Nov. 1, 2005

ECE 6440 (HW 11.1, 11.12, 11.13, 11.14)



## Optical source coupling

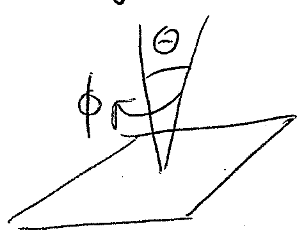
brightness - optical power radiated ~~pt~~ per unit solid angle per unit surface area $W/cm^2/sr$

total power $P_s = A_s \int_0^{2\pi}\int_0^{\pi/2} B(\theta,\phi)\sin\theta\, d\theta\, d\phi$

Lambertian source - uniform light radiation across area

$B(\theta,\phi) = B_0\cos\theta$ (projected area dec. as $\cos\theta$)

$B_0$ = brightness normal incidence




other extreme is laser, single mode

LED's and laser diodes

$$\frac{1}{B(\theta,\phi)} = \frac{\sin^2\phi}{B_0\cos^T\theta} + \frac{\cos^2\phi}{B_0\cos^L\theta}$$

Lambertian $T=L=1$

laser $T\sim L\sim 100$

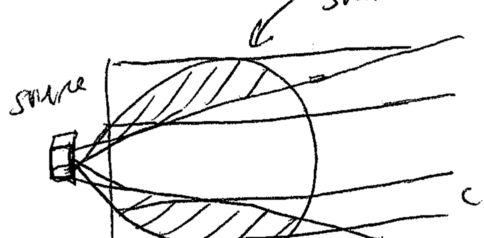
~~asym~~ asymmetry of emission area

(Figure 11.6 and table 11.1)

coupling

must overlap area and numerical aperture

f = w.g.
s = source




source area calc. @ w.g. entrance

coupled w.g.

$$P = \int_{A_f} dA_s \int_{\Omega_f} d\Omega_s\, B(A_s,\Omega_s)$$

min. of source w.g.

$$= \int_0^{r_{min}}\int_0^{2\pi}\left[\int_0^{2\pi}\int_0^{\theta_{max}} B(\theta,\phi)\sin\theta\, d\theta\, d\phi\right] d\theta_s\, r\, dr$$

or $dA_s$ — cir. symm.

$\sin\theta_{max} = \sqrt{n_f^2 - n_s^2}$

$\theta_{max}$ = NA of w.g.

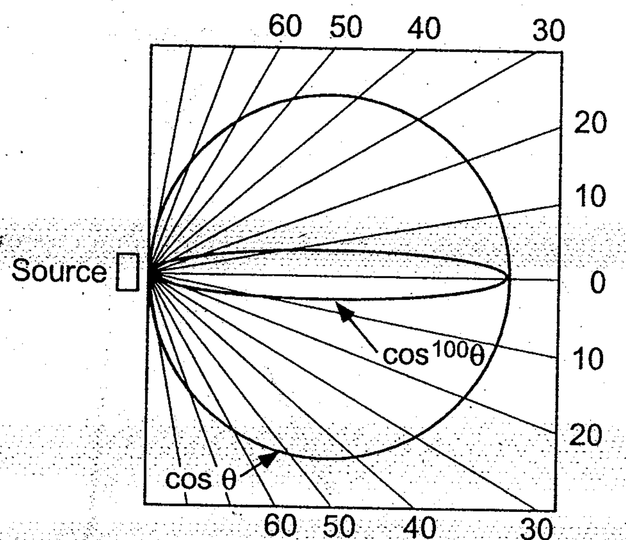



*Figure 11.6* The radiance pattern of a Lambertian ($\cos\theta$) source and of a laser ($\cos^{100}\theta$). The plots are normalized to unity $B_0$.

*Table 11.1.* Brightness of common optical sources

| *Source* | Power | $\Delta\lambda$ (nm) | Area | I (W/m$^2$) | Sterads | Brightness (W/cm$^2$/sr) |
|---|---|---|---|---|---|---|
| Filament | 14.4 W | 20 | 1 cm$^2$ | 14.4 | $2\pi$ | 2.3 |
| LED | 20 mW | 20 | (50 $\mu$m)$^2$ | 800 | $2\pi$ | 125 |
| Diode Laser | 10 mW | 10 | 5 by 10$\mu$m | $2 \times 10^4$ | 0.1 | $2 \times 10^5$ |
| HeNe laser | 1 mW | 0.1 | 1 mm$^2$ | 0.1 | $10^{-7}$ | $1 \times 10^6$ |

radiation laws over a large spectral bandwidth. For the purposes of this table, we restricted the source bandwidth to be 20 nm or less, centered at 1 $\mu$m.

Inspection of the data in Table 11.1 shows the reason why lasers and LEDS are the preferred sources for optical waveguide communication. The common filament light source, calculated in this case for a filament temperature of 2700°K, is relatively low in brightness compared to the other sources. That, along with the poor overall optical conversion efficiency and relatively slow modulation rate, effectively rules out the use of blackbody sources for efficient waveguide excitation.

The semiconductor LED is also a Lambertian source which radiates over $2\pi$ sterads, but due to its small size, and relatively narrow spectral emission bandwidth, its brightness is sufficient for many purposes, especially in low frequency (less than 100 MHz) communication links. The semiconductor laser, due to its much smaller area, and smaller solid angle of emission, ...

coupling to step-index wg.

direct end-fire coupling to circular wg. from LED (surf. emitter)

$$P = \int_0^{r_s}\int_0^{2\pi}\left(2\pi B_0 \int_0^{\theta_{max}} \cos\theta \sin\theta\, d\theta\right) d\theta_s\, r\, dr$$

$$= \pi B_0 \int_0^{r_s}\int_0^{2\pi} \sin^2\theta_{max}\, d\theta_s\, r\, dr = \pi B_0 \iint (NA)^2\, d\theta_s\, r\, dr$$

if source smaller than wg.

$$P = \pi^2 r_s^2 B_0 (NA)^2$$

power emitted by LED

$$P_s = A_s \int_0^{2\pi}\int_0^{\pi/2} B(\theta,\phi) \sin\theta\, d\theta\, d\phi = \pi^2 r_s^2 B_0$$

$P = P_s (NA)^2$ or $P = \left(\frac{a}{r_s}\right)^2 P_s (NA)^2$ if source > fiber rad. a.

↳ typical of coupling to multi-mode.

using a lens

cannot improve brightness, but can transform area to divergence angle

for Lambertian, can be used to enlarge source and reduce divergence angle by factors of M.

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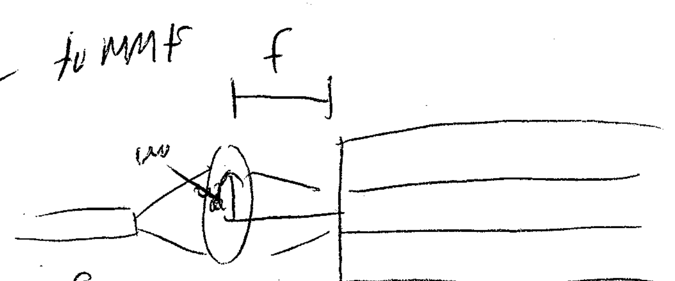
for laser to MMF




$$\frac{2\lambda}{\pi} \cdot \frac{f}{2w_0} < 2a$$

$$w_0/f < \sqrt{n_f^2 - n_s^2}$$

for single mode, use overlap integral