# Formula sheet

$E_{(x,y,z)} = E_0 \frac{\omega_0}{\omega(z)} e^{-\frac{r^2}{\omega^2(z)}} \cdot e^{-j\frac{kr^2}{2R(z)}} \cdot e^{-j(kz - tan^{-1}(\frac{z}{z_0}))}$ $\omega^2(z) = \omega_0^2\left(1 + \left(\frac{\lambda_0 z}{\pi n \omega_0^2}\right)^2\right) = \omega_0^2(1 + (\frac{z}{z_0})^2)$ $z_0 = \frac{n\pi\omega_0^2}{\lambda_0}$ $R(z) = z\left(1 + \left(\frac{\pi n \omega_0^2}{\lambda_0 z}\right)^2\right) = z(1 + (\frac{z_0}{z})^2)$ divergence angle $\theta = \frac{2\omega_0}{z_0}$

$E_{\ell m(x,y,z)} = E_0 \frac{\omega_0}{\omega(z)} e^{-\frac{r^2}{\omega^2(z)}} H_\ell(\frac{\sqrt{2}x}{\omega(z)}) H_m(\frac{\sqrt{2}y}{\omega(z)}) \cdot e^{-j\frac{kr^2}{2R(z)}} \cdot e^{-j(kz-(1+\ell+m)tan^{-1}(\frac{z}{z_0}))}$

$H_m(u) = (-1)^m e^{u^2} \frac{d^m}{du^m} e^{-u^2}$ $\mathrm{FSR} = \frac{c}{2nd}$ $\mathrm{T} = \frac{(1-R_1)(1-R_2)}{(1-\sqrt{R_1R_2})^2 + 4\sqrt{R_1R_2} sin^2 kd}$ $\mathrm{F} = \frac{FSR}{\Delta v_{1/2}}$

$\Delta v_{1/2} = \frac{c}{2nd} \cdot \frac{1-\sqrt{R_1R_2}}{\pi (R_1R_2)^{1/4}}$ $\mathrm{Q} = \frac{v_0}{\Delta v_{1/2}} = \frac{\omega_0}{\Delta\omega_{1/2}} = \frac{\lambda_0}{\Delta\lambda_{1/2}}$ $\frac{dN_2}{dt} = -A_{21}N_2$ $\frac{dN_2}{dt} = B_{12}\rho N_1$

$\gamma = \sigma(N_2 - N_1)$ $\frac{N_2}{N_1} = e^{-\frac{hv}{kT}}$ $\sigma = \frac{hv}{c/n} B_{21} g(v) = \frac{hv}{c/n} B_{12} g(v) = A_{21} \frac{\lambda^2}{8\pi n^2} g(v)$

$g(v) = \frac{1}{2\pi} \cdot \frac{\Delta v}{(v-v_0)^2 + \left(\frac{\Delta v}{2}\right)^2}$ $g(v) = \sqrt{\frac{4ln2}{\pi}} \frac{1}{\Delta v_D} e^{-4ln2(\frac{v-v_0}{\Delta v_D})^2}$, where $\Delta v_D = \sqrt{\frac{8K_BTln2}{Mc^2}} v_0$

$\gamma_{th} = \frac{1}{2l} ln \frac{1}{R_1R_2}$ $hv_0 \approx E_g + \frac{1}{2}kT$ $h\Delta v \approx 3kT$

$\eta_{IQE} = \frac{1/\tau_r}{1/\tau_r + 1/\tau_{nr}} = \frac{\Phi}{I/e}$ $\eta_{EE} = \frac{\Phi_{out}}{\Phi} = \frac{P_{out}/hv}{\eta_{IQE} \times \frac{I}{e}}$ $\eta_{EQE} = \frac{\Phi_{out}}{I/e}$

$\eta_{PCE} = \frac{P_{out}}{IV}$ $\eta_{LE} = \frac{\Phi_V}{IV}$, where $\Phi_V = P_o \times 683 \times V(\lambda)$ $\eta_{EQE} = \frac{I_{ph}/e}{P_o/hv}$

$I_{ph} = \frac{P_o}{hv} \times (1-R) \times (1 - e^{-\alpha d}) \times \eta_{IQE} \times e$ $\boldsymbol{R} = \frac{I_{ph}}{P_o}$ $\mathrm{I} = I_s\left(e^{\frac{eV}{kT}} - 1\right) - I_{ph}$

$t_{drift} = \frac{w}{V_d}$ $C_{dep} = \frac{\epsilon A}{w}$ $i_{rms,ph} = \sqrt{2eI_dB}$ $i_{rms,th} = \sqrt{\frac{4kTB}{R_L}}$

$\mathrm{FF} = \frac{V_{max}I_{max}}{V_{oc}I_{sc}}$ $\boldsymbol{H}_x = -\frac{1}{h^2}(j\beta \frac{\partial \boldsymbol{H}_z}{\partial x} - j\omega\epsilon \frac{\partial \boldsymbol{E}_z}{\partial y})$, $\boldsymbol{H}_y = -\frac{1}{h^2}(j\beta \frac{\partial \boldsymbol{H}_z}{\partial y} + j\omega\epsilon \frac{\partial \boldsymbol{E}_z}{\partial x})$,

$\boldsymbol{E}_x = -\frac{1}{h^2}(j\beta \frac{\partial \boldsymbol{E}_z}{\partial x} + j\omega\mu \frac{\partial \boldsymbol{H}_z}{\partial y})$, $\boldsymbol{E}_y = -\frac{1}{h^2}(j\beta \frac{\partial \boldsymbol{E}_z}{\partial y} - j\omega\mu \frac{\partial \boldsymbol{H}_z}{\partial x})$ $(\alpha d)^2 + (hd)^2 = d^2(k_1^2 - k_2^2)$

$\beta = \frac{2\pi}{\lambda_g}$ $k^2 = h^2 + \beta^2$ $V = d\frac{2\pi}{\lambda}\sqrt{n_1^2 - n_2^2}$ $\sin\alpha_{max} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} = \frac{NA}{n_0}$

$\Delta\tau_m = |D_m|\Delta\lambda L$ $\Delta\tau_w = |D_w|\Delta\lambda L$ $\alpha_{dB} = \frac{1}{L}10log\frac{P_{in}}{P_{out}}$