LECTURE 16 — GUIDING / DIRECTING LIGHT

(1)

OPTOELECTRONICS — electronics + optics

PHOTONICS — optics alone traditionally
now — optoelectronics, too.

ELECTRO-OPTIC — $n(\vec{E})$

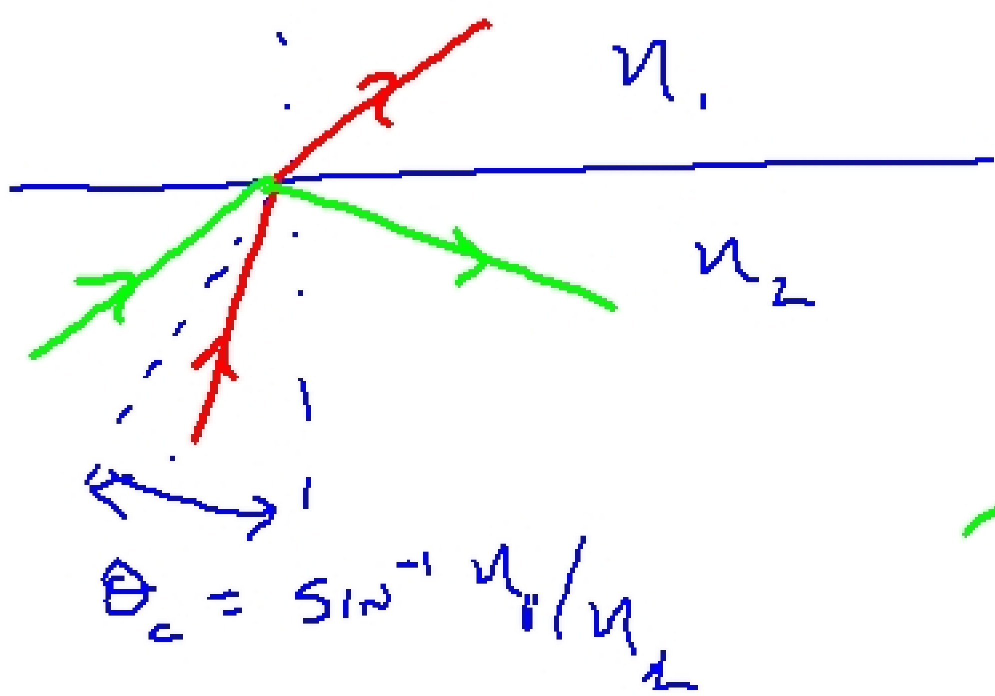
NEW COMPONENTS — had transistors, now

- ✓ WIRES for light
- ✓ SOURCES — LED's, LD's — electric in → optical out
- ✓ DETECTORS — optical in → electrical out
- ✓ MODULATORS

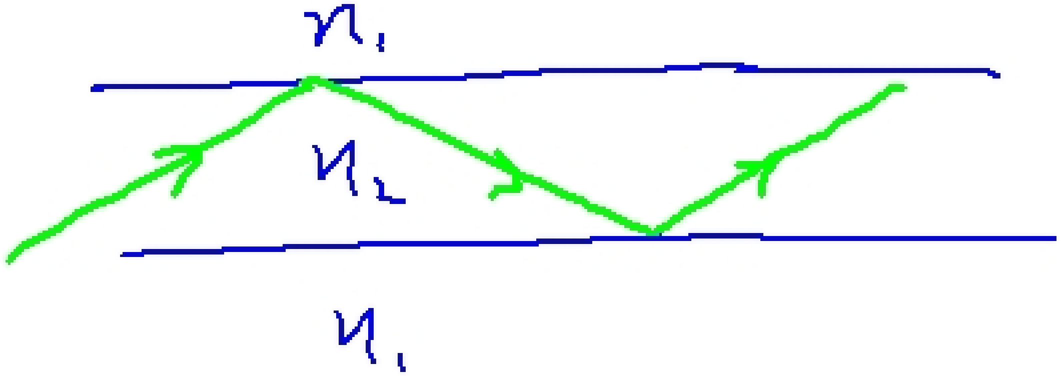
- ✓ INTEGRATION

Directing / Guiding Light

- ✓ Free space optics
  lenses, mirrors, holographic elements
- ✓ Dielectric waveguides
  ⟹ based on total internal reflection

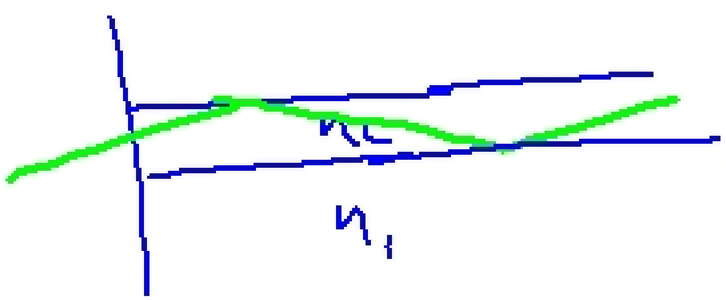


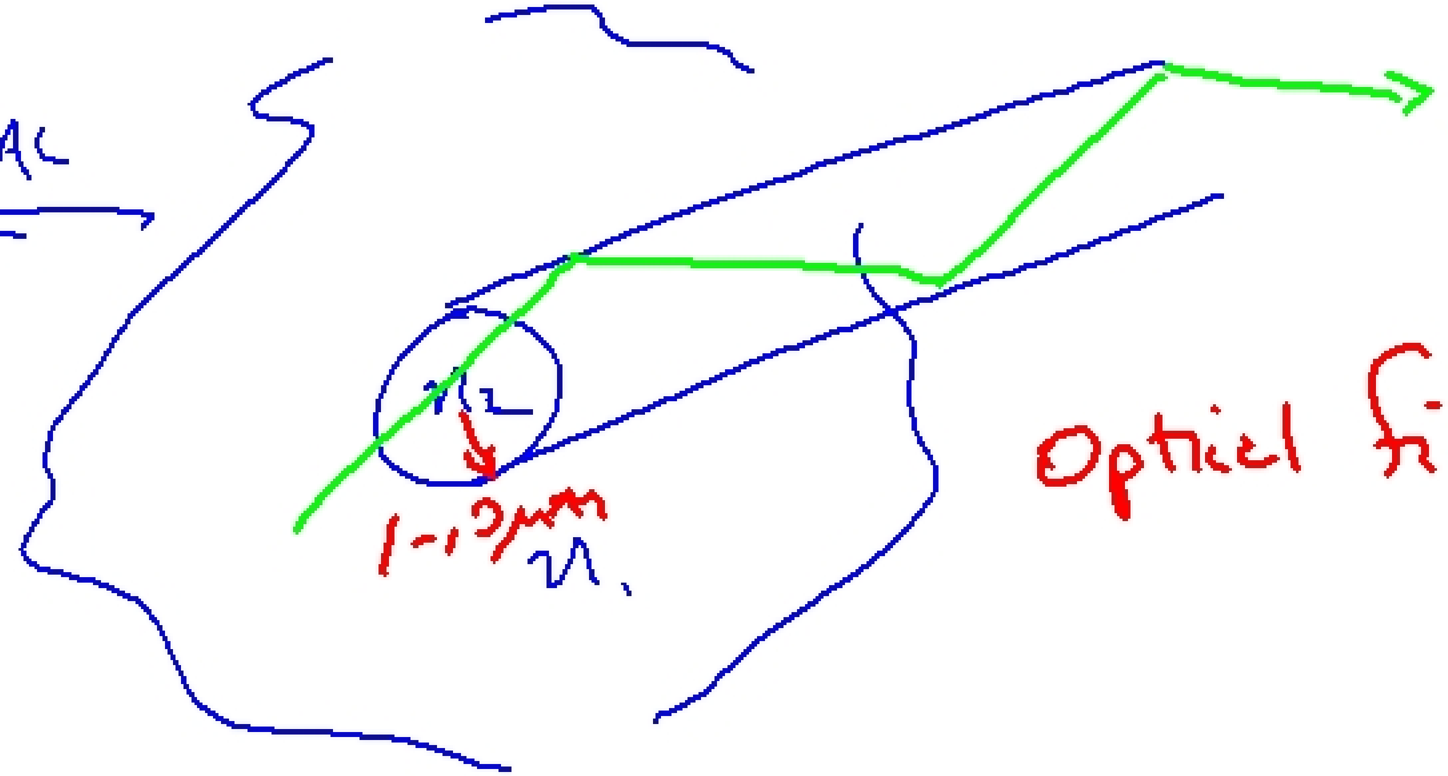
$n_1 > n_2$



Two geometries

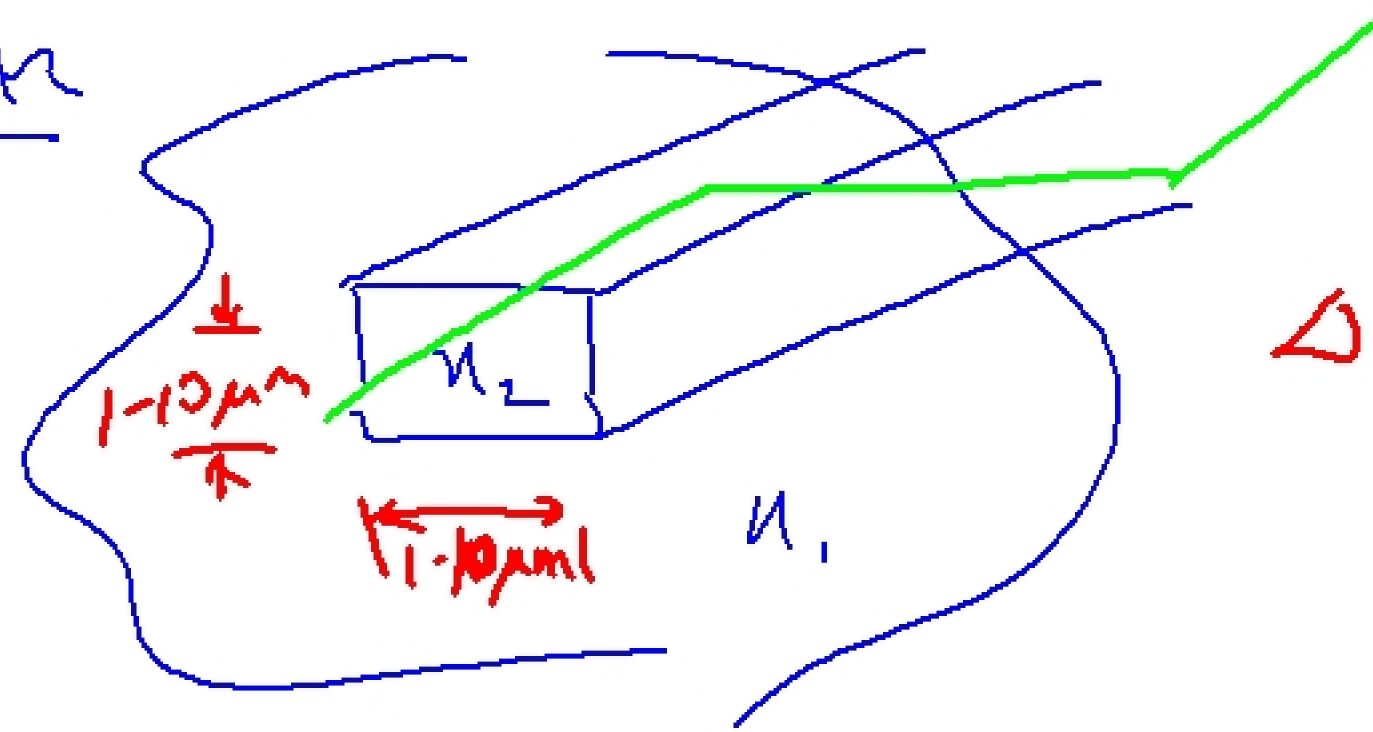
Cylindrical





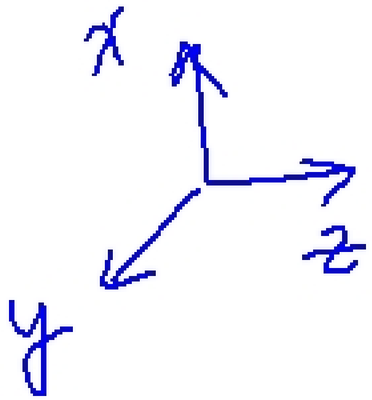
Optical fiber

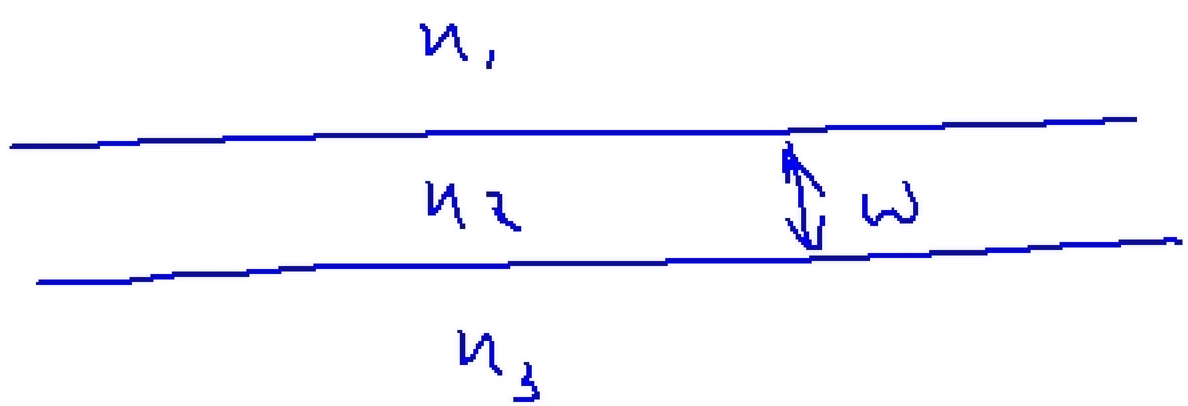
Rectangular



$\Delta n = n_2 - n_1$

SLAB WAVEGUIDE





only $n(x)$

TE wave traveling in z-direction

$E_y(x, z, t)$ $\qquad H_y = H_x$

SATISFIES

$$\frac{\partial^2 E_y}{\partial x^2} + \frac{\partial^2 E_y}{\partial z^2} = \mu_0 \epsilon_i \frac{\partial^2 E_y}{\partial t^2}$$

We can write $E_y = X(x)\, Z(z)\, T(t)$

$$T(t) = \mathrm{Re}\left[A e^{-j\omega t}\right] \qquad \omega \text{ is "known"}$$

$$Z(z) = \mathrm{Re}\left[e^{j\beta_n z}\right]$$

Leaving

$$\frac{d^2 X_n(x)}{dx^2} - \left(\beta_n^2 - \mu_o \epsilon_i \omega^2\right) X_n(x) = 0$$

↑ region index (1, 2, 3)

n = mode index

$$\mu_o \epsilon_i = \mu_o \epsilon_o \epsilon_{ri} \quad \text{where} \quad \epsilon_{ri} = n_i^2$$

$$\mu_o \epsilon_i \omega^2 = \mu_o \epsilon_o n_i^2 \omega^2$$

$$k_o^2 = \left(\frac{2\pi}{\lambda_o}\right)^2 = \frac{\omega_o^2}{c^2}$$

$$\frac{d^2 X_m(x)}{dx^2} - (\beta_m - n_i^2 k_o^2) X_m(x) = 0$$

$\hookrightarrow k_o = 2\pi/\lambda_o$

$X_m(x)$: Decaying exponentials if

$$\beta_m > n_i^2 k_o^2$$

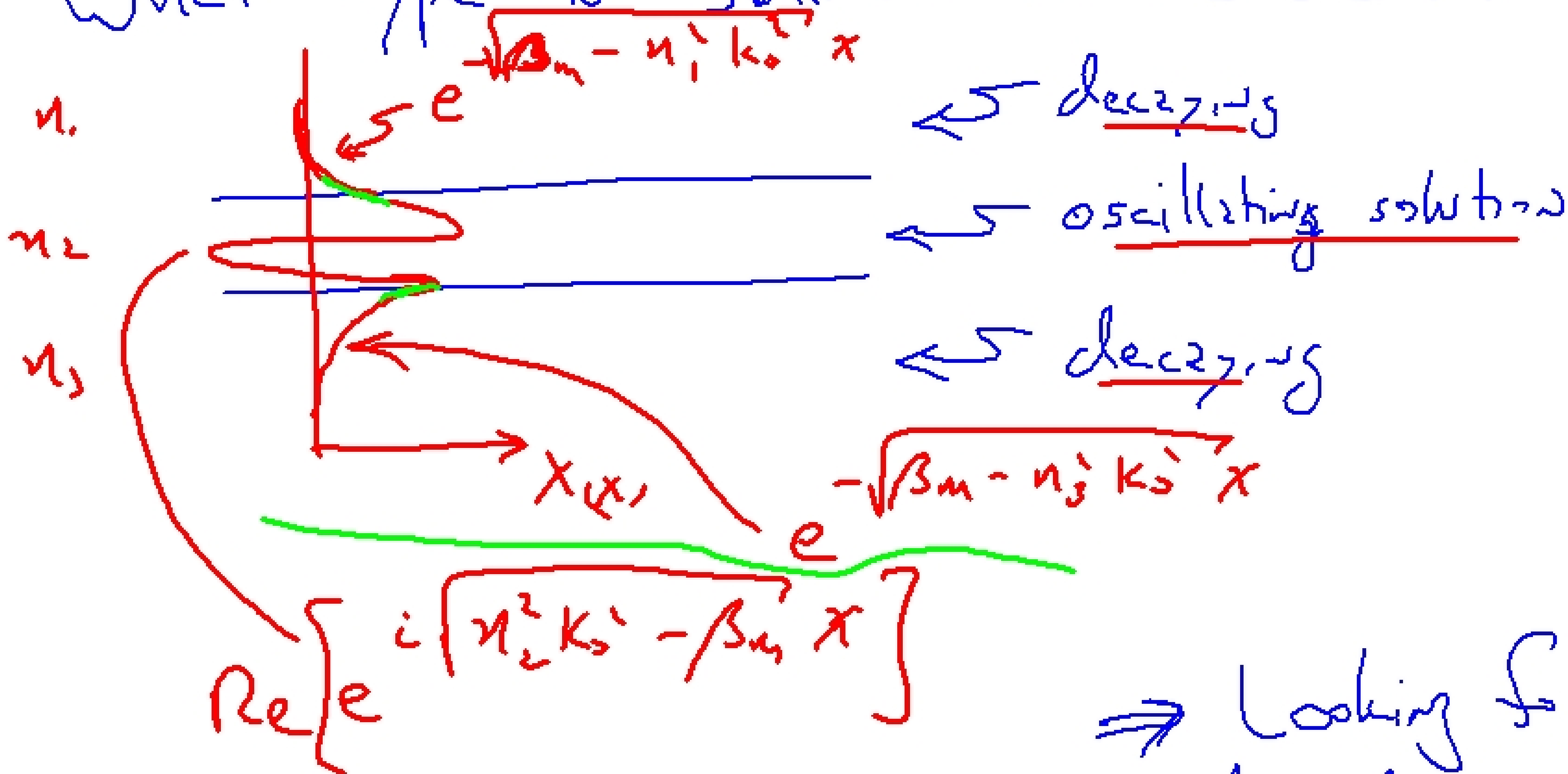
: Oscillating function if

$$\beta_m < n_i^2 k_o^2$$

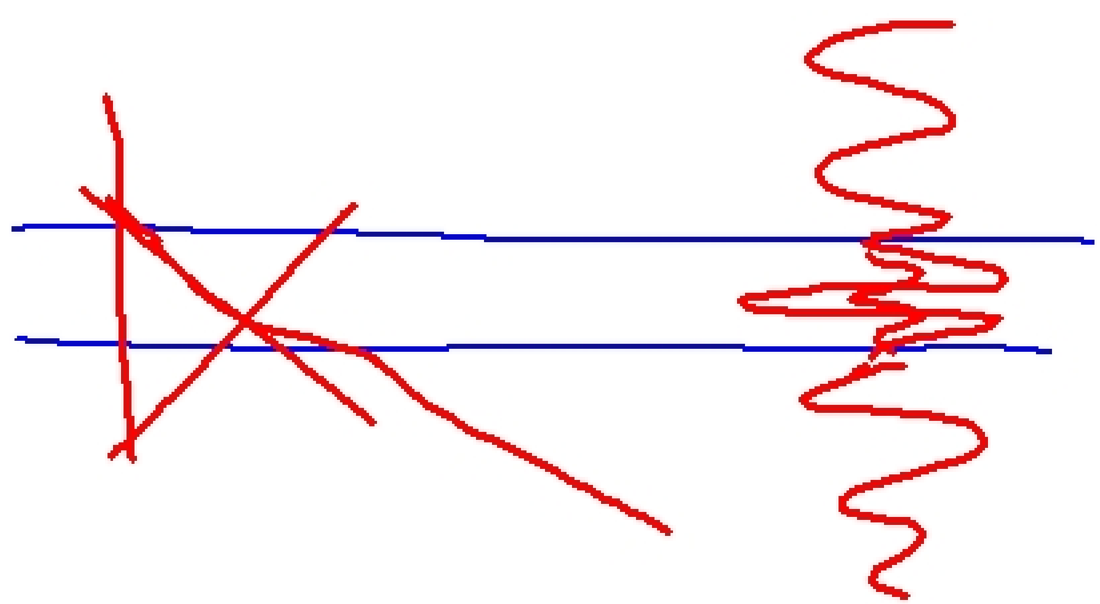
Recall: $Z(z) = Re[e^{+j\beta_m z}]$

$T(t) = Re[Ae^{-j\omega t}]$

What type of solution do we want?



⇒ Looking for the β_m's that make this work.



β_m

$$Z(z)\,T(t) = \mathrm{Re}\left[A e^{i[\beta_m z - i\omega t]}\right]$$

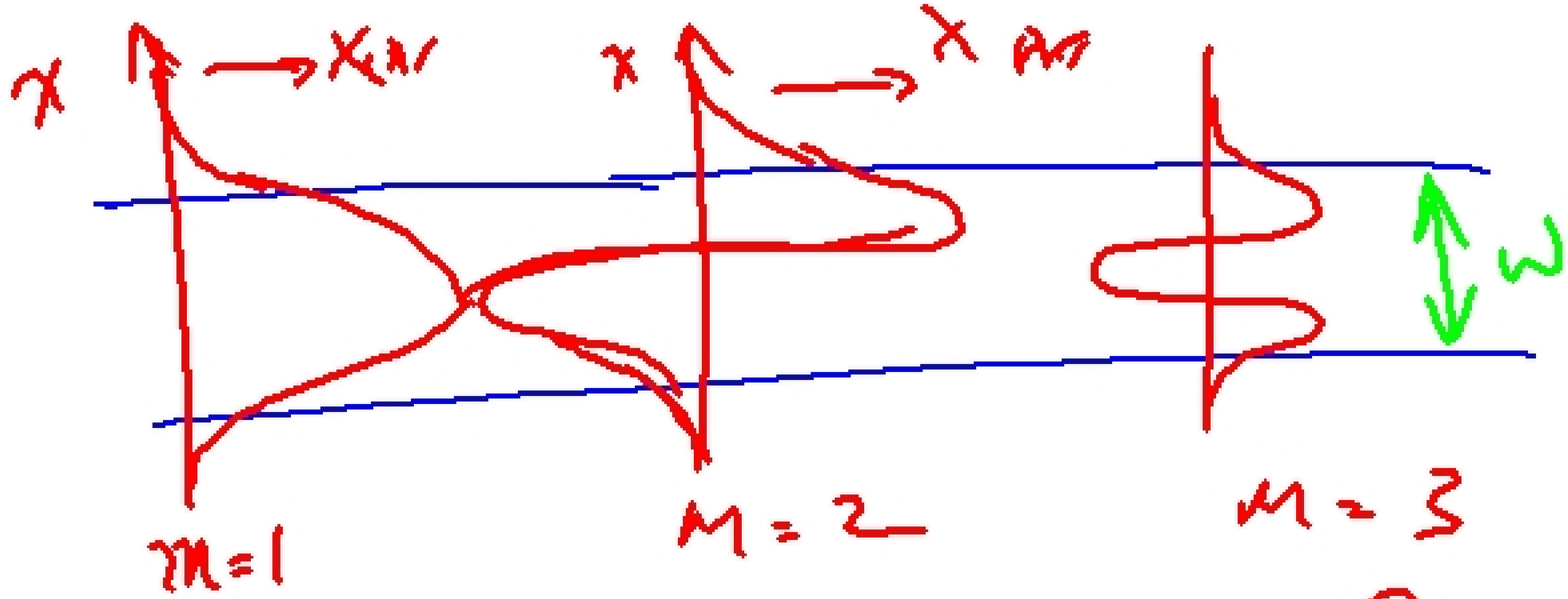
$$s_i = \frac{c}{n_i}$$

$$n_{eff,m} = \frac{\beta_m}{k_0^2}$$

$n_{eff,m}$

Single mode guide $\Rightarrow$ only one β_1

$\Rightarrow$ only one n_{eff} $\Rightarrow$ all light travels at same velocity down guide



mode # = # of oscillations in guide

General observations

As $\omega \uparrow$, # of modes $\uparrow$

$\omega \downarrow$, # of modes $\downarrow$

As $\Delta n \uparrow$, # of modes $\uparrow$

$\Delta n \downarrow$, # of modes $\downarrow$

∴ to get single mode

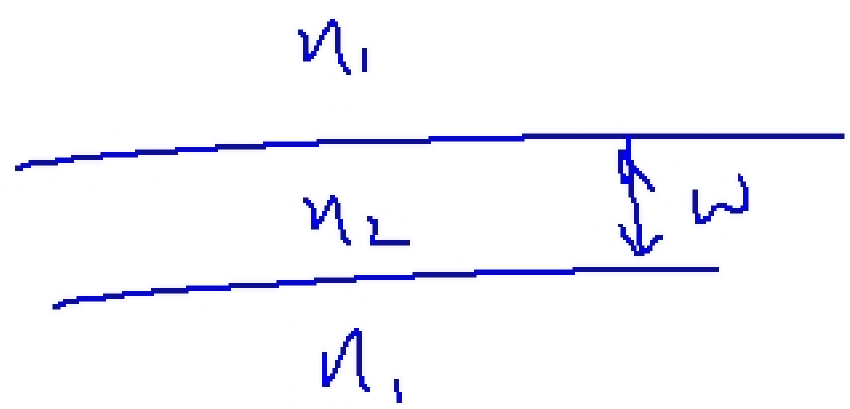
$\Rightarrow$ narrow guides and/or small Δn

but narrow guides are harder to make & harder to get light into,

and guides with small Δn are not guiding the light strongly

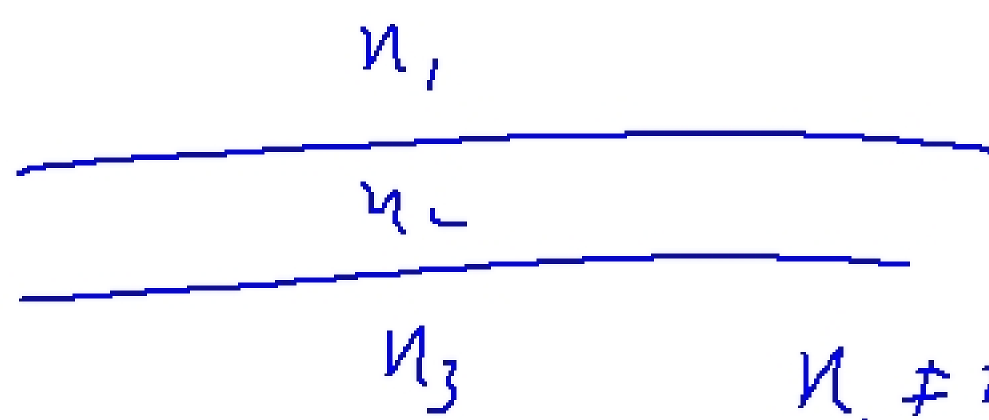
[i.e. are "weakly" guiding]

Symmetrical guide

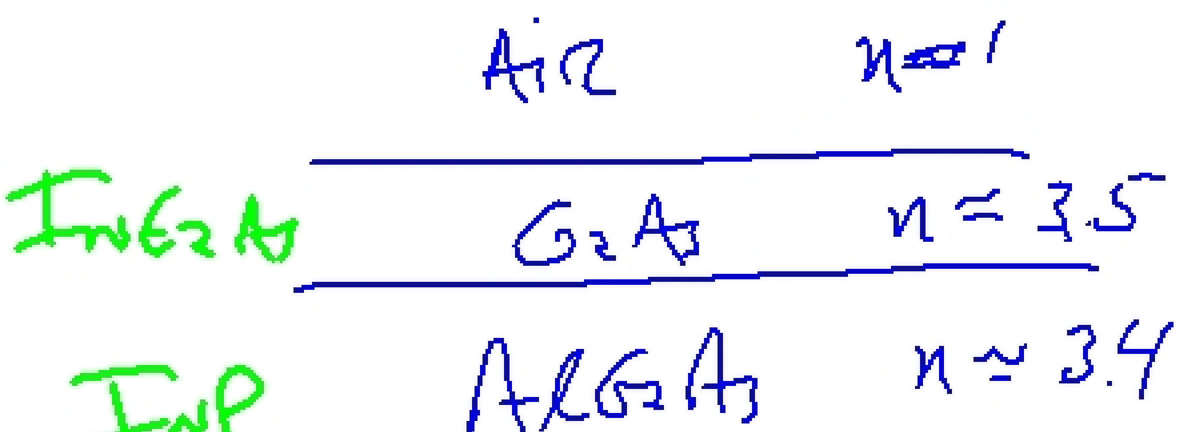


find min W for guiding

Asymmetrical guides



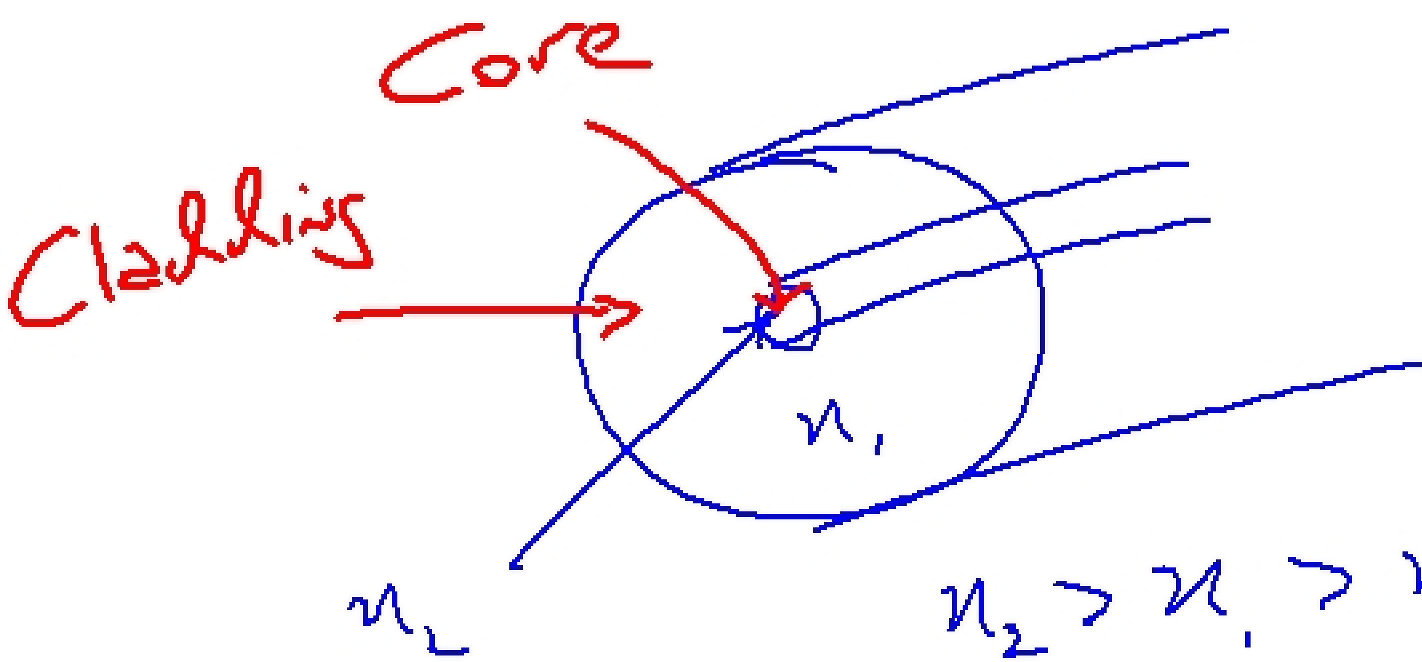
$n_1 \neq n_3$



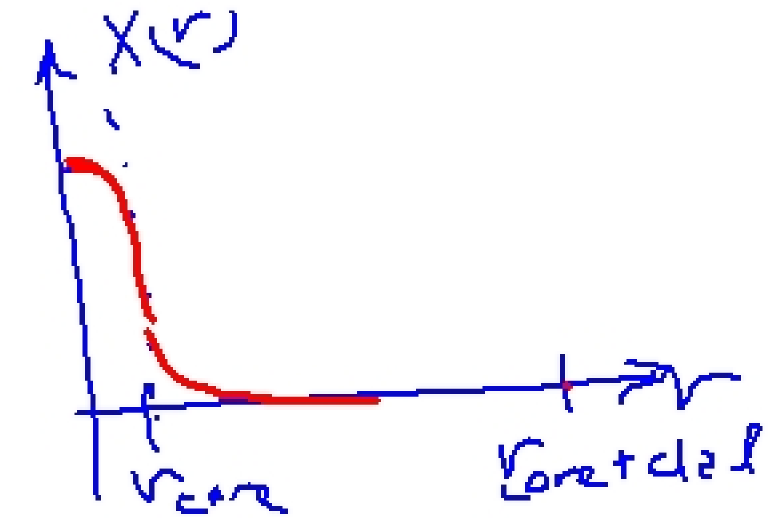
→ here there is a minimum W

TWO-DIMENSIONAL CONFINEMENT

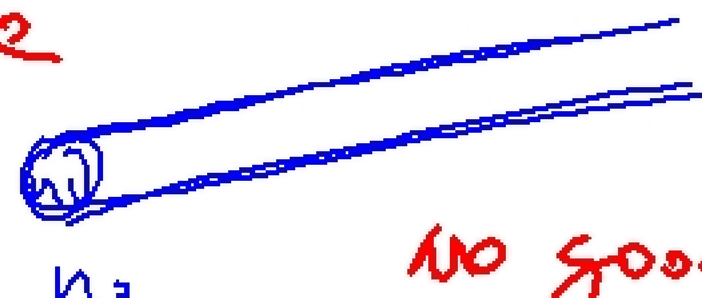
1. CYLINDER [fiber]



$n_2 > n_1 > n_0$



Bare core



no good
unprotected
(Δn very large too)

Rectangular guides

n_1	n_2	n_3
n_4	n_5	n_6
n_7	n_8	n_9

$n_5 > n_{1,2,3,4,6,7,8,9}$

often

$n_1 = n_3$

$n_7 = n_9$

$n_4 = n_6$

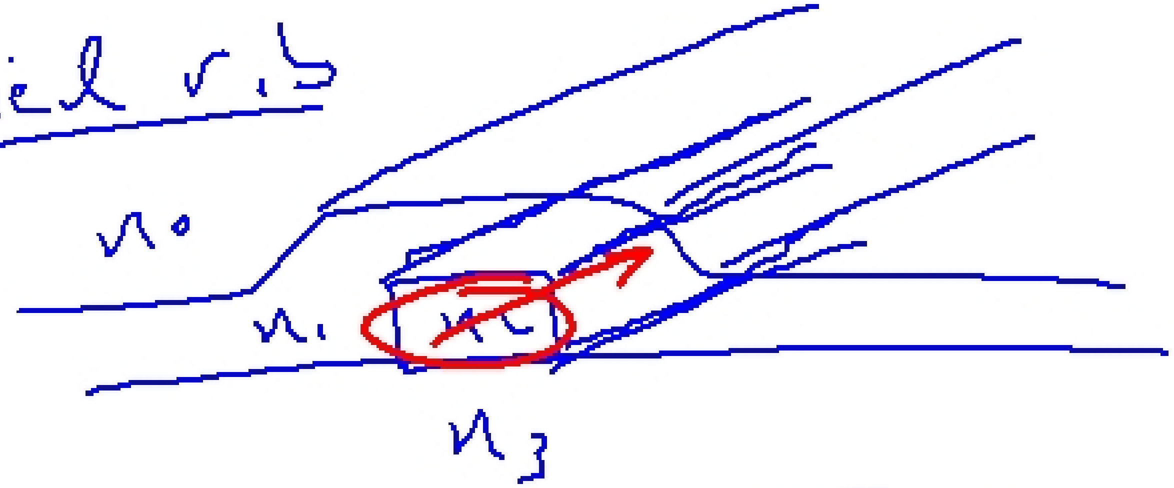
n_1	n_2	n_1
n_7	n_4	n_3
n_5	n_6	n_5

Examples

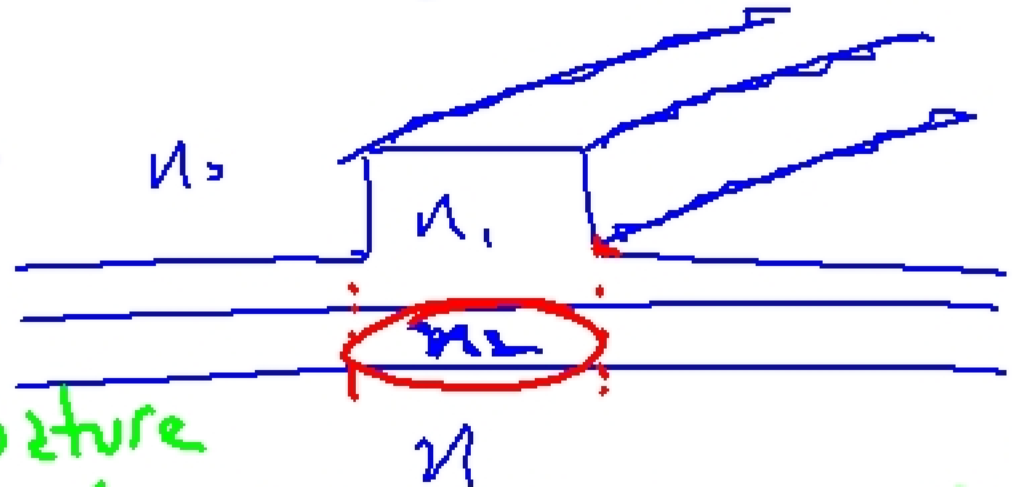
① 

Rib guide

(2) Buried rib



(3) Ridge



GaAlAs	InP
GaAs	InGaAsP
GaAlAs	InP

⇒ induced nature of guiding reduces sensitivity to edge roughness

(4) ION IMPLANTED / DIFFUSED