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Digital Broadcasting and Broadband Technologies (Master Studies)
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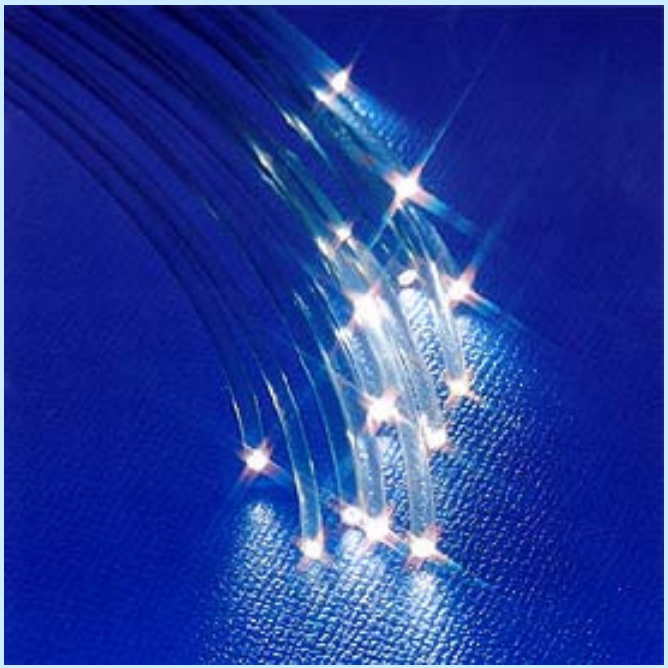
DBBT

Digital Broadcasting & Broadband Technologies

OPTIČKI MEDIJI PRENOSA

Optičko vlakno – prenosne karakteristike

- Djeluje kao talasovod na frekvencijama od 10^{14} do 10^{15} Hz
  - Dijelovi infracrvenog i vidljivog spektra
- Light Emitting Diode (LED)
  - jeftinija
  - širi radni temperaturni opseg
  - dugotrajnija
- Injection Laser Diode (ILD)
  - efikasnija
  - veća brzina prenosa



- Wavelength Division Multiplexing (multipleksiranje po optičkim dužinama)

Prednost optičkih kablova u telekomunikacijama

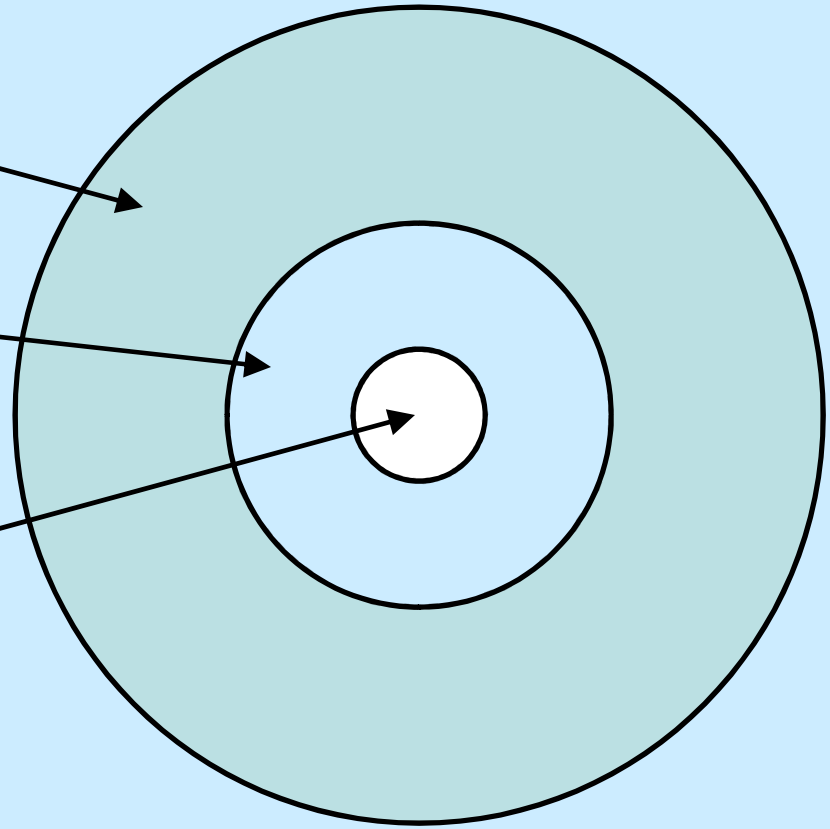
- mali prenosni gubici (<0.2 dB/km na 1.5 μm)
- širok propusni opseg (±100 THz)
- otpornost na elektromagnetni šum
- niska cijena
- visoka hemijska stabilnost
- prisutnost materijala u prirodi
- male dimenzije
- jak, fleksibilan materijal

Presjek optičkog vlakna

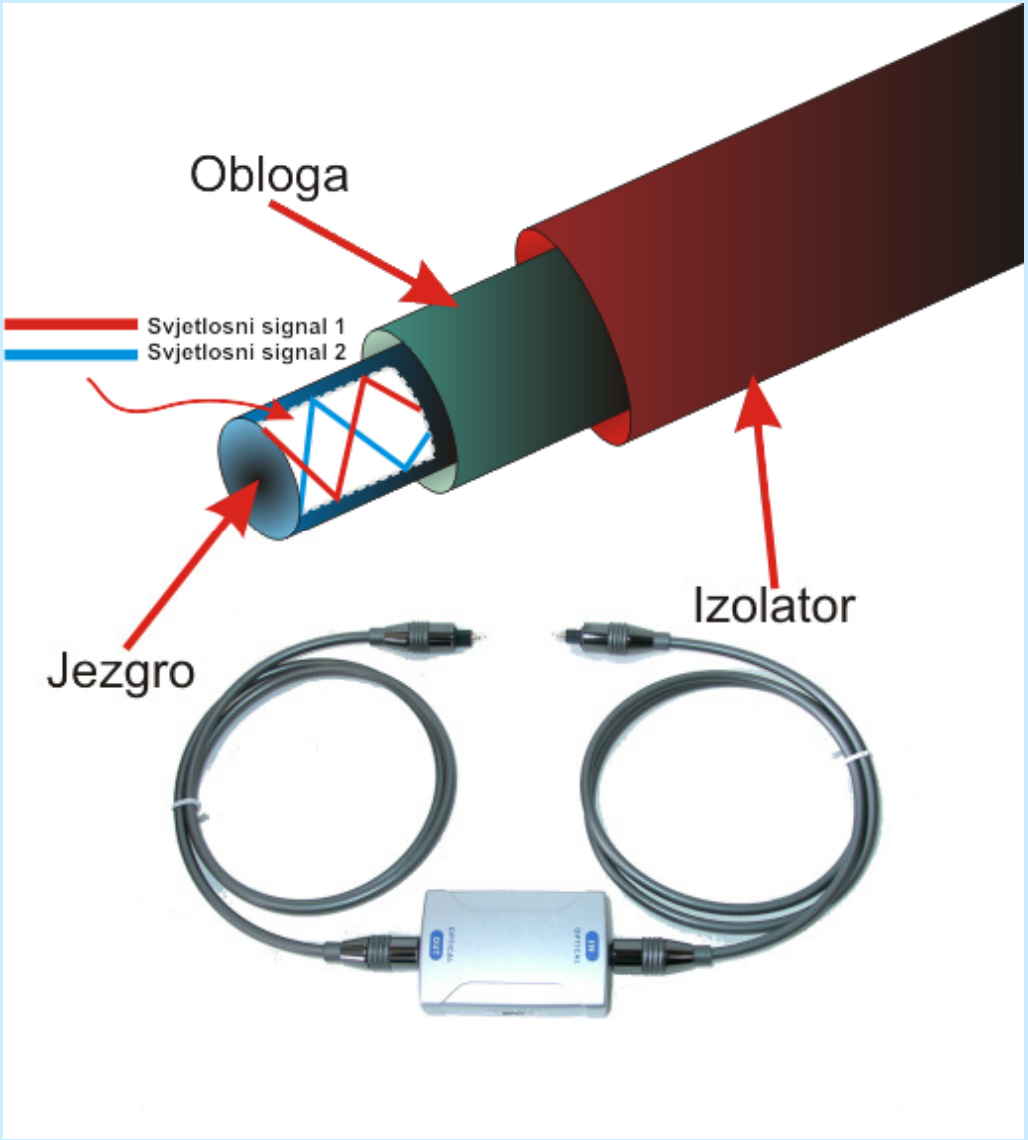
Zaštitni omotač
plastika (250 or 900 μm)

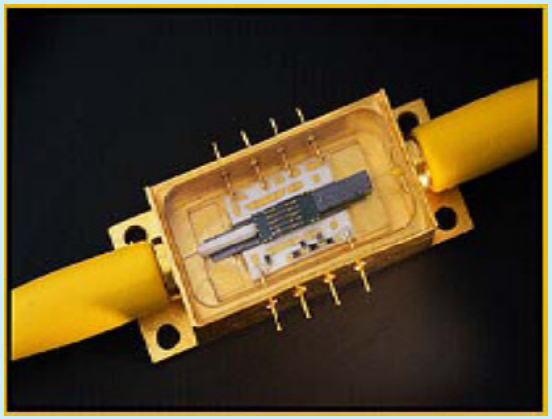
Omotač
čisti silicijum (125 μm)

Jezgro
dopirani silicijum (9 – 62.5 μm)
Tipične vrijednosti step-indeksa:
n = 0.001 - 0.01 **index profil**

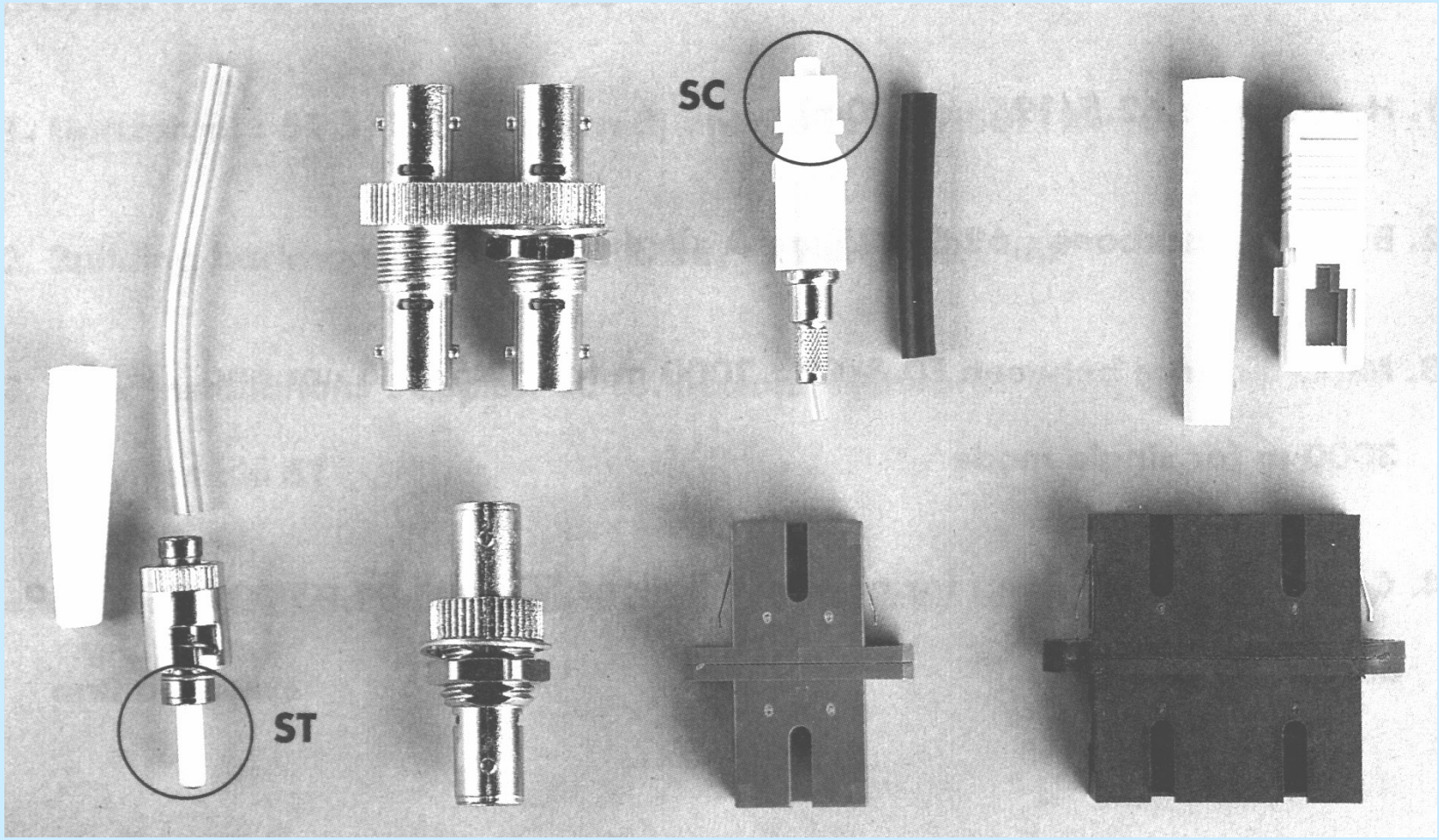


Komponente

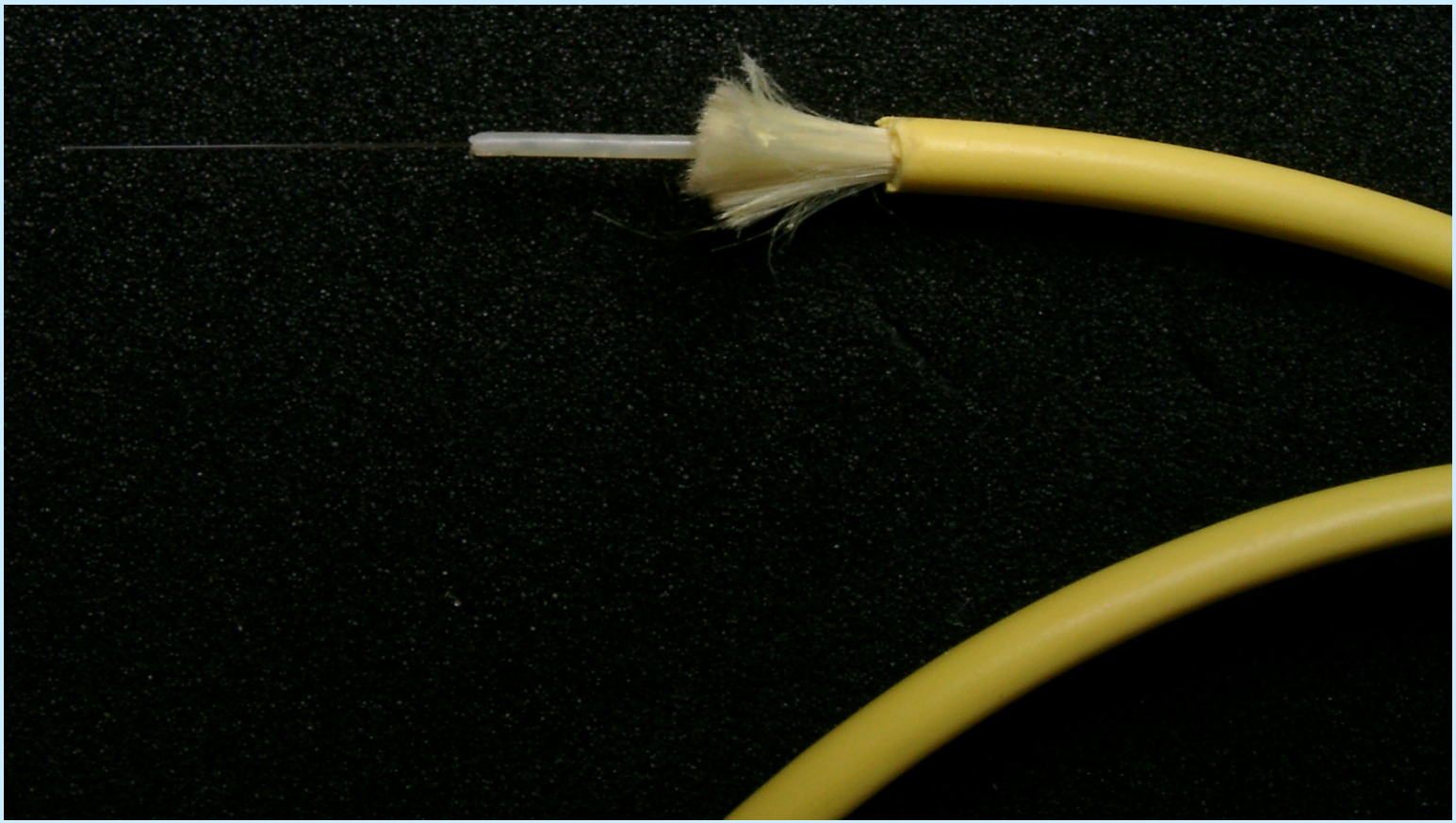

Obloga
Svjetlosni signal 1
Svjetlosni signal 2
Izolator
Jezgro



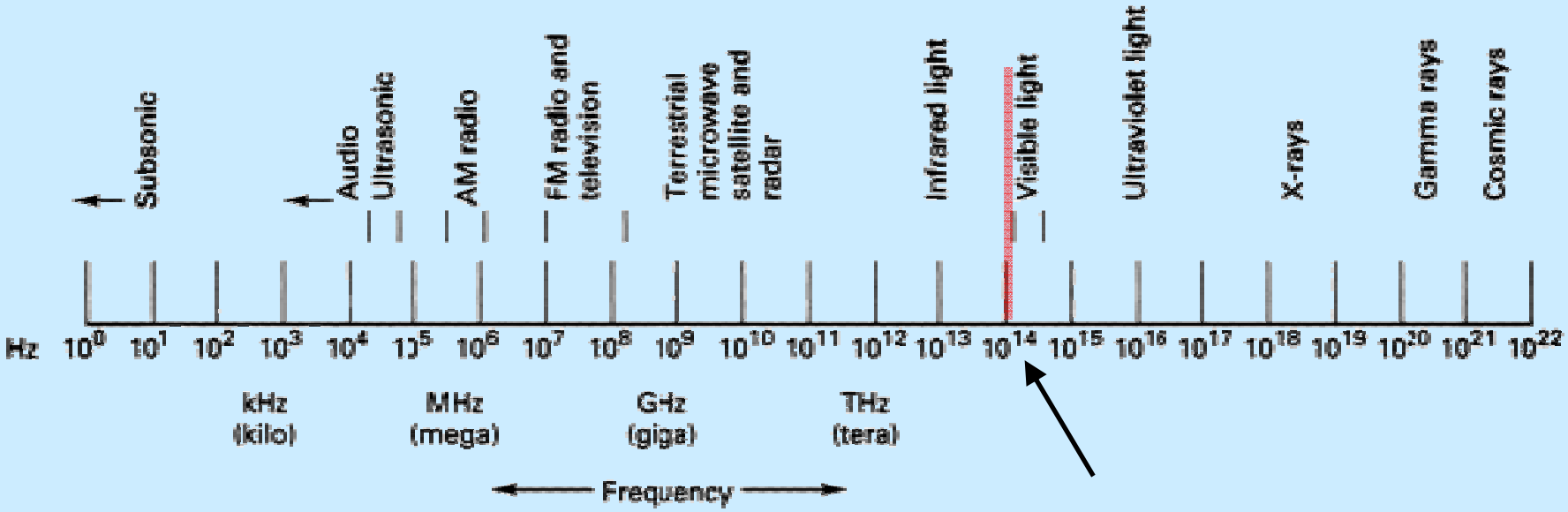
Konektori za optičke kablove



Optičko vlakno



Elektromagnetski spektar



$$\lambda = \frac{c}{f}$$

λ = 1550 nm = 1.55 μm

f = 193 10^{12} Hz = 193 THz

Propusni opseg za optičke telekomunikacije

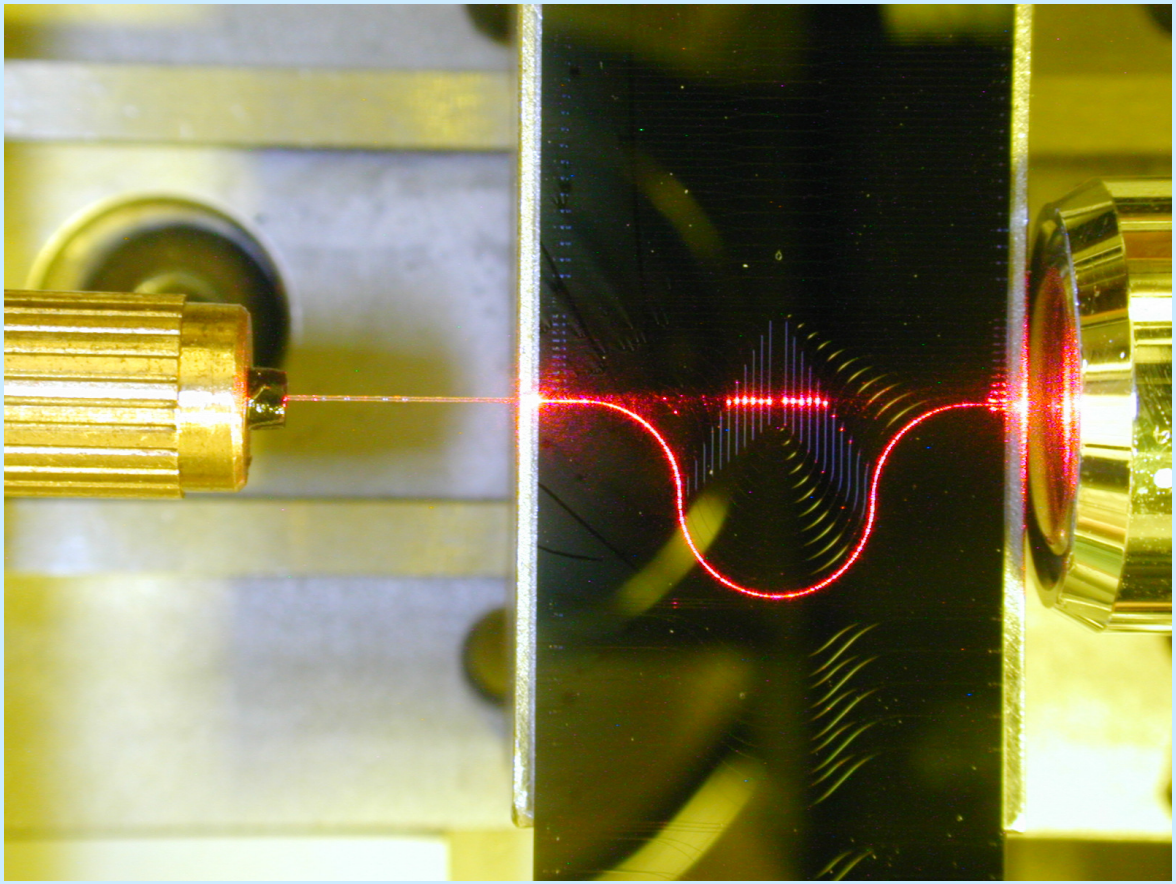
$$\lambda = \frac{c}{f}$$

$\lambda = 1 - 1.6\ \mu m$

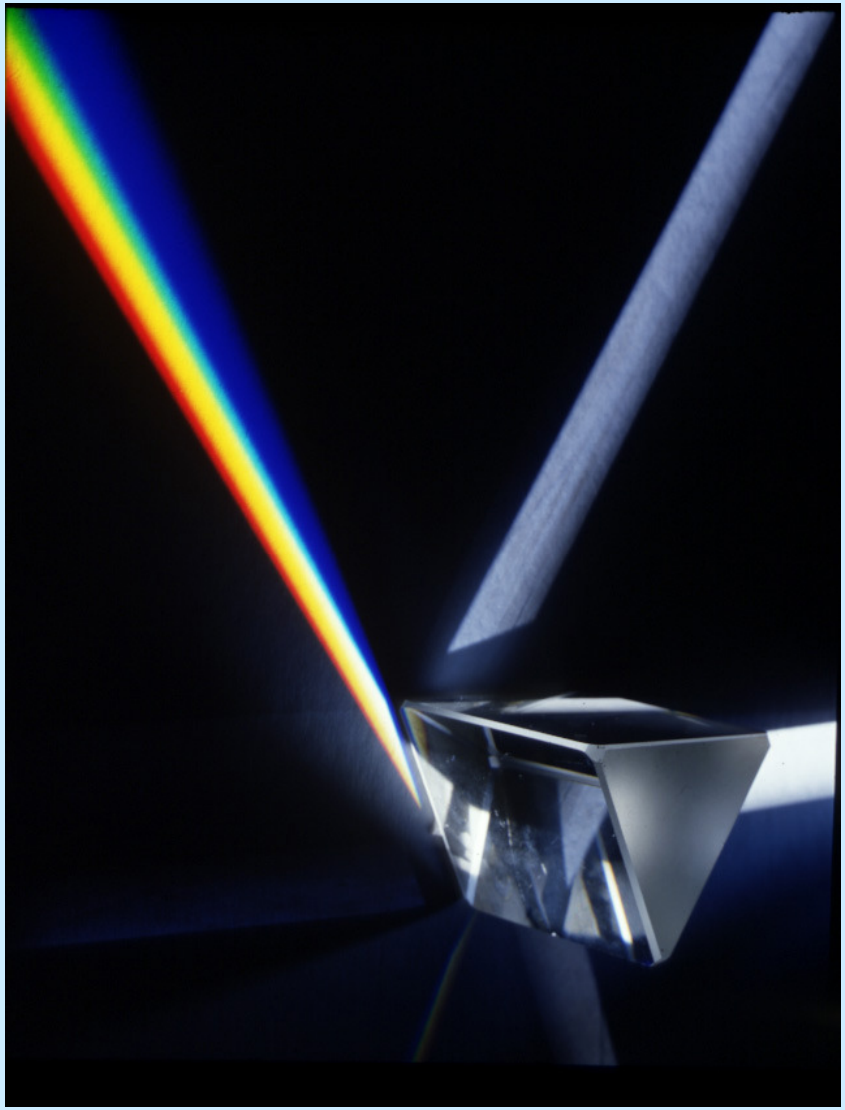
$\Delta f = 3 \times 10^{14} - 1.9 \times 10^{14}$ Hz

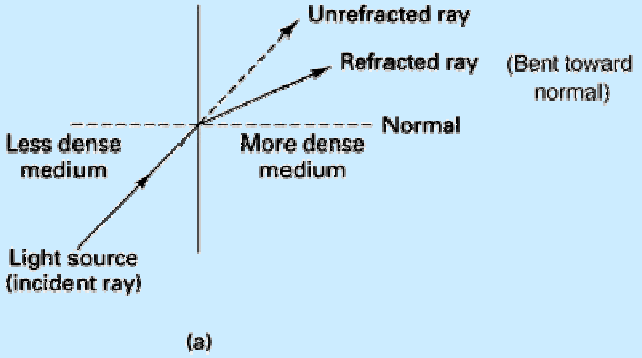
BW = 1.1×10^{14} Hz = 110 THz

Optičko vlakno i čip

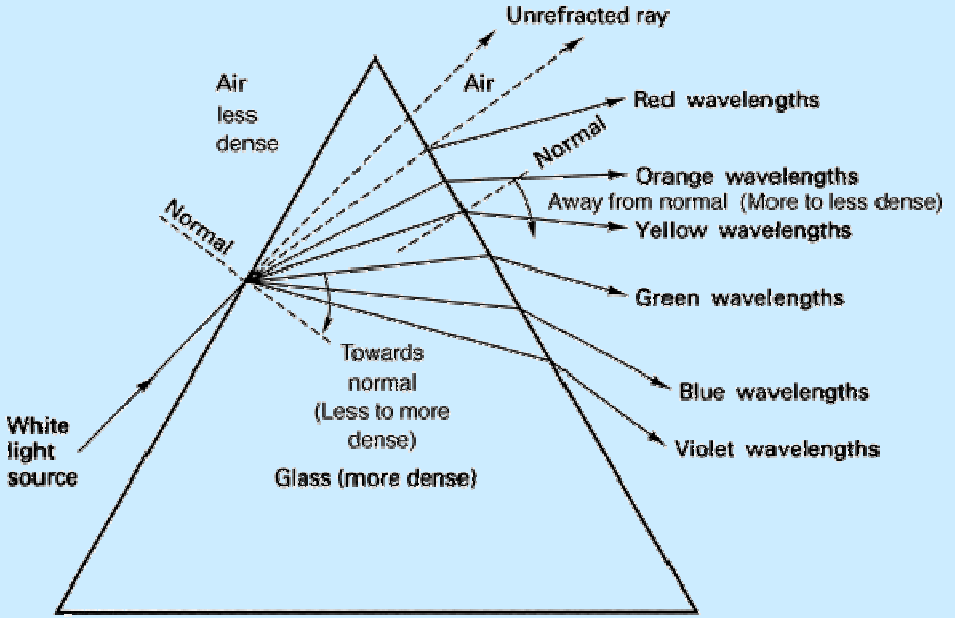


Refrakcija i disperzija





(a)



Indeks refrakcije

$$n = \frac{c}{v}$$

n = indeks refrakcije (bez dimenzije)

c = brzina svjetlosti u slobodnom prostoru

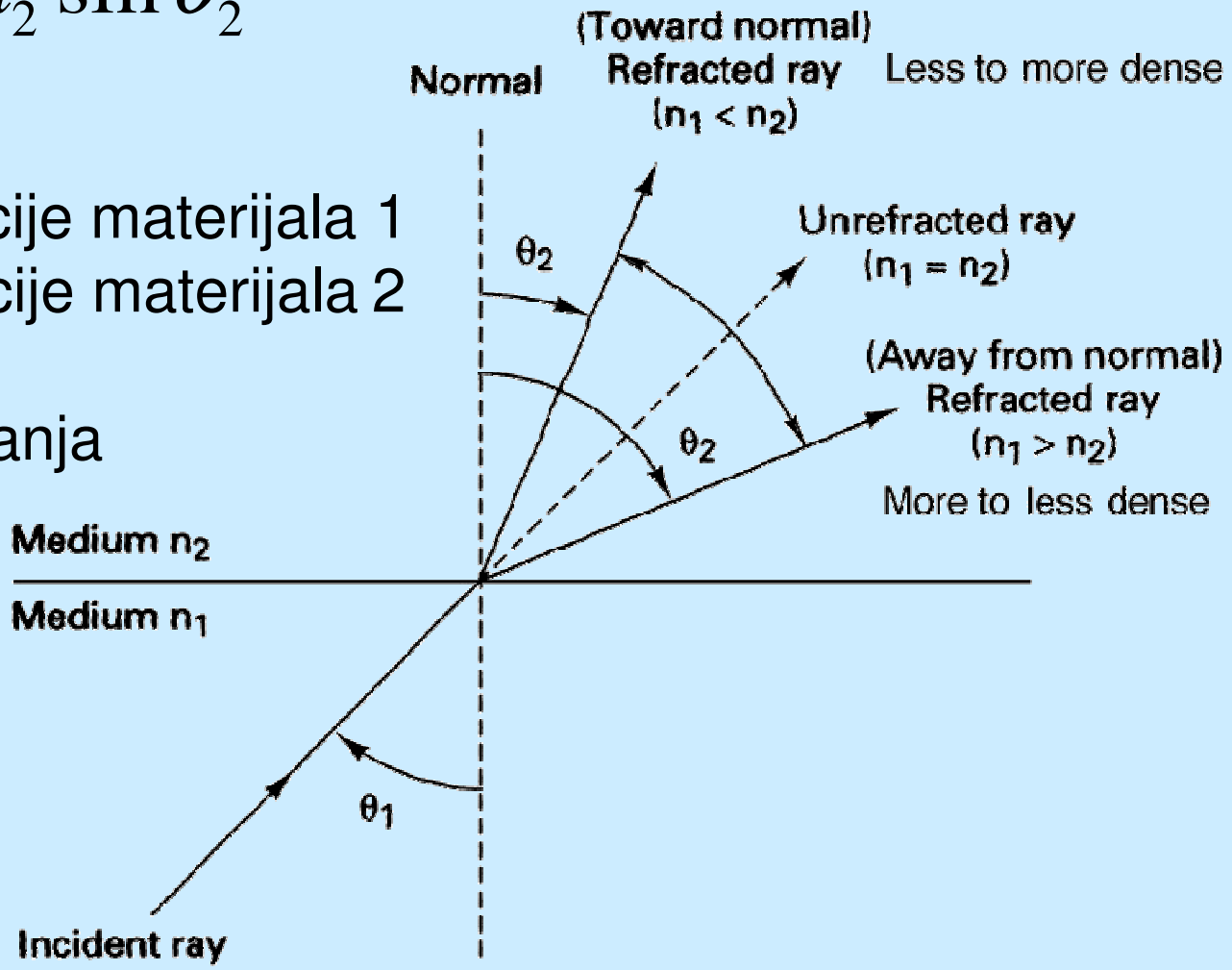
(300.000.000 m/s)

v = brzina svjetlosti u datom materijalu

Snell –ov zakon

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

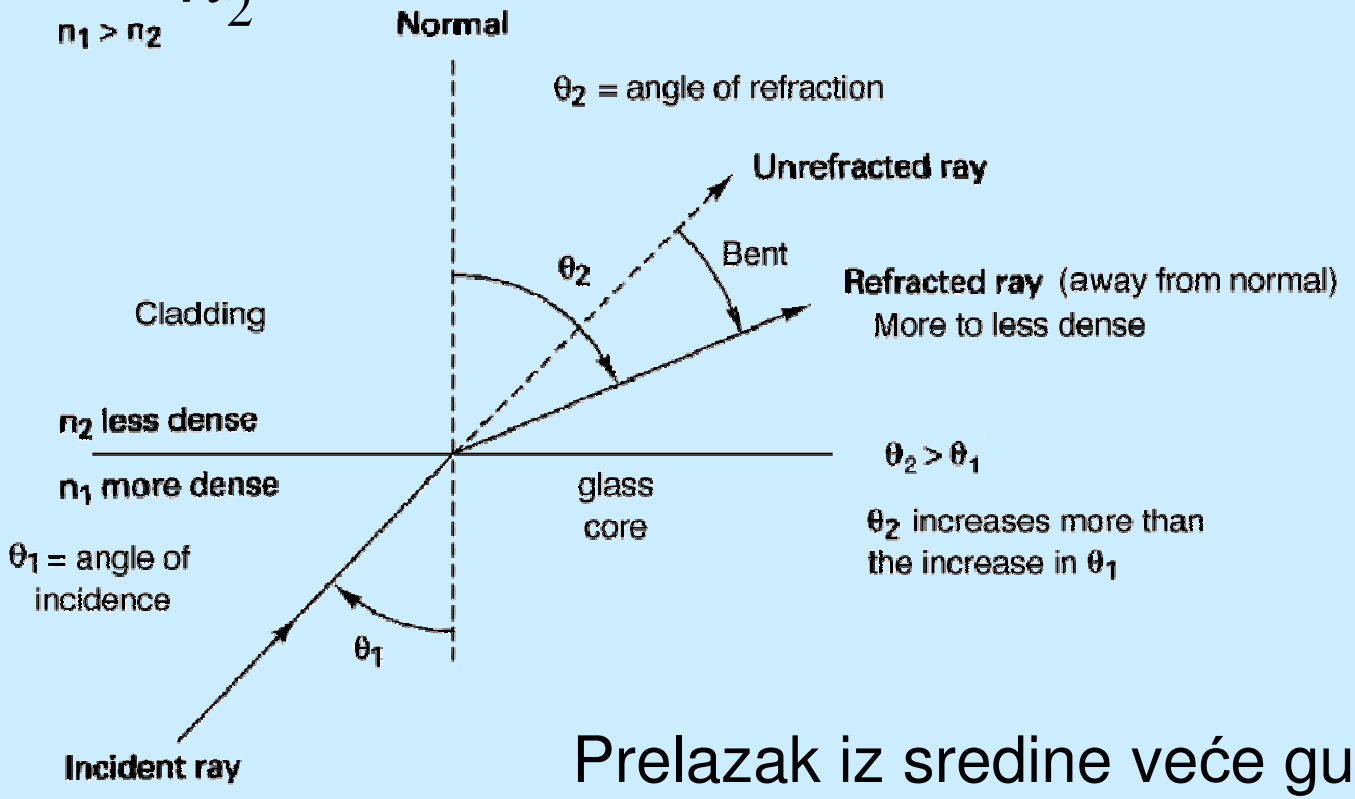
n_1 = indeks refrakcije materijala 1
n_2 = indeks refrakcije materijala 2
θ_1 = upadni ugao
θ_2 = ugao prelamanja



Snell –ov zakon

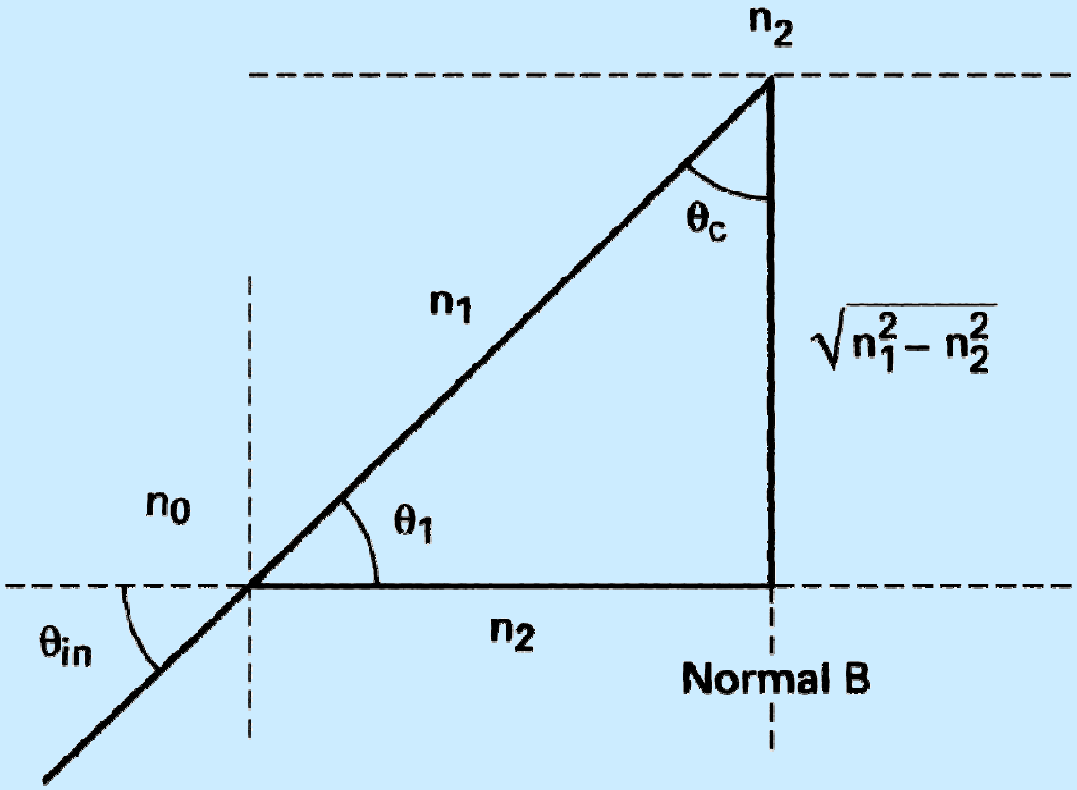
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\theta_2 = \arcsin \frac{n_1}{n_2} \sin\theta_1$$



Prelazak iz sredine veće gustine u sredinu manje gustine

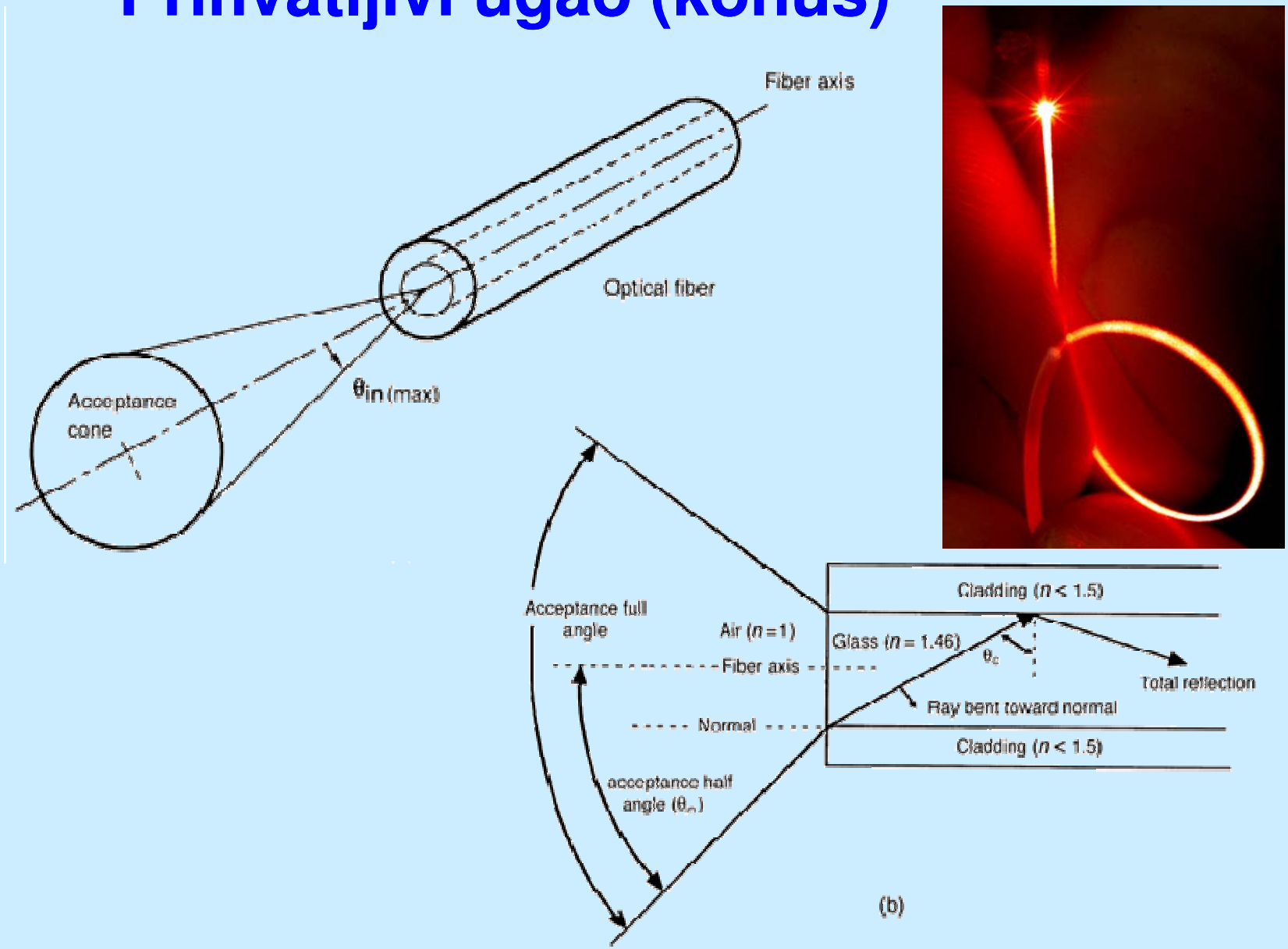
Prihvatljivi ugao



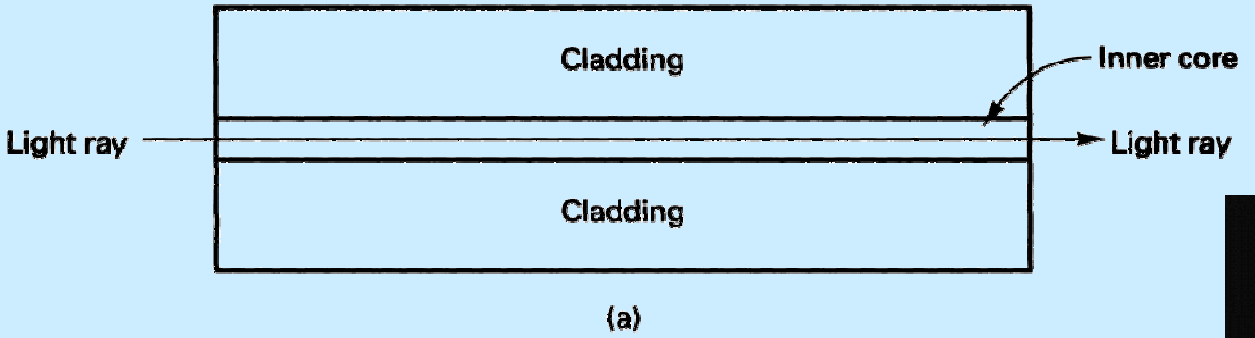
$$\theta_{in(\max)} = \arcsin \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

$$NA = \sin \theta_{in} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

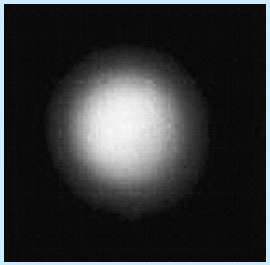
Prihvatljivi ugao (konus)

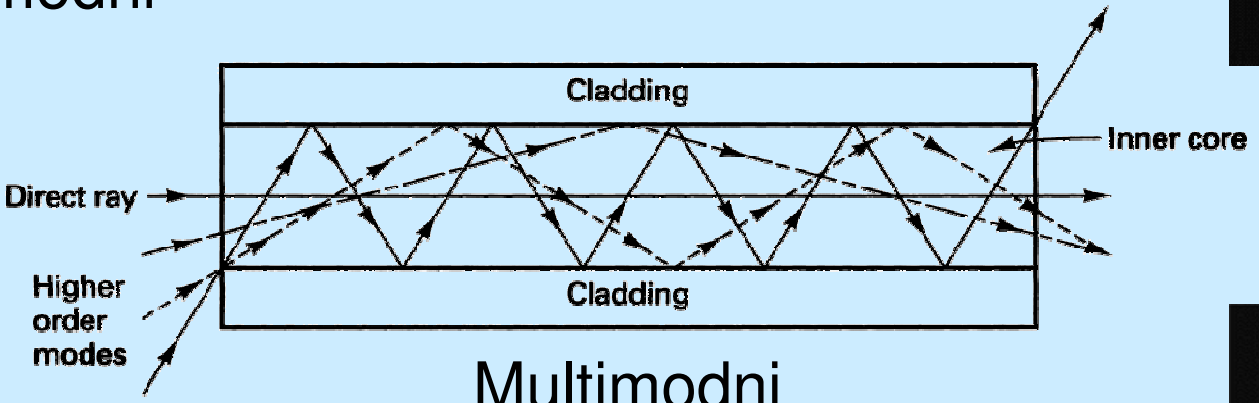


Konfiguracije optičkog vlakna: Modovi propagacije

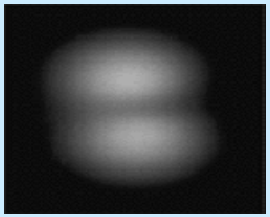


Jednomodni





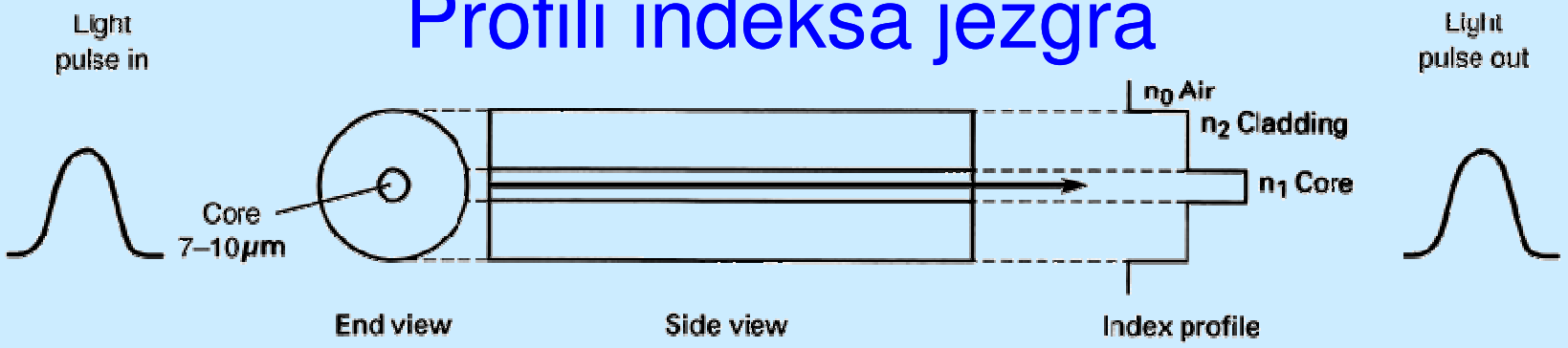
Multimodni



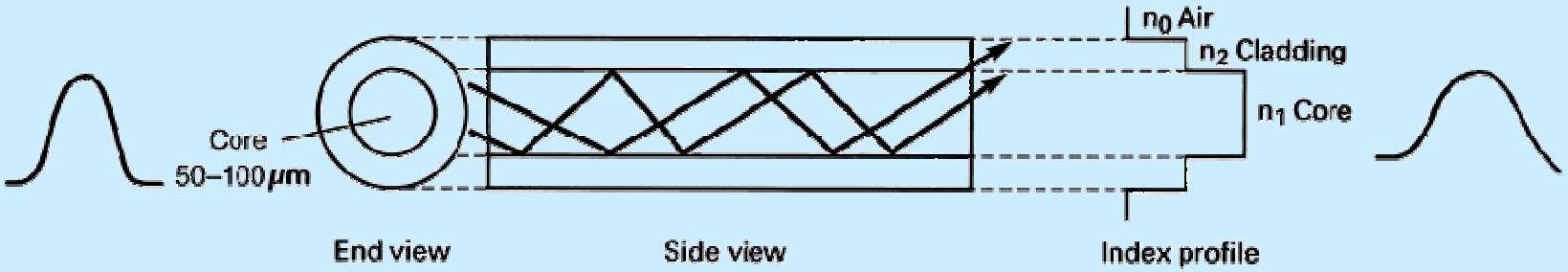
Broj modova

$$N \approx \left(\frac{\pi d}{\lambda} \sqrt{n_1^2 - n_2^2} \right)^2$$

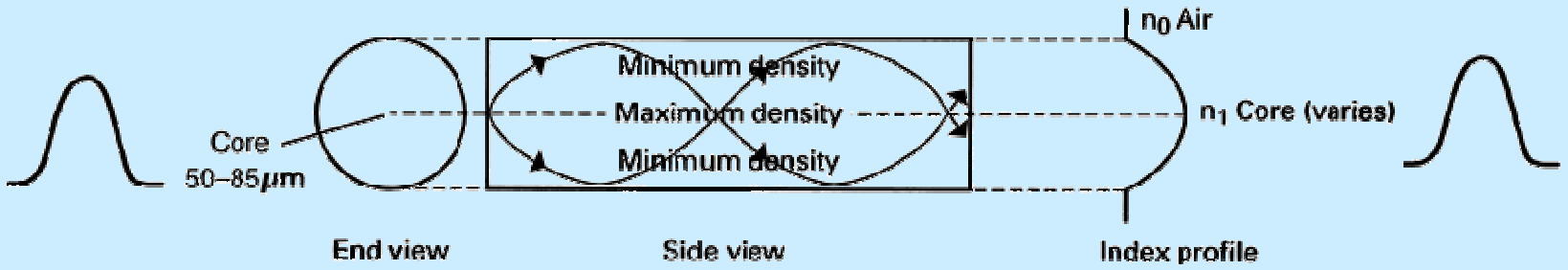
Profili indeksa jezgra



Single-mod step indeks



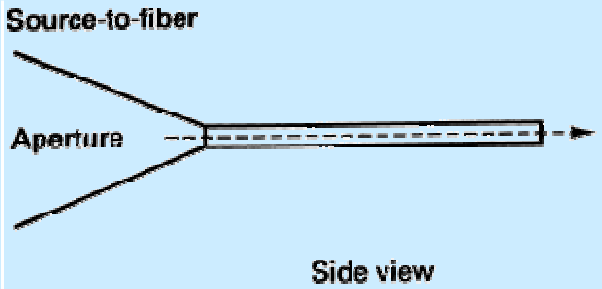
Multimodni step indeks

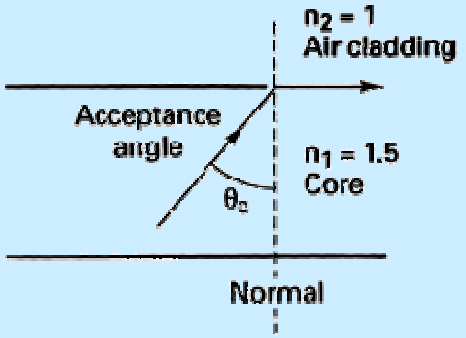


Multimodni gradijentni indeks

Omotač

Vazdušni omotač





$\theta_c = \sin^{-1} n_2/n_1$

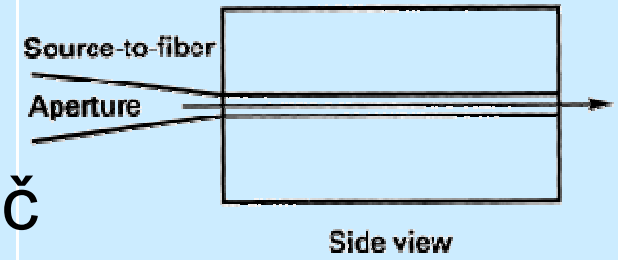
$\theta_c = \sin^{-1} 1/1.5 = 41.8°$

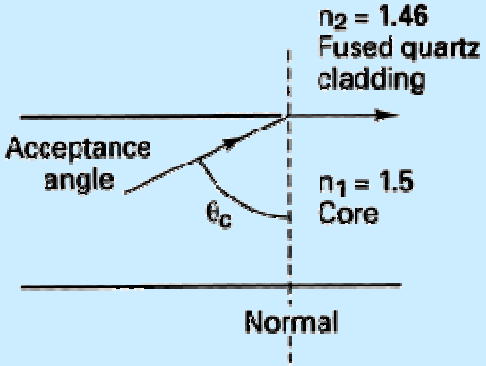
Acceptance angle $= 90 - \theta_c = 48.2°$

(a)

Stakleni omotač

- jači
- manji prihvatljivi ugao



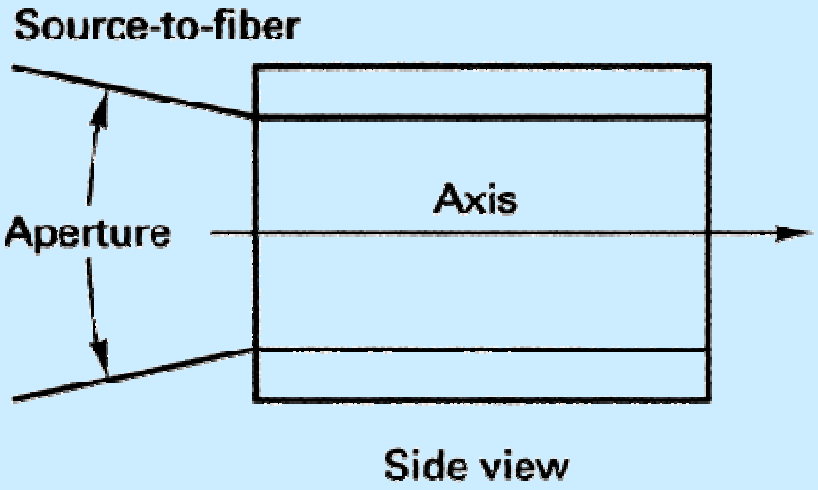


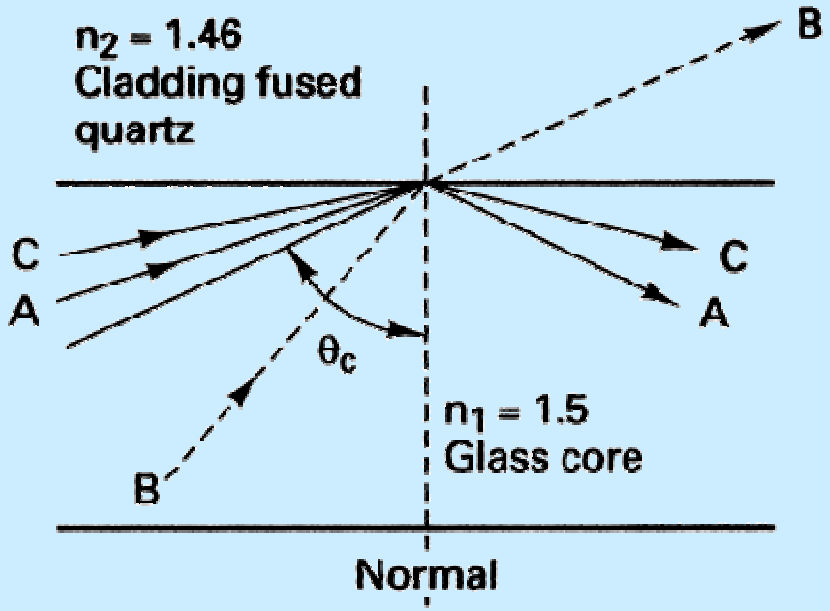
$\theta_c = \sin^{-1} n_2/n_1$

$\theta_c = \sin^{-1} 1.46/1.5 = 76.7°$

Acceptance angle $= 90 - \theta_c = 13.3°$

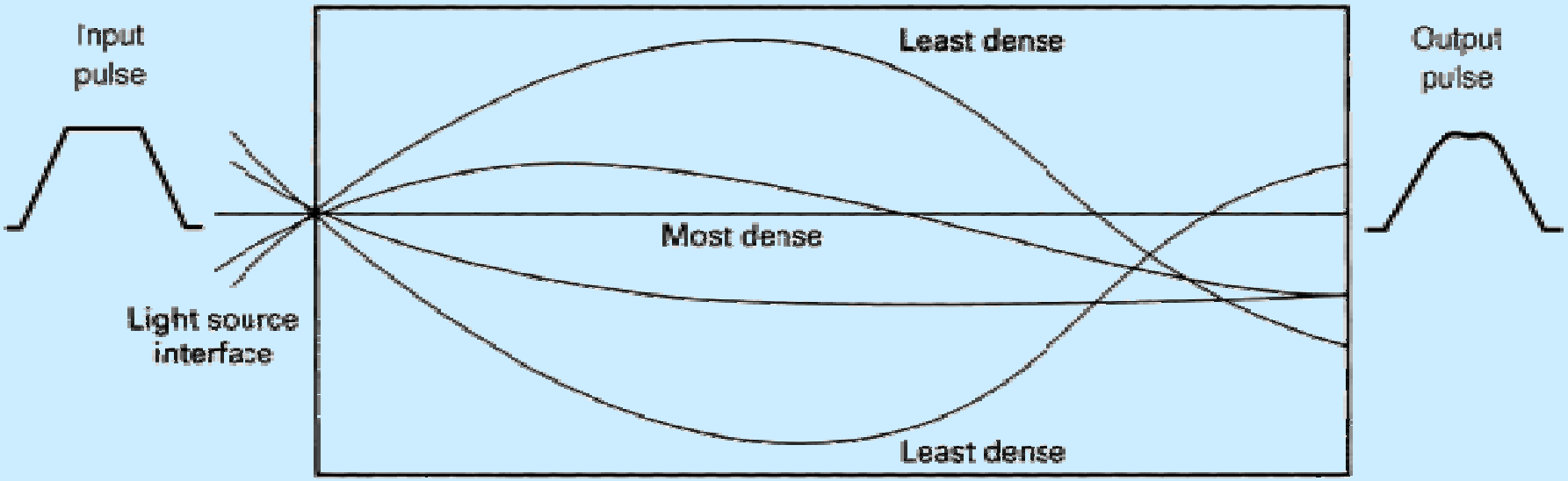
Multimodni step indeks optičkog vlakna





Zraci se prostiru različitim putanjama

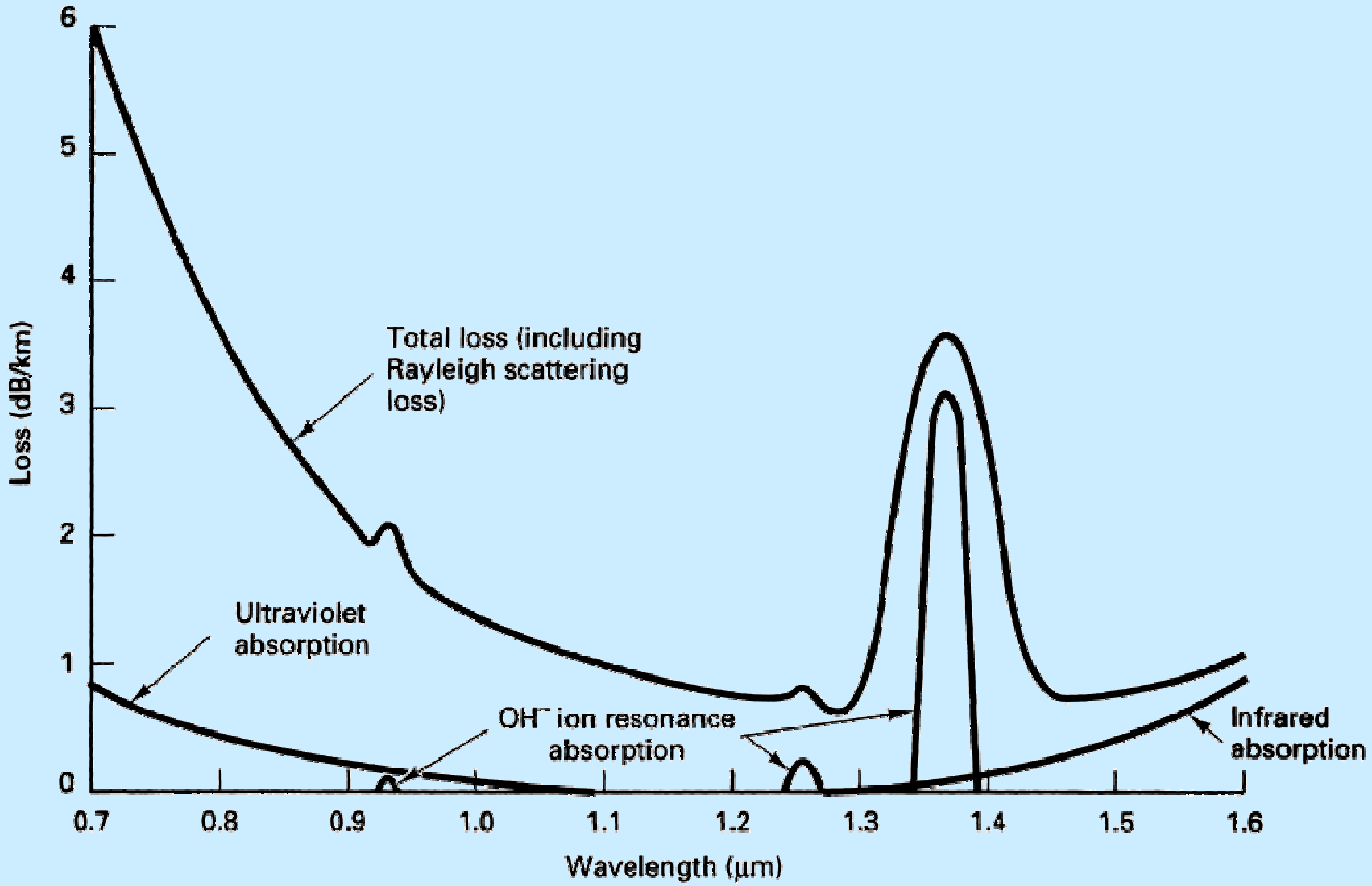
Multimodni gradijentni indeks optičkog vlakna



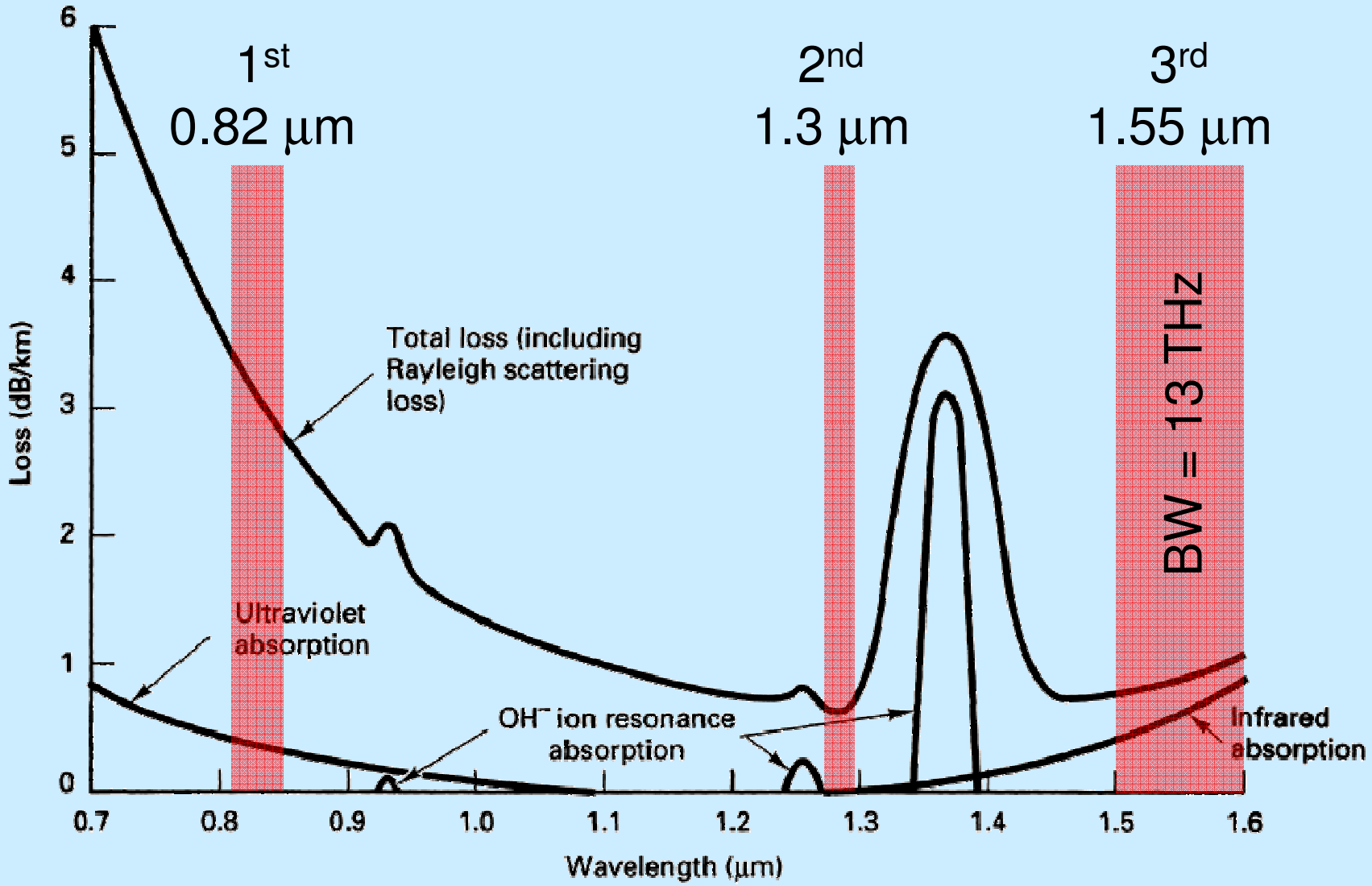
Poređenje tipova optičkih vlakana

- Jednomodni step-indeks
  - \+ minimalna disperzija (nema modalne disperzije)
  - \- mala NA
  - \- skup
- Multimodni step-indeks
  - \+ relativno jeftin
  - \+ velika NA
  - \- multimodna disperzija
- Multimodni gradijentni-indeks
  - \- skupo
  - \+ velika NA
  - \+ mala multimodna disperzija

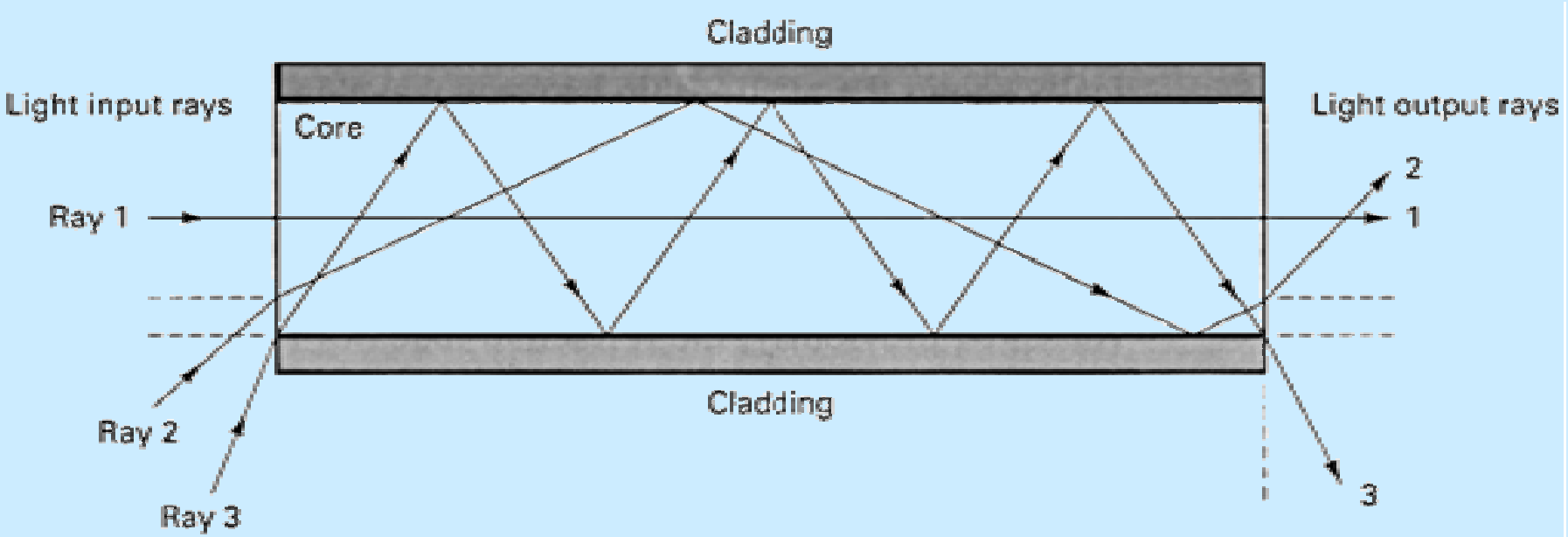
Gubici u optičkom kablu



Gubici u optičkom kablu



Multimodno step-indeks vlakno

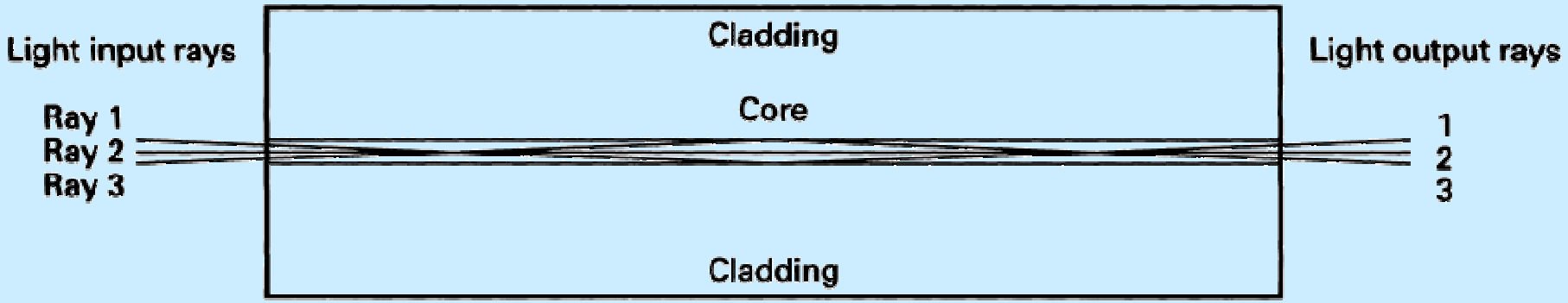


Modalna disperzija

Proizvod propusnog opsega i dužine

BLP = 20 Mb/s x km

Singl-mod step-indeks vlakno

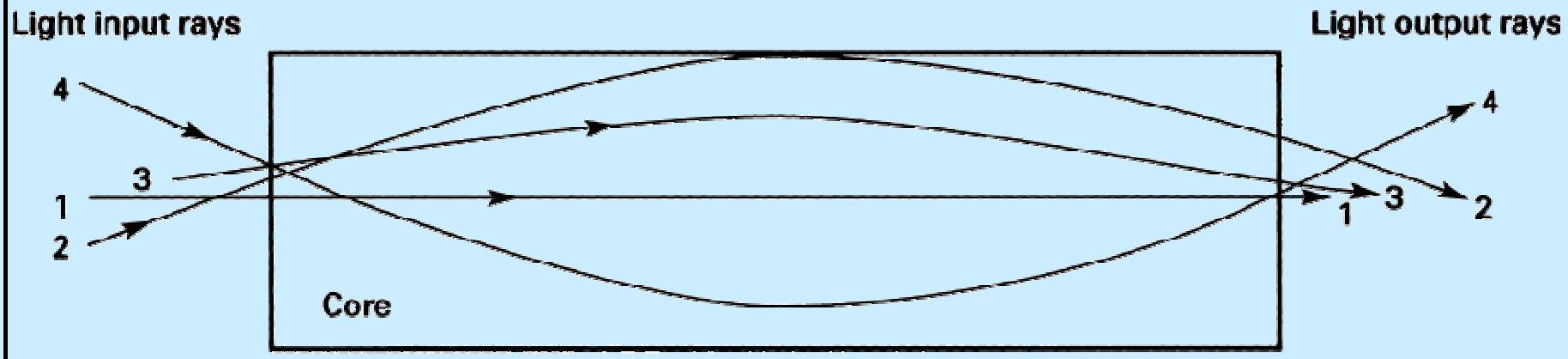


Samo jedan mod (jedan ugao) se prostire unutar vlakna!!!!!

Nema modalne disperzije

3 THz propusni opseg u 1.55 μm prozoru (1.5 – 1.6)

Multimodni gradijentni indeks

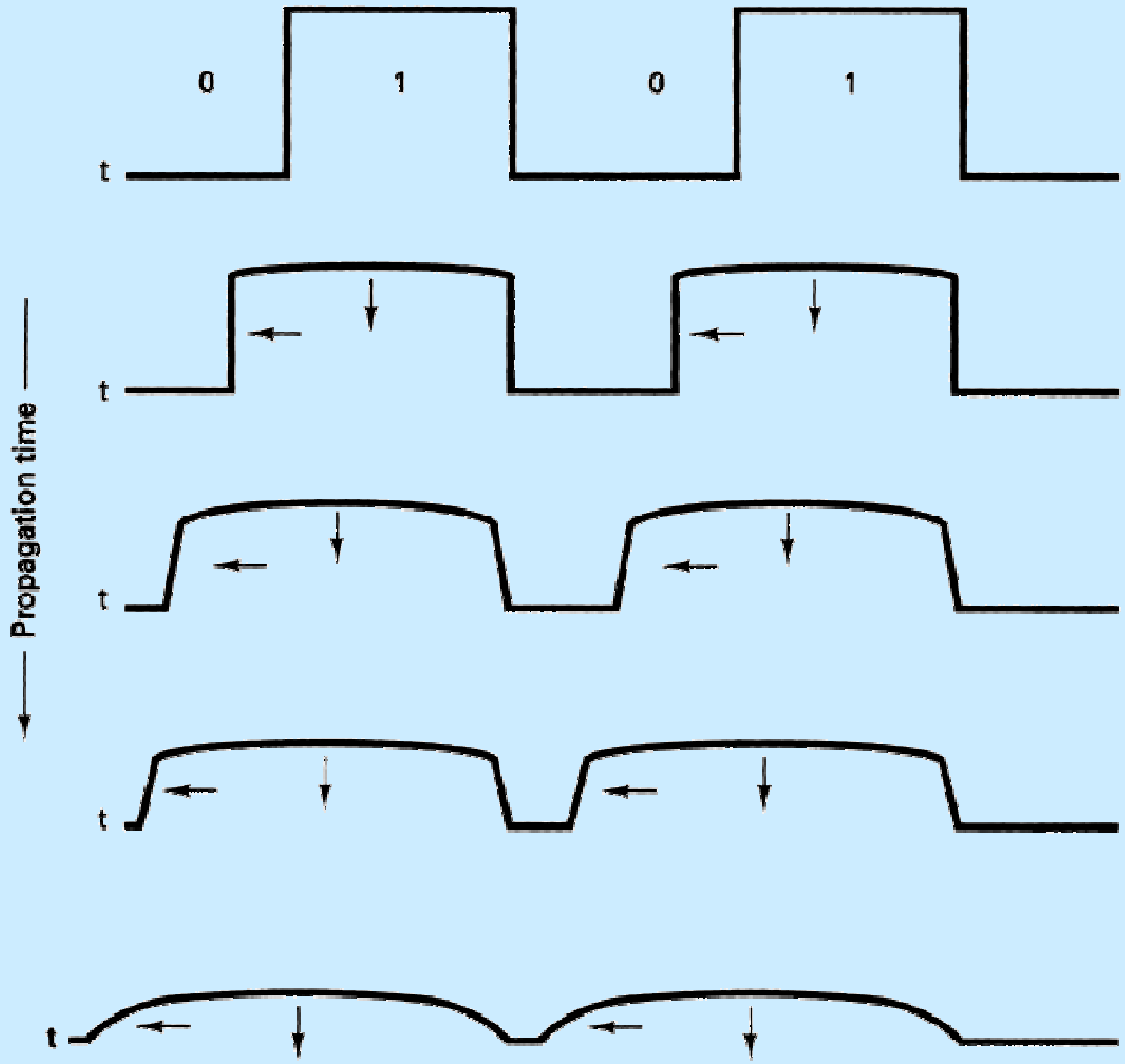


Više uglova (više modova) !!!!!

Mala modalna disperzija

2 Gb/s x km

Prostiranje impulsa



Originalni biti

Teško je razlikovati bite

Gubici i distorzija u optičkom kablu

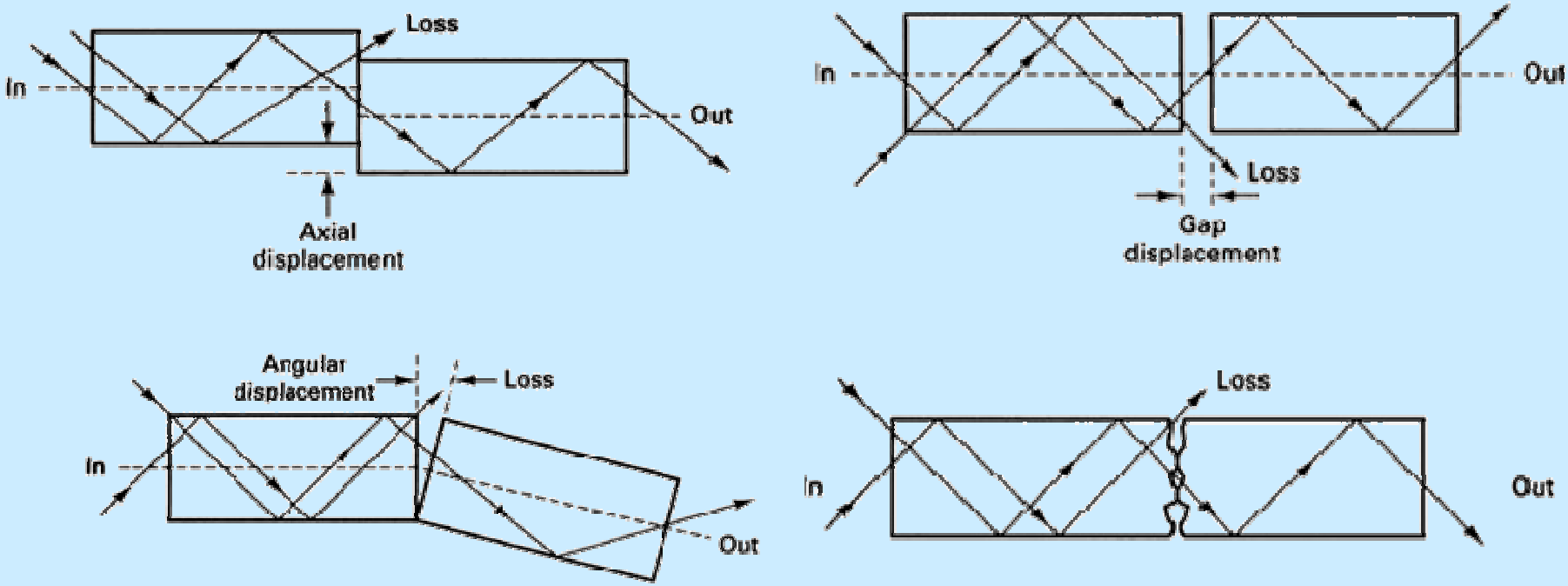
Gubici usljed apsorpcije
- ultraljubičasta apsorpcija
- infracrvena apsorpcija
- ION rezinantna apsorpcija (OH^-)

Gubici materijala (Rayleigh, Scattering Losses)
- submikroskopske neregularnosti

Radijacioni gubici
- Bending loss
- Microbending

Modalna disperzija
- samo u multimodnim vlaknima

Gubici usljed povezivanja (spajanja)



- Loss splice (or fuse) < 0.02 dB
- Gubici konektora ± 0.5 dB

Pregled

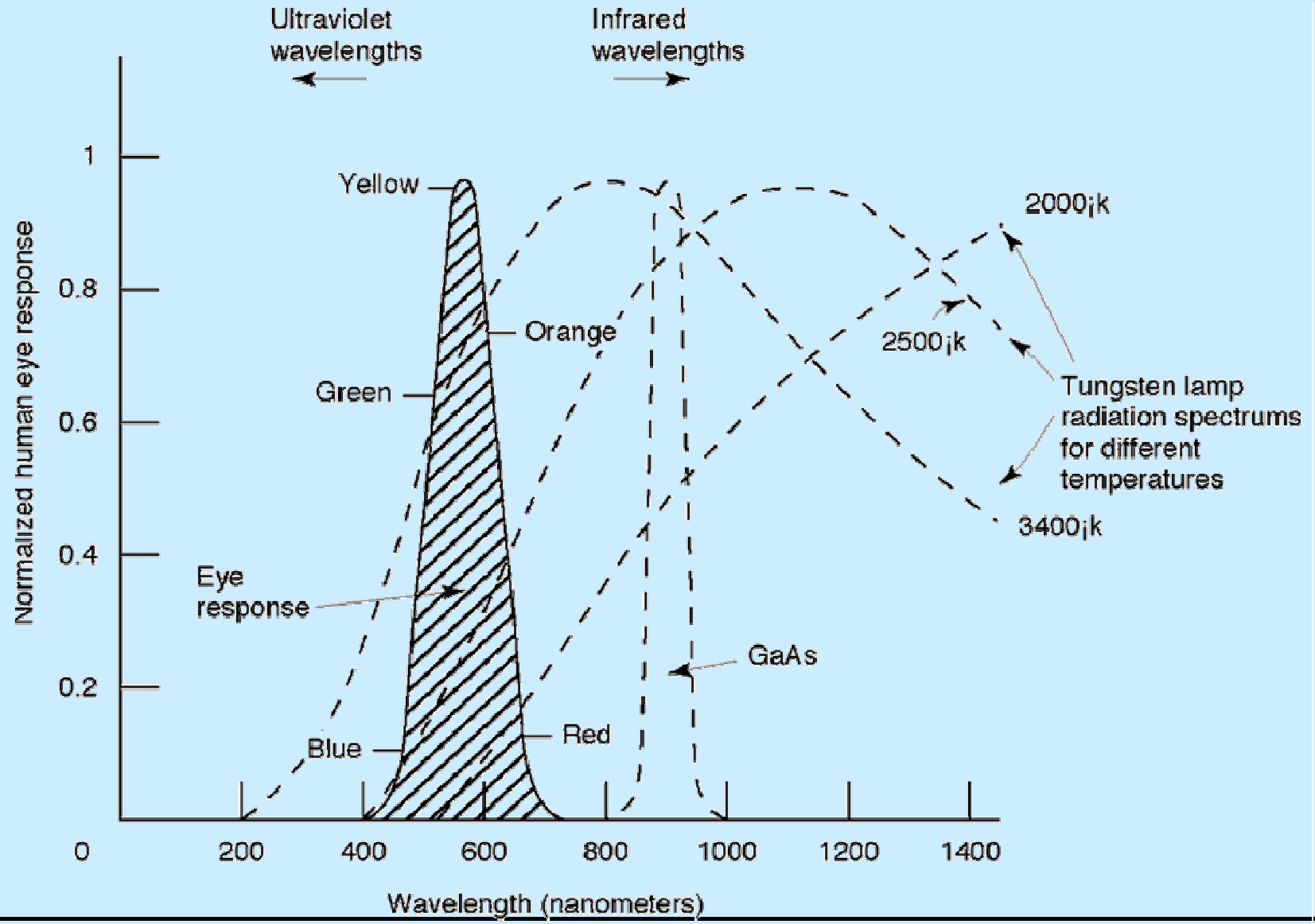
Multimodna vlakna

- primjena u lokalnim računarskim mrežama (LAN)
- kapacitet je ograničen zbog intermodalne disperzije:
  - 20 Mb/s x km (step index)
  - 2 Gb/s x km (gradijentni index)

Jednomodna vlakna

- koriste se na dugim rastojanjima
- propusni opseg 13 THz u 1.5 – 1.6 μm prozoru
- kapacitet je ograničen zbog hromatske disperzije
- Disperzija (D) može biti pozitivna, negativna ili nula
- $D = 0$ @ 1.3 μm u standardnim silicijumskim vlaknima
- Disperzija u talasovodu može se regulisati pomoću indeksnog profila
  - Dispersion shifted fiber (DSF): D = 0 @ 1.55 μm

Izvori svjetlosti



Izvori svjetlosti

Sijalica (Tungsten)

- spektralna širina > 1000 nm

LED dioda

- spektralna širina 30 – 50 nm

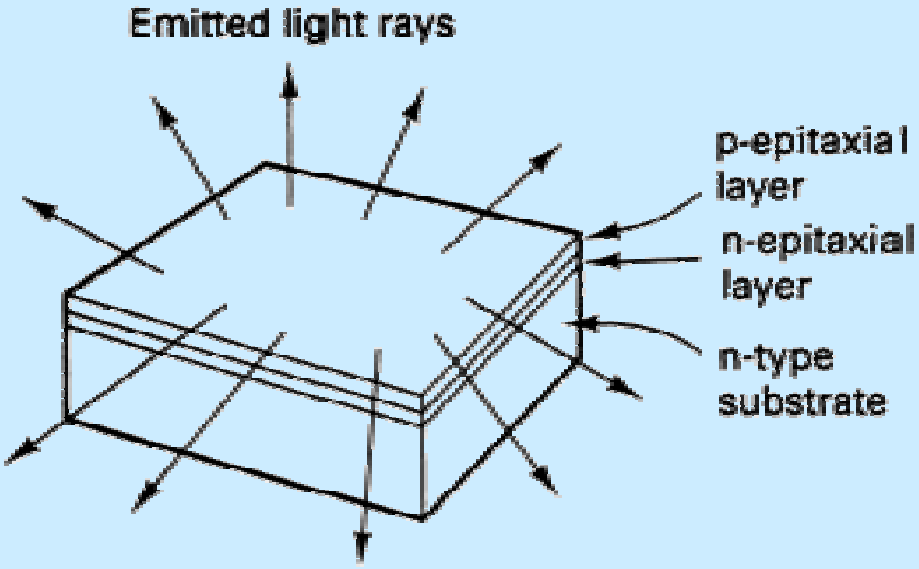
ILD dioda

- spektralna širina 1 – 3 nm

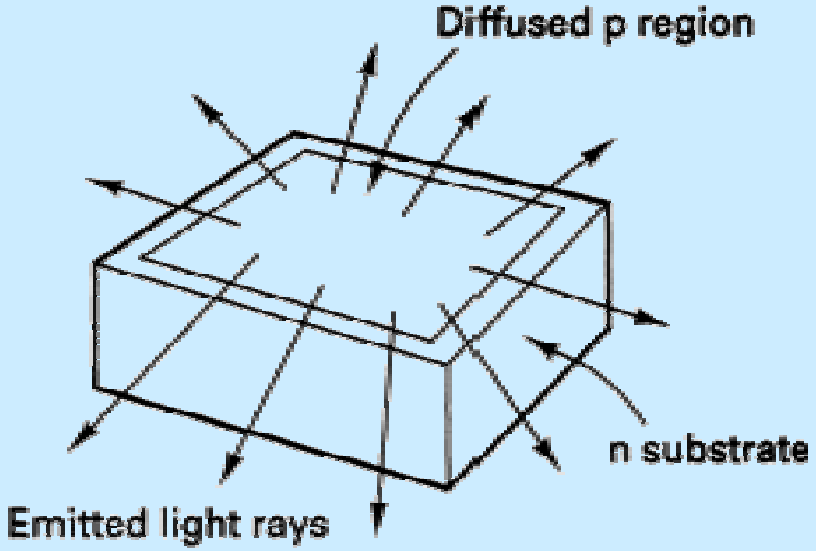
LED

Jednospojni LED

- izlazna snaga 2 mW (3 dBm)



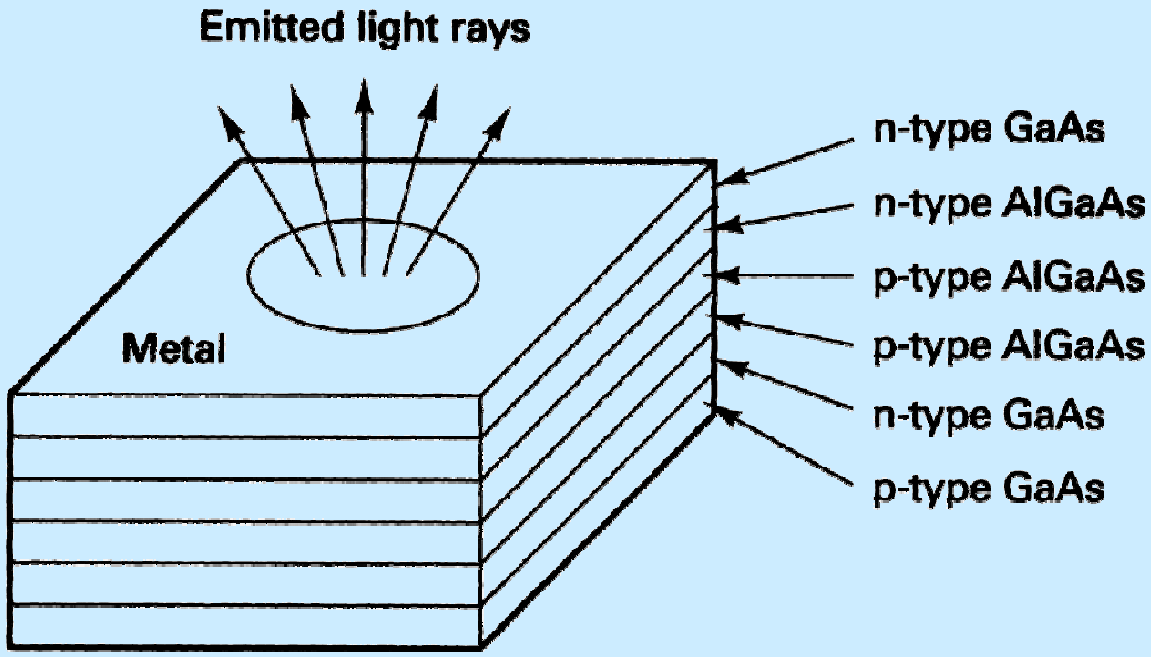
silicon-dopirani galijum arsenit



planarna difuzuja

----- neusmjereno svjetlosno zračenje

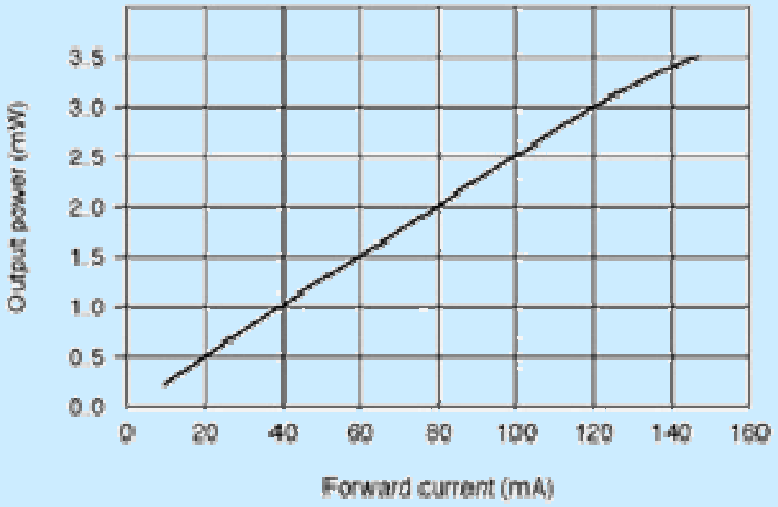
Višespojni LED

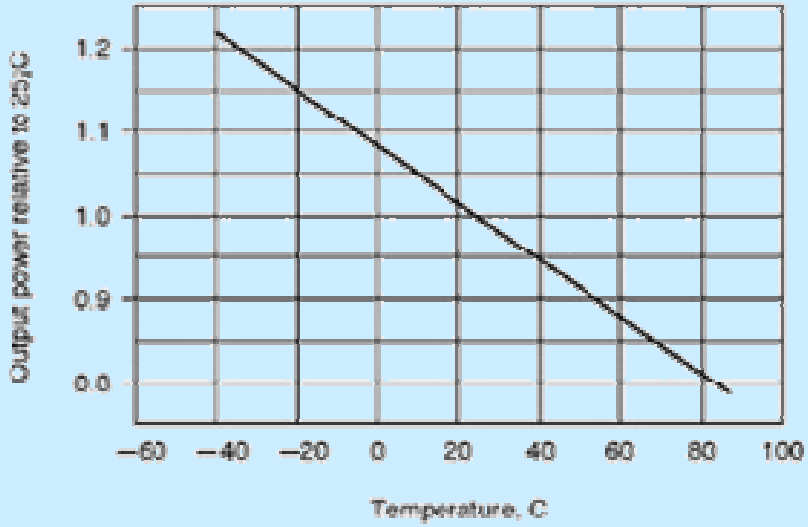


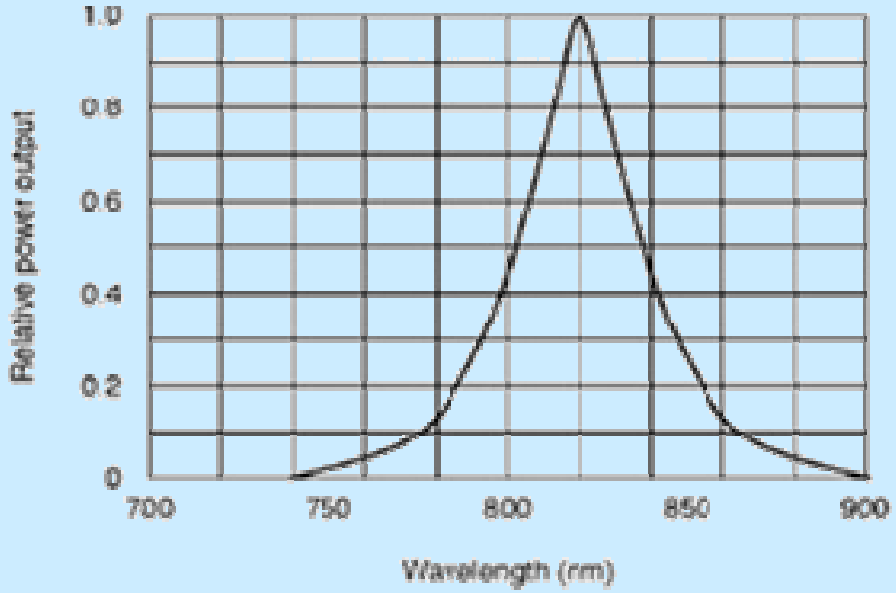
Prednosti:

- povećanje gustine struje
- manja emisiona površina → jednostavniji uvod svjetlosti u vlakno
- manja efektivna površina ima manju kapacitivnost → veće brzine prenosa

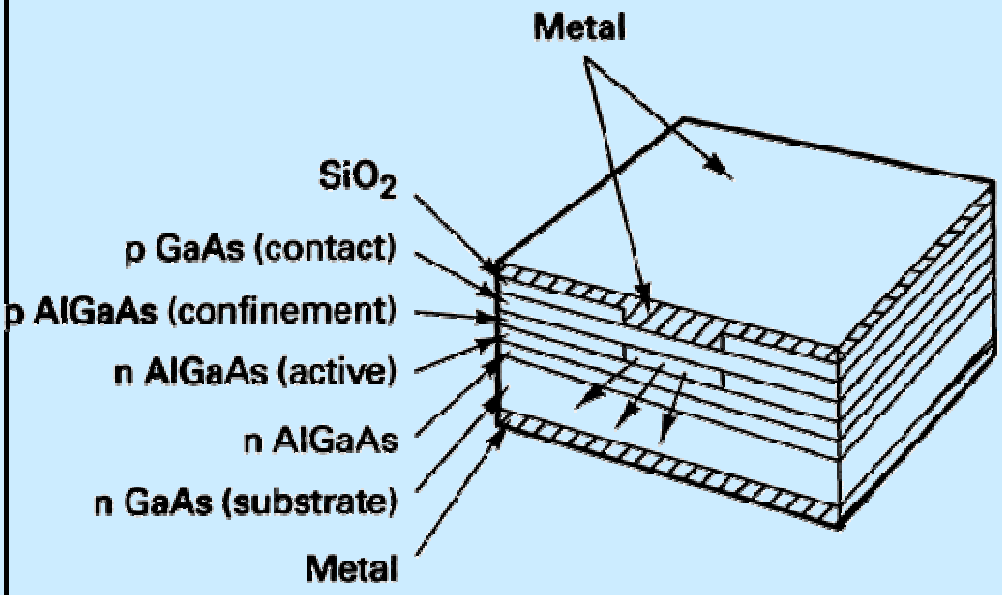
Karakteristike LED

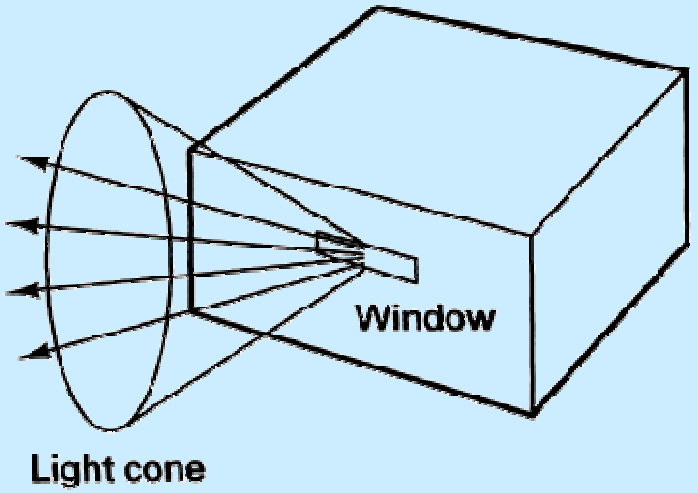






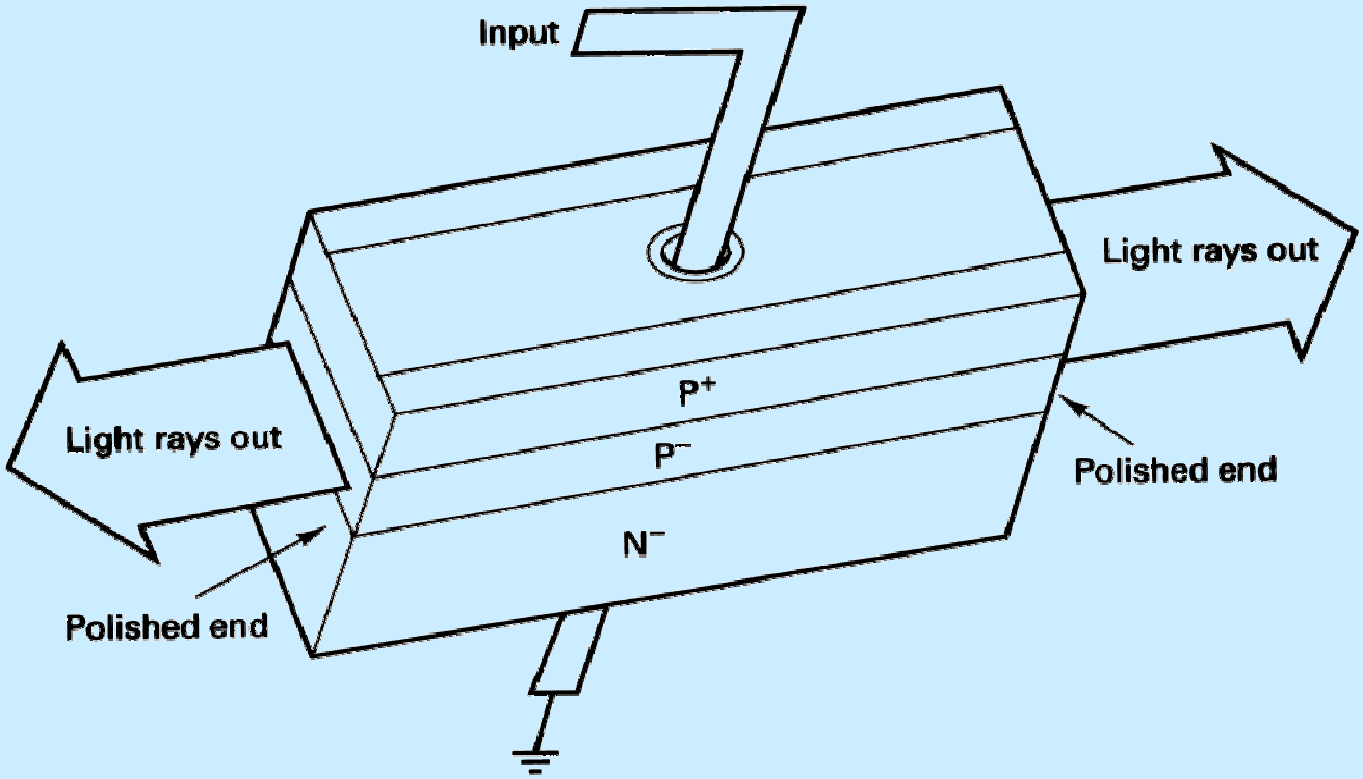
Edge-emitting LED





Veća usmjerenost svjetlosnog snopa

Injection laser diode (ILD)

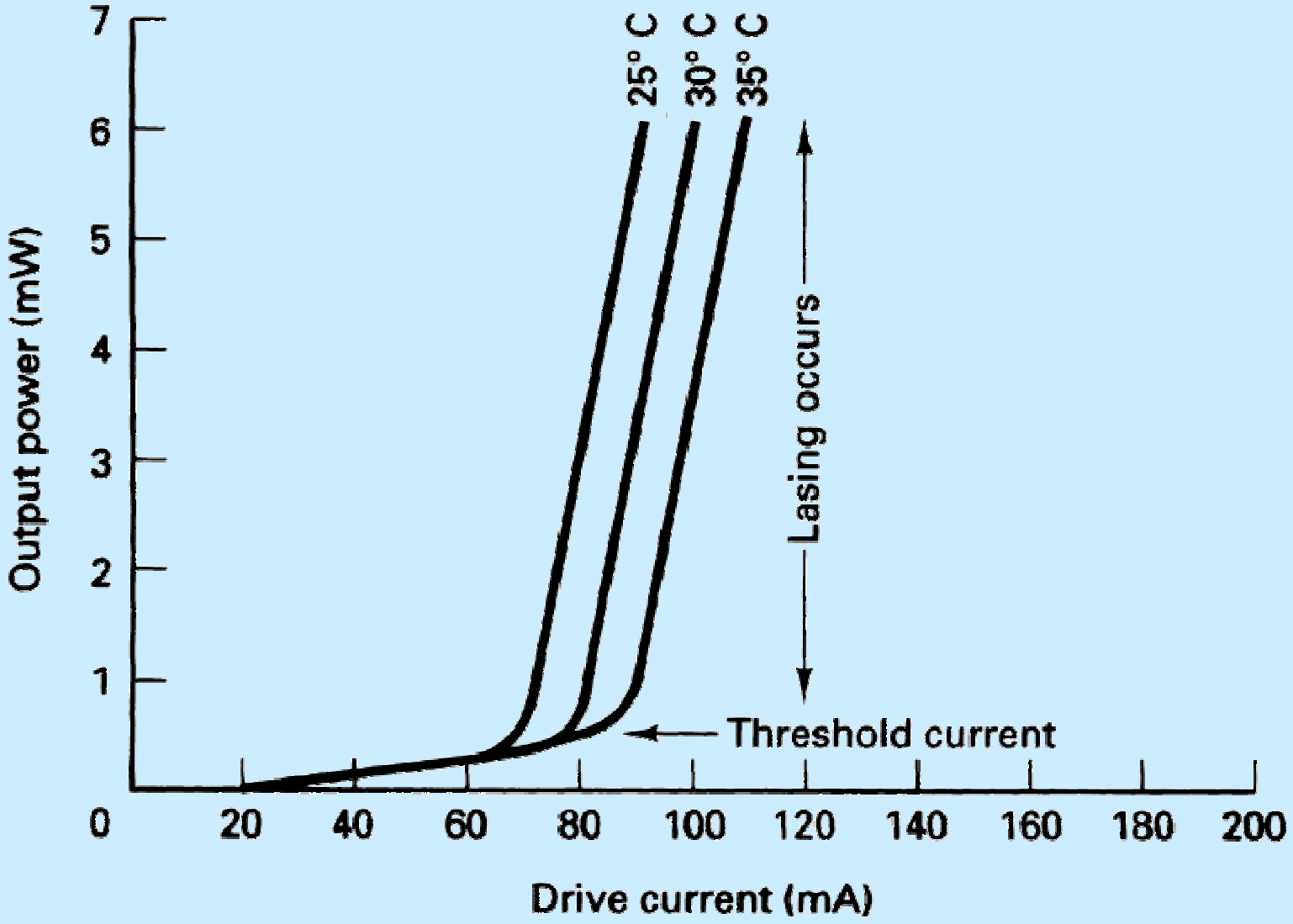


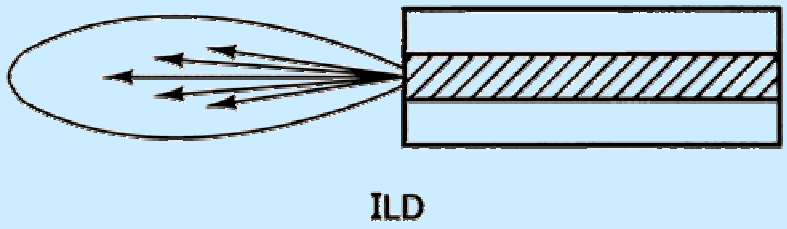
Poređenje ILD sa LED

- koherentna svjetlost
- veća izlazna snaga
- veće bitske brzine
- monohromatska svjetlost: manja disperzija

- 10 puta skuplje od LED
- kraći vijek trajanja
- veća temperaturna zavisnost

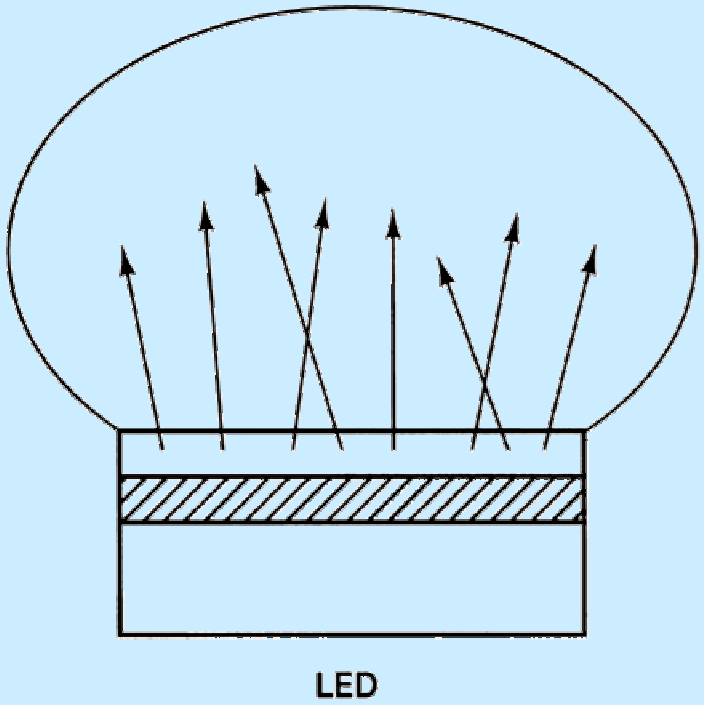
Izlazna snaga za ILD





Usko-koncentrisan snop

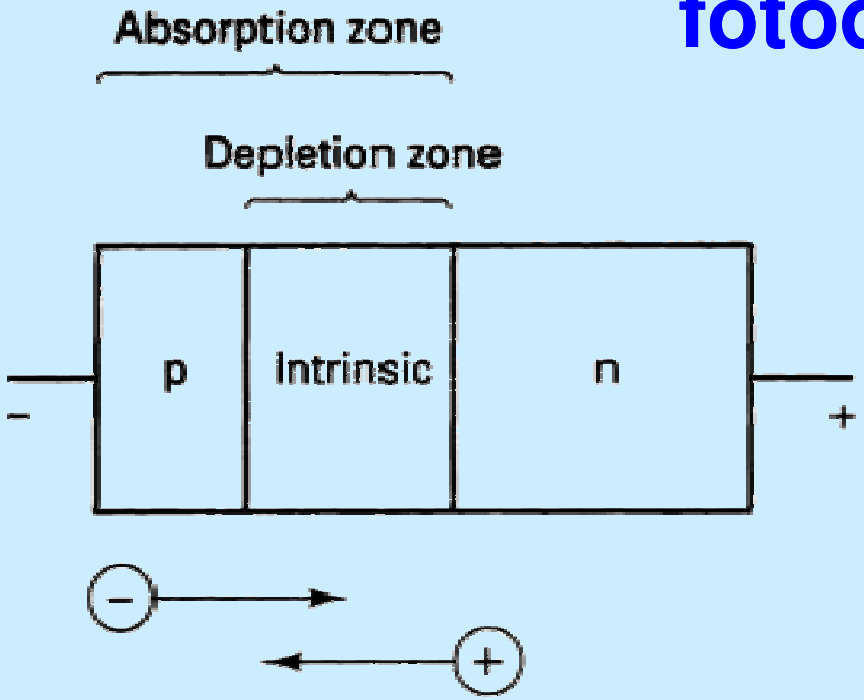
Veća usmjerenost zračećeg snopa

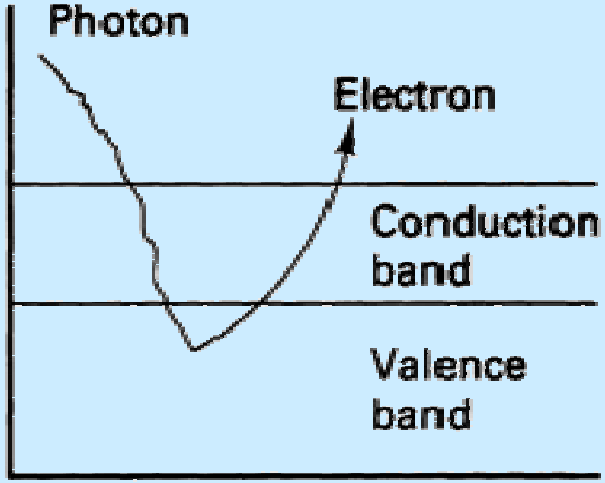


Širok snop

Manje usmjeren zračeći snop

Detektori svjetlosti: PIN fotodiode





Photon adds sufficient energy to allow electron to move from valence band to conduction band

Energetski gap za silicijum

$$E_g = 1.12 \text{ eV} = 1.79 \cdot 10^{-19} \text{ J}$$

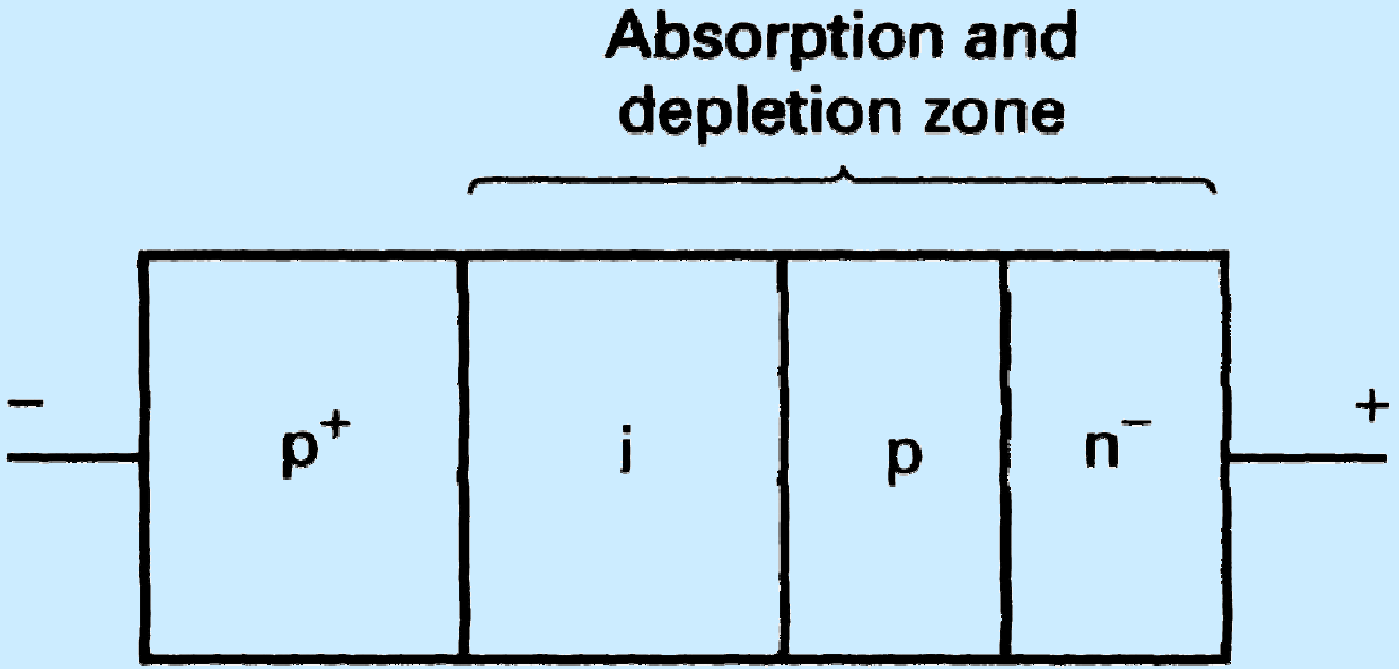
Energija fotona

$$E_p = hf$$

$\lambda \geq 1109$ nm

h = Plankova konstanta = 6.63 10^{-34} J/Hz

Avalanche fotodioda



Avalanche efekat

APD je osjetljivija od PIN diode

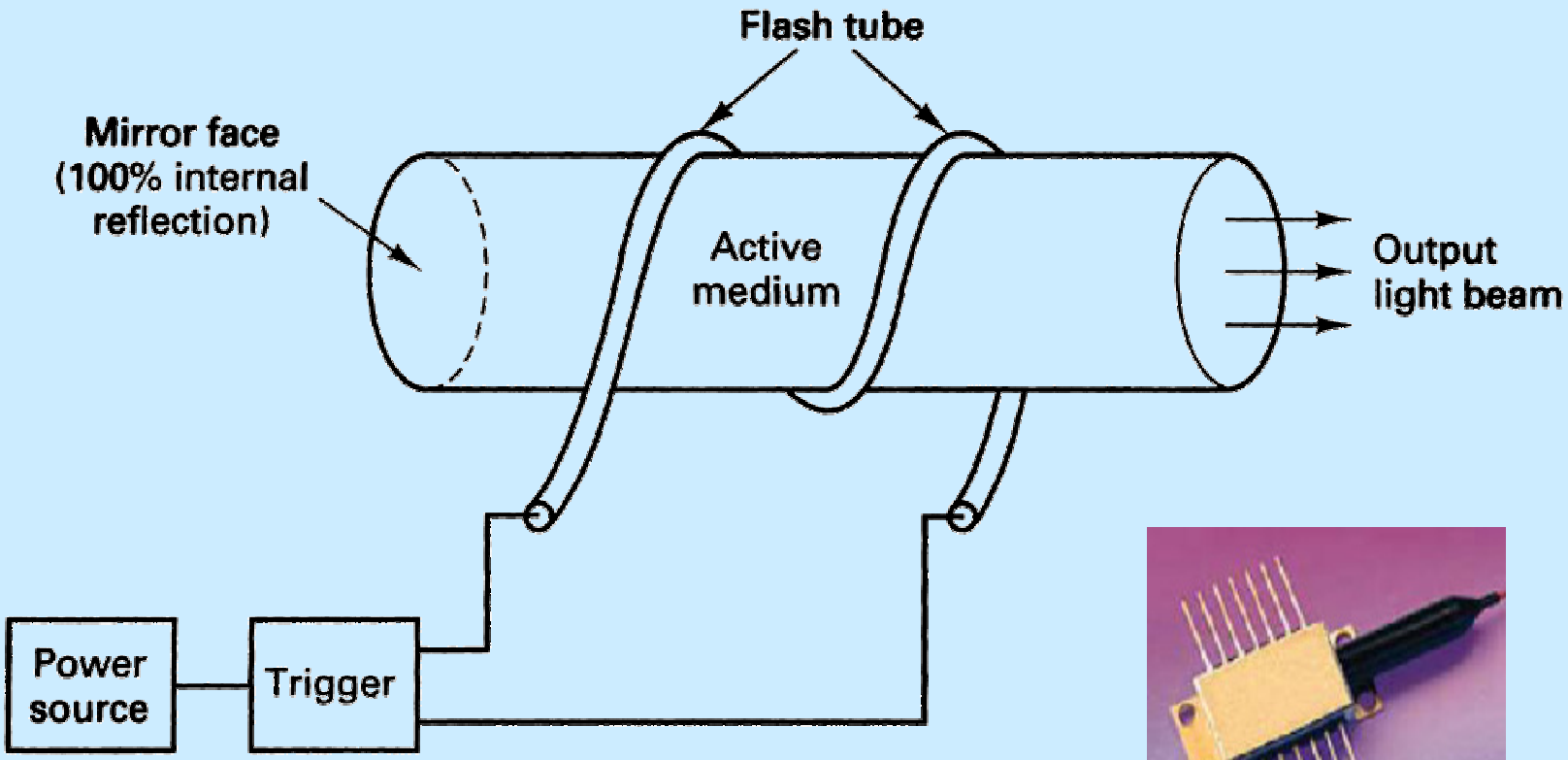
Karakteristike detektora svjetlosti

R: mjera efikasnosti konverzije fotodetektora

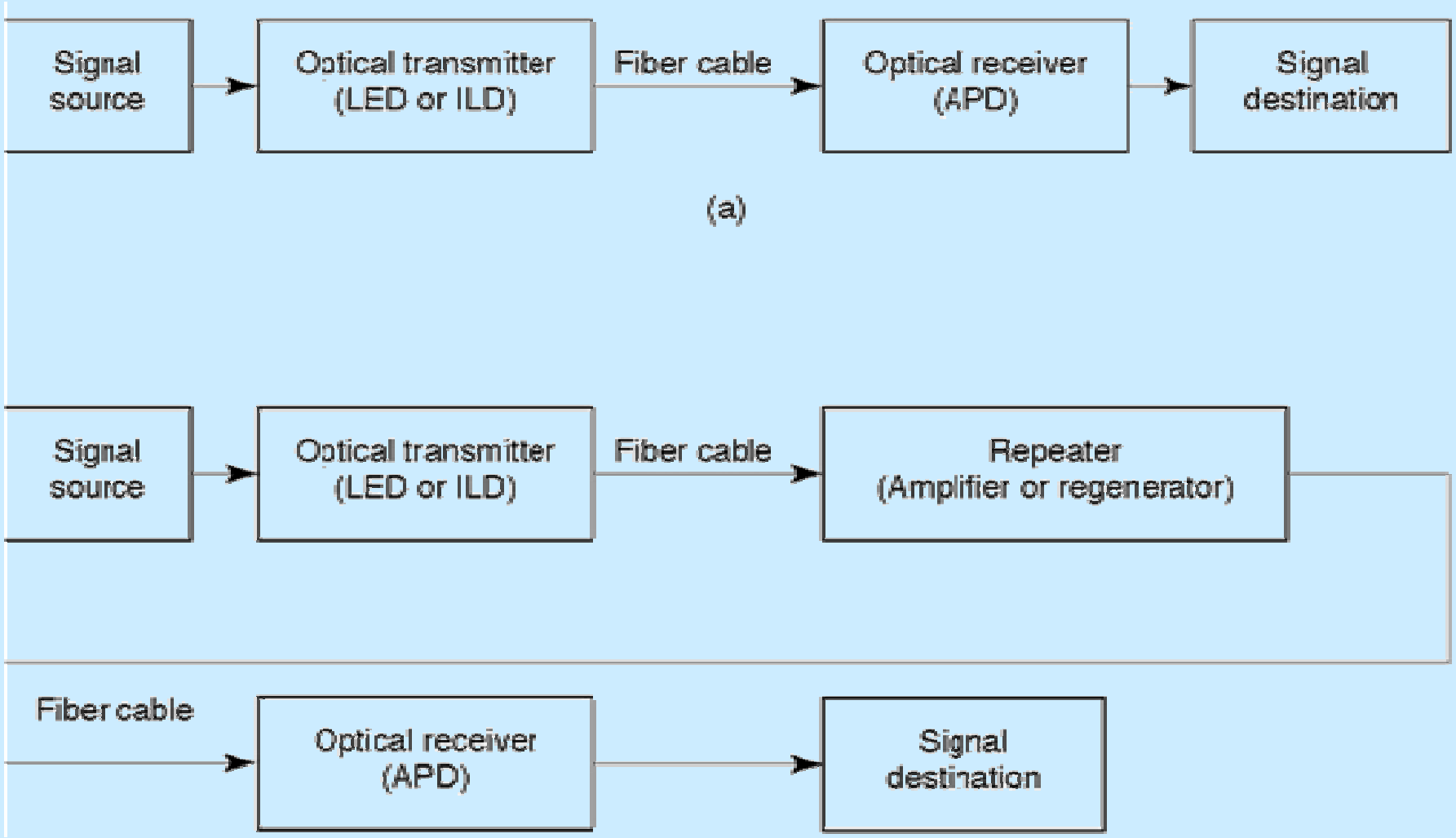
$$R = \frac{e\eta G}{h\nu} \quad [\mathrm{A/W}]$$

e = naelektrisanje elektrona (1.6 10^{-19} Cu)
ν = frekvencija svjetlosti
η = kvantna efikasnost
G = interno pojačanje (>1 for APD)

LASER


Flash tube
Mirror face
(100% internal
reflection)
Active
medium
Output
light beam
Power
source
Trigger

Proračun gubitaka



Gubici

$$P_r = P_t - \textbf{gubici}$$

P_r = prijemna snaga (dBm)
P_t = predajna snaga (dBm)
$gubici$ = zbir svih gubitaka (dB)

- gubici u kablu
- gubici konektora
- gubici na spoju izvor-kabl
- gubici na spoju kabl-svjetlost
- gubici usljed povezivanja opt. vlakana
- povezivanje kablova

P_r mora biti veće od praga osjetljivosti prijemnika

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