1. 1D Transport Equations

1.1. Generation Equations

Photon Recycling

The equation to describe the generation of photons at a given depth x due to photon re-absorption (recycling) follows:

$$
\begin{aligned}
Gen(x) = \int_0^L \alpha \left(\frac{\delta R_{Rad}(x')}{2}\right) e^{-\alpha(x-x')} dx' + \alpha \left(\frac{\delta R_{Rad}(x)}{2}\right) \\
+ \int_0^x \alpha \left(1 - f_{PL}\right) \left(\frac{\delta R_{Rad}(x')}{2}\right) e^{-\alpha(x+x')} dx' - \alpha \left(1 - f_{PL}\right) \left(\frac{\delta R_{Rad}(x)}{2}\right) e^{-2\alpha x} \\
+ \int_x^L \alpha \left(R_{Back}\right) \left(\frac{\delta R_{Rad}(x')}{2}\right) e^{-\alpha(2L-x-x')} dx' - \alpha \left(R_{Back}\right) \left(\frac{\delta R_{Rad}(x)}{2}\right) e^{-2\alpha(L-x)}
\end{aligned}
\tag{1}
$$

where α is the absorption coefficient, R_{Rad} is the radiative recombination rate at a given depth, f_{PL} is the fraction of carriers emitted as PL from the film surface — i.e. not internally reflected —, R_{Back} is the back surface reflection, and L is the film thickness. Here we use the term δ to account for the fraction of R_{Rad} which overlaps with the absorption spectrum for the material (since we are not considering an integration over the wavelength of emitted light at this point); for similar reasons, α represents the average absorption coefficient for the photons in δR_{Rad}. Note: For this 1D simulation, R_{Rad} is considered to emit equally in the $+x$ and $-x$ directions, hence the factor of $\frac{1}{2}$. The first two terms in Equation 1 consider photons originating at all points x' towards x, with a correction at $x = x'$. The second two terms in Equation 1 consider photons originating between 0 and x which are emitted away from x then internally reflected back towards x, with a correction at $x = x'$. The final two terms in Equation 1 consider photons originating between x and L which are emitted away from x then internally reflected back towards x, with a correction at $x = x'$. Here we only consider photons with a single surface reflection.

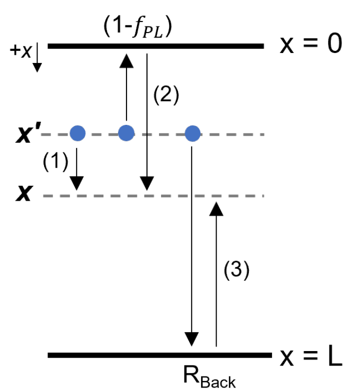

Figure 1. Graphical representation of the three photon re-absorption processes described for Equation 1 for photon emission at x' (blue) and subsequent re-absorption at x.

A graphical description of the various photon emission processes considered in Equation 1 is shown in Figure 1.

No photon recycling

The equation to describe the generation of photons in the absence of photon re-absorption (recycling) follows:

$$Gen(x) = 0 \tag{2}$$

Equation 2 can also be recovered by setting $\delta = 0$ in Equation 1.

1.2. PL Equations

Photon recycling

The equation to describe the PL photon flux emitted from a film surface in the presence of photon recycling follows:

$$\begin{aligned} PL = \int_0^L (1-\delta) R_{Rad}(x) dx + \int_0^L \delta \left(\frac{R_{Rad}(x)}{2} \right) e^{-\alpha x} dx \\ + \int_0^L \delta R_{Back} \left(\frac{R_{Rad}(x)}{2} \right) e^{-\alpha (x+L)} dx \end{aligned} \tag{3}$$

The first term in Equation 3 considers all photons generated at a depth x whose energy does not overlap with the absorption spectrum of the material. The second term in Equation 3 considers photons which can be reabsorbed with the absorption coefficient α and are emitted towards the film surface. The third term in Equation 3 considers photons which can be reabsorbed with the absorption coefficient α and are emitted away from the film surface which subsequently reflect off of the back surface.

No photon recycling

The equation to describe the PL photon flux emitted from a film surface in the absence of photon recycling follows:

$$PL = \int_0^L R_{Rad}(x) dx \tag{4}$$

Equation 4 can also be recovered by setting $\delta = 0$ in Equation 3.