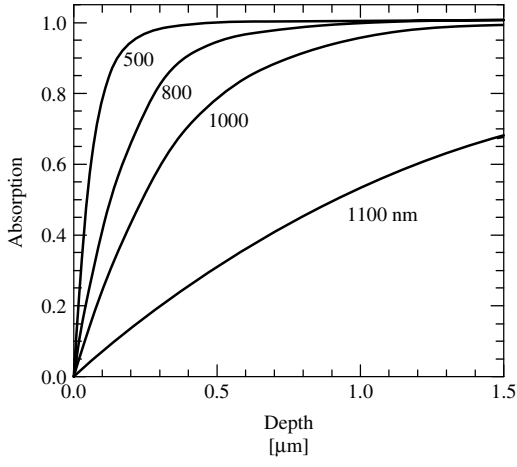

Figure 13.15 Absorption of light with different wavelengths in Cu(InGa)Se_2 with $x = 0.2$

The absorption of light with different wavelengths in Cu(InGa)Se_2 with $x = 0.2$ is shown in Figure 13.15. At thickness d, this is given by $\exp(-\alpha d)$ with α calculated at each wavelength using equation (13.3) and the data in Figure 13.6. If the effective collection length $L + W$ is smaller than 0.5 to 1 μm, a significant fraction of electrons are generated deeper into the Cu(InGa)Se_2 layer, and their incomplete collection can be a significant loss mechanism for Cu(InGa)Se_2 devices [116, 165]. The effect of $J_L(V)$ on current–voltage behavior increases with forward voltage bias and therefore has its largest effect on the fill factor and V_{OC} [166, 167]. The effect of a voltage-dependent collection on J_{SC} is illustrated in Figure 13.14 by the increase in QE measured at -1 V applied voltage bias compared to that measured at 0 V.

13.5.2 Recombination

The current–voltage ($J-V$) behavior of Cu(InGa)Se_2/CdS devices can be described by a general diode equation:

$$J = J_D - J_L = J_O \exp\left[\frac{q}{AkT}(V - R_S J)\right] + GV - J_L \tag{13.7}$$

with the diode current J_O given by:

$$J_O = J_{OO} \exp\left(-\frac{\Phi_b}{AkT}\right) \tag{13.8}$$

The ideality factor A, barrier height Φ_b, and prefactor J_{OO} depend on the specific recombination mechanism that dominates J_O, while the series resistance R_S and shunt conductance G are losses that occur in series or parallel with the primary diode. General expressions for A, Φ_b, and J_{OO} in the cases of recombination through the interface, space charge region, or bulk of the absorber layer can be found in various textbooks (see, for example [168]).