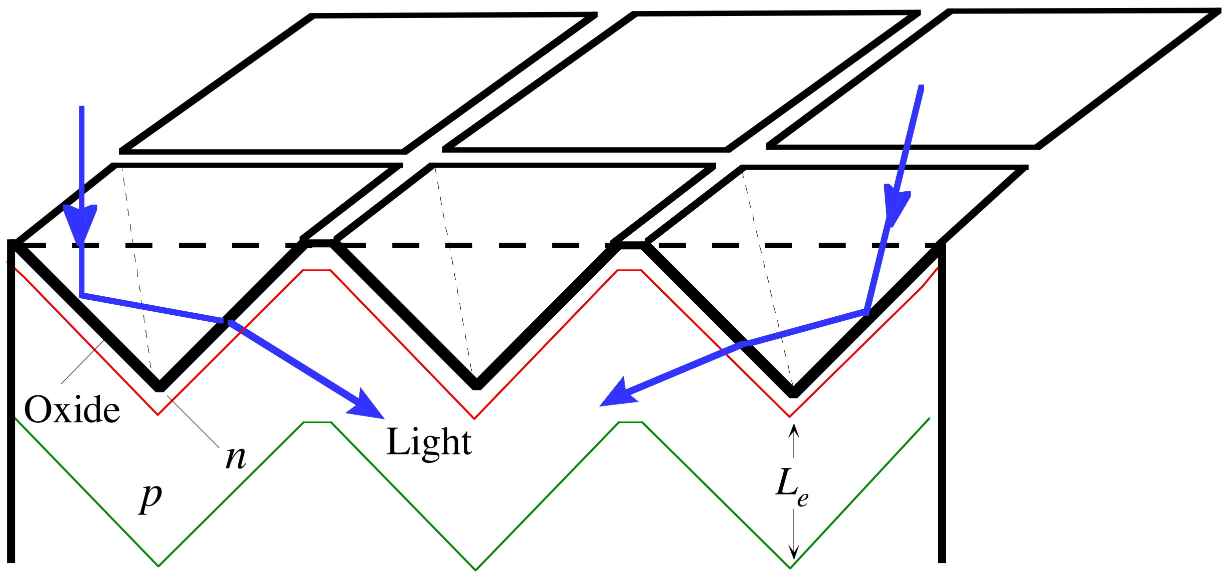
Current vs. Voltage and Power vs. Current characteristics of one cell and two cells in parallel. The two parallel devices have $R_s/2$ and $2I_{ph}$.



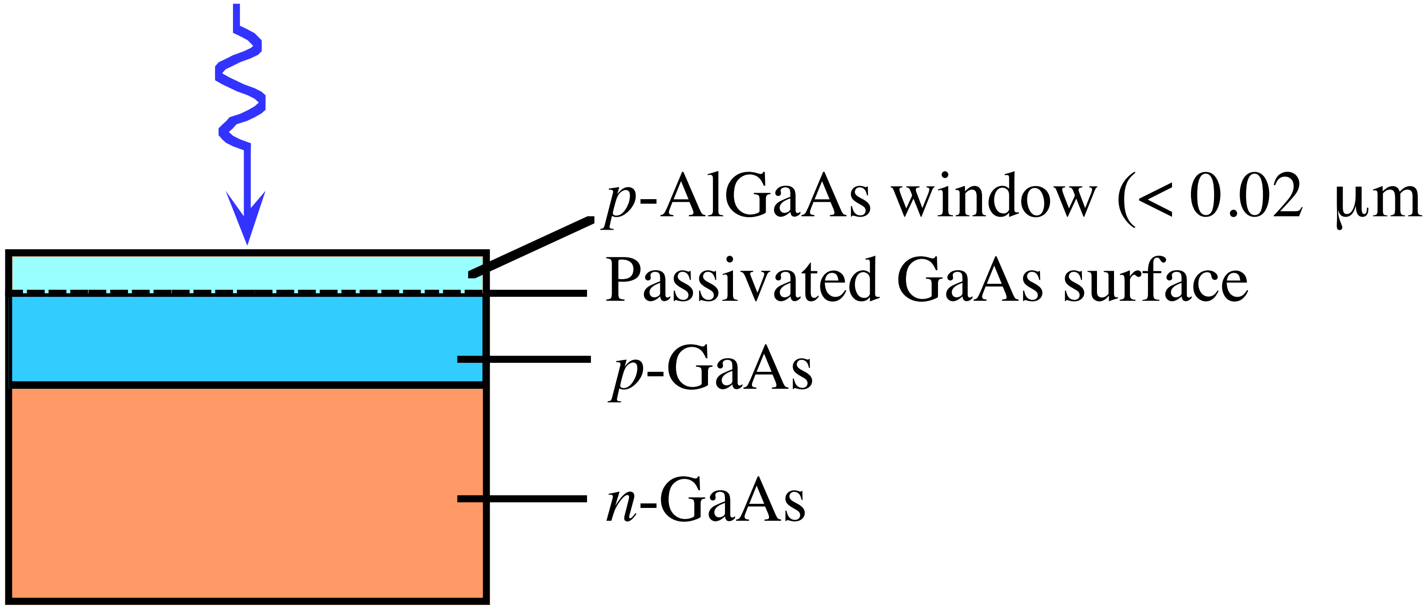
Two identical solar cells in parallel under the same illumination and driving a load R_L.



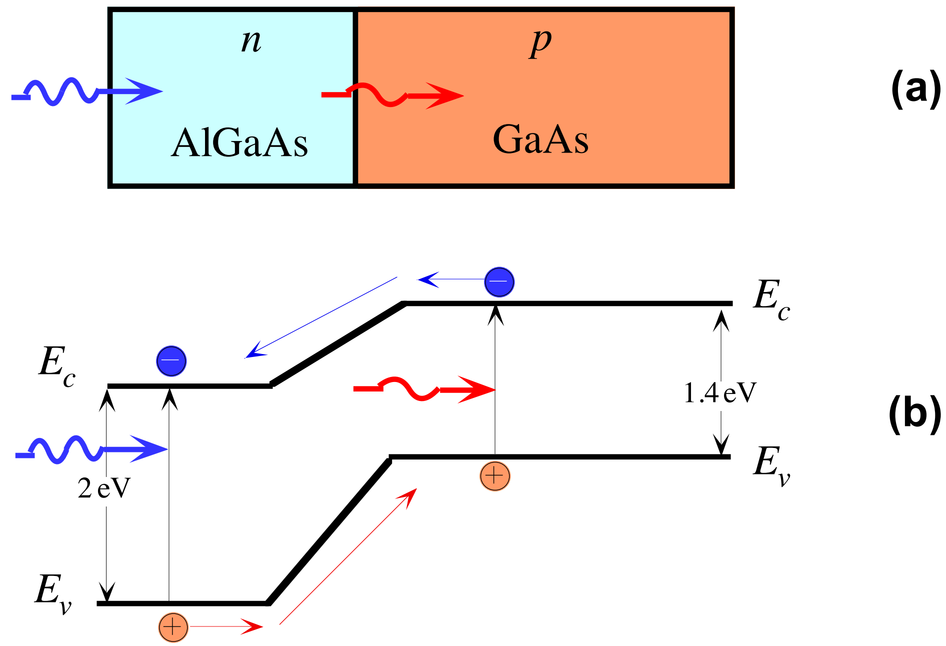
Accounting for various losses of energy in a high efficiency Si solar cell. Adapted from C. Hu and R. M. White, *Solar Cells* (McGraw-Hill Inc, New York, 1983, Figure 3.17, p. 61).



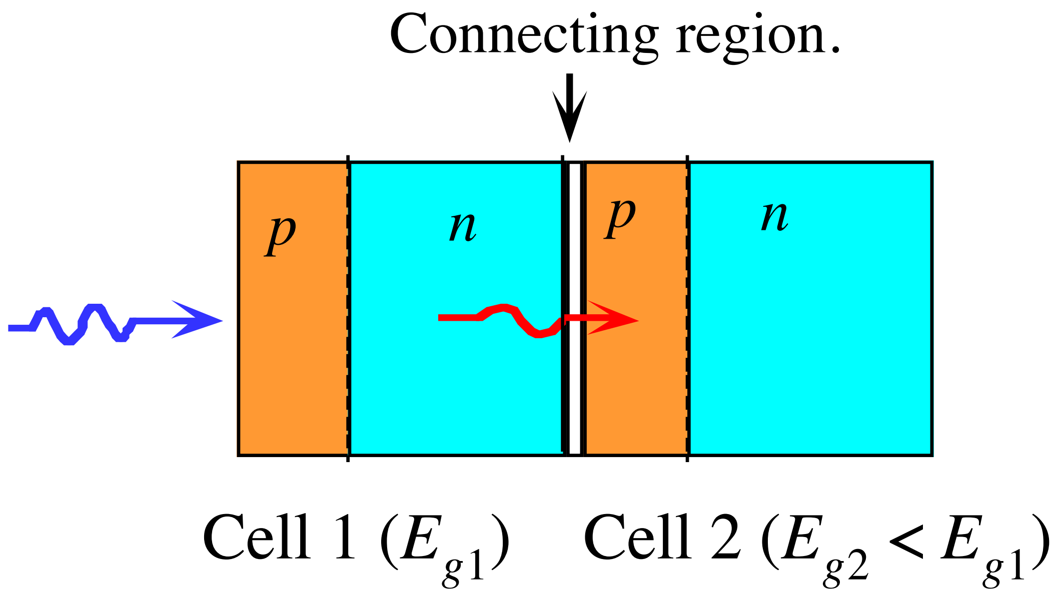
Inverted pyramid textured surface substantially reduces reflection losses and increases absorption probability in the device



AlGaAs window layer on GaAs passivates the surface states and thereby increases the low wavelength photogeneration efficiency



A heterojunction solar cell between two different bandgap semiconductors (GaAs and AlGaAs)



A tandem cell. Cell 1 has a wider bandgap and absorbs energetic photons with $h\upsilon > E_{g1}$. Cell 2 absorbs photons that pass cell 1 and have $h\upsilon > E_{g2}$.