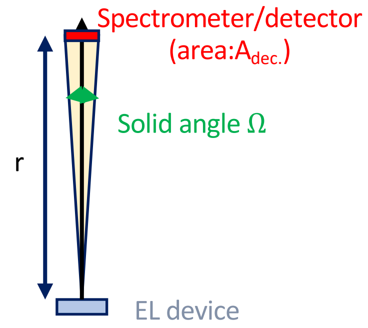
Method (1)



- (a) the total outcoupling efficiency from device to far field, η_{total}
- (b) normalized far field's pattern, $\bar{\bar{I}}_{FF}(\theta,\phi)\ [\frac{1}{sr}]$ (without λ dependent)
- (c) normalized spectrum at normal direction, $\overline{\overline{Sp}}_{FF}(\lambda,\theta=0^o)\ [\frac{1}{nm}]$

- The relation between the injection current ($\mathrm{I_{inj.}}$) and far field photon number (N_{FF})

$$\frac{N_{FF}}{\Delta t} = \mathrm{IQE}\times\left(\mathrm{I_{inj.}}\times 6.241\times 10^{18}\right)\times\eta_{total}\ \left[\frac{1}{s}\right]$$

- N_{FF} should also equal to the integration of far field intensity with absolute value.
  - Assume the spectra are same over all the angles. As a result, the angular dependent far field spectrum with absolute value should equal to (α strength)

$$\alpha\overline{\overline{Sp}}_{FF}(\lambda,\theta=0^o)\bar{\bar{I}}_{FF}(\theta,\phi)\ \left[\frac{W}{nm\cdot sr}\right]$$

Then,

$$\left(\frac{hc}{\lambda}\right)_{avg.}\frac{N_{FF}}{\Delta t}[W] = \int\int \alpha\overline{\overline{Sp}}_{FF}(\lambda,\theta=0^o)\bar{\bar{I}}_{FF}(\theta,\phi)d\lambda\, d\Omega$$

Method (2)

$$\frac{N_{FF}}{\Delta t} = \frac{1}{\left(\frac{hc}{\lambda}\right)_{avg.}} \int\int \alpha \overline{\overline{Sp}}_{FF}(\lambda, 0^o)\bar{\bar{I}}_{FF}(\theta, \phi) d\lambda\, d\Omega = \mathrm{IQE}\times\left(\mathrm{I_{inj.}}\times 6.241\times 10^{18}\right)\times\eta_{total}$$

Then,

$$\alpha = \left(\frac{hc}{\lambda}\right)_{avg.} \frac{\mathrm{IQE}\times\left(\mathrm{I_{inj.}}\times 6.241\times 10^{18}\right)\times\eta_{total}}{\int \overline{\overline{Sp}}_{FF}(\lambda, 0^o) d\lambda \int \bar{\bar{I}}_{FF}(\theta, \phi) d\Omega}$$

As a result, the spectrum at normal direction with absolute value is

$$\alpha \overline{\overline{Sp}}_{FF}(\lambda, 0^o)\bar{\bar{I}}_{FF}(0^o)\ \left[\frac{W}{nm\cdot sr}\right]$$

Then current efficiency would become

$$\eta_{\mathrm{cd}}(0^o) = \frac{K\int_\lambda\ \alpha \overline{\overline{Sp}}_{FF}(\lambda, 0^o)\bar{\bar{I}}_{FF}(0^o)V(\lambda)d\lambda}{I_{\mathrm{inj.}}}\left[\frac{lm}{sr\cdot A} = \frac{cd}{A}\right]$$

$$= \frac{K}{I_{\mathrm{inj.}}} \underset{\alpha}{\boxed{\left(\frac{hc}{\lambda}\right)_{avg.} \frac{\mathrm{IQE}\times\left(\mathrm{I_{inj.}}\times 6.241\times 10^{18}\right)\times\eta_{total}}{\int \overline{\overline{Sp}}_{FF}(\lambda, 0^o) d\lambda \int \bar{\bar{I}}_{FF}(\theta, \phi) d\Omega}}} \bar{\bar{I}}_{FF}(0^o) \int_\lambda\ \overline{\overline{Sp}}_{FF}(\lambda, 0^o)V(\lambda)d\lambda$$

Method (3)

$$\eta_{\mathrm{cd}}(0^o) = K\left(\frac{hc}{\lambda}\right)_{avg.} \frac{\mathrm{IQE}\times\eta_{total}\times 6.241\times 10^{18}}{\int \overline{\overline{Sp}}_{FF}(\lambda,0^o)d\lambda \int \bar{\bar{I}}_{FF}(\theta,\phi)d\Omega} \bar{\bar{I}}_{FF}(0^o)\int_{\lambda} \overline{\overline{Sp}}_{FF}(\lambda,0^o)V(\lambda)d\lambda$$

Rearrange

$$\eta_{\mathrm{cd}}(0^o) = \underbrace{\boxed{\mathrm{IQE}\times\eta_{total}}}_{\mathrm{EQE}}\times 6.241\times 10^{18}\left(\frac{hc}{\lambda}\right)_{avg.} \frac{\bar{\bar{I}}_{FF}(0^o)}{\int \bar{\bar{I}}_{FF}(\theta,\phi)d\Omega} \frac{K\int_{\lambda} \overline{\overline{Sp}}_{FF}(\lambda,0^o)V(\lambda)d\lambda}{\int \overline{\overline{Sp}}_{FF}(\lambda,0^o)d\lambda}$$

,where

$$\left(\frac{hc}{\lambda}\right)_{avg.} = \frac{\int_{\lambda} \left(\frac{hc}{\lambda}\right)\overline{\overline{Sp}}_{FF}(\lambda,0^o)d\lambda}{\int_{\lambda} \overline{\overline{Sp}}_{FF}(\lambda,0^o)d\lambda}$$

$$\int \bar{\bar{I}}_{FF}(\theta,\phi)d\Omega = \int\int \bar{\bar{I}}_{FF}(\theta,\phi)\sin\theta\, d\theta\, d\phi \approx 2\pi \int \bar{\bar{I}}_{FF}(\theta,\phi)\sin\theta\, d\theta$$