PH 201

OPTICS & LASERS

Lecture_Lasers_15

Ref.: K. Thyagarajan & A. K. Ghatak, *LASERS; Theory & Applications*, Macmillan India Ltd. (2008)

Laser Applications

- Scientific applications
- Military applications
- Medical applications
- Industrial applications
- Commercial applications
- Communication applications

Scientific Applications

- Interferometric techniques
- Spatial frequency filtering
- Spectroscopy & Raman spectroscopy
- Atmospheric remote sensing
- Investigating nonlinear optics phenomena
- Holography
- Laser-based light detection & ranging (LIDAR)
- Adaptive optics - telescopes
- Material processing
- Photochemistry
- Laser cooling (atom trapping)
- Nuclear fusion
- Microscopy

Military Applications

- **Target Designator & Range Finder**
- **Defensive IR Countermeasures**
  Systems use lasers to confuse the seeker heads on heat-seeking anti-aircraft missiles.
- **Communications**
- **High Power Lasers (e.g., 100 KW) to destroy cruise missiles, artillery, rockets**
- **STARWARS**
  - **Ground-based or space-based laser systems can destroy incoming intercontinental ballistic missiles.**
- **Laser Dazzlers**
  - **This unit illuminates an opponent with harmless low-power laser light & can have effect of dazzling or disorienting the subject or causing him to flee.**

Laser Target Designator

Revolver equipped with a Laser Sight mounted on the trigger guard

Medical Applications

- ❖ **Cosmetic surgery: removing Tattoos, Scars, Stretch marks, Sunspots, Wrinkles, Birthmarks, Hairs (laser hair removal).**

Lasers in Dermatology: **Ruby (694 *nm*), pulsed diode array (810 *nm*), Nd:YAG (1064 *nm*), Ho:YAG (2090 *nm*), Er:YAG (2940 *nm*).**

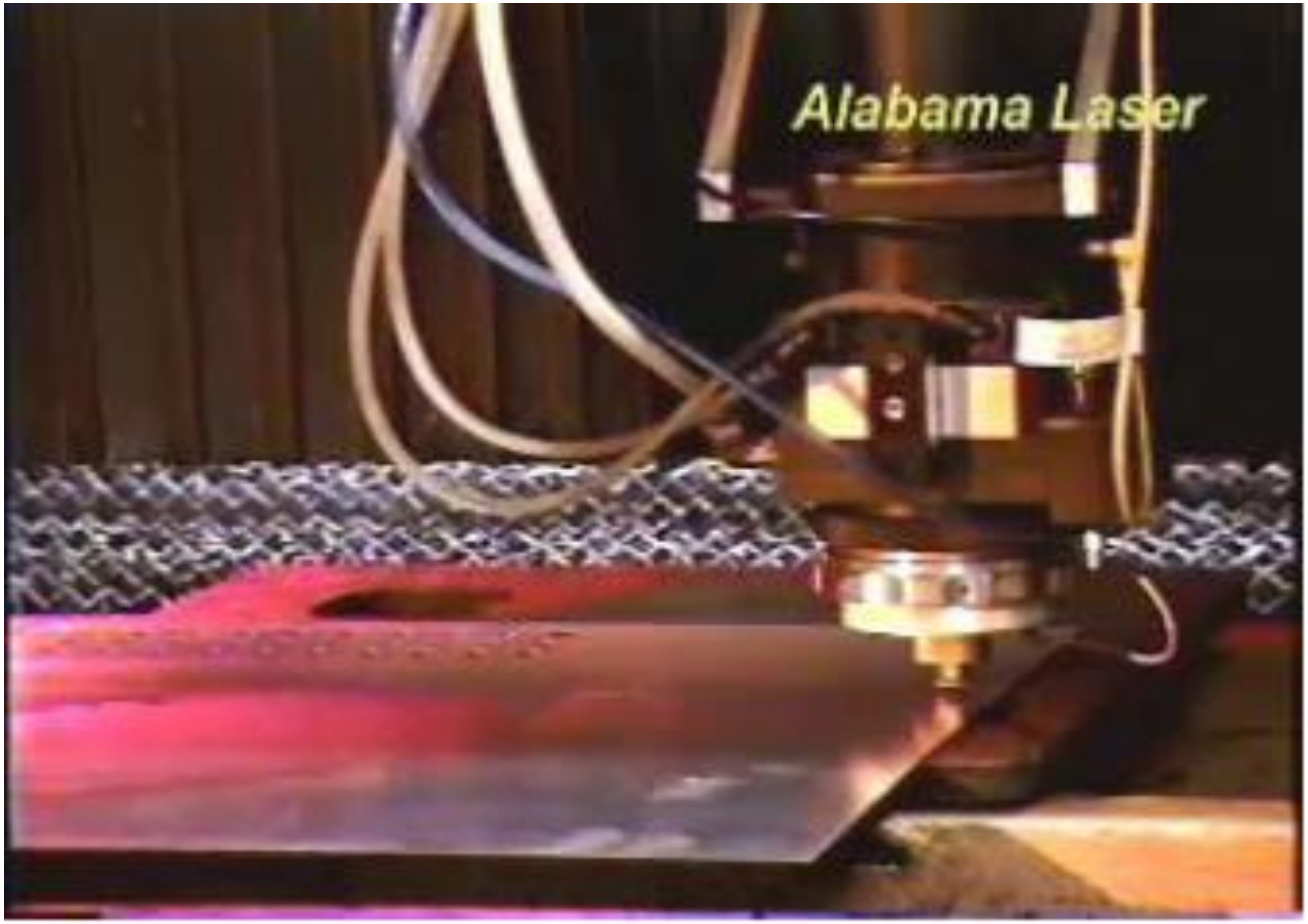
- ❖ **Eye surgery & Refractive surgery**
- ❖ **Soft tissue surgery: CO_2, Er:YAG laser**
- ❖ **Laser scalpel: general surgery, gynecological, urology, laparoscopic**
- ❖ **Photobiomodulation: Laser therapy**
- ❖ **“No-touch” removal of tumors, especially of brain & spinal cord**
- ❖ **Dentistry: Tooth whitening, oral surgery**

Laser Therapy: Application of electromagnetic wave 600-1100 *nm* over injuries or lesions to improve wound / soft tissue healing & give relief for both acute & chronic pain.

Industrial & Commercial Applications

- Cutting & peening of metals & other materials, welding, marking
- Guidance systems (e.g., Ring Laser Gyroscopes)
- Range finder/surveying
- LIDAR/pollution monitoring
- Barcode readers, laser pointers, laser printers, laser scanners, CD readers/writers
- Laser bonding of additive marking materials for decoration & identification
- Photolithography
- Optical tweezers

Leveling of ceramic tiles floor with a laser device.



Metal cutting

Laser light show: lasers used for visual effects during a musical performance.

Lightwave Communications

Radio waves : ~ 10^6 Hz

Microwaves : ~ 10^9 Hz

Optical waves : ~ 10^{15} Hz

Since optical frequencies are extremely large as compared to radio waves & microwaves, a light beam acting as a carrier wave is capable of carrying far more information.

Soon after the discovery of laser, experiments on propagation of information carrying lightwaves through open atmosphere were carried out, but it was realized that because of vagaries of terrestrial atmosphere – e.g., rain, fog, etc. – in order to have an efficient & dependable communication system, one would require a guiding medium in which information carrying lightwaves could be transmitted.

initially, attempts were made to send light beams through conduits, which could be evacuated & fitted with lenses & mirrors at periodic distances for beam guidance, or could be filled with a gas in which a temp gradient could be set-up.

Glass fibers – total internal reflection

If an input power P_1 results in an output power P_2, then loss in decibels (dB) is given by

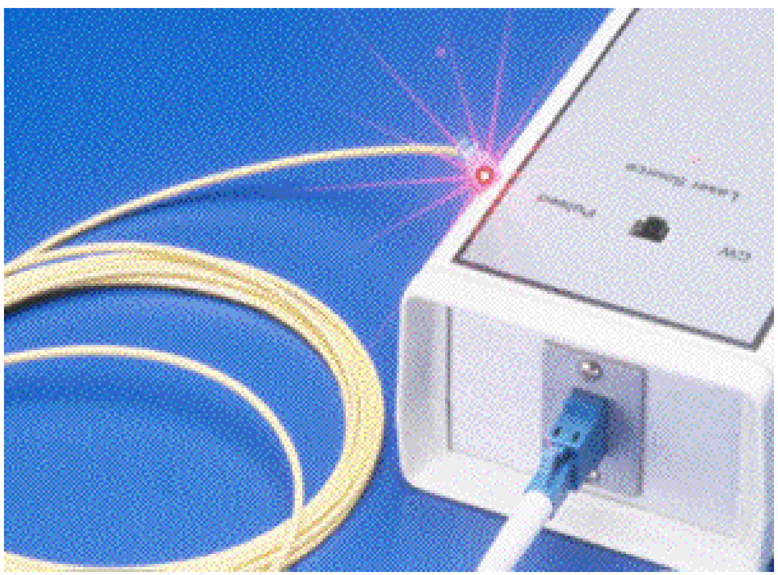
$$10 \log_{10}\left(\frac{P_1}{P_2}\right)$$

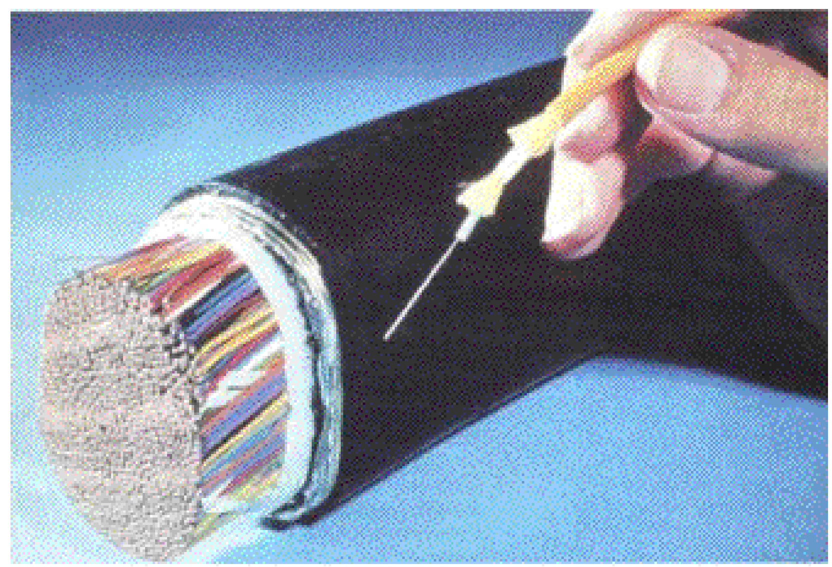
If output power is only half of input power, then loss is 10log2 = 3 dB.

A loss of 30 dB corresponds to an output power to input power ratio of 1/1000. Thus, a loss of 1000 dB/km amounts to the fact that when light beam travels through a kilometer length of fiber, only a negligibel amount reaches output end.

What is Fiber Optics?

- Transmitting communication signals over hair thin strands of glass or plastic.
- Not a "new" technology but concept has been a century old.
- 1st installation for telephone signals in Chicago in 1976.





What is Fiber Optics?

- An optical fiber is essentially a waveguide for light.
- It consists of a core & cladding that surrounds core.
- Index of refraction of cladding is less than that of core, causing rays of light leaving core to be refracted back into core.
- A light-emitting diode (LED) or laser diode (LD) is used as a source.
- Advantages of optical fiber include:
  - Greater bandwidth than copper
  - Lower loss
  - Immunity to crosstalk
  - No electrical hazard

Fiber Optic Communications

Applications include:

- **Telephones**
- **Internet**
- **LANs – local area networks**
- **CATV – for video, voice, & internet connections**
- **Utilities – management of power grid**
- **Security – closed circuit TV & intrusion sensors**
- **Military – everywhere!**

Why Use Fiber Optics?

- Economics
- Speed
- Distance
- Weight/size
- Freedom from interference
- Electrical isolation
- Security

Why Use Fiber Optics?

- Fiber is least expensive, most reliable method for high speed &/or long distance communications
- While we already transmit signals at Gigabits per second speeds, we have only started to utilize the potential bandwidth of fiber.
- Single-mode fiber used in telecommunications & CATV has a bandwidth of greater than a Terahertz.
- Standard systems today carry up to 64 channels of 10 Gigabit signals - each at a unique wavelength.

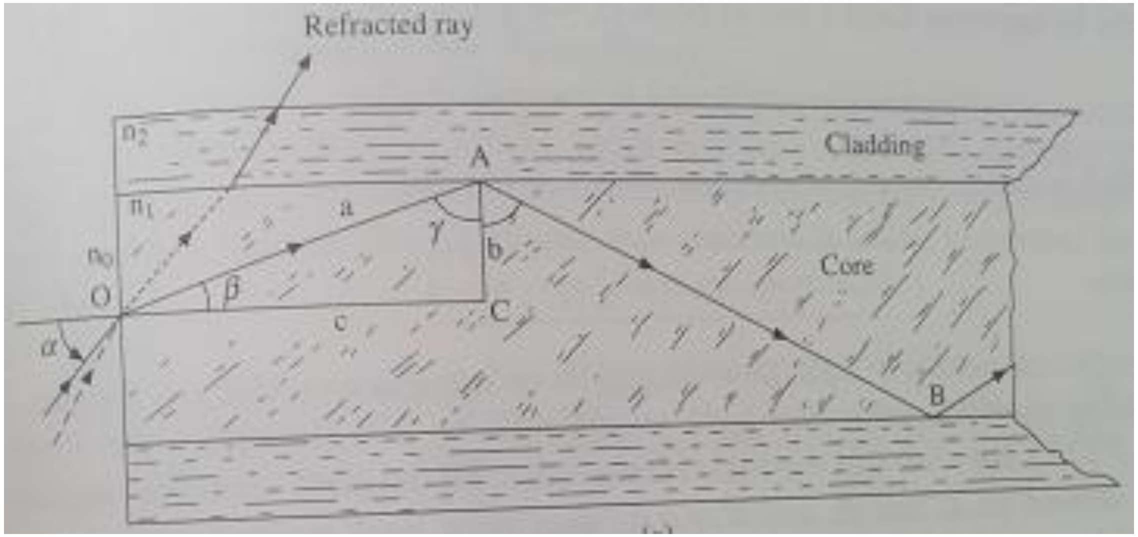
Fiber Optic Applications

Fiber is already used in

- > 90% of all long distance telephony
- > 50% of all local telephony
- Becoming popular for FTTH (fiber to the home)
- Most CATV networks
- Most LAN (computer networks) backbones
- Many video surveillance links

Propagation of Light in Fiber

$n_1 > n_2 > n_0$



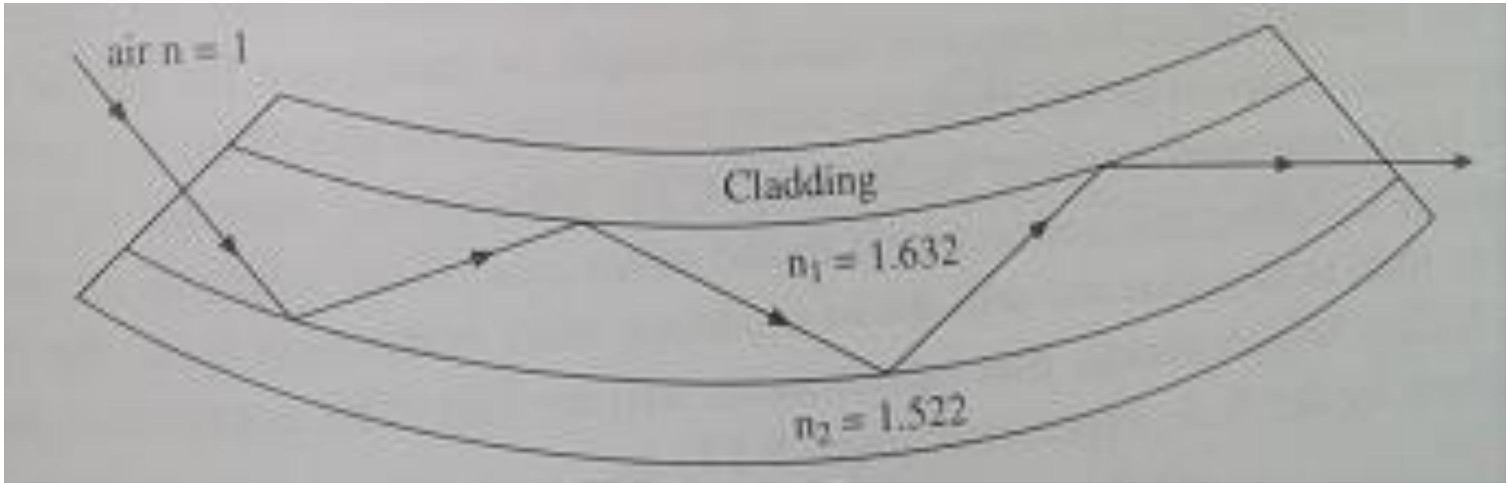
n_0 = Refractive index of air

n_1 = Refractive index of core

n_2 = Refractive index of cladding

α = Angle of incidence

β = Angle of refraction (air-core boundary)



If ray OA makes an angle $\gamma \geq i_c$ with normal at A, glass-cladding interface, it will suffer total internal reflection (TIR) & will travel along AB.

In a similar way beam will continuously suffer TIR until it emerges out of glass-core at other end. Even if fiber curves gradually, light will travel its entire length & arrive at other end.

Loss per reflecting point is as low as 0.04% due to absorption etc.

For TIR to take place, $\gamma \geq i_c, \qquad \sin\gamma = \frac{n_2}{n_1}$

$$\sin i_c = \sin\gamma = \frac{n_2}{n_1} = \frac{c}{a}$$

$$i_c = \gamma = \sin^{-1}\frac{n_2}{n_1}$$

From ΔOAC, OA = *a*, OC = *c*, AC = *b*

$$a^2 = b^2 + c^2$$

$$1 = \frac{b^2}{a^2} + \frac{c^2}{a^2}$$

$$\frac{b^2}{a^2} = 1 - \frac{c^2}{a^2} = 1 - \frac{n_2^2}{n_1^2}$$

$$\frac{b}{a} = \sqrt{1 - \frac{n_2^2}{n_1^2}} = \sin\beta$$

Applying Snell's law at point O, $$n_0 \sin\alpha = n_1 \sin\beta$$

$$n_0 \sin\alpha = n_1 \sqrt{1 - \frac{n_2^2}{n_1^2}} = \sqrt{n_1^2 - n_2^2}$$

which is called *Numerical Aperture* (NA) of fiber. It is a measure of ability of fiber to accept light for transmission.

$$\boxed{NA = n_0 \sin\alpha = \sqrt{n_1^2 - n_2^2}}$$

For efficient transfer of light, there should be no refraction at A, B, etc. the glass-cladding interface, otherwise light energy will be lost through walls.

It is clear that angle of incidence γ at glass-cladding interface will depend on α & β & if $\gamma \geq i_c$, then only TIR is possible.

Condition for TIR requires that – angle of incidence for all rays at entrance should be less than acceptance angle of fiber.

Acceptance angle is maximum angle of incidence (*α*) for which TIR is possible & fiber can conduct light to other end.

$$\alpha = \sin^{-1}\left(\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right)$$

Different Types of Optical Fiber

- **Cladless fiber: It does not have cladding.**

- **Graded index fiber (GRIN fiber): Core of fiber is made with varying refractive index, which is a function of core radius.**

- **Step index fiber: Central core is made up of glass RI (n_1) between 1.5 & 1.6. This core is surrounded by cladding material like fused quartz RI (n_2 = 1.425) or plastic (n_2 = 1.25) or glass. Around cladding there is a buffer coating.**

- **Passive & Active fiber: A passive fiber merely guides light incident on it from an external source. An active fiber emits light as well as guides part of it along its length. Scintillating fibers & lasing fibers are examples of active fiber.**