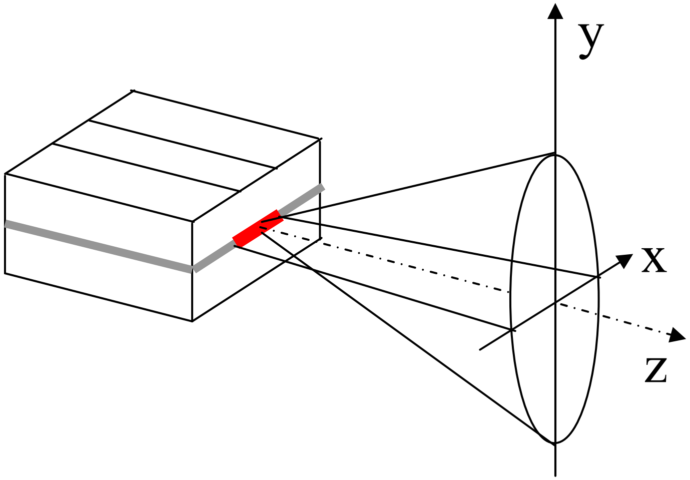
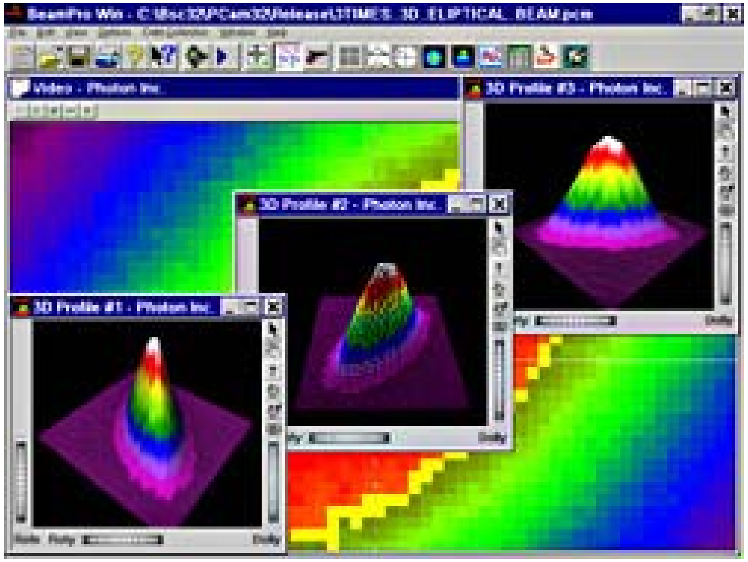
Diode laser emission



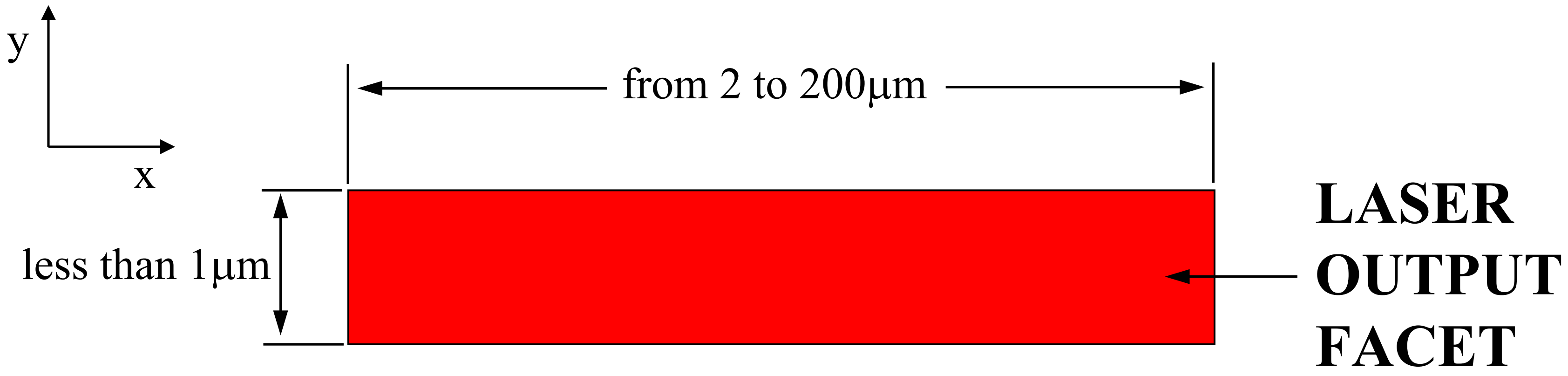


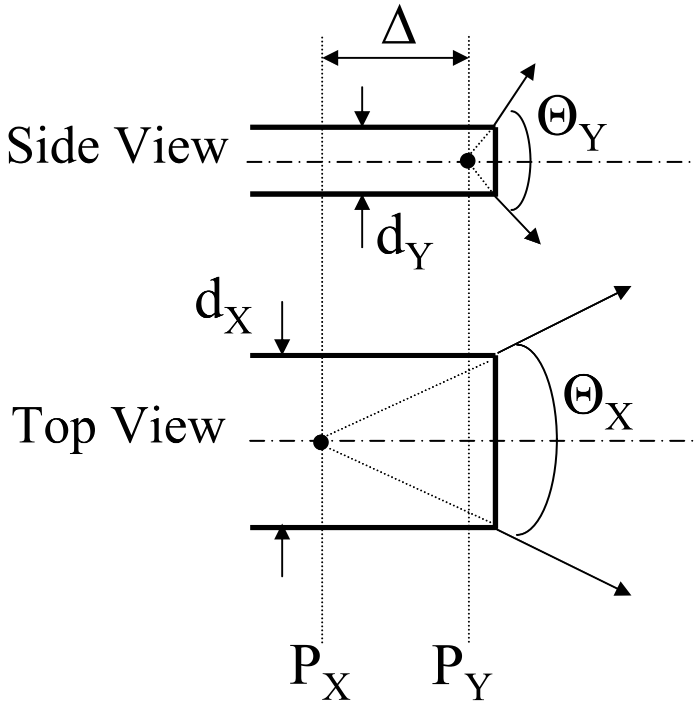
Diode laser emission has elliptical cross-section.

Y-axis with large divergence angle is called fast axis

X-axis with smaller divergence angle is called slow axis

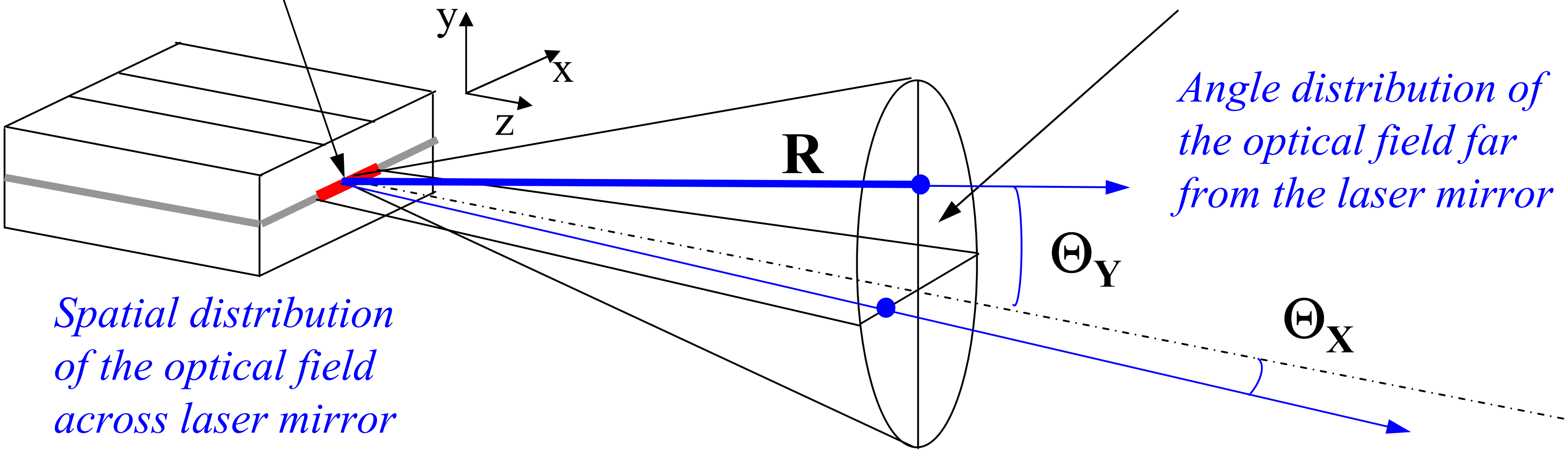
Laser emission: beam divergence and astigmatism





Beam emitted from a small facet is equivalent to the beam emitted by an imaginary point source P. When d_X is larger than d_Y the distance between P_X and P_Y can be nonzero. This phenomenon is called astigmatism, and the distance Δ between P_X and P_Y is the numerical description of astigmatism.

Laser emission: far and near field emission patterns



Field emitted from the laser
NEAR FIELD - $E(x,y)$

At distances larger than d_i^2/λ

FAR FIELD – $E_F(\Theta_X,\Theta_Y)$

Angle distribution of the optical field far from the laser mirror

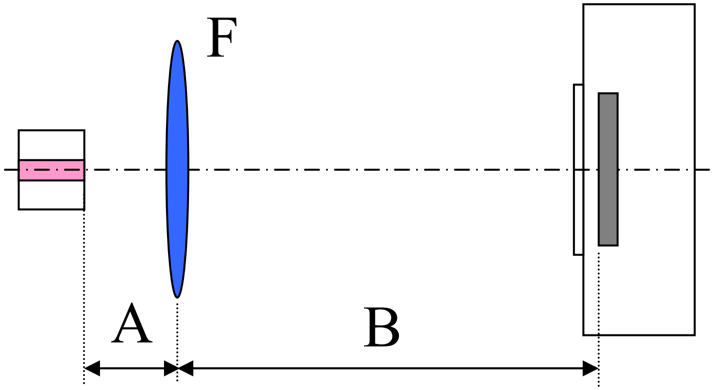
Spatial distribution of the optical field across laser mirror

In paraxial approximation (small angles) and for $\Theta_X=0$, at R from facet

$$\left|E_F(0,\Theta_Y)\right|^2 = \frac{\cos^2(\Theta_Y)}{\lambda_0^2\cdot R^2}\cdot\left|\int_{-\infty}^{\infty} E(0,y)\cdot\exp(j\cdot k_0\cdot y\cdot\sin(\Theta_Y))dy\right|^2$$

Measurements of the laser near field

General approach is to amplify image of the laser output facet and project it on video camera.



$$\frac{1}{A}+\frac{1}{B}=\frac{1}{F}$$

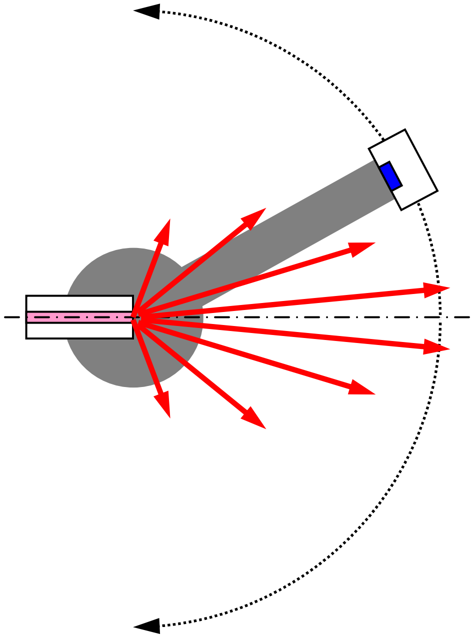
$$M = {}^{B}\!/_{A}$$

Magnification of 10-100 times or more is required for well resolved image

** Near field microscopy is another option: fiber tip is scanned with submicron resolution along laser output facet. This technique is accurate and free from aberrations that could be introduced by imaging optics.*

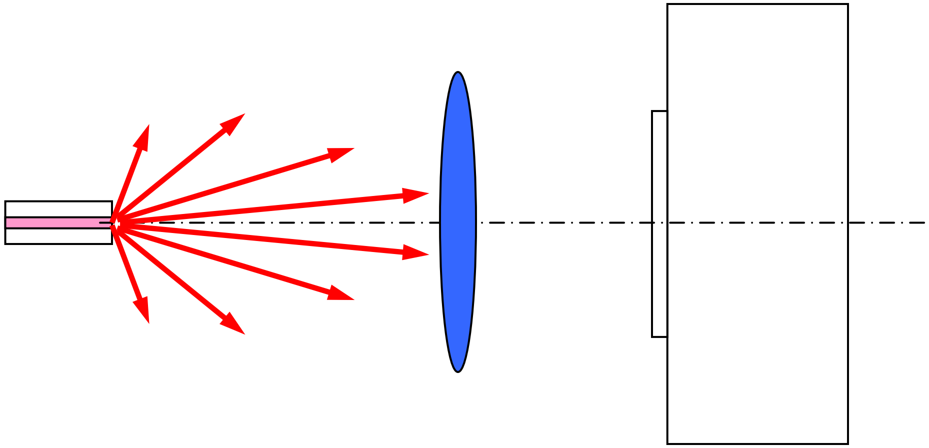
Measurements of the laser far field

Scanning of the single detector



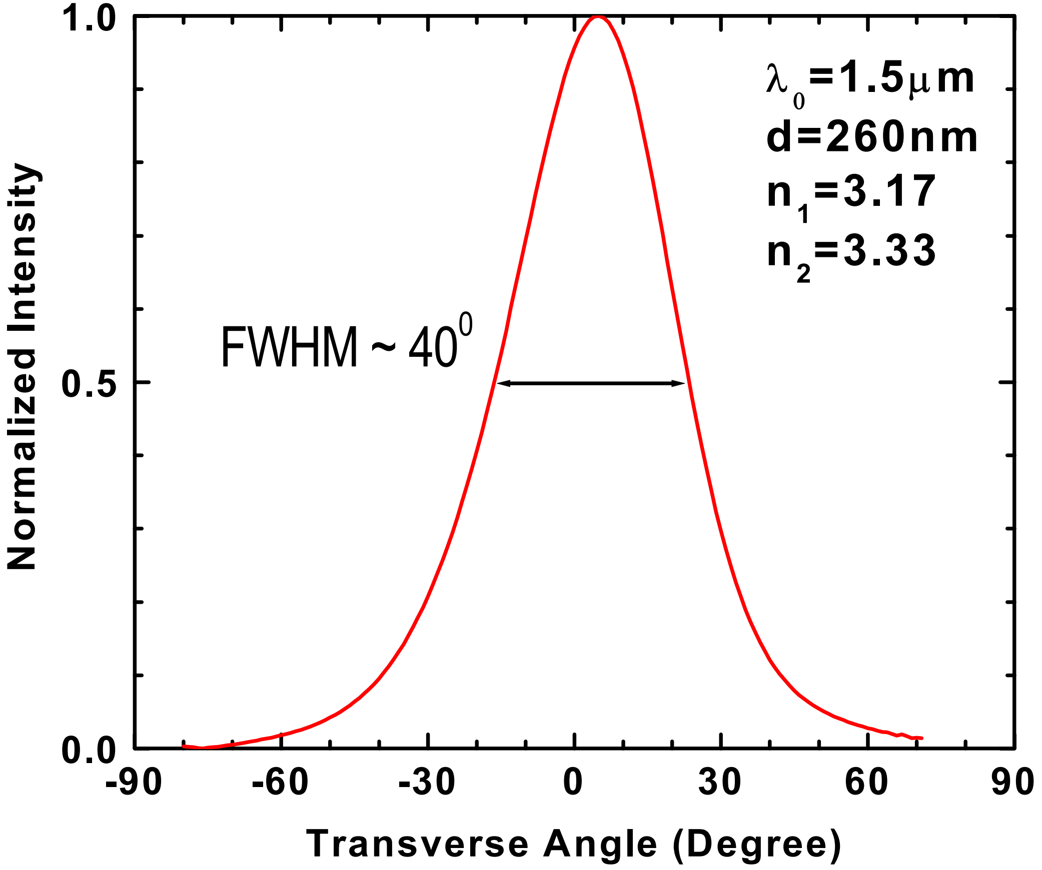
High resolution
true far field for all angles
Slow and only one dimension at a time

Detector array (CCD) or Vidicon camera



Fast image of the 2D far field pattern
Easy alignment and adjustment
Special optics required due to limited size of the photosensitive matrix

Typical diode laser transverse (Y) far field pattern

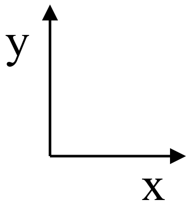


Approximate expression for full angle at half intensity for small d

$$\Theta_{\perp}(\mathrm{rad}) \approx 4 \cdot \left(n_2^2 - n_1^2\right) \cdot \frac{d}{\lambda_0}$$

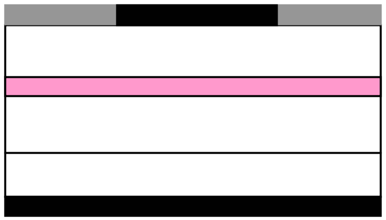
Single mode operation (diffraction limited beam)

Beam divergence is current independent



Lateral optical confinement (X-direction)

Gain-guided



Oxide-Stripe

Current Confinement

Gain modifies Imε

I(x) leads to Imε(x)

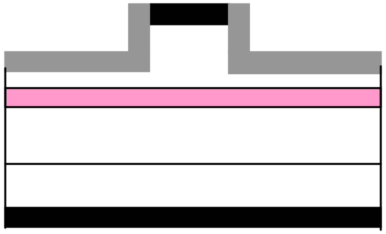
Multimode

Im index step ~ 0.001

**Dependent on pumping level*

**Antiguiding*

Weakly Index-guided



Ridge

Current Confinement

Optical Confinement

Reε(x) & Imε(x)

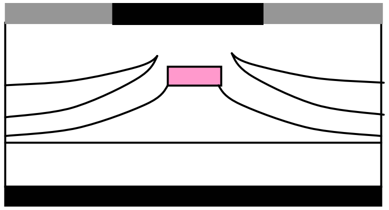
Single mode

Refractive index step < 0.01

**Antiguiding*

**Expensive*

Strongly Index-guided



CMBH

Current Confinement

Optical Confinement

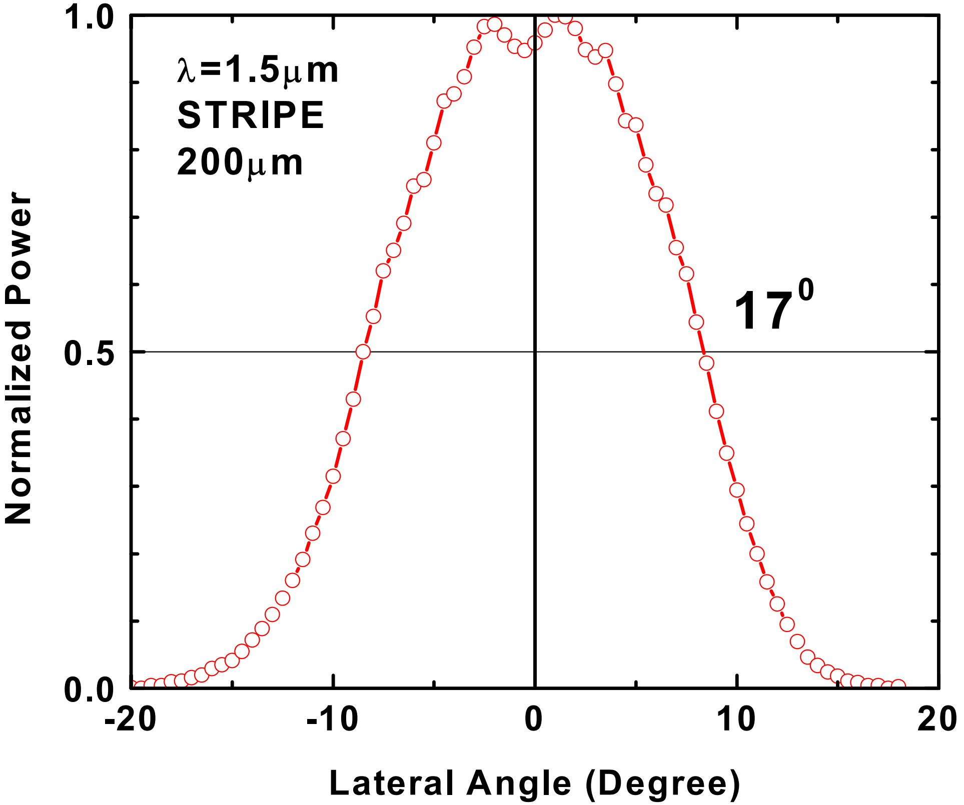
Reε(x)

Stable single mode

Refractive index step >0.1

**Very expensive*

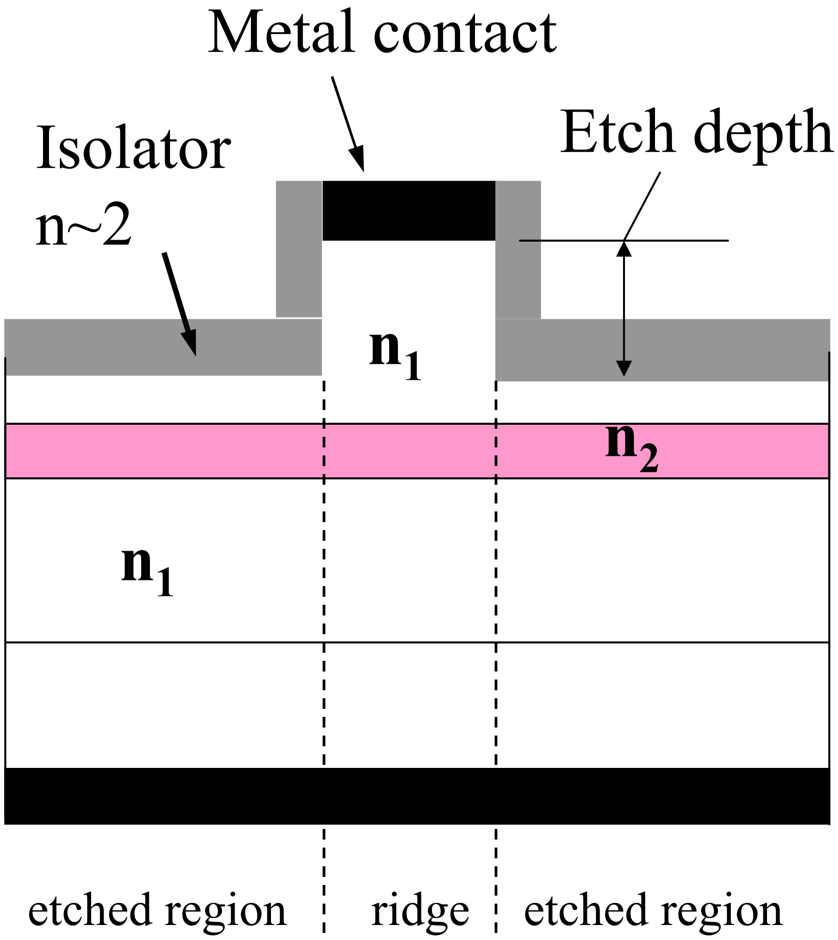
Lateral (X) far field pattern of wide stripe (200µm) gain guided laser



Multimode operation

Beam divergence is current dependent and orders of magnitude higher than diffraction limited

Ridge waveguide lasers and effective index technique



1. Find transverse effective indexes in ridge and etched sections, n_{ridge} and n_{etched}

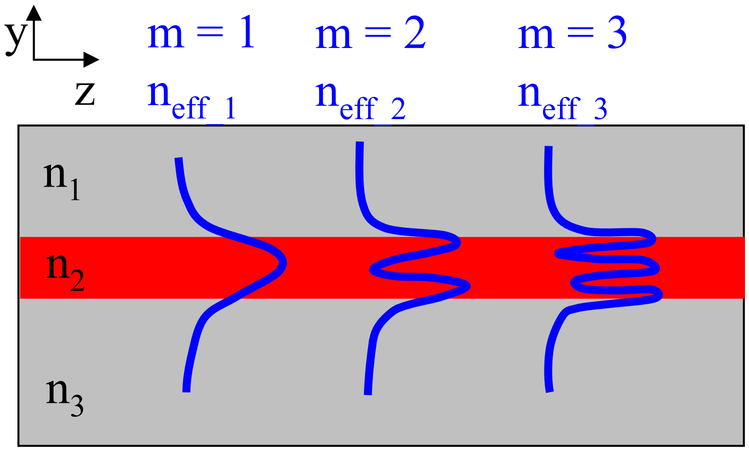
2. Use n_{ridge} and n_{etched} to find lateral field distribution with effective index $n_{lateral}$

3. Use n_{ridge} for transverse near/far field calculations and $n_{lateral}$ for lateral near/far field calculations.

*Current spreading and gain guiding are usually important and should be taken into account.

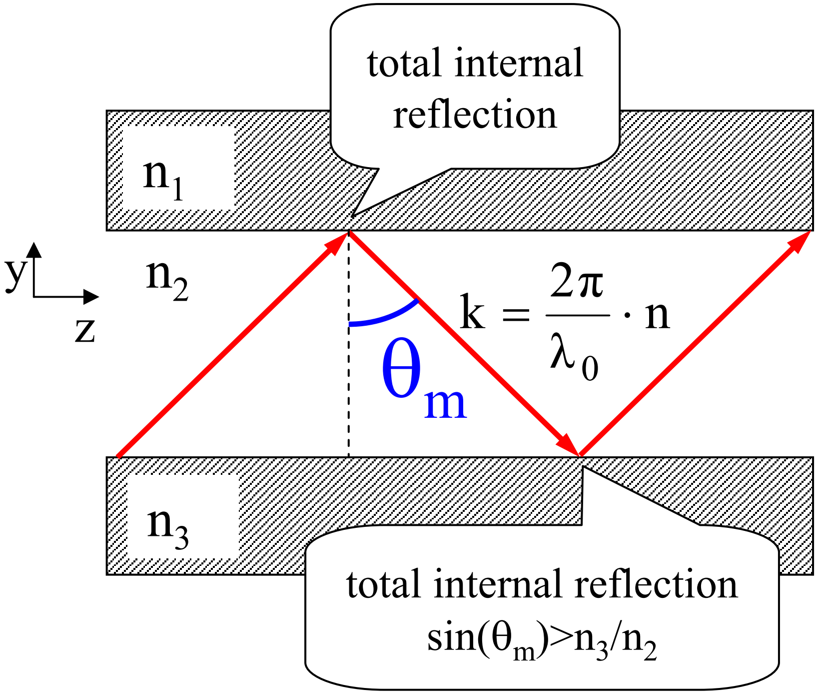
* For CMBH devices lateral and transverse waveguide dimensions are comparable and exact 2D waveguide problem should be solved numerically.

The effective refractive index



In y-direction the standing wave is formed. Optical field is not fully confined in region with refractive index n_2 but has an exponentially decaying tails within regions n_1 and n_3. Effective refractive index can be understood as the weighted average between n_1, n_2 and n_3 if optical field exists in all these regions.

ZigZag waves model can be applied and θ_m can be assigned to each mode



$$k_{z\_m} = k \cdot \sin(\theta_m) = \frac{2\pi}{\lambda_0} \cdot n \cdot \sin(\theta_m) = \frac{2\pi}{\lambda_0} \cdot n_{eff\_m}$$

$$k_{y\_m} = k \cdot \cos(\theta_m) = \frac{2\pi}{\lambda_0} \cdot n \cdot \cos(\theta_m) =$$

$$= \frac{2\pi}{\lambda_0} \cdot n \cdot \sqrt{1 - \sin^2(\theta_m)} = \frac{2\pi}{\lambda_0} \cdot \sqrt{n^2 - n_{eff\_m}^2}$$

Mode effective refractive index determines shape and group velocity for a given mode