and

$$n_P(x_P) = \frac{n_i^2}{N_A} e^{qV/kT}. \tag{3.104}$$

3.4.2 Generation Rate

For light incident at the front of the solar cell, $x = -W_N$, the optical generation rate takes the form (see equation 3.35)

$$G(x) = (1-s)\int_\lambda (1-r(\lambda)) f(\lambda)\alpha(\lambda) e^{-\alpha(x+W_N)}\, d\lambda. \tag{3.105}$$

Only photons with $\lambda \leq hc/E_G$ contribute to the generation rate.

3.4.3 Solution of the Minority-carrier Diffusion Equation

Using the boundary conditions defined by equations (3.96), (3.98), (3.103), and (3.104) and the generation rate given by equation (3.105), the solution to the minority-carrier diffusion equation, equation (3.80), is easily shown to be

$$\Delta p_N(x) = A_N \sinh[(x + x_N)/L_p] + B_N \cosh[(x + x_N)/L_p] + \Delta p'_N(x) \tag{3.106}$$

in the n-type region and

$$\Delta n_P(x) = A_P \sinh[(x - x_P)/L_n] + B_P \cosh[(x - x_P)/L_n] + \Delta n'_P(x) \tag{3.107}$$

in the p-type region. The particular solutions due to $G(x)$, $\Delta p'_N(x)$, and $\Delta n'_P(x)$ are given by

$$\Delta p'_N(x) = -(1-s)\int_\lambda \frac{\tau_p}{(L_p^2\alpha^2 - 1)}[1 - r(\lambda)] f(\lambda)\alpha(\lambda) e^{-\alpha(x+W_N)}\, d\lambda \tag{3.108}$$

and

$$\Delta n'_P(x) = -(1-s)\int_\lambda \frac{\tau_n}{(L_n^2\alpha^2 - 1)}[1 - r(\lambda)] f(\lambda)\alpha(\lambda) e^{-\alpha(x+W_N)}\, d\lambda. \tag{3.109}$$

Using the boundary conditions set above, A_N, B_N, A_P, and B_P are easily obtained.

3.4.4 Terminal Characteristics

The minority-carrier current densities in the quasi-neutral regions are just the diffusion currents, since the electric field is negligible. Using the active sign convention for the current (since a solar cell is typically thought of as a battery) gives

$$\vec{J}_{p,N}(x) = -qD_p \frac{d\Delta p_N}{dx} \tag{3.110}$$