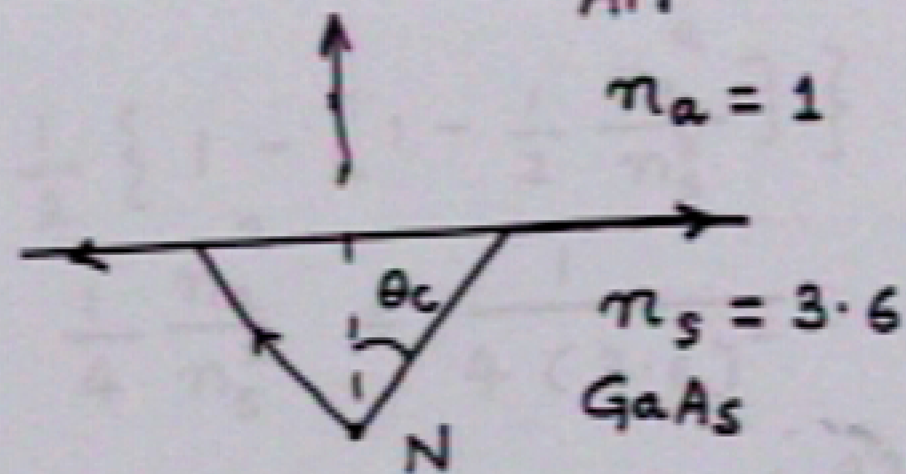
$$\eta_{ext\,1} = \frac{1}{2}\left\{1 - \left[1 - \frac{1}{2}\frac{n_a^2}{n_s^2}\right]\right\}$$

$$= \frac{1}{4}\frac{n_a^2}{n_s^2} = \frac{1}{4(3.6)^2}$$

$$\simeq 0.0193 \quad \text{i.e} \quad 1.93\%$$



$$\eta_{ext\,1} = \frac{2\pi \int_0^{\theta_c} \sin\theta \, d\theta}{4\pi}$$

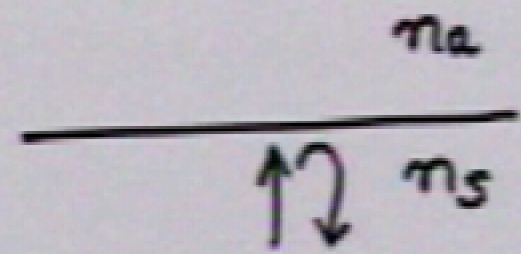
$$= \frac{1}{2}\left[-\cos\theta\right]_0^{\theta_c} = \frac{1}{2}\left[1 - \cos\theta_c\right]$$

$$\sin\theta_c = \frac{n_a}{n_s} \Rightarrow \cos\theta_c = \sqrt{1 - \sin^2\theta_c}$$

$$\simeq \left(1 - \frac{1}{2}\sin^2\theta_c\right)$$

$$\Rightarrow \cos\theta_c \simeq 1 - \frac{1}{2}\, n_a^2/n_s^2$$

Partial Reflection:



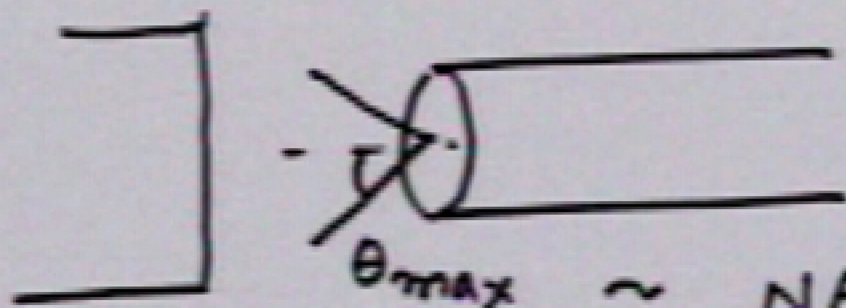
Power Ref. coeff. $\Gamma = \left(\frac{n_s - n_a}{n_s + n_a} \right)^2$

Transmission Coeff $\tau_{rans} = 1 - \Gamma$

$$= \frac{4 n_a n_s}{(n_s + n_a)^2}$$

$$\eta_{ext2} = \frac{4 \times 3.6}{(3.6 + 1)^2} \simeq 0.68$$

$\eta_{ext3} \rightarrow$ Absorption in the material



$\approx NA$

solid angle. $2\pi \cdot (NA)^2$

$$\eta_{ext4} = \frac{2\pi (NA)^2}{2\pi} = (NA)^2$$

$NA = 0.2 - 0.3$ $\quad \eta_{ext4} = 0.04 - 0.09$

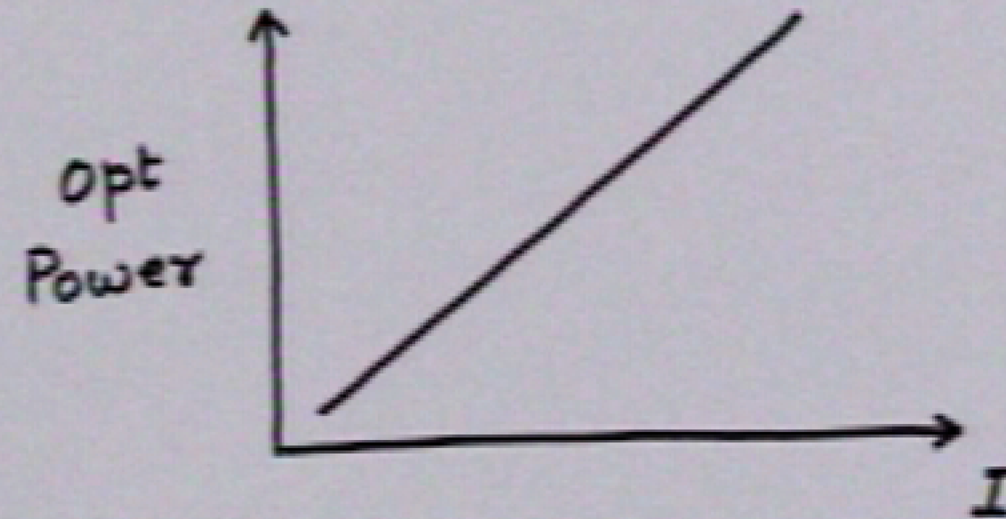
Total external quantum eff.

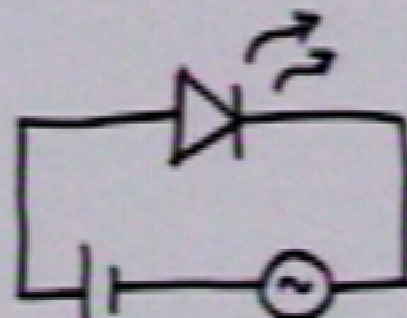
$$\eta_{ext} = \eta_{ext1} \cdot \eta_{ext2} \cdot \eta_{ext3} \cdot \eta_{ext4}$$

$$= 0.0193 \times 0.68 \times 0.7 \times 0.09$$

$$\simeq 10^{-3}$$

optical power $\propto$ LED current





Modulation of LED

$$n_0 \, , \, p_0$$

Rate of Recombination $= r\, n_0 p_0$

$=$ Thermal generation rate

Net Recomb. rate

$$= r(n_0 + \Delta n)(p_0 + \Delta p) - r\, n_0 p_0$$

$$= r(n_0 + p_0 + \Delta n)\Delta n$$

$\boxed{\Delta n = \Delta p}$ $\quad -\dfrac{\partial \Delta n}{\partial t} = r(n_0 + p_0 + \Delta n)\Delta n$

Low injection: $\Delta n << n_0$

$$-\frac{\partial \Delta n}{\partial t} = r(n_0 + p_0)\Delta n$$

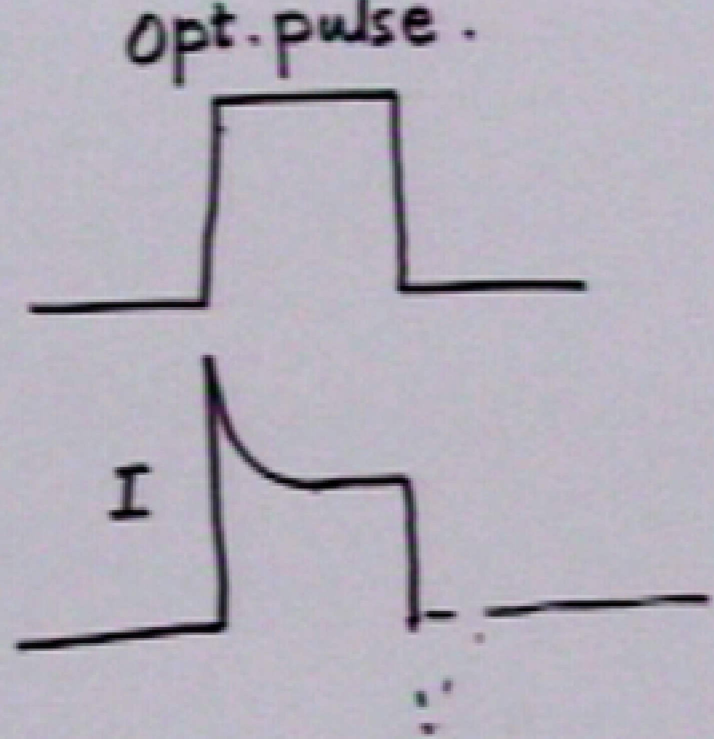
$$\tau = \frac{1}{r(n_0 + p_0)}$$ Independent of current

High injection: $\Delta n >> n_0$

$$-\frac{\partial \Delta n}{\partial t} = r(\Delta n)^2$$

$$\tau = \left(\frac{-\partial \Delta n/\partial t}{\Delta n}\right)^{-1} = \frac{1}{r\Delta n}$$

$$\propto \frac{1}{\text{current}}$$



Opt. pulse.
I