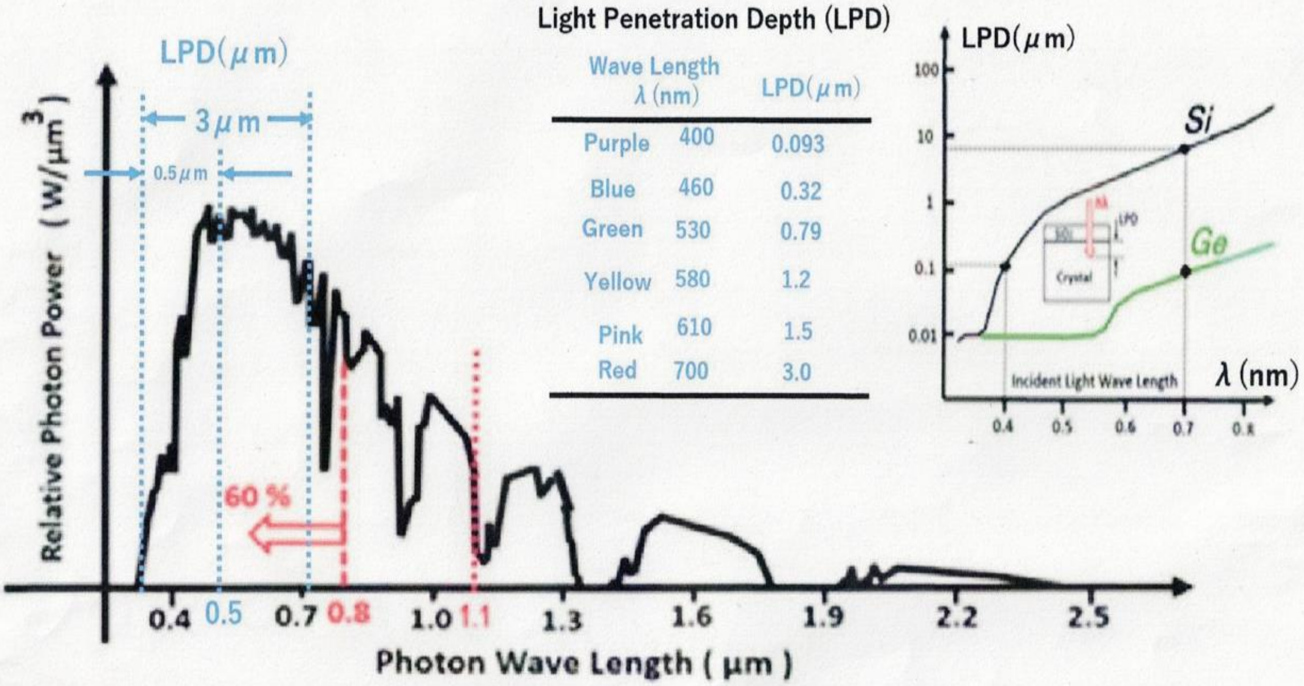


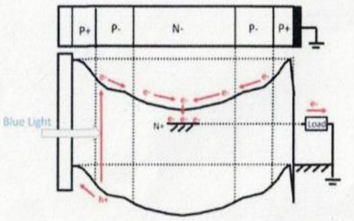
Light Penetration Depth (LPD)

Wave Length	λ (nm)	LPD(μm)
Purple	400	0.093
Blue	460	0.32
Green	530	0.79
Yellow	580	1.2
Pink	610	1.5
Red	700	3.0

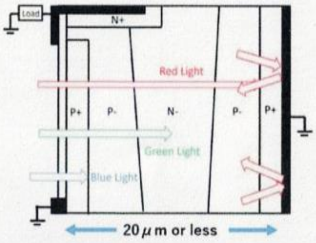
Figure 16 The relative photon power of the sun light and the light penetration depth (LPD) of the silicon(Si) and the germanium (Ge) crystals are shown as functions of the photon wave length λ in μm. The energy band gap (Eg) of the silicon crystal is 1.1 eV. The infrared -light photons with the wave length more than λ = 1.24 / Eg = 1.11 μm will not be converted into the electron energy in the silicon crystal. Besides, short-wave blue light photons cannot pass thru into the silicon crystal surface more than 0.1 ~0.2 μm in depth. They all will be wasted as heat. However, the surface P+P doping variation scheme invented by Hagiwara in 1975 can create the surface conduction -band bending, enhancing photo electron and hole separations at the silicon surface and results in the high quantum efficiency(QE) for solar cells.

Blue light has a very short Light Penetration Depth (LPD) of less than 0.05 μm

Circuit Model of P+P-N-P-P+ Double Junction type Solar Cell



Completely Depleted Buried N- Region with an empty potential of a strong electric field, collecting the photo electrons very effectively.



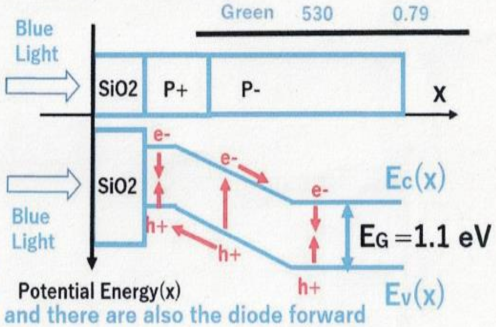
Short-wave blue-light cannot penetrate more than 0.1 μm in depth at the silicon crystal surface.

$$\Delta V_{barrier} = kT \ln(P+/P)$$

$$\Delta W_{barrier} >> LPD$$

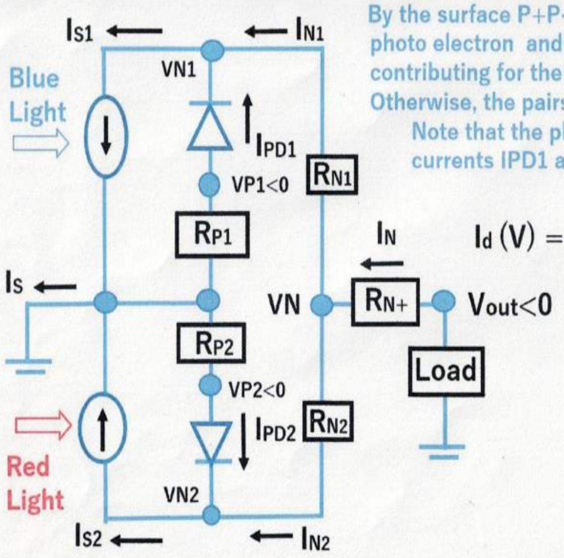
Light Penetration Depth (LPD)

Wave Length	λ (nm)	LPD(μm)
Purple	400	0.093
Blue	460	0.32
Green	530	0.79



By the surface P+P- conduction band bending, photo electron and hole pairs can be separated, contributing for the high quantum efficiency (QE). Otherwise, the pairs are recombined and wasted .

Note that the photodiodes are forward biased and there are also the diode forward currents IPD1 and IPD2 which degrade the effective quantum efficiency (QE).



I/V equation of a general PN junction diode:

$$I_d (V) = (AD/NL)\, n_i^2 \{ \exp(-V/kT) - 1 \} \; ; \quad n_i^2 = N_C N_V \exp(- E_G/kT) \; ;$$

$$IPD1 = (A1) \exp(- E_G/kT) \{ \exp((VP1 - VN1)/kT) - 1 \}$$

$$IPD2 = (A2) \exp(- E_G/kT) \{ \exp((VP2 - VN2)/kT) - 1 \}$$

In order to achieve the desired high quantum Efficiency (QE), the P+P surface resistance, RP1 and RP2, must be minimized. The silicon chip thickness is desired to be less than 20μm. The outlet resistance RN+ region must also be minimized too. Since the completely depleted N-buried region with a very strong electric field helps separating the photo electron and hole pairs, directing them swiftly to the small outlet N+ region, resulting in very small values of RN1 and RN2 resistance .