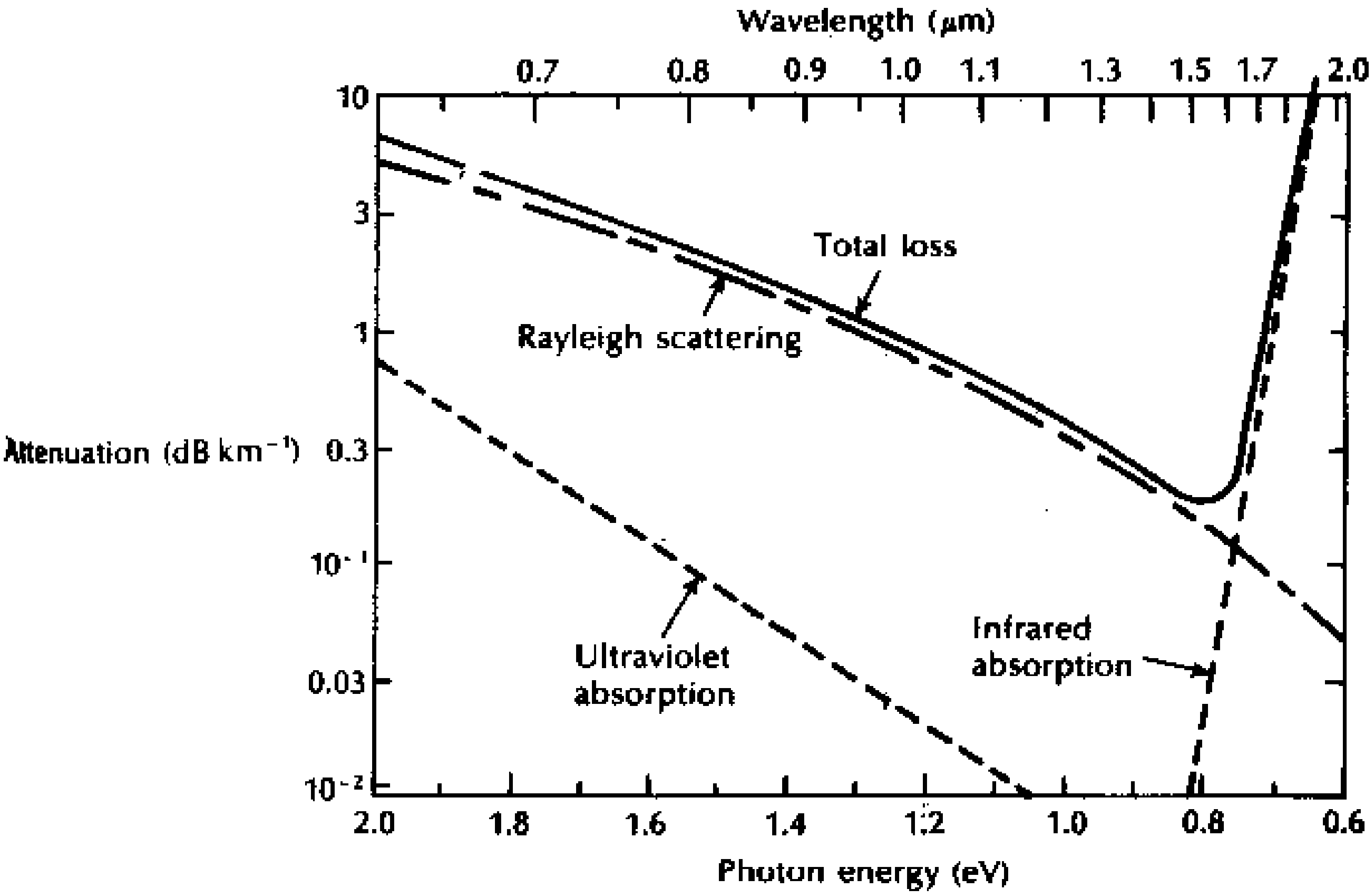
Section B
Lecture 5

FIBER CHARACTERISTICS

Material absorption Losses

- Material absorption is a loss mechanism related to material composition and fabrication process for the fiber.
- This results in dissipation of some of the transmitted optical power as heat in the wave guide.
- Absorption
  - Intrinsic (due to major components of glass)
  - Extrinsic (caused by impurities)

Material absorption Losses (contd.)



The attenuation spectra for the intrinsic loss mechanisms in pure GeO_2SiO_2 glass

Material absorption Losses (contd.)

- Attn. Spectra for intrinsic loss mechanism in pure GeO_2 - SiO_2 Glass
- Pure silicate glass has little intrinsic absorption, due to its basic material structure in the near infra-red region.
- Loss is due to stimulation of electron transitions within Glass!

Extrinsic Absorption

It is due to impurities (metal elements)

Impurities	Loss (due to 1 part in 10^9) in dB/Km
Cr^{3+}	1.6
Cu^{2+}	1.1
Fe^{2+}	0.68
Ni^{2+}	0.1

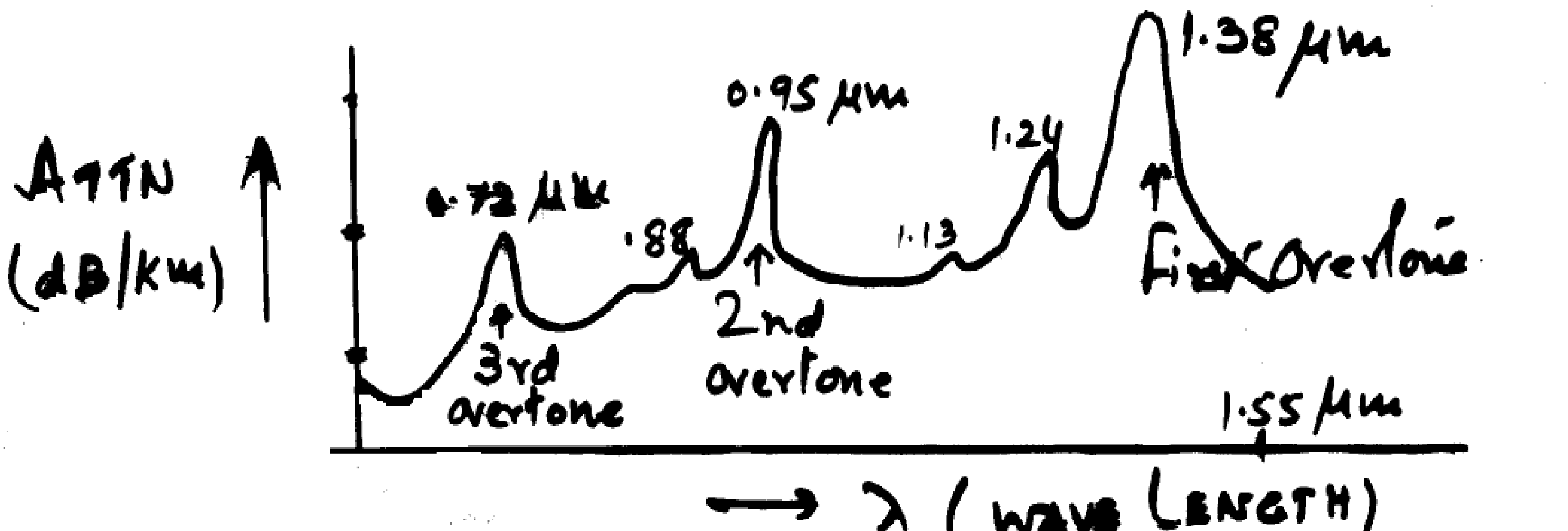
These transition element impurities can be reduced to acceptable levels (one part in 10^{10}) by glass refining techniques.

Another major extrinsic loss mechanism is due to water (oH ion) dissolved in glass .

At 0.95µm- 1.38µm, ATTN is 1-2 db/Km (1 ppm of OH)

Extrinsic Absorption (Contd.)

- Lowest ATTN for this fiber occurs at a wavelength of 1.55 µm and is about 0.2db/Km (Min possible is 0.18 db/Km.)



ABSORPTION SPECTRUM FOR OH GROUP IN SILICA

Linear Scattering

Two types of linear scattering

-**Rayleigh Scattering**

-MIE Scattering

Rayleigh Scattering

Dominant intrinsic loss mechanism between ultraviolet and infrared absorption regions.

It is due to changes in ref. index (inhomogeneties of a random nature)

The inhomogeneties are because of **density & composition variations** which are frozen into glass lattice on cooling.

Glass is composed of randomly connected network of molecules.

Rayleigh Scattering(contd)

Attenuation- $\gamma_R = \frac{8\Pi^3 n^8 p^2 \beta_c K T_F}{3\lambda^4}$

(Rayleigh'Scattering Co-efficient)

p=average photo elastic coefficient

β_c = Isothermal compressibility at a fictive temp.

K= Boltzman's Constant

$T_{F=}$ temp at which glass can reach a state of thermal equilibrium.

MIE Scattering

This results from non perfect cylindrical structure of the waveguide, and fiber imperfections, eg.

-Core, cladding interface irregularities

-Ref. index variation along fiber length

-Dia. fluctuations

-Strains & bubbles.

MIE Scattering(contd)

Scattering created is in the forward direction.

The inhomogenties can be reduced by

-**removing imperfections due to glass mfg. process.**

-**controlled extrusion & coating of fiber**.

- **Increasing the fiber guidance by increasing the relative ref. index difference**.

Note: There is no change of freq. on scattering with all linear processes.

-

TRANMISSION CHARACTERISTICS OF FIBERS

Attenuation (or loss)

Band width

Unit of attenuation: dB

$$dB = 10 \log_{10} P_i / P_o$$

where P_i = input opt. power into the fiber

P_o= output opt. power

By definition : $10^{dB/10} = P_i / P_o$

In OFC ,attenuation is generally expressed in decibels per unit length (dB/km)

TRANSMISSION CHARACHTERISTICS OF FIBERS

$$\therefore \alpha \, dB \, . L = 10 \log_{10} P_i / P_o$$

where, α is the signal attenuation per unit length & L is fiber length.

Note : OFC became specially attractive when transmission losses of fibers were reduced below those of competing metallic conductors.

($< 5dB / km$)

TRANSMISSION CHARACHTERISTICS OF FIBERS (contd)

- **BANDWIDTH**

-This is limited by the signal dispersion within the fiber, which determines the no of bits of information transmitted in a given time period.

Note : Today wideband fiber bandwidths of many tens of GHz over a number of Km are available

DISPERSION

DISPERSION MECHANISM CAUSES BROADENING OF THE TRANSMITTED LIGHT PULSES. (AS THEY TRAVEL ALONG THE CHANNEL)

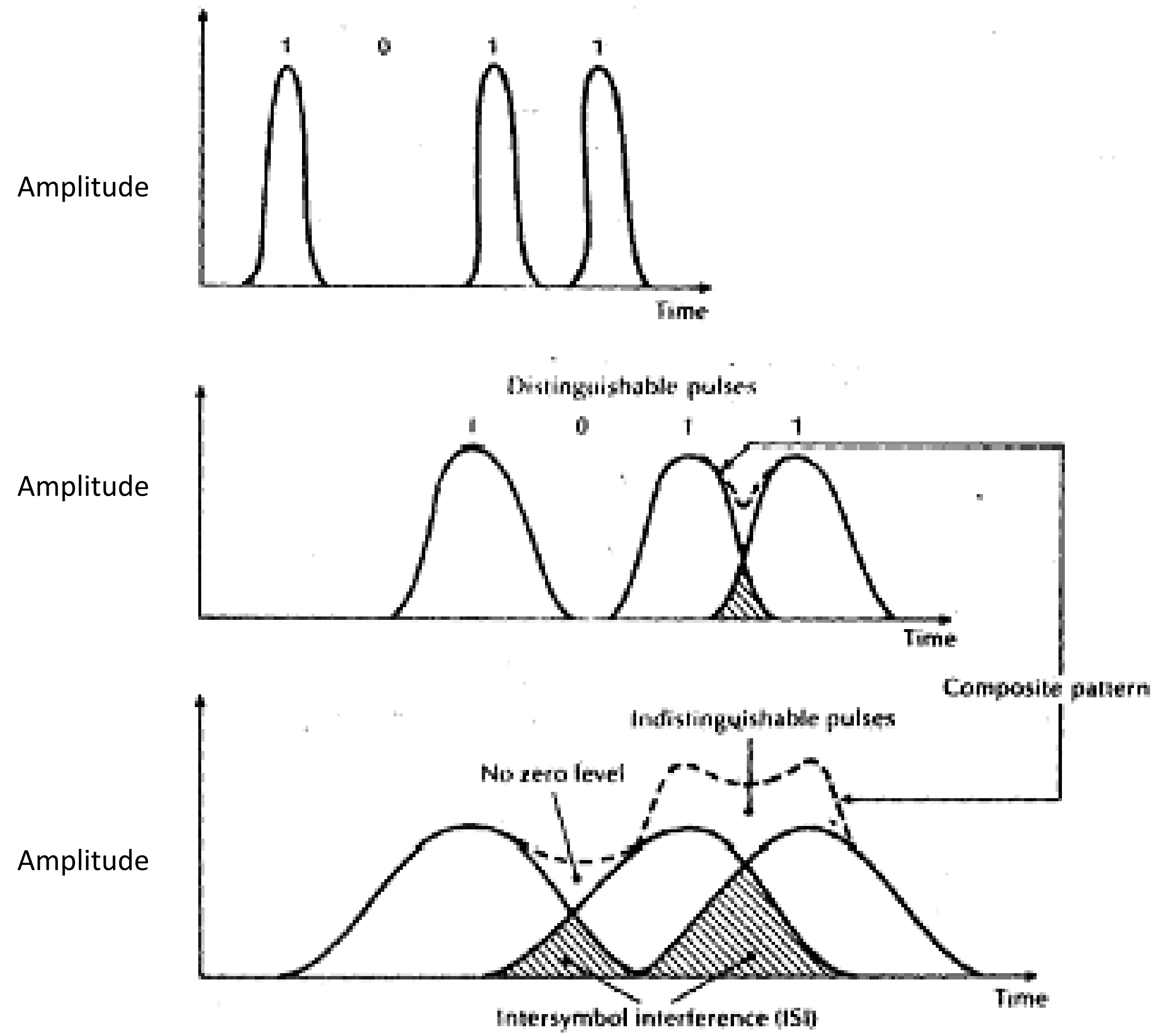
EACH PULSE BROADENS AND OVERLAPS WITH ITS NEIGHBOURS. THE EFFECT IS KNOWN AS

INTERSYMBOL INTERFERENCE (ISI)

ISI

- ISI RESULTS IN AN ERROR RATE WHICH IS A FUNCTION OF SIGNAL ATTENUATION AND SNR AT THE RECEIVER.
- SIGNAL DISPERSION LIMITS THE MAX. BANDWIDTH ATTAINABLE (TO THE POINT WHERE INDIVIDUAL SYMBOLS CAN NO LONGER BE DISTINGUISHED

- INTERSYMBOL INTERREFRENCE (ISI)



An illustration using the digital bit pattern 1011 of the broadening of light pulses as they are transmitted along a fiber: (a) fiber input; (b) fiber output at a distance L1;(c) fiber output at a distance L2> L1.

FOR NO OVERLAPPING OF LIGHT PULSES

DIGITAL BIT RATE, $B_T \leq 1/2\tau$

WHERE τ = INPUT PULSE DURATION

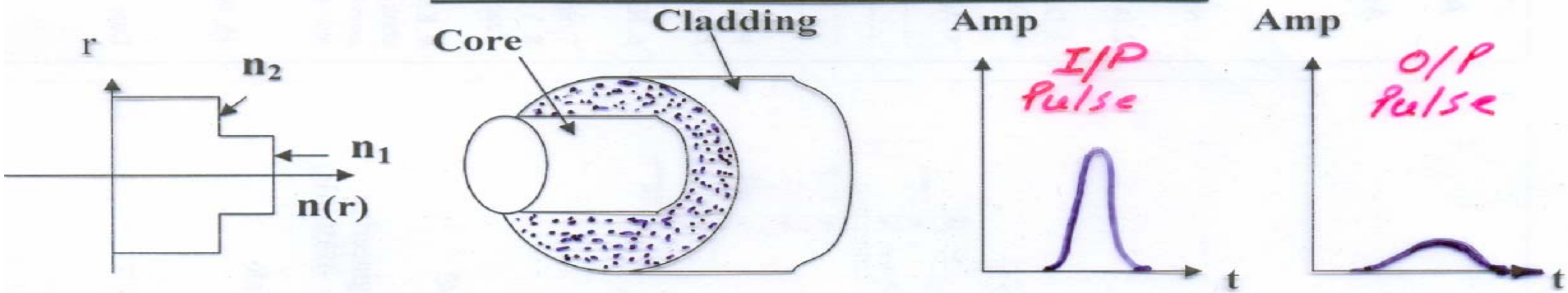
= PULSE BROADENING DUE TO DISPERSION

ALTERNATIVELY

$B_T = (1/4\sigma)/(1/\ 5\sigma)$

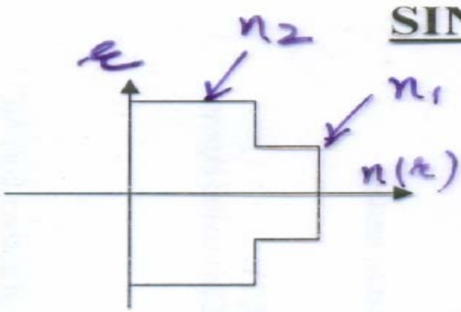
WHERE σ = RMS WIDTH OF GAUSSIAN SHAPE AT THE OUTPUT.

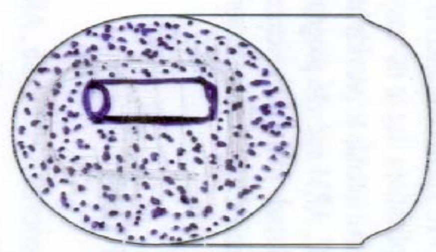
MULTIMODE STEP INDEX FIBER

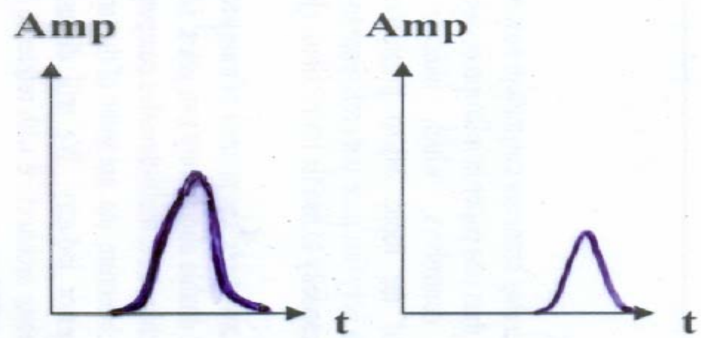


MULTIMODE GRADED INDEX FIBER

SINGLE MODE STEP INDEX FIBER







SINGLE MODE FIBER GIVES MIN PULSE BROADENING & THUS YIELDS MAX TRANSMISSION BW

INTRAMODAL DISPERSION

OPTICAL SOURCES DO NOT EMIT JUST A SINGLE FREQ, BUT A BAND OF FREQUENCIES.

THIS RESULTS IN PROPAGATIQNAL DELAY DIFFERENCES BETWEEN THE DIFFERENT SPECTRAL COMPONENTS OF THE Tx SIGNAL.

THIS CAUSES **BROADENING OF EACH TRANSMITTED MODE (INTRAMODAL DISPERSION).**

THE INTRAMODAL DISPERSION MAY BE CAUSED BY **MATERIAL DISPERSION** AND **WAVE GUIDE DISPERSION.**

MATERIAL DISPERSION

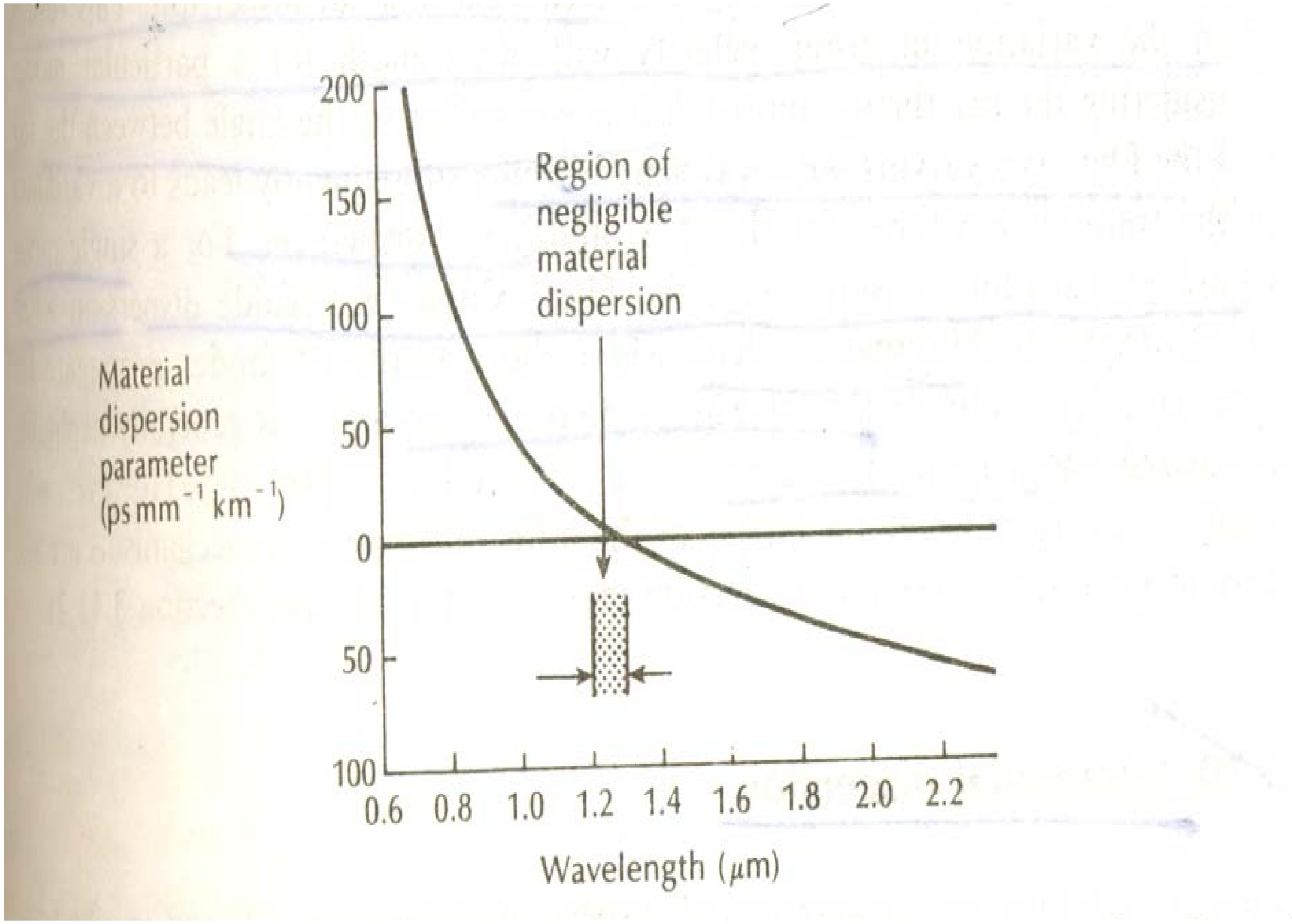
PULSE BROADENING RESULTS FROM DIFF.GROUP VELOCITIES OF VARIOUS SPECTRAL COMPONENTS LAUNCHED INTO OPTICAL FIBRE SOURCE.

PHASE VELOCITY OF WAVE VARIES NON-LINEARLY WITH WAVELENGTH.

A MATERIAL IS SAID TO EXHIBIT MATERIAL DISPERSION WHEN

$d^2n/ d\lambda^2 \neq 0$

- **0.1-0.2 ns / km in multimode fibers**



The material dispersion parameter for silica as a function of wavelength .

WAVE GUIDE DISPERSION

THIS RESULTS FROM VARIATION IN GROUP VELOCITY WITH WAVELENGTH FOR A PARTICULAR MODE.

IT IS EQUIVALENT TO VARIATION OF ANGLE BETWEEN RAY AND FIBER AXIS WITH WAVELENGTH, RESULTING IN VARIATION IN TRANSMISSION TIMES FOR THE RAYS, AND HENCE DISPERSION.

SINGLE MODE FIBER EXHIBITS WAVEGUIDE DISPERSION WHEN $d^2\beta/d\lambda 2 \neq 0$

MULTIMODE FIBERS ARE NORMALLY FREE OF WAVEGUIDE DISPERSION.

INTERM0DAL / MODAL/ MODE DISPERSION

PULSE BROADENING RESULTS FROM THE PROPAGATION DELAY DIFFERENCES BETWEEN MODES WITHIN A MULTIMODE FIBER

.

DIFFERENT MODES IN A MULTIMODE FIBER
TRAVEL ALONG THE CHANNEL AT DIFFERENT
GROUP VELOCITIES.

INTERM0DAL / MODAL/ MODE DISPERSION

MULTIMODE STEP INDEX FIBERS EXHIBIT MAX INTERMODAL DISPERSION.

GRADED INDEX FIBERS EXHIBIT FAR LESS PULSE BROADENING THAN THE ABOVE CASE (TYPICALLY BY A FACTOR OF 100). **SO HIGHER BW IS AVAILABLE**.

SINGLE MODE STEP INDEX FIBERS EXHIBIT LEAST PULSE BROADENING AND HENCE THE GREATEST POSSIBLE BW.

REDUCING INTERMODAL DISPERSION

- BY ADOPTION OF AN OPTIMUM REF. INDEX PROFILE

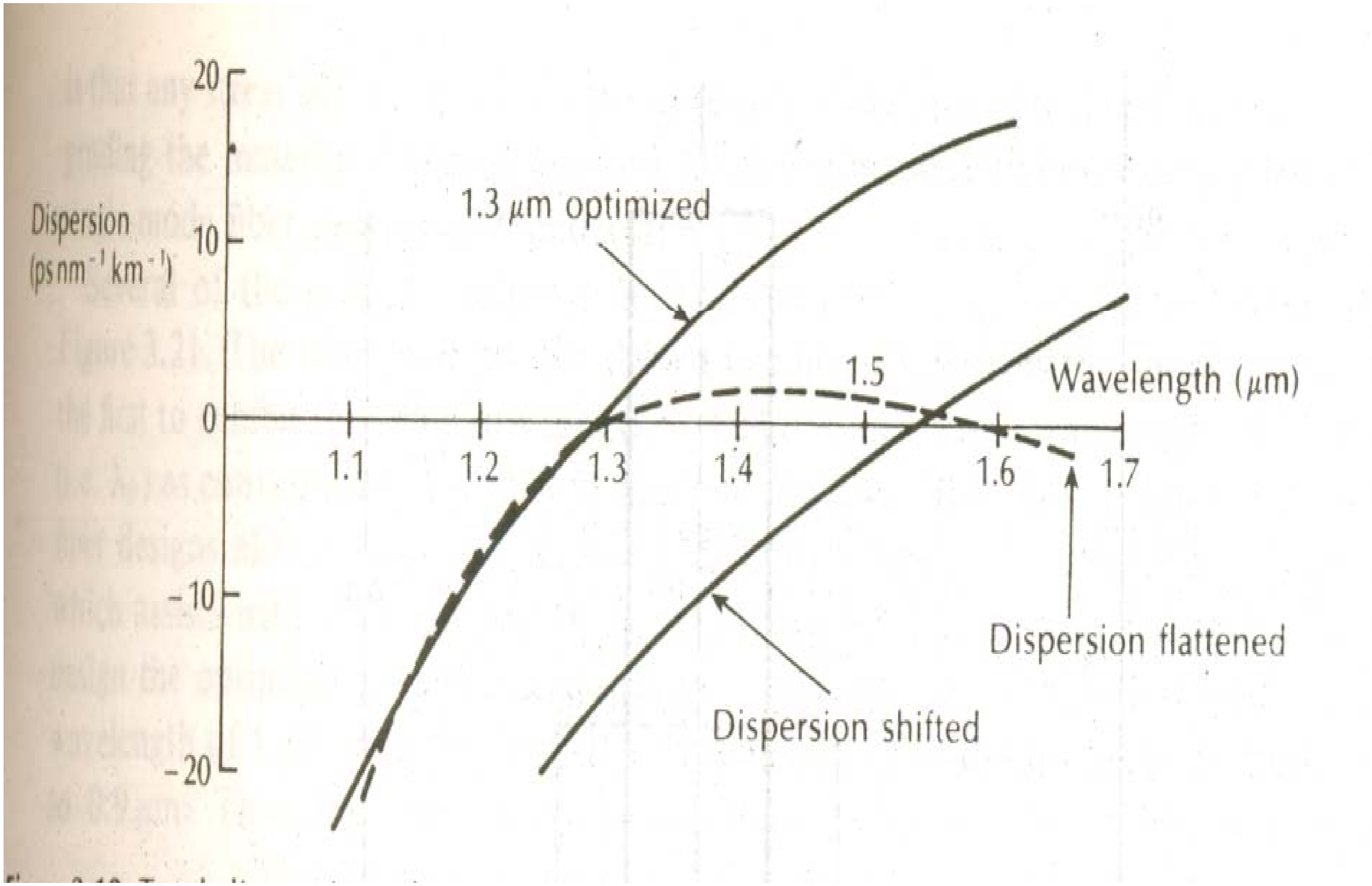
GRADING THE CORE REFRACTIVE INDEX TO FOLLOW A NEAR PARABOLIC PROFILE.

DISPERSION SHIFTED FIBERS

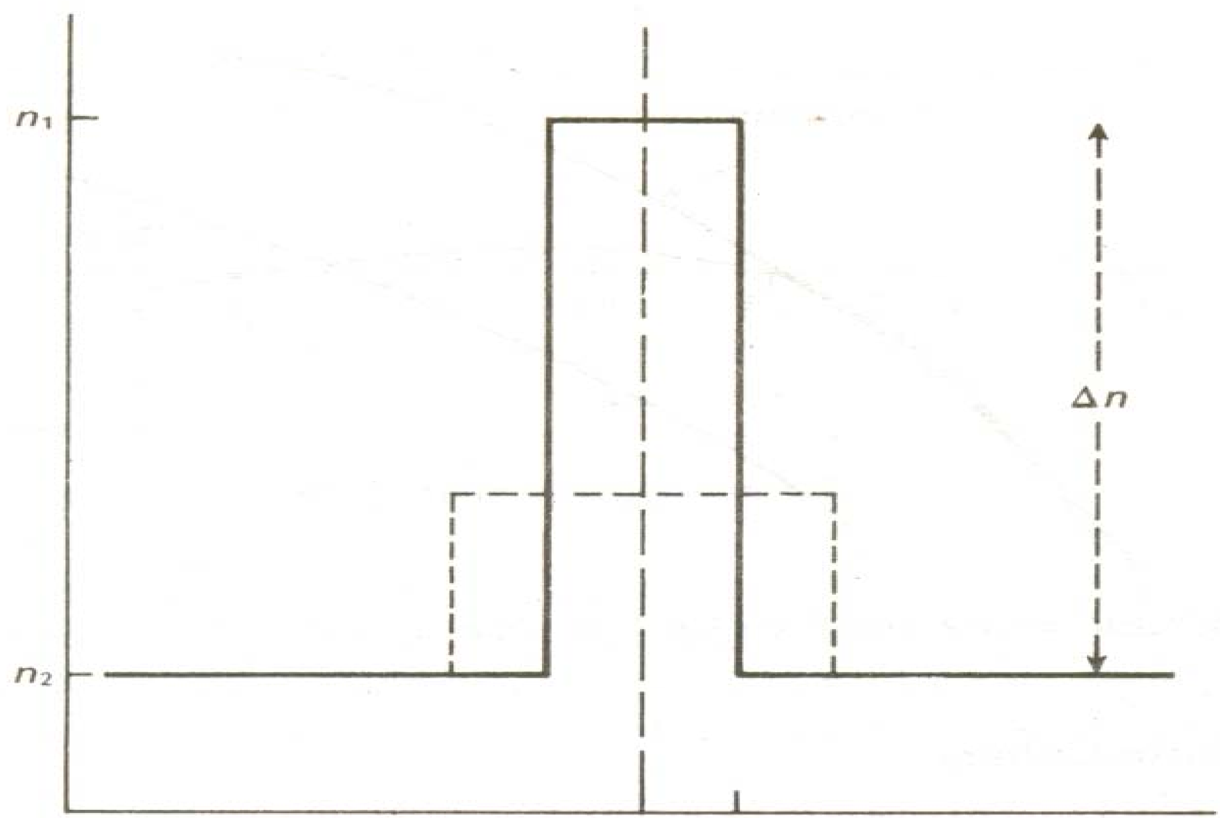
- Refractive Index profile can be modified in order to tune to zero dispersion wavelength point
- **Shift to a longer wavelength by reducing the core dia and increasing the fractional refractive index difference(fig)**
- **Higher concentration of the dopant causes a shift to longer wavelength**

DISPERSION SHIFTED FIBERS(contd)

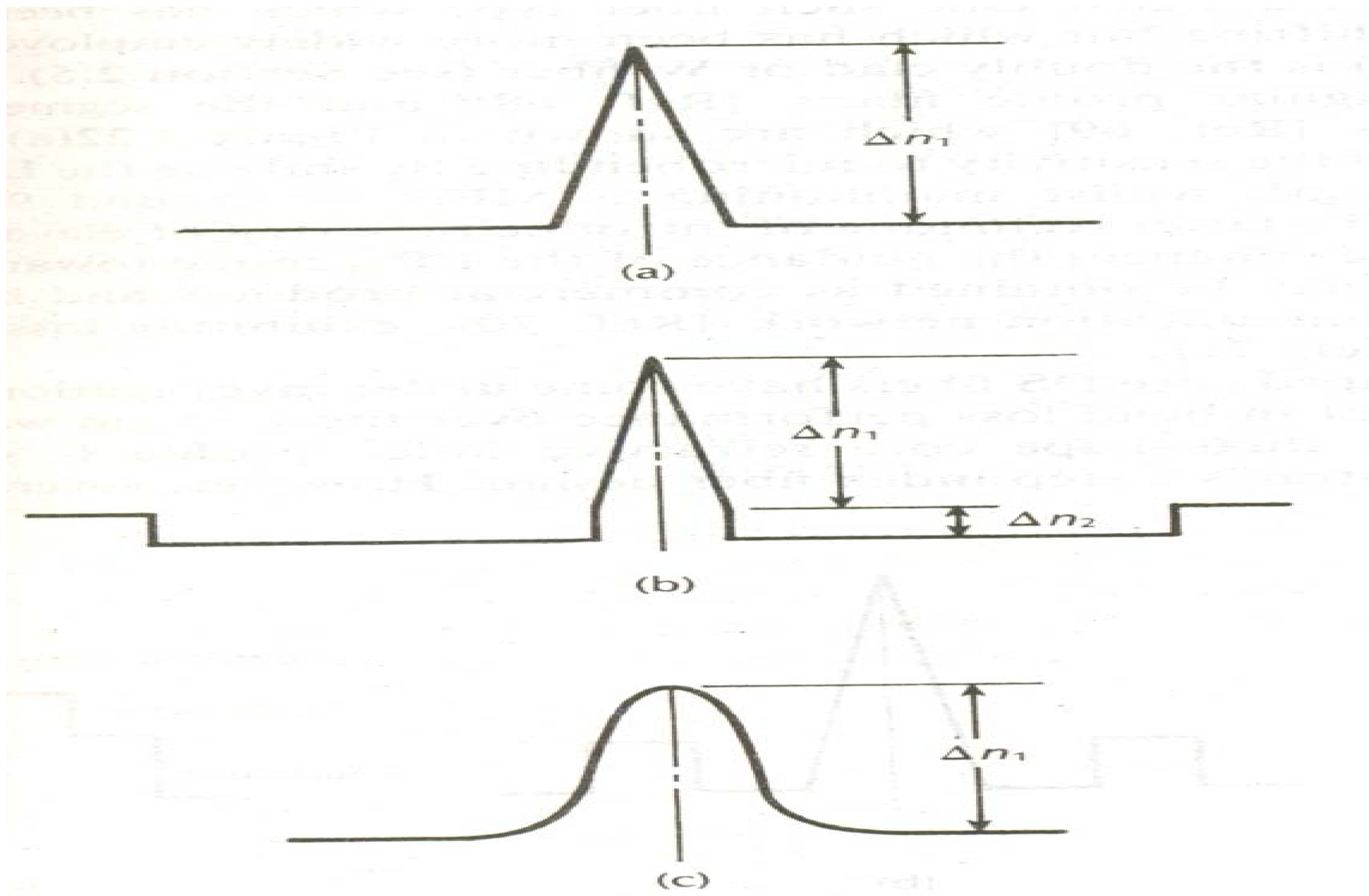
- **Increased dopant level however causes higher loss (2 dB / km).** This is overcome by using triangular profile. The loss is reduced to 0.24 dB / km at a wavelength of 1.56 μm (fig)
- The triangular profile is sensitive to bend induced losses. Remedy is to employ a triangular index profile combined with depressed cladding index or use a guassian refractive index profile. (fig)



Total dispersion characteristics for the various types of single – mode fiber .



Refractive index profile of a step index dispersion shifted fiber (solid) with a conventional nonshifted profile design (dashed)



Refractive index profiles for graded index dispersion shifted fibers:
a) triangular profile ;
b) depressed cladding triangular profile
c) Gaussian profile