1. In a direct gap semiconductor the minimum in conduction band is directly above maximum in valence band (at the same value of wavevector \( k \)). In an indirect gap semiconductor this is not the case:

\[
\text{Direct} \quad E \quad \text{Indirect} \quad E
\]

\[ k \]

2. Electrical conductivity for electrons, \( \sigma_e = ne\mu_e \), electrical conductivity for holes \( \sigma_h = pe\mu_h \)
The total conductivity is \( \sigma_{\text{total}} = ne\mu_e + pe\mu_h \)

   
   If \( \lambda \leq 1.00 \times 10^{-6} \text{m} \), then photons of sunlight have energy
   \[
   E \geq \frac{hc}{\lambda_{\text{max}}} = \frac{(6.626 \times 10^{-34} \text{Js})(3.00 \times 10^8 \text{m/s})}{1.00 \times 10^{-6} \text{m}} \left( \frac{1 \text{eV}}{1.60 \times 10^{-19} \text{J}} \right) = 1.24 \text{eV}
   \]
   Thus, the energy gap for the collector material should be \( E_g \leq 1.24 \text{eV} \)
   Since Si has an energy gap \( E_g \approx 1.14 \text{eV} \), it will absorb radiation of this energy and greater.
   Therefore, Si is acceptable as a material for a solar collector.

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   If the photon energy is 5.5 eV or higher, the diamond window will absorb. Here,
   \[
   (hf)_{\text{max}} = \frac{hc}{\lambda_{\text{min}}} = 5.5 \text{ eV}: \quad \lambda_{\text{min}} = \frac{hc}{5.5 \text{eV}} = \left( \frac{6.626 \times 10^{-34} \text{Js}}{5.5 \text{eV}} \right) \left( \frac{3.00 \times 10^8 \text{m/s}}{(5.5 \text{eV})(1.60 \times 10^{-19} \text{J/eV})} \right)
   \]
   \[ \lambda_{\text{min}} = 2.26 \times 10^{-7} \text{m} = 226 \text{ nm} \]

5. (a) For \( \lambda = 250 \text{nm} \) \( E_\lambda = \frac{hc}{\lambda} = \left( \frac{6.63 \times 10^{-34} \text{Js}}{250 \times 10^{-9}} \right) = 7.96 \times 10^{-19} \text{ J} = 4.97 \text{ eV} \).
   
   The resistance stays the same until the wavelength reaches the gap wavelength, i.e.
   \[
   \lambda = \frac{hc}{E} = \lambda_g = \frac{hc}{E_g} \quad \text{E}_g(\text{GaAs}) = 1.52 \text{ eV} = 2.43 \times 10^{-19} \text{ J} \]
   
   (b) \( \lambda_g = \frac{hc}{E_g} = 933 \text{ nm} \)
(c) Resistance increases when wavelength exceeds the gap wavelength \(\lambda > \lambda_g\) because there is a drop in the number of photo-excited charge carriers. A drop in the number of charge carriers leads to an increase in resistance because \(\sigma = \frac{1}{\rho} = n\mu + p\mu_h\).

7. (a) The photon energy is \(E = \frac{hc}{\lambda} = 3.16 \times 10^{-19} \text{J}\)

(b) The number of photons per second striking the semiconductor is
\[
\frac{0.5}{3.16 \times 10^{-19} \text{(10}^{-4} \text{m}^2)} = 1.58 \times 10^{14}
\]
(effective surface area \(S\) of the photodetector is 1mm\(\times\)100mm = \(10^{-4} \text{ m}^2\))

(c) There are \(1.58 \times 10^{14}\) e-h pairs created assuming each absorbed photon creates a pair.

(d) \(\Delta N, \Delta P\) are the number of extra (photo-excited) electrons and holes due to illumination.

The conductivity is \(\sigma = n\mu\). The conductance is \(G = \frac{A}{L}\). (\(A\) is the cross-sectional area of photodetector, \(L\) is its length).

N.B. \(S\) is the effective surface area, \(A\) is the cross-sectional area of the photodetector.

Using \(\sigma = n\mu\), in the presence of illumination,
\[
\Delta \sigma = \frac{e(\Delta N\mu_e + \Delta P\mu_h)}{AL}
\]
where \(\mu_e, \mu_h\) are the respective electron and hole mobilities and \(AL\) is the volume of the semiconductor photodetector (=cross-sectional area \(A\) x length \(L\)). The change in conductance is
\[
\Delta G = \frac{e(\Delta N\mu_e + \Delta P\mu_h)}{L^2}
\]
giving
\[
\Delta G = \frac{(1.6 \times 10^{-19} \text{C})(1.58 \times 10^{14})(1.0) + (1.58 \times 10^{14})(0.001)}{L^2}
\]
substituting the electron and hole mobilities and putting \(L = 1 \text{mm} = 1 \times 10^{-3} \text{m}\),
\[
\Delta G = \frac{(1.6 \times 10^{-19} \text{C})(1.58 \times 10^{14})(1.0) + (1.58 \times 10^{14})(0.001)}{(1 \times 10^{-3})^2}
\]
\(= 25.3 \text{ S (siemens)}\)
(\(\text{Note, due to much lower mobility the hole contribution to the conductance is negligible}\))

8. \(E_g = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} \text{J.s})(3.00 \times 10^8 \text{m/s})}{650 \times 10^{-9} \text{m}} \approx 1.91 \text{eV}\)