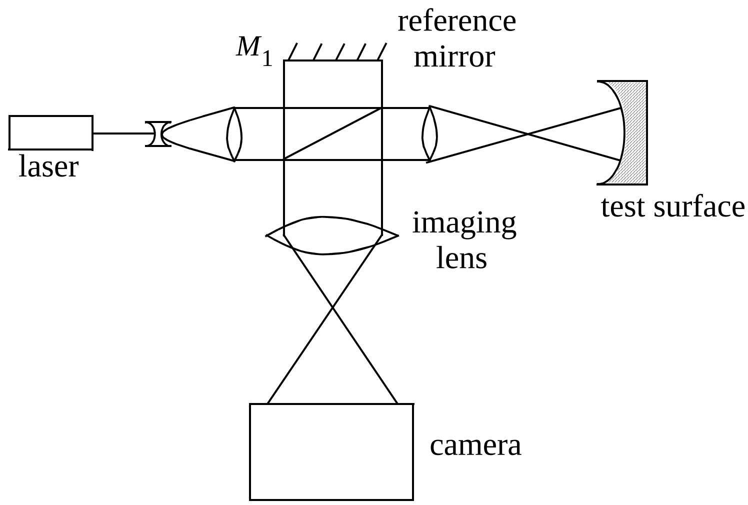
Lecture 21

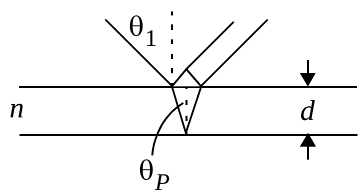
Twyman-Green interferometer



If the test surface is perfect, then the path length is identical across the beam, and the intensity is uniform on the camera. M_1 can be translated, and then like the Michelson interferometer, the intensity varies $\max \rightarrow \min$ uniformly over the camera. If the mirror has aberration, then a fringe pattern appears on the camera that gives a signature of the aberration.

A very accurate measurement of the aberration is made by varying M_1 . At each point in the image there is an oscillation in intensity as M_1 moves. With aberration, there are variations in the phase from point to point. This can be determined very accurately. This technique is called *Phase-Shifting Interferometry* (PSI).

Thin film interference



thin film, thickness d, index n

The phase difference between the reflected rays can be shown to be

$$\boxed{\delta = \pi + \frac{4\pi n}{\lambda} d \cos\theta_P}$$

For $\boxed{\delta = 2m\pi}$, we get a bright fringe; for $\boxed{\delta = (2m+1)\pi}$, we get a dark fringe.

Variations in d, λ, n, or θ give rise to fringes.

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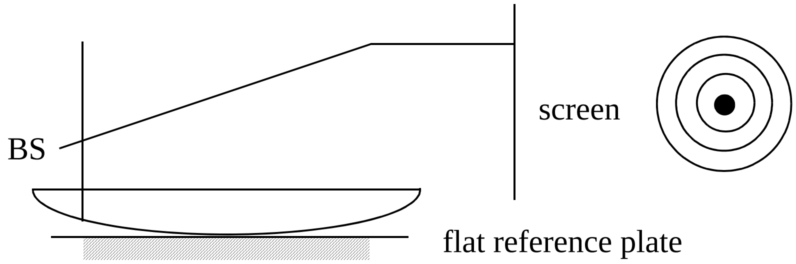
Newton rings

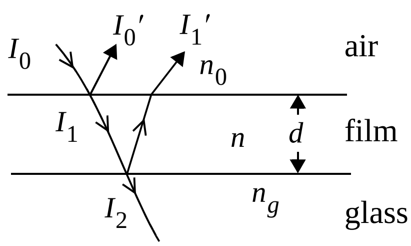


If the test surface is spherical, concentric ring fringes are observed. The reference surface must be well-known.

– Useful for testing flats. Quick test on spheres.

– Reference surface could also be spherical.

Anti-reflection (AR) coating



The Fresnel reflection coefficient at the top surface is

$$R_o = \left(\frac{n - n_0}{n + n_0}\right)^2 \qquad I_o' = R_o I_o$$

where the typical value for R_o is ~ 4%.

At the bottom surface:

$$R_g = \left(\frac{n_g - n}{n_g + n}\right)^2 \qquad I_1' \cong I_o R_g$$

I_1' and I_o' interfere *destructively* if

$$\boxed{\delta = \frac{4\pi nd}{\lambda} = (2m+1)\pi \qquad m = 0, 1, 2, \ldots}$$

or $nd = (2m+1)\dfrac{\lambda}{4} = \dfrac{\lambda}{4}, \dfrac{3\lambda}{4}, \dfrac{5\lambda}{4}, \ldots$

"quarter wave"

The *net* reflected intensity is zero if I_1' and I_o' are equal, but out of phase.

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So,
$$\frac{n - n_o}{n + n_o} = \frac{n_g - n}{n_g + n}$$

$$(n - n_o)(n_g + n) = (n_g - n)(n + n_o)$$

$$n^2 - n_o n_g - n_o n + n n_g = n_g n - n^2 - n n_o + n_o n_g$$

$$2n^2 = 2 n_o n_g$$

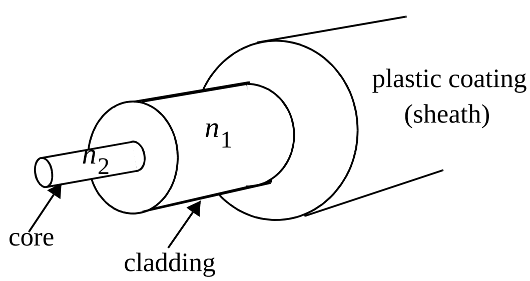
$$\boxed{n = \sqrt{n_o n_g}}$$

GUIDED WAVE OPTICS

[Reading Assignment, Hecht 5.6]

Optical fibers

The step index circular waveguide is the most common fiber design for optical communications



For guiding to occur, we will see that the necessary condition is that $\boxed{n_2 > n_1}$.

For communications, optical fibers offer extraordinary advantages over either free-space radio, or coaxial cable as a transmission medium:

1.low loss

2.no crosstalk between fibers

3.no electromagnetic interference

4.small, light, flexible

5.huge bandwidth

For analysis simplicity – we consider an infinite slab waveguide. This allows us to perform a simpler 2D analysis in Cartesian coordinates. However, this planar waveguide configuration is not just aca-

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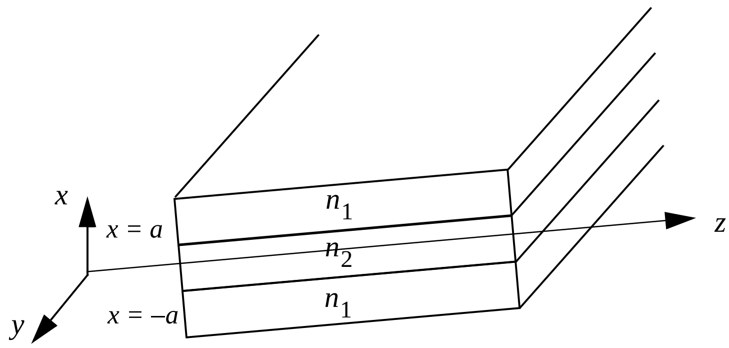
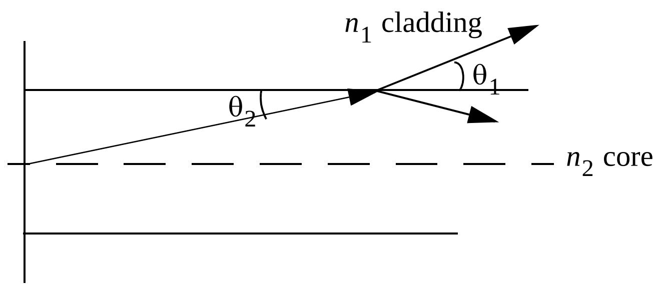
demic - this is the structure used in double-heterostructure laser diodes and other integrated optical devices.



Consider 2D analysis (infinite in y-direction)

<u>We first consider a ray optics analysis:</u>



By Snell's law

$$\boxed{\begin{aligned} n_2 \cos\theta_2 &= n_1 \cos\theta_1 \\ \cos\theta_1 &= \frac{n_2}{n_1}\cos\theta_2 \end{aligned}}$$

Note: not our usual definition of the angles

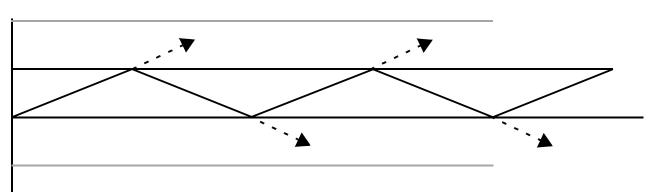
Note the use of the grazing angle (angle with respect to the surface) instead of the incidence angle (angle with respect to the normal). This leads to the cosine instead of the sine form of Snell's law.

If $n_2 > n_1$, then at the critical angle θ_c

$$\boxed{\frac{n_2}{n_1}\cos\theta_c = 1 \qquad \theta_1 = 0}.$$

For $\theta_2 < \theta_c$, there is no refracted ray due to total internal reflection.

The ray then reaches opposite interface at same θ_2, and is reflected again:



For $\theta_2 < \theta_c$, there is never a transmitted ray at the interface, so there is no loss.

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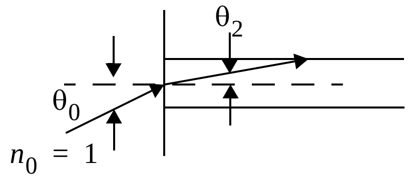
But for $\theta_2 > \theta_c$, light leaks out to the cladding, and there is rapid attenuation along z.

This shows us that the input rays should be at a small angle to be guided.

What about refraction at the input face?



Snell's law at the input face: $\boxed{\sin\theta_0 = n_2 \sin\theta_2}$

For guiding to occur, we then see that there is the following condition on the input angle:

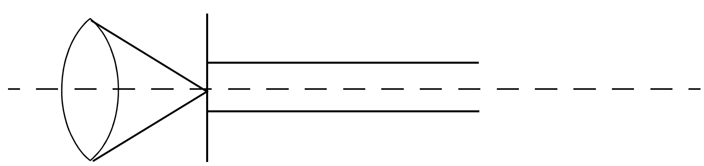
$$\begin{aligned}\sin\theta_0 &< n_2 \sin\theta_c \\ &< n_2(1 - \cos\theta_c^2)^{1/2} \\ \sin\theta_0 &< (n_2^2 - n_1^2)^{1/2}\end{aligned}$$

For optical fiber, we also use the concept of numerical aperture, $\mathrm{NA} = \sin\theta_{max}$. So the NA of the fiber is given simply by: $\boxed{\mathrm{NA} = (n_2^2 - n_1^2)^{1/2}}$.

Example: $n_2 = 1.5 \qquad n_1 = 1.4$

$$\mathrm{NA} = \sqrt{(1.5^2 - 1.4^2)} = 0.54$$

$$\theta_{max} = 32°$$



The usefulness of this definition is that we can see how large the lens NA should be to efficiently couple light into the fiber.

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