Optoelectronică, structuri şi tehnologii

Curs 2

2014/2015

Cuprins

- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire – splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
- **Emiţătoare optice** (LED şi dioda laser – realizare fizică şi functionare)
- **Receptoare optice** (dioda PIN, dioda cu avalanşă – realizare fizică şi functionare)
- **Amplificatoare transimpedanţă** (parametri, scheme tipice, TIA în buclă deschisă, cu reacţie, diferenţiale, control automat al câştigului)
- **Realizarea circuitelor pentru controlul emiţătoarelor optice (**parametri, scheme tipice, controlul puterii, multiplexoare**)**
- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

Fotografii

Studentii care au trimis fotografiile

Grupa: 5402

Nr.	Nume
1	APETRII MARIA

Grupa: 5403

Nr.	Nume
1	ALEXANDRESCU SEBASTIAN

Grupa: 5404

Nr.	Nume
1	APERGHIS MIHAI-ALIN

Grupa: 5405

Nr.	Nume
1	ANGHELUS MARIU

Studentii care inca nu au trimis fotografiile

Grupa: 5304

Nr.	Nume

Grupa: 5402

Nr.	Nume

Grupa: 5403

Nr.	Nume

Grupa: 5404

Nr.	Nume

Fotografii

FLORESCU DAN-CONSTAN
Date:
Grupa 5405 (2008)
Specializarea Tehnologii si sisteme
Marca 3275
Note obtinute
Disciplina Tip Data Descriere Nota Ob
DCMR Dispozitive si circuite de microunde pentru radiocomunic
Nota 19/06/2009 Nota finala 10
Exam 19/06/2009 Examen DCMR 9
Tema 05/06/2009 Proiect DCMR 10

FLORESCU DAN-CONSTA
Date:
Grupa 5405 (2008)
Specializarea Tehnologii si sister
Marca 3275
Detalii
Finantare Buget
Bursa Bursa de Studii
Domiciliu Iasi, judet Iasi
Promovare Promovare Integrala
Credite 60
Media 8.86

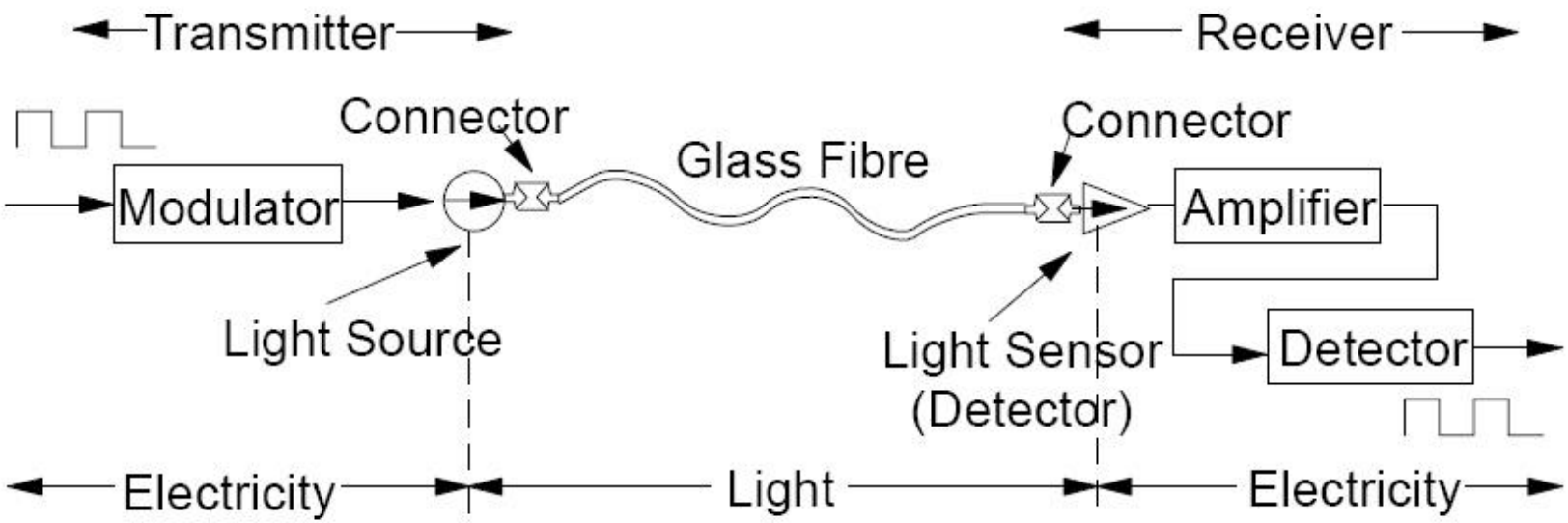
Examen

- subiecte individuale
- Note
  - 2007: 9.67±0.66/8.81±1.22
  - 2008: 6.24±1.36/ 4.82±2.10
  - 2009: 5.10±1.46
  - 2010: 3.89±1.32
- La prima aplicare (neanuntata)
  - 50% din studenti au parasit examenul in primele 10 minute
  - 50% din cei ramasi nu au promovat
  - promovabilitate totala 25%, rata contestatiilor: 0%
- Urmatoarele examinari (anuntate)
  - rata contestatiilor: 0%

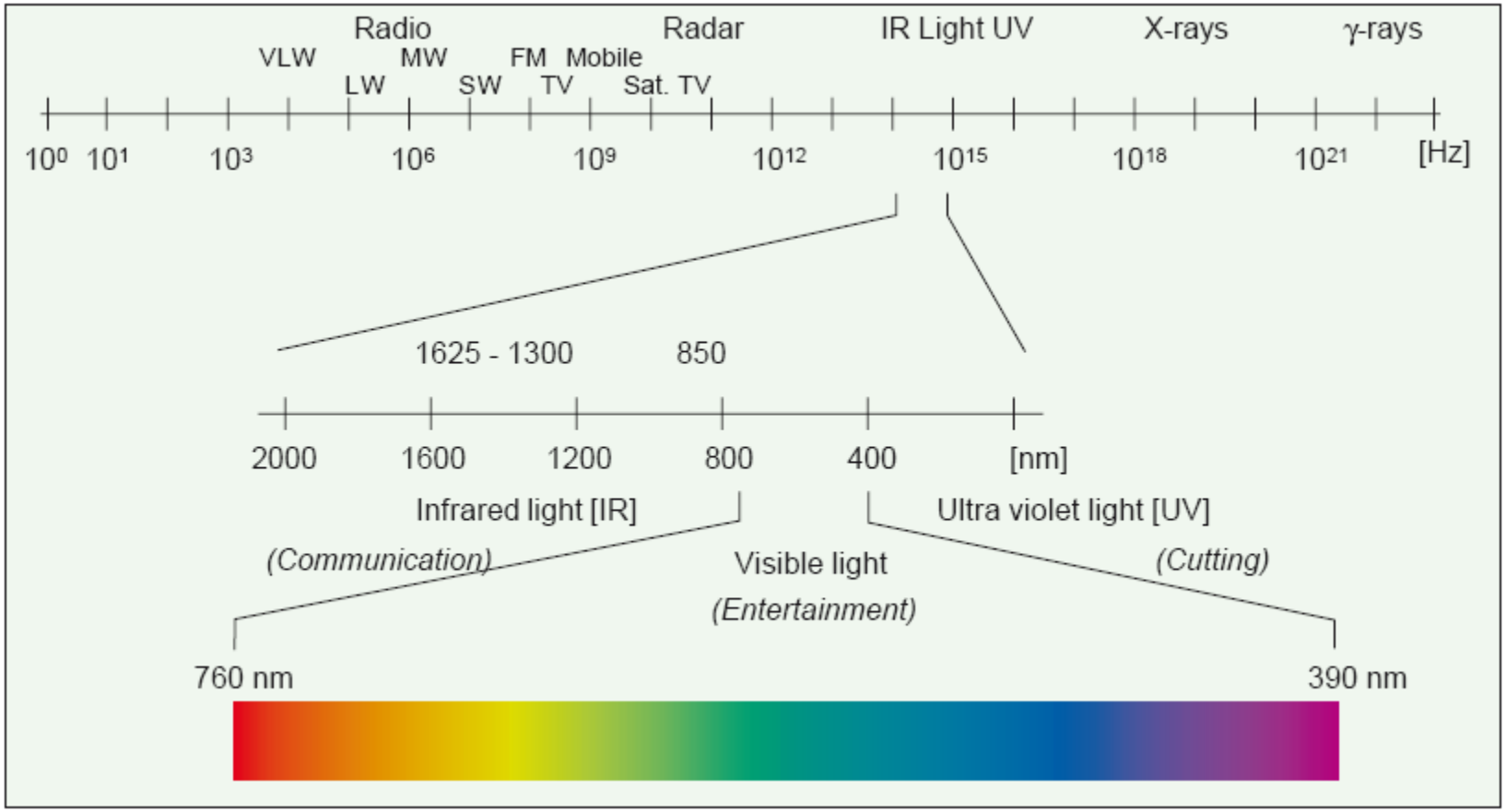
Introducere

Capitolul 1

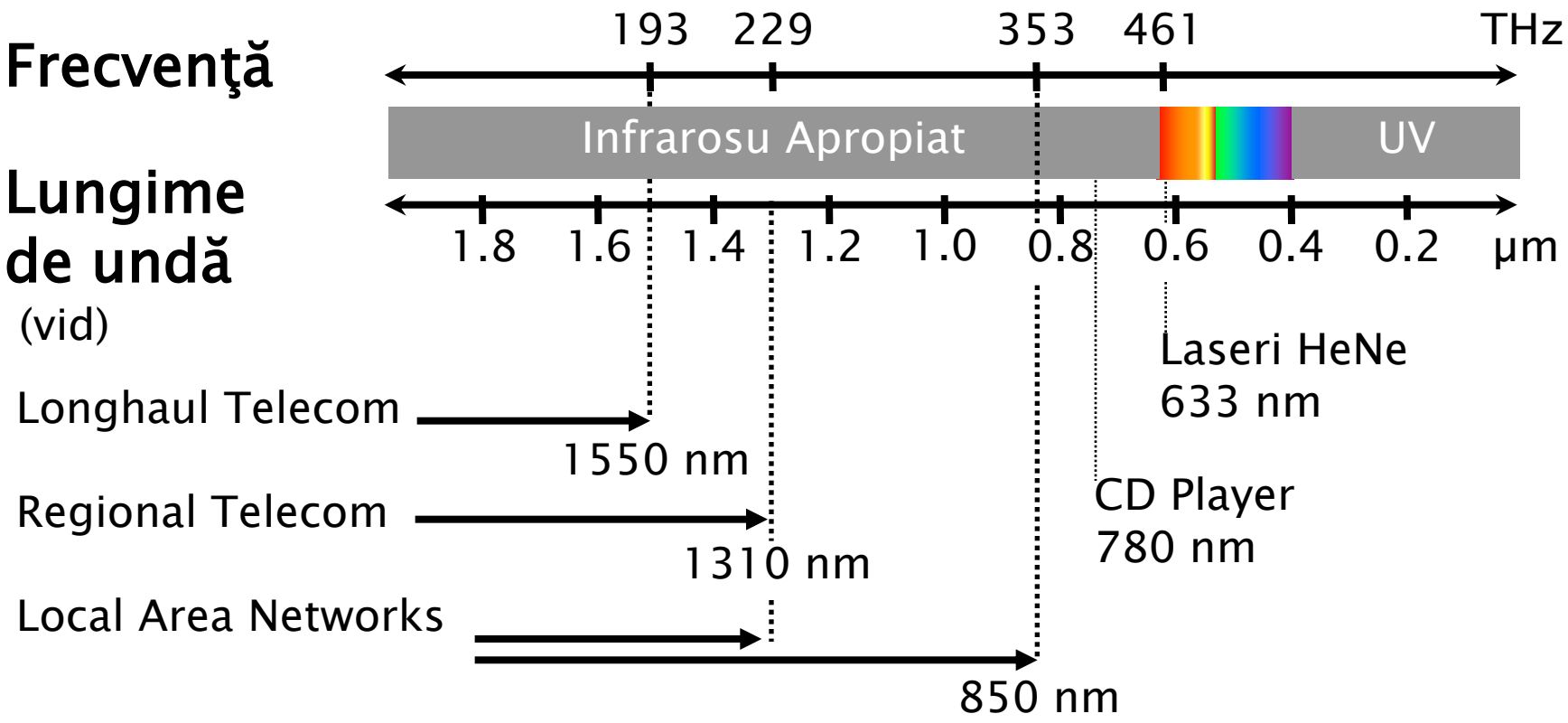
(Strict) Transmisia optica



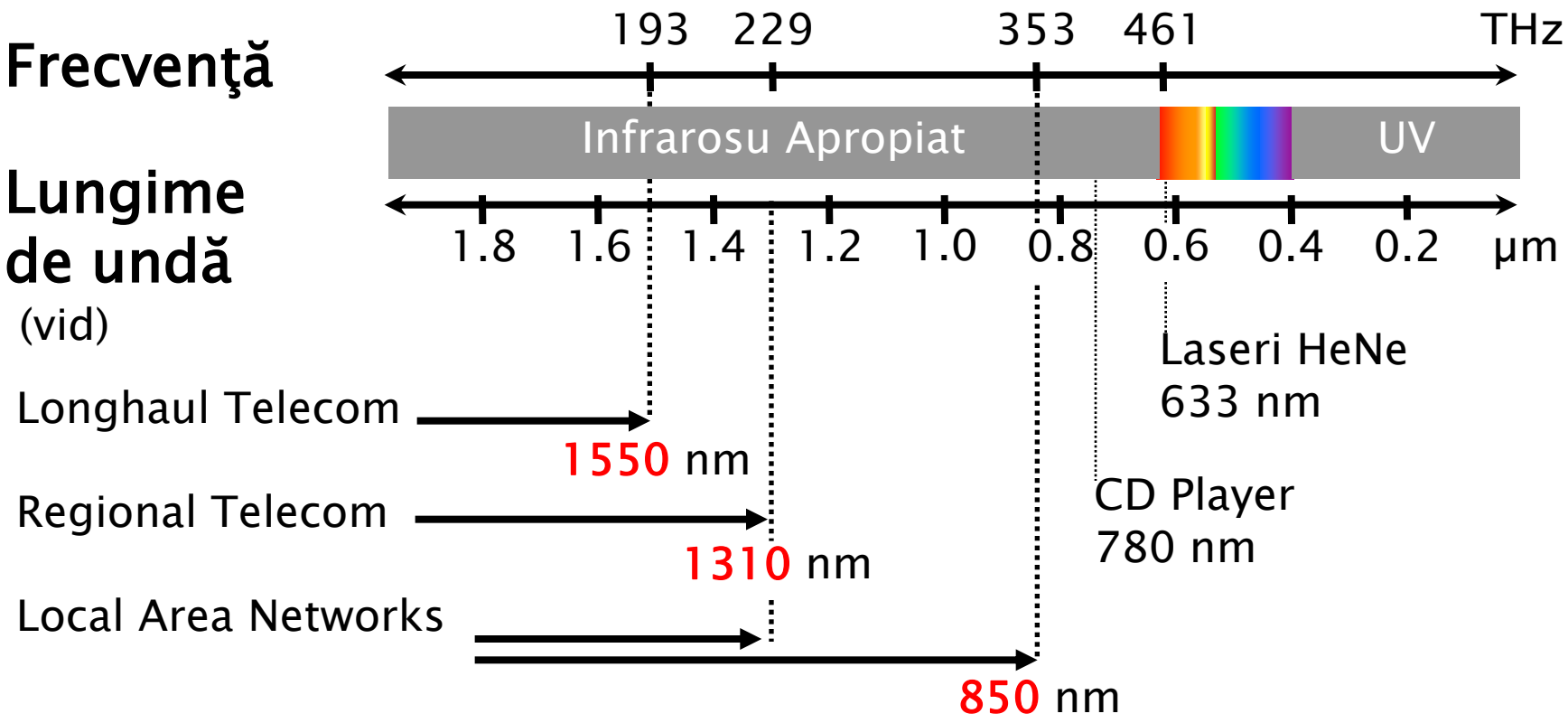
Spectrul electromagnetic



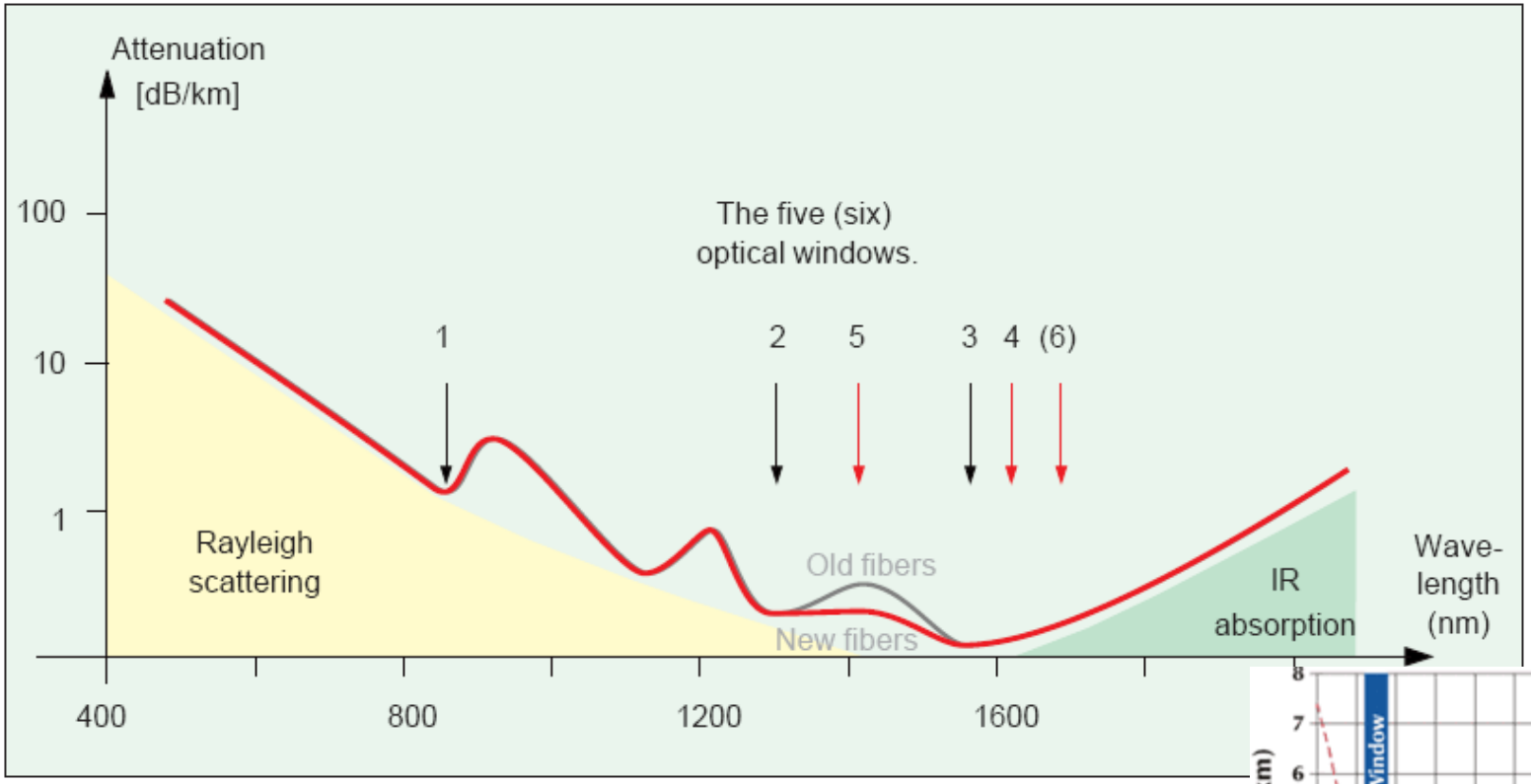
Benzi de lucru in comunicaţiile optice

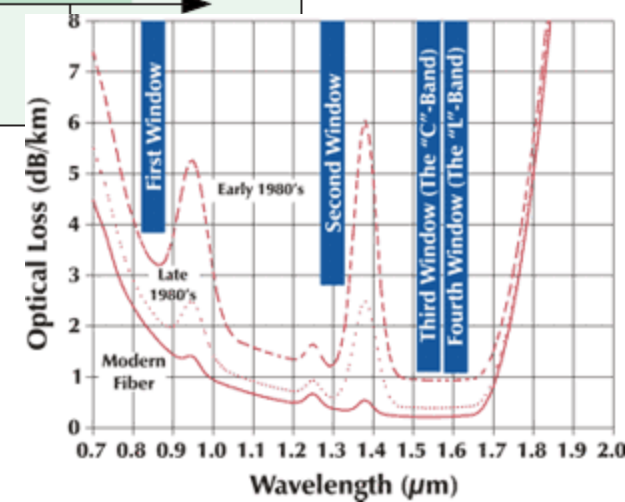


Benzi de lucru in comunicaţiile optice



Atenuarea în fibra optică (SiO_2)





850nm, 1310nm, 1550nm

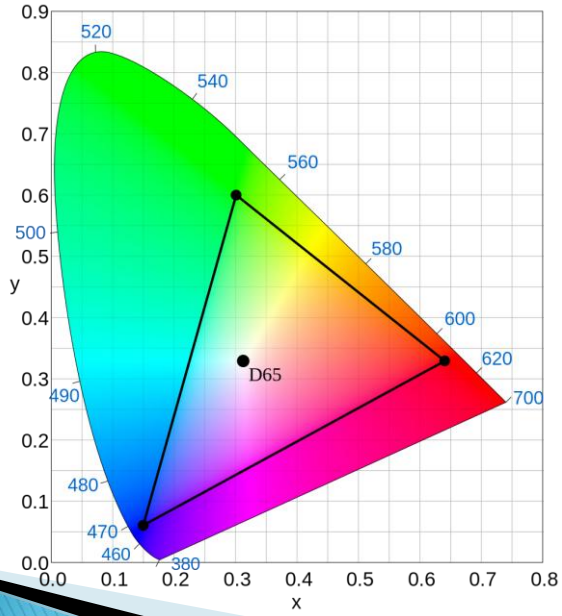
Aplicatii majore LED

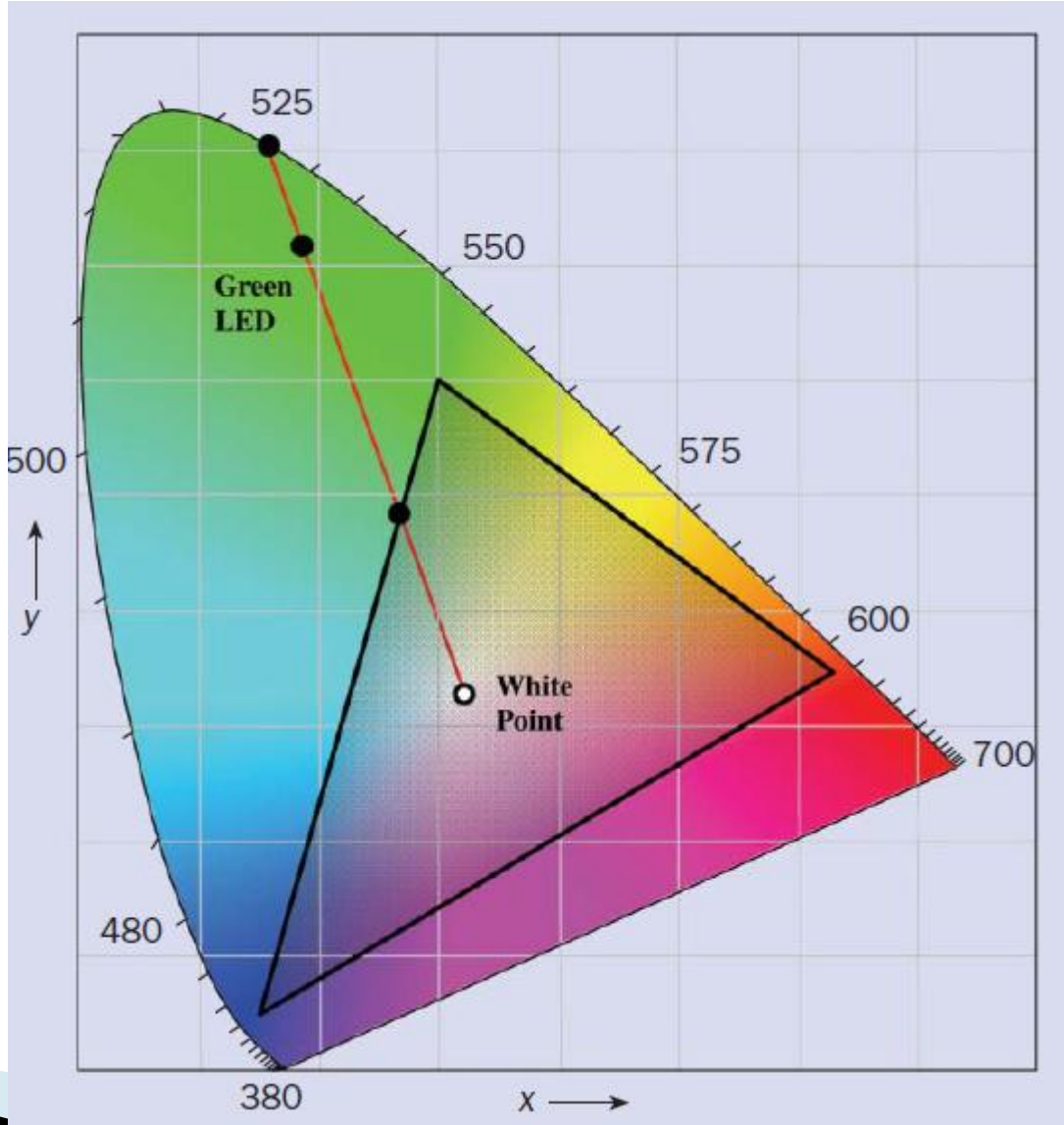
- Comunicatii
  - Infrarosu (InGaAsP)
- Vizibil
  - Spectru vizibil (GaAlAs)
- Iluminare
  - Putere ridicata, lumina alba (GaInN)

ITU-R BT.709

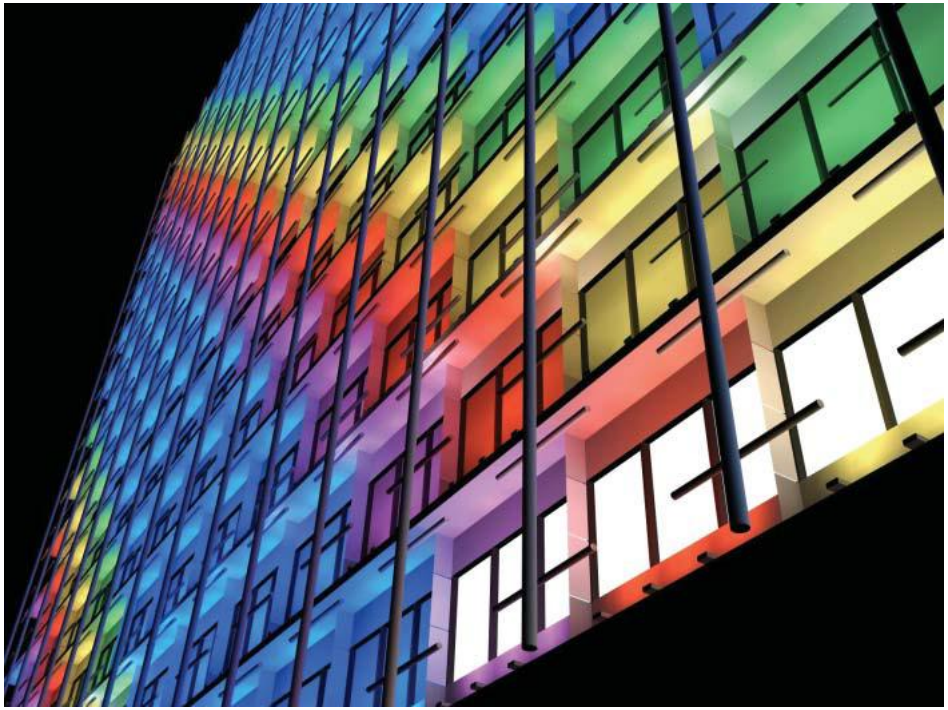
ITU-R BT.709 phosphor properties		
Phosphor	**x**	**y**
Red	0.640	0.330
Green	0.300	0.600
Blue	0.150	0.060

Data refers to xy chromaticity co-ordinates of ITU-R BT.709 phosphors which are used in most CRT displays [1].





ITU-R BT.709



RGB values for Luxeon LEDs

LED color	Dominant wavelength λ_D (nm)	RGB values
Royal blue	455	0.05, 0.00, 0.95
Blue	470	0.00, 0.11, 0.89
Cyan	505	0.00, 0.63, 0.37
Green	530	0.00, 0.77, 0.23
Amber	590	0.70, 0.30, 0.00
Red-orange	615	0.97, 0.00, 0.03
Red	625	0.92, 0.00, 0.08

Aplicatii majore LED

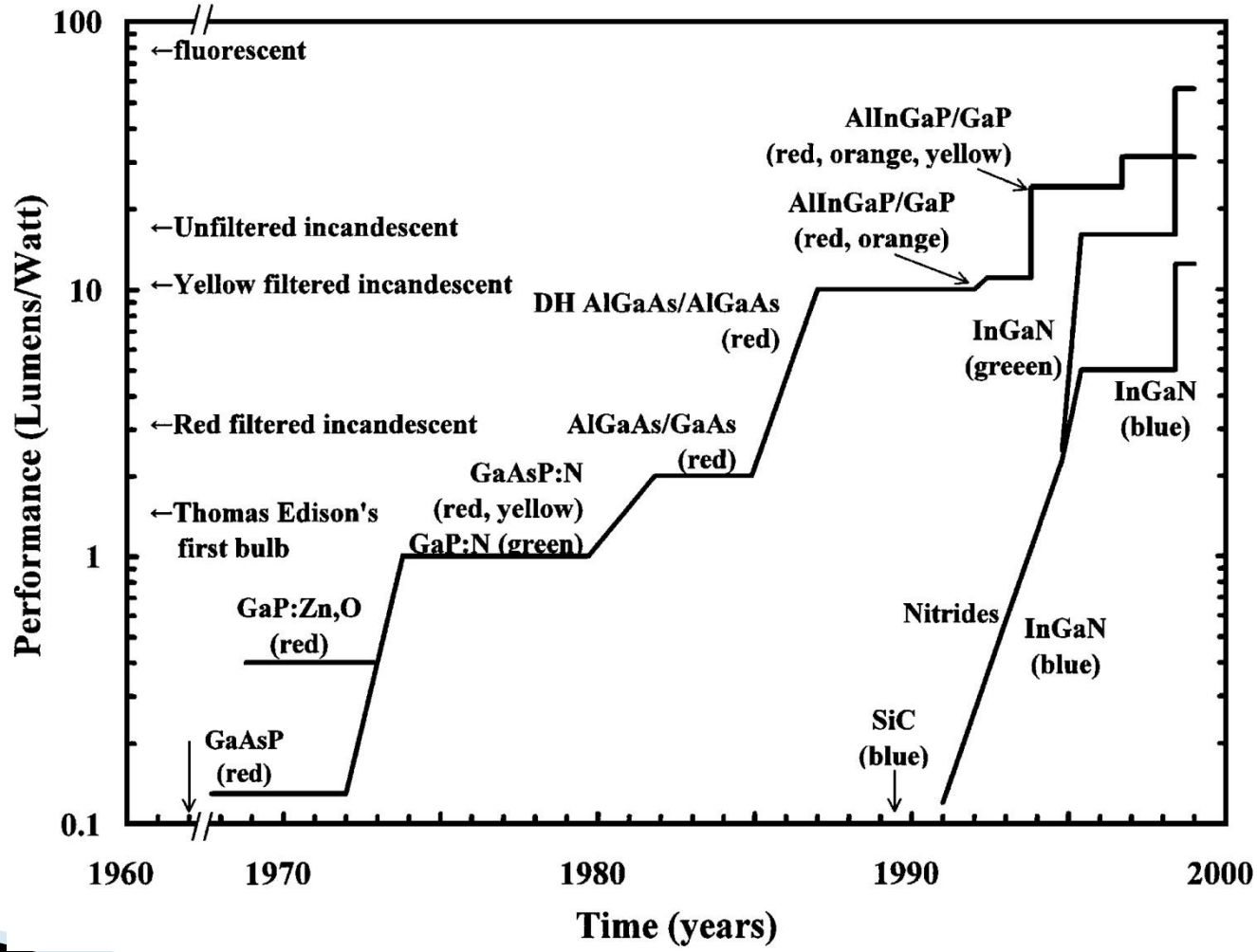
- Comunicatii
  - Infrarosu (InGaAsP)
- Vizibil
  - Spectru vizibil (GaAlAs)
- Iluminare
  - Putere ridicata, lumina alba (GaInN)

Eficienta

- Bec cu incadescenta
  - 16 lm/W
- Tub fluorescent
  - 100 lm/W
- LED
  - curent: 250 lm/W
  - curand: 300 lm/W

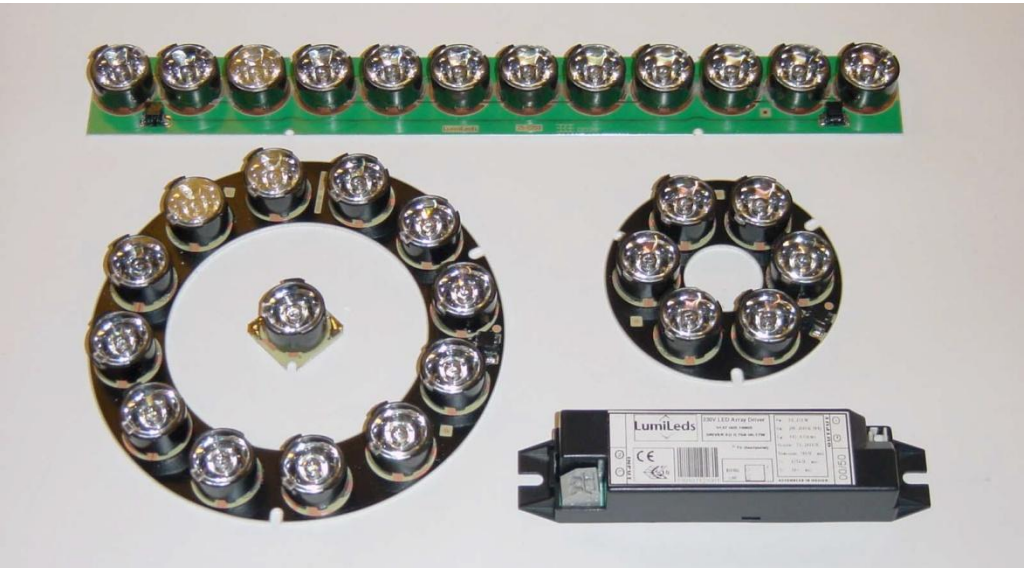
Premiul Nobel, Fizica, 2014

Eficienta in timp

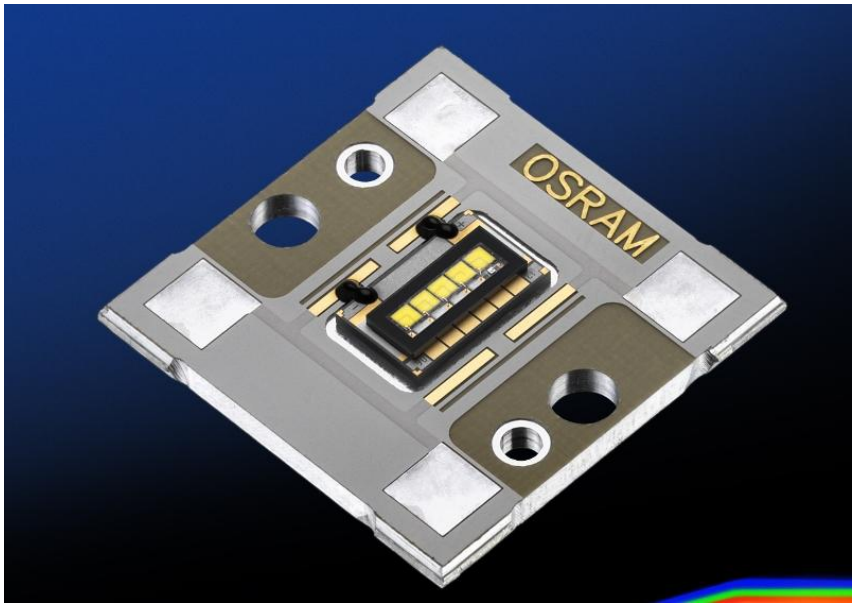


Aplicatii

- auto



Aplicatii

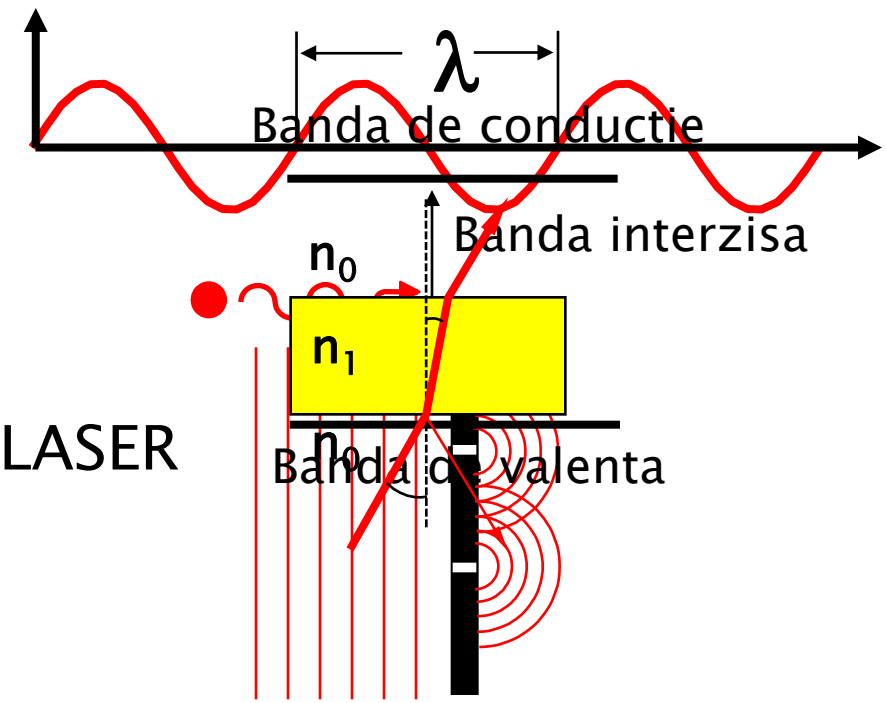


Modelarea luminii

(tot) Capitolul 1

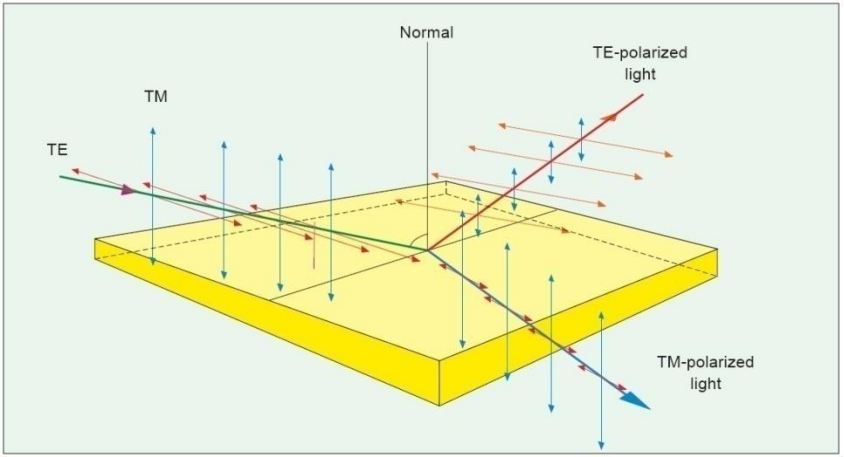
Modelarea luminii

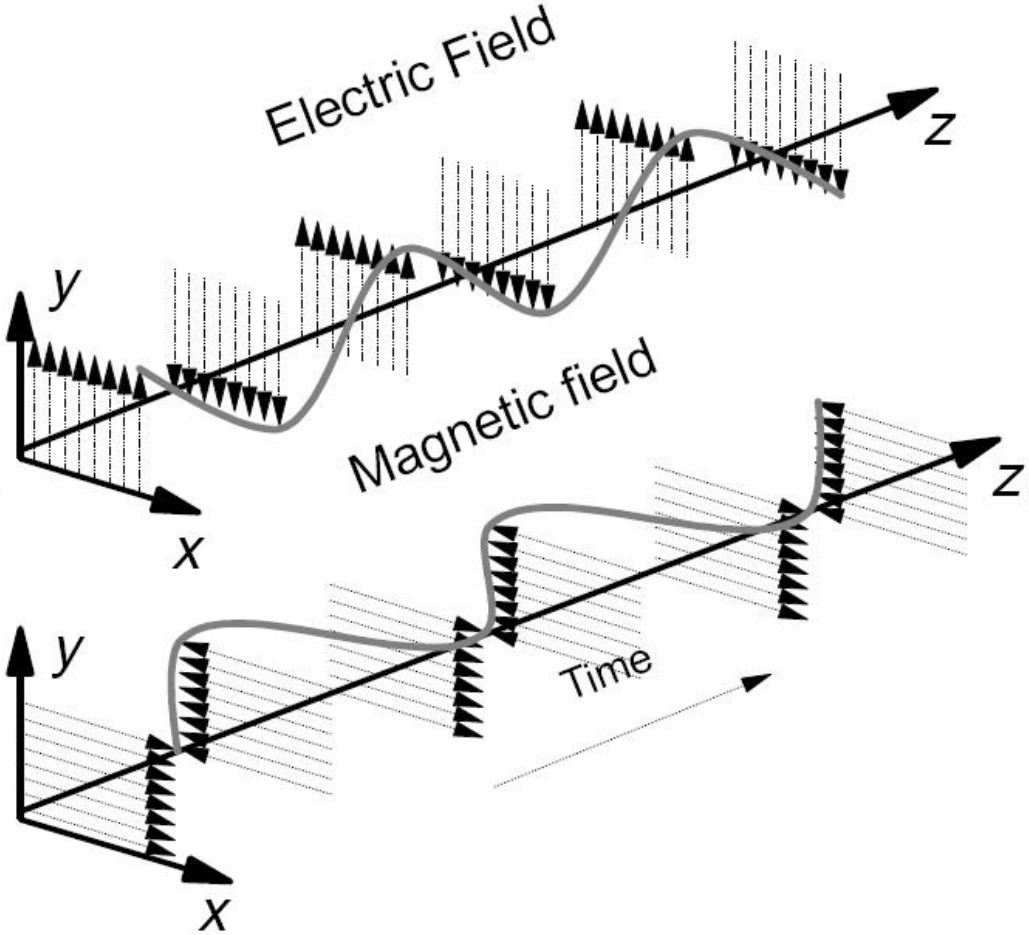
- Undă electromagnetică
  - Ecuaţiile lui Maxwell
  - λ, ε, ω, f
- Teoria cuantică
  - Benzi energetice $E = h\,\nu$
  - fotoni, emisie stimulată, LASER
- Optică geometrică
  - n, θ
  - raze de lumină
  - intuitivă



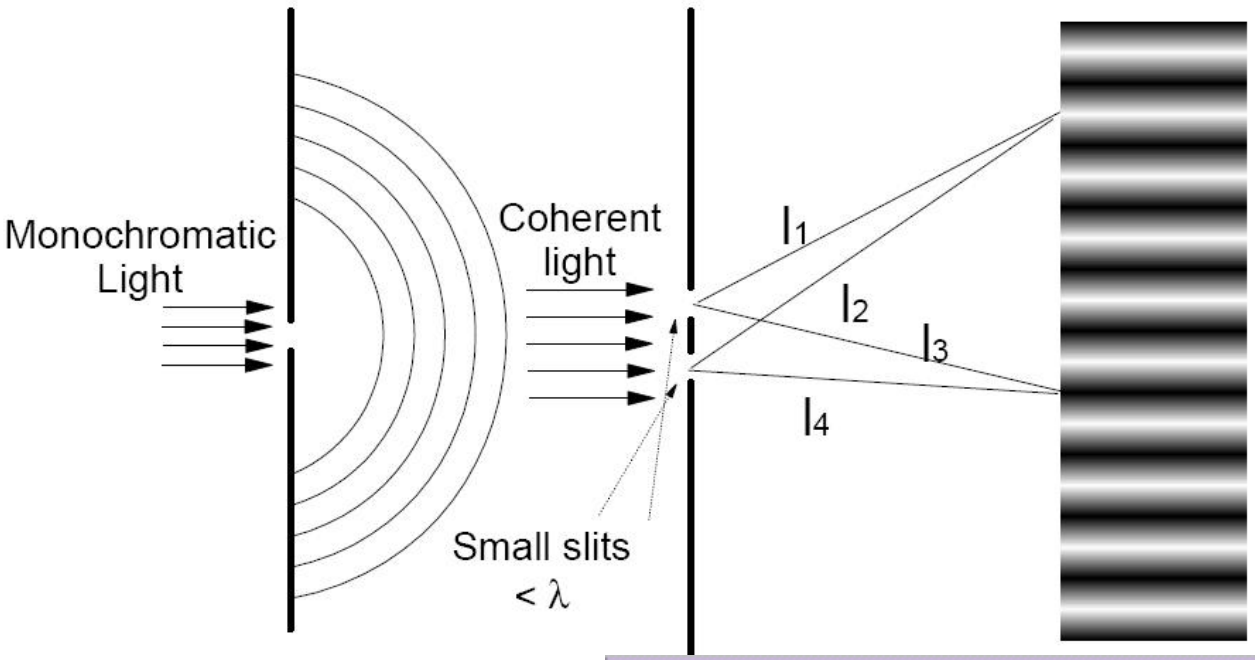
Unda electromagnetica

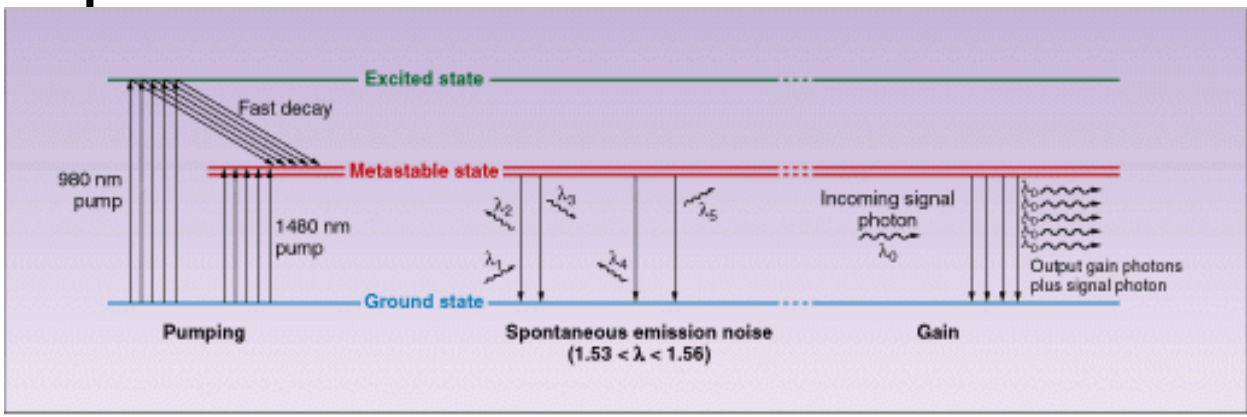
- Dispersie
- Fibre monomod
- Interferenta
- Polarizare





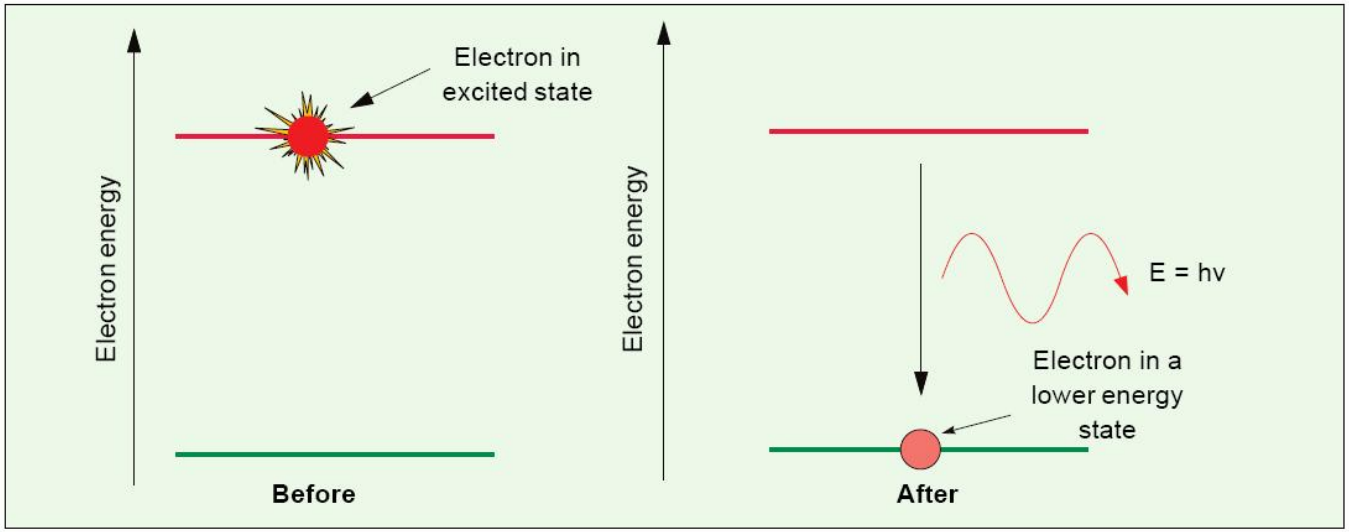
Fotoni/Unda





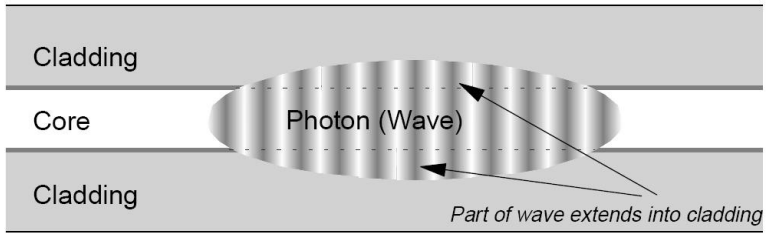
8-FEA-4 97 Fig. 2

Model cuantic – foton

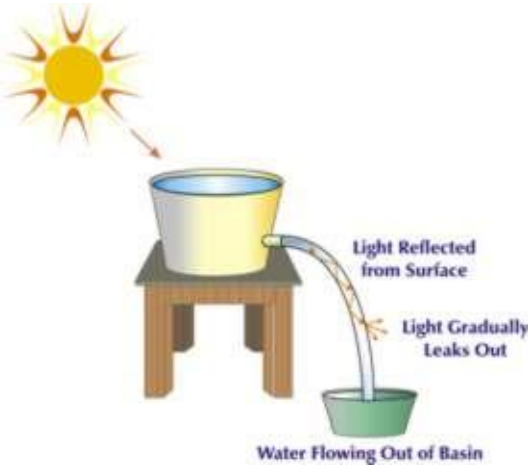


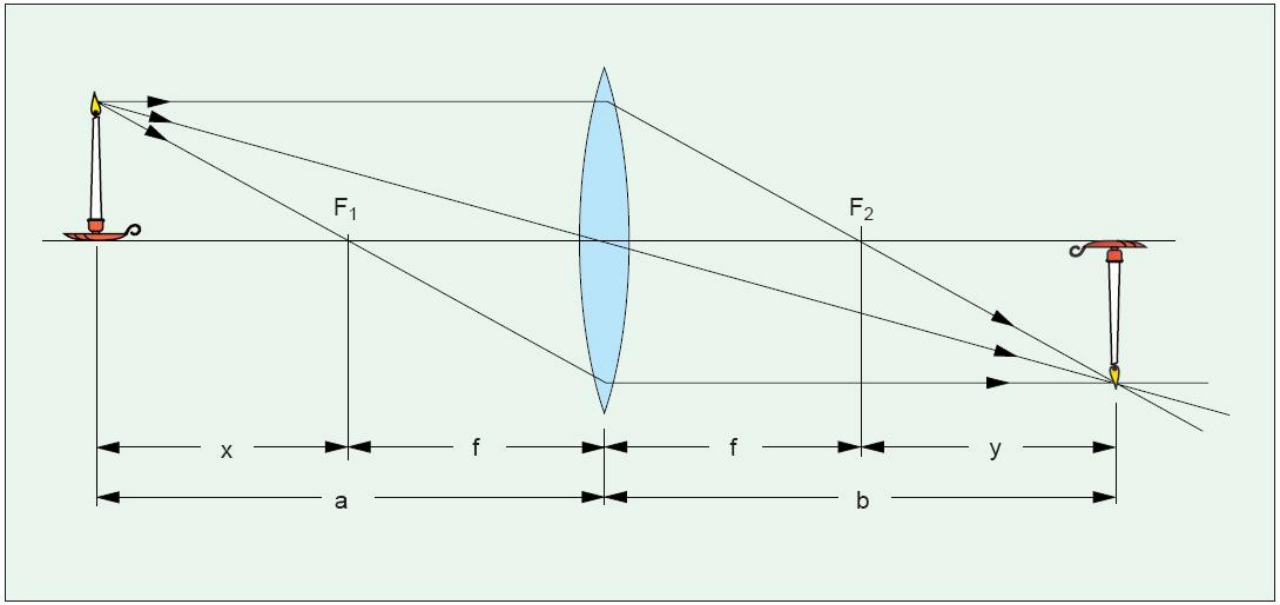
$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}; \quad \lambda[\mu m] = \frac{1.240}{E_g[eV]}$$

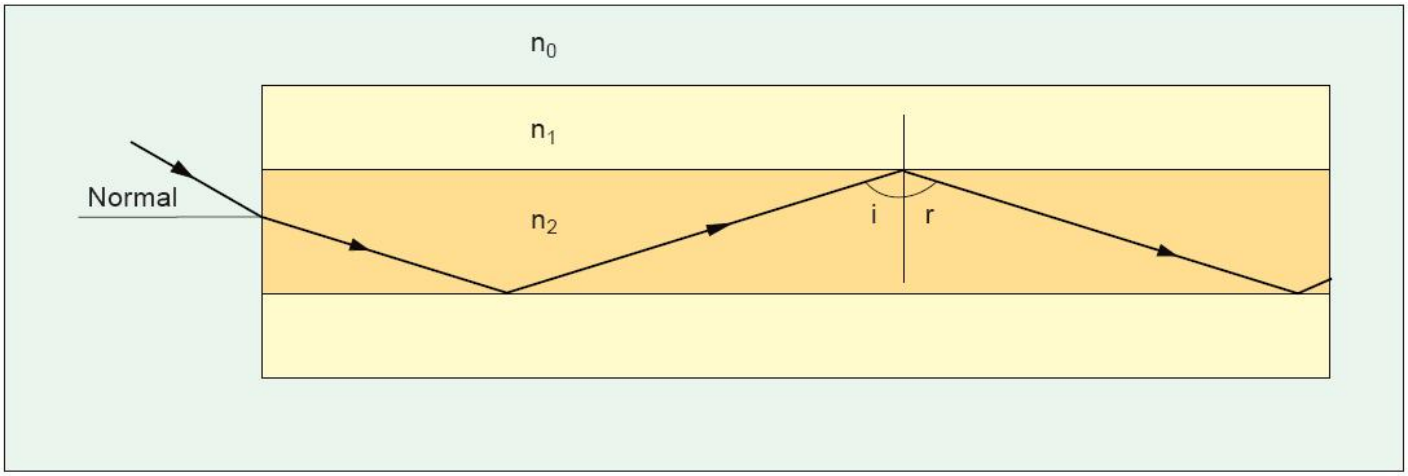
- h constanta lui Plank $6.62 \cdot 10^{-32}$ Ws^2
- c viteza luminii in vid $2.998 \cdot 10^8 m/s$



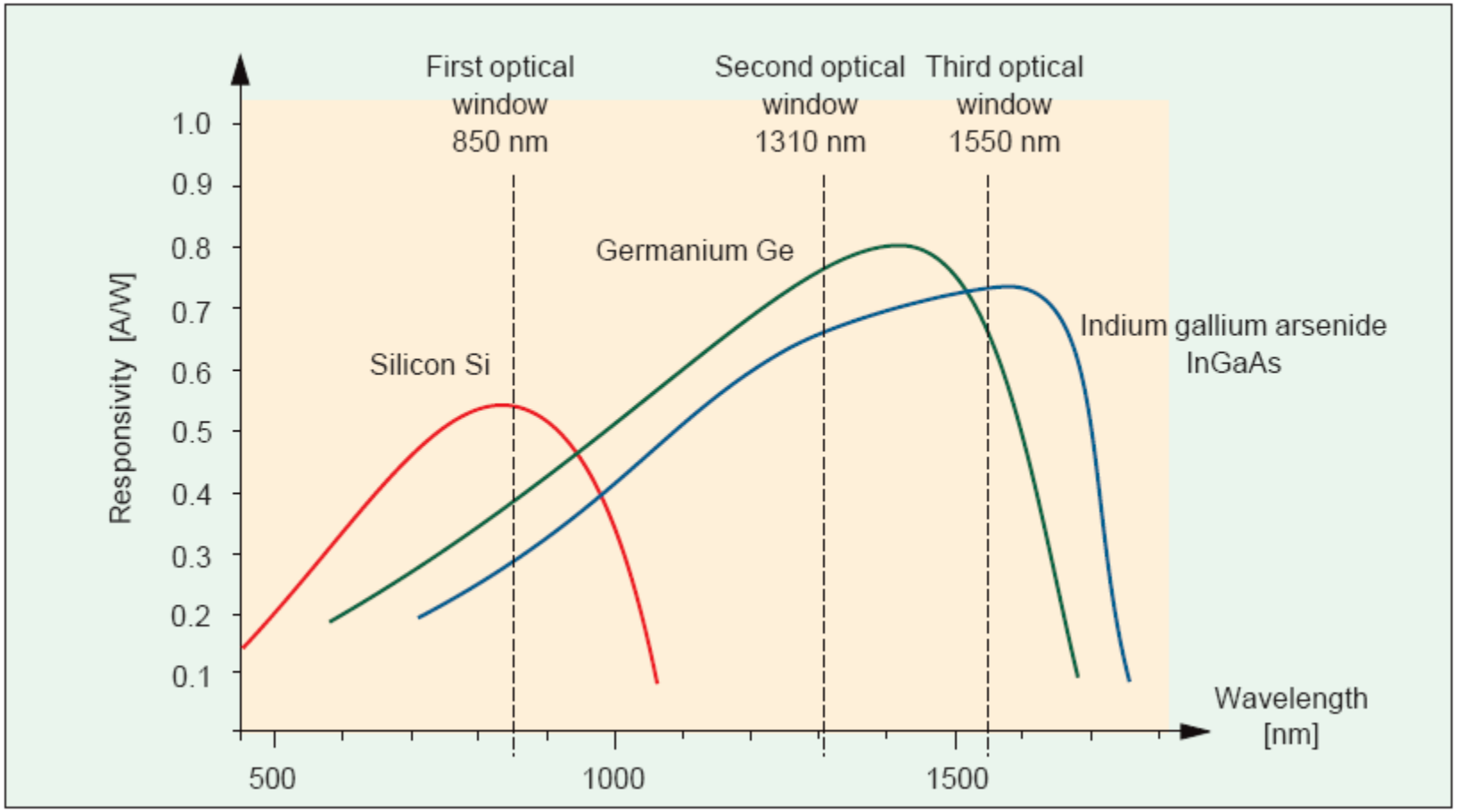
Optica geometrica







Materiale semiconductoare utilizate in optoelectronică



Lăţimea benzii interzise/lungime de undă pentru materialele uzuale

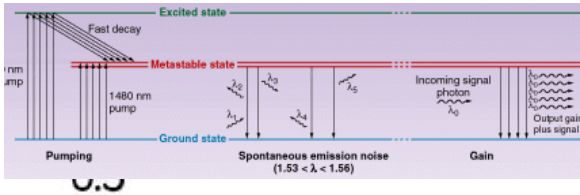
$$\lambda = \frac{hc}{E_g}$$

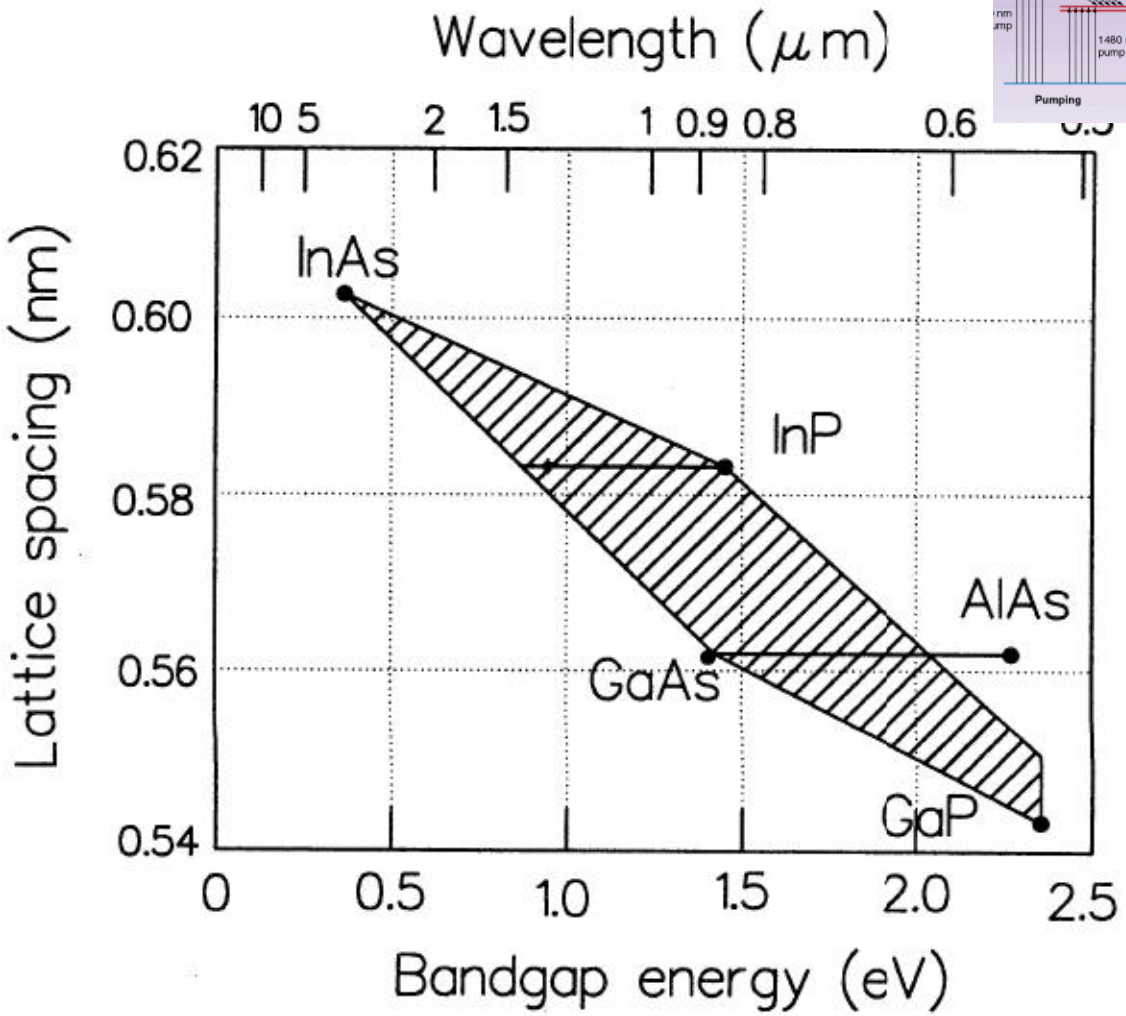
h - este constanta lui Planck, $6.62 \cdot 10^{-34}$ Ws^2;

c - viteza luminii, $2.998 \cdot 10^8$ m/s;

Material	Formula	Wavelength Range λ (μm)	Bandgap Energy W_g (eV)
Indium Phosphide	InP	0.92	1.35
Indium Arsenide	InAs	3.6	0.34
Gallium Phosphide	GaP	0.55	2.24
Gallium Arsenide	GaAs	0.87	1.42
Aluminium Arsenide	AlAs	0.59	2.09
Gallium Indium Phosphide	GaInP	0.64-0.68	1.82-1.94
Aluminium Gallium Arsenide	AlGaAs	0.8-0.9	1.4-1.55
Indium Gallium Arsenide	InGaAs	1.0-1.3	0.95-1.24
Indium Gallium Arsenide Phosphide	InGaAsP	0.9-1.7	0.73-1.35

Dependenţa benzii interzise de constanta reţelei



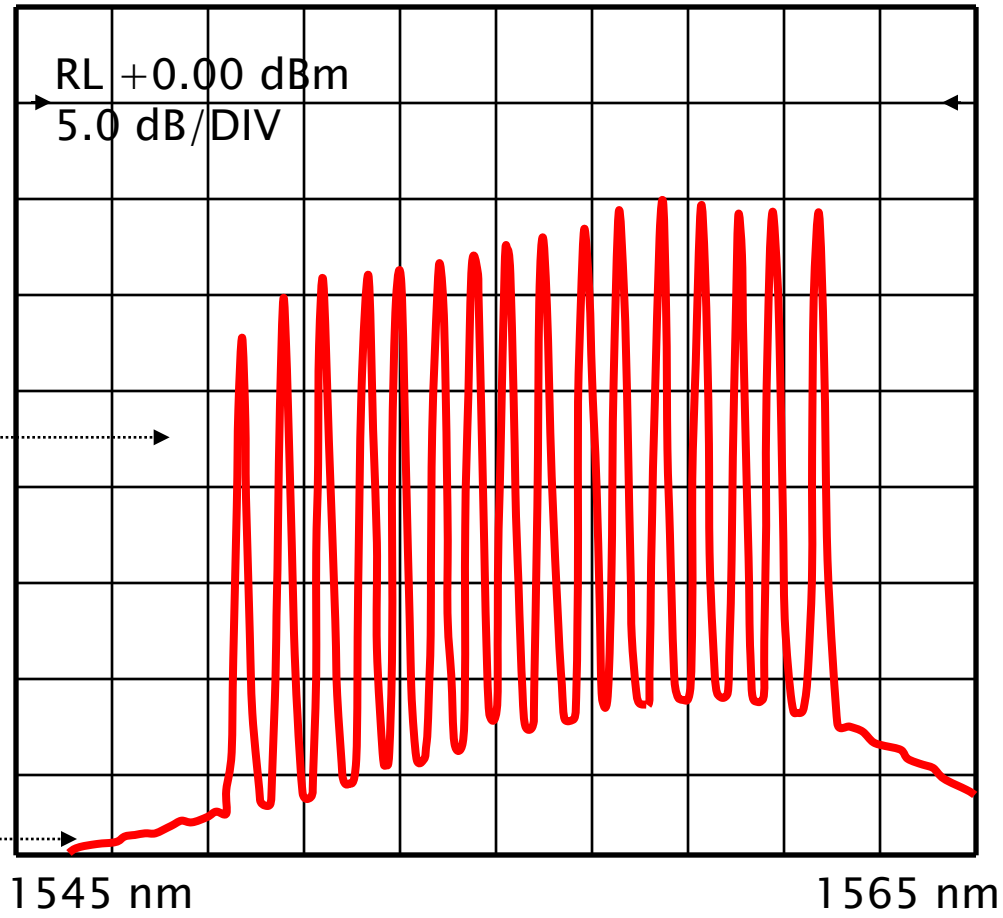


Spectrul WDM – Wavelength Division Multiplexing

- Reglaj
- in limite reduse

Canale: 16
Spaţiere: 0.8 nm

Emisie spontană
Amplificată (ASE)



Reprezentare logaritmică

$dB = 10 \cdot \log_{10} (P_2 / P_1)$

$dBm = 10 \cdot \log_{10} (P / 1\ mW)$

0 dB	= 1
+ 0.1 dB	= 1.023 (+2.3%)
+ 3 dB	= 2
+ 5 dB	= 3
+ 10 dB	= 10
−3 dB	= 0.5
−10 dB	= 0.1
−20 dB	= 0.01
−30 dB	= 0.001

0 dBm	= 1 mW
3 dBm	= 2 mW
5 dBm	= 3 mW
10 dBm	= 10 mW
20 dBm	= 100 mW
−3 dBm	= 0.5 mW
−10 dBm	= 100 μW
−30 dBm	= 1 μW
−60 dBm	= 1 nW

[dBm] + [dB] = [dBm]

[dBm/Hz] + [dB] = [dBm/Hz]

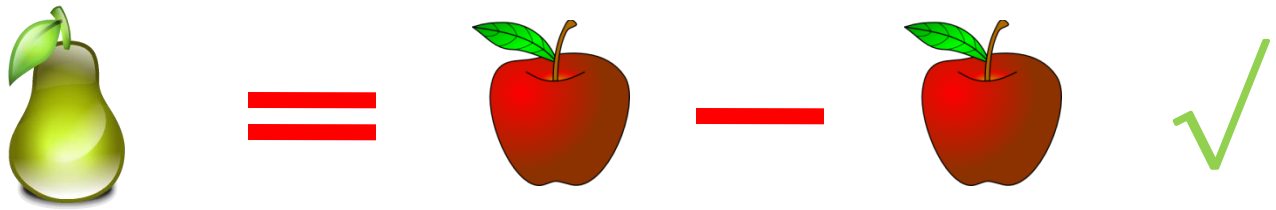
[x] + [dB] = [x]

Calculul atenuarii

$$\text{Pierderi} = \frac{P_{out}}{P_{in}}$$

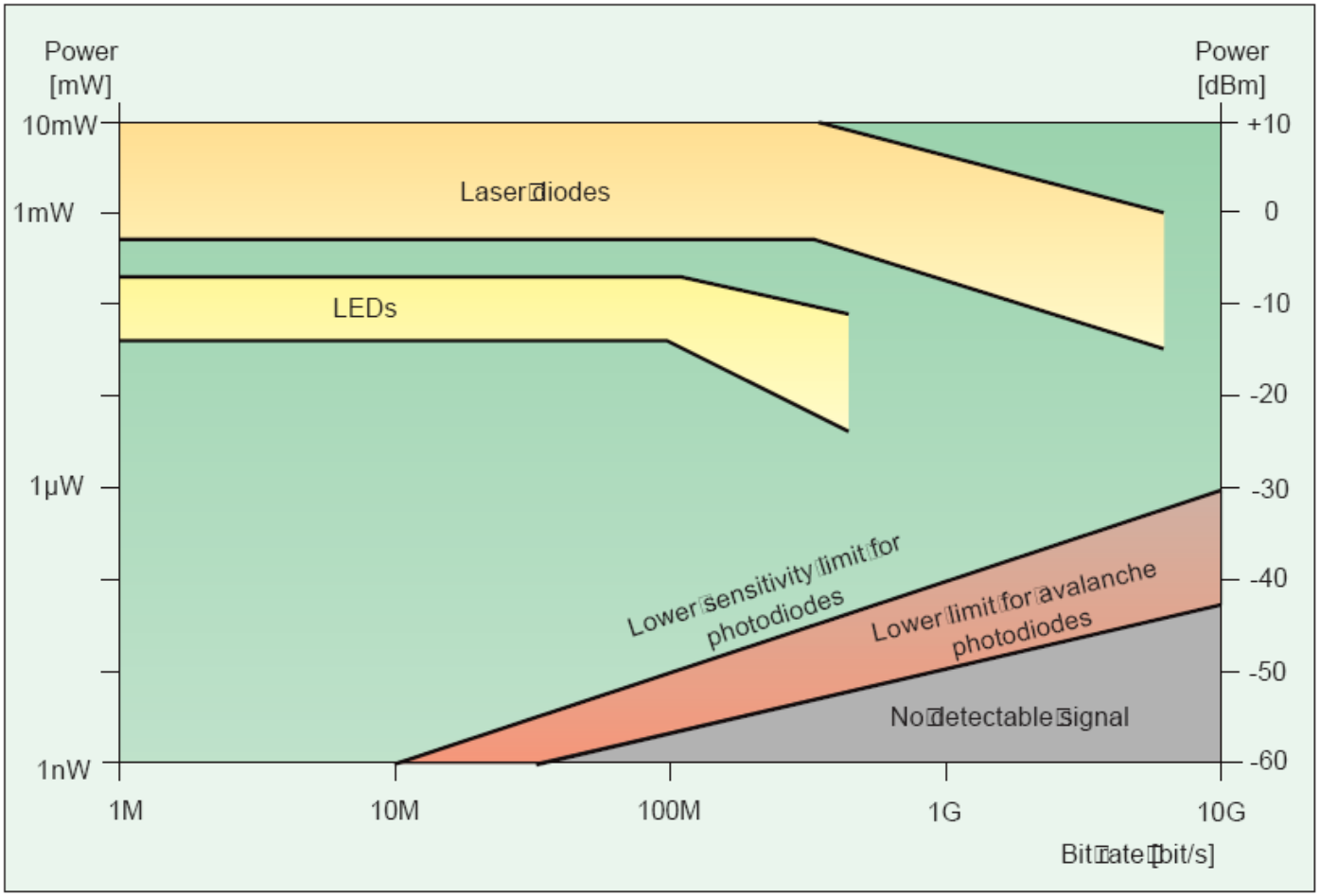
$$\text{Pierderi}[\text{dB}] = [-]10 \cdot \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

$$\text{Pierderi}[\text{dB}] = [-]\left(P_{out}[\text{dBm}] - P_{in}[\text{dBm}]\right)$$



$$\text{Atenuare}[\text{dB/km}] = \frac{\text{Pierderi}[\text{dB}]}{\text{lungime}[\text{km}]}$$

Limite putere/bandă a dispozitivelor optoelectronice



Lumina ca undă electromagnetică

Capitolul 2

Ecuatiile lui Maxwell

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = \frac{\partial D}{\partial t} + J$$

$$\nabla \cdot D = \rho$$

$$\nabla \cdot B = 0$$

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t}$$

- Ecuatii constitutive

$$D = \varepsilon \cdot E$$

$$B = \mu \cdot H$$

$$J = \sigma \cdot E$$

- In vid

$$\mu_0 = 4\pi \times 10^{-7}\ H/m$$

$$\varepsilon_0 = 8{,}854 \times 10^{-12}\ F/m$$

$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8\ m/s$$

Câmpuri electromagnetic cu variaţie armonică în timp

$$X = X_0 e^{j\cdot\omega\cdot t} \quad \frac{\partial X}{\partial t} = j\cdot\omega\cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t)\cdot e^{-j\omega t}dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega)\cdot e^{j\omega t}d\omega$$

- Simplificarea ecuatiilor lui Maxwell

$$\nabla^2 E + \omega^2 \varepsilon\mu E = j\omega\mu J + \frac{1}{\varepsilon}\nabla\rho$$

$$\nabla^2 H + \omega^2 \varepsilon\mu H = -\nabla\times J$$

$$\nabla\cdot E = \frac{\rho}{\varepsilon}$$

$$\nabla\cdot H = 0$$

- Ecuaţiile Helmoltz sau ecuaţiile de propagare

Mediu lipsit de sarcini electrice

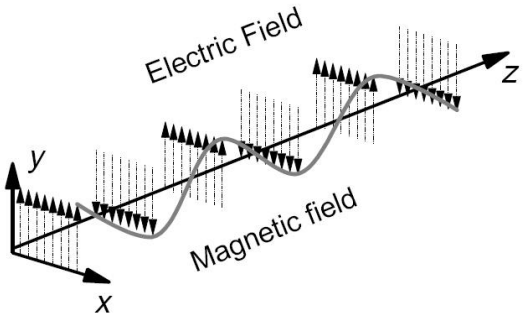
$$\nabla^2 E - \gamma^2 E = 0$$

$$\nabla^2 H - \gamma^2 H = 0$$

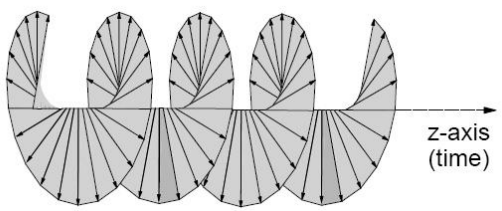
$$\gamma^2 = -\omega^2\varepsilon\mu + j\omega\mu\sigma$$

γ – Constanta de propagare

Solutia ecuatiilor de propagare



Propagare



Polarizare circulara

Camp electric dupa directia Oy, propagare dupa directia Oz

$$E_y = E_+ e^{-\gamma \cdot z} + E_- e^{\gamma \cdot z}$$

$$\gamma = \sqrt{-\omega^2 \varepsilon \mu + j\omega\mu\sigma} = \alpha + j \cdot \beta$$

Exista numai unda progresiva $E_+ => A$

$$E_y = A e^{-(\alpha + j \cdot \beta) \cdot z}$$

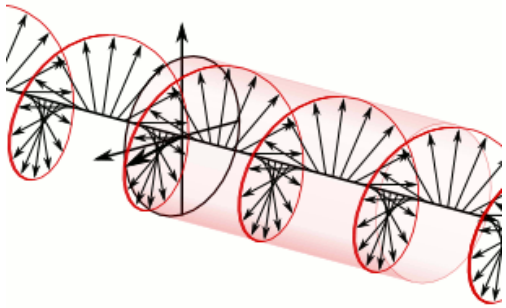
Camp armonic

$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$$

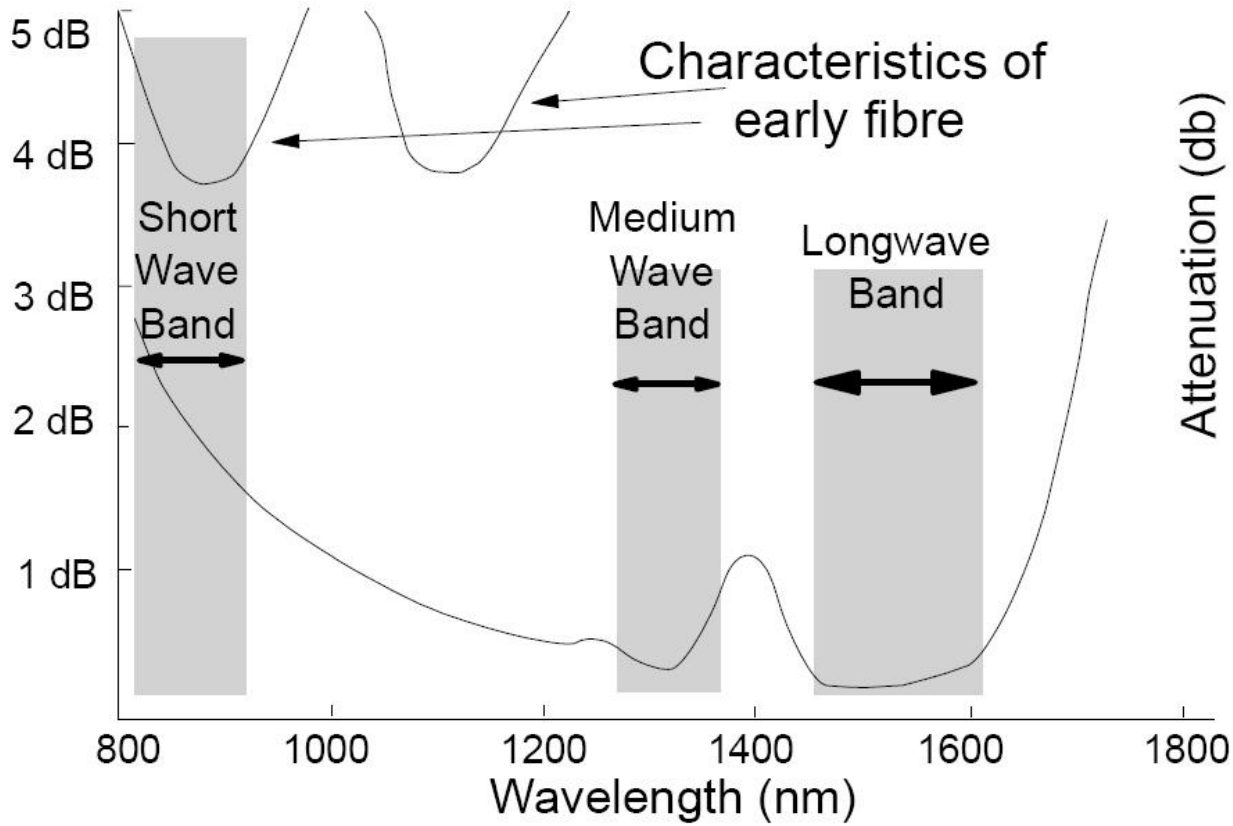
Amplitudine

Atenuare

Propagare
(variatie in timp si spatiu)



Atenuarea pe 1 km in SiO_2



Atenuare

$$E_y(z_1) = Ct \cdot e^{-\alpha \cdot z_1} \cdot e^{j(\omega \cdot t - \beta \cdot z_1)} \qquad E_y(z_2) = Ct \cdot e^{-\alpha \cdot z_2} \cdot e^{j(\omega \cdot t - \beta \cdot z_2)}$$

$$W, P \sim \int E^2$$

$$A = \frac{P_2}{P_1} = \frac{Ct^2 \cdot e^{-2\alpha \cdot z_2}}{Ct^2 \cdot e^{-2\alpha \cdot z_1}} = e^{-2\alpha \cdot (z_2 - z_1)}$$

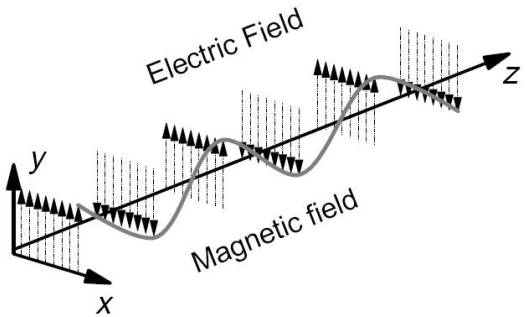
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

$$A[dB] = -20 \cdot \alpha \cdot (z_2 - z_1) \log_{10} e = -8.686 \cdot \alpha \cdot (z_2 - z_1)$$

$$A / L[dB / km] = -8.686 \cdot \alpha < 0$$

- Atenuarea se exprima de obicei in **dB/km**
  - de obicei valori pozitive
  - semnul = **implicit**

Parametri de propagare



$$\nabla \times E = -j\omega\mu \cdot H$$

$$H_x = \frac{j\gamma \cdot E_y}{\omega\mu}$$

Mediu fara pierderi, $\sigma = 0$ $\quad \gamma = j\omega \cdot \sqrt{\varepsilon\mu}$

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\varepsilon}}$$ Impedanta intrinseca a mediului

$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$ punctele de faza constanta: $(\omega \cdot t - \beta \cdot z) = \text{const}$

Viteza de faza $\quad v = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{\varepsilon\mu}}$

Viteza de grup $\quad v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta}$ in medii dispersive unde $\beta = \beta(\omega)$

Parametri de propagare

- In vid

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \qquad v = v_g = c_0 \qquad c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8 \ m/s$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f} \qquad T = \frac{2\pi}{\omega} = \frac{1}{f}$$

Periodicitate in spatiu Periodicitate in timp

- In mediu nedispersiv ε_r

$$c = \frac{1}{\sqrt{\varepsilon \cdot \mu_0}} = \frac{1}{\sqrt{\varepsilon_0 \varepsilon_r \cdot \mu_0}} = \frac{c_0}{\sqrt{\varepsilon_r}}$$

$n = \sqrt{\varepsilon_r}$ Indice de refractie al mediului $c = \frac{c_0}{n}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f} \qquad \lambda = \frac{2\pi}{\beta} = \frac{c}{f} \qquad \lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

Parametri, dependenta de mediu

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega$$

$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8 \ m/s$$

$n = 1$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f}$$

$$\eta = \frac{\eta_0}{n}$$

$$c = \frac{c_0}{n}$$

$n = \sqrt{\varepsilon_r}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

ITU G.692

"the allowed channel frequencies are based on a 50 GHz grid with the reference frequency at 193.10 THz"

SI

"a source that emits monochromatic radiation of frequency $540 \cdot 10^{12}$ Hz"

Dispersia

- In medii dispersive $\beta = \beta(\omega)$, $n = n(\omega)$

$$\frac{d\beta}{d\omega} = \frac{d}{d\omega}\left(\frac{\omega \cdot n}{c}\right) = \frac{1}{c}\left(n + \omega\frac{dn}{d\omega}\right)$$

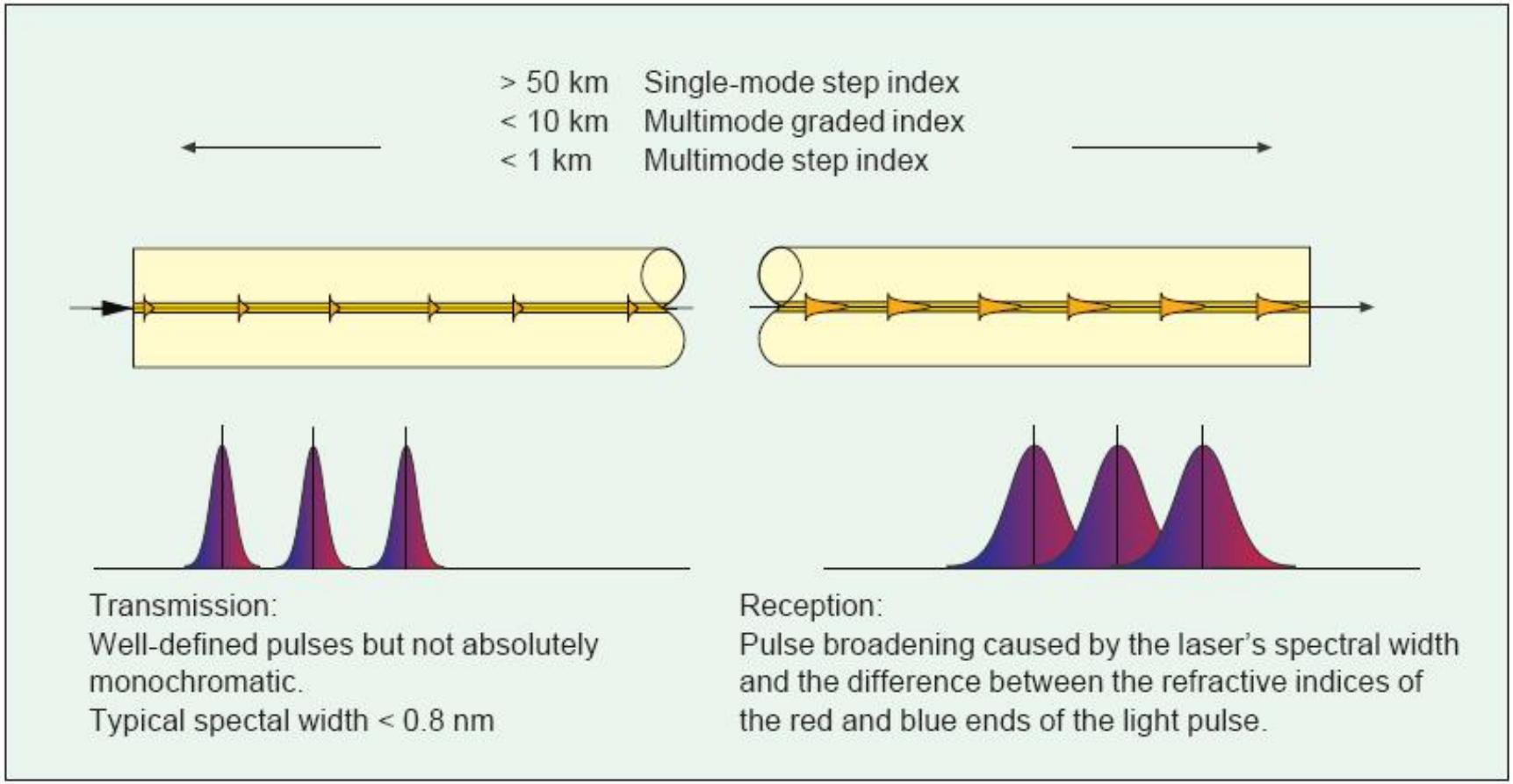
$$\frac{d\beta}{d\omega} = -\frac{\lambda}{\omega}\cdot\frac{d\beta}{d\lambda} = \frac{1}{c}\left(n - \lambda\frac{dn}{d\lambda}\right) = \tau \quad (s/m)$$

$$D = \frac{d\tau}{d\lambda} = \frac{1}{c}\left(\frac{dn}{d\lambda} - \lambda\frac{d^2n}{d\lambda^2} - \frac{dn}{d\lambda}\right) = -\frac{\lambda}{c}\frac{d^2n}{d\lambda^2} \quad (s/m^2)$$

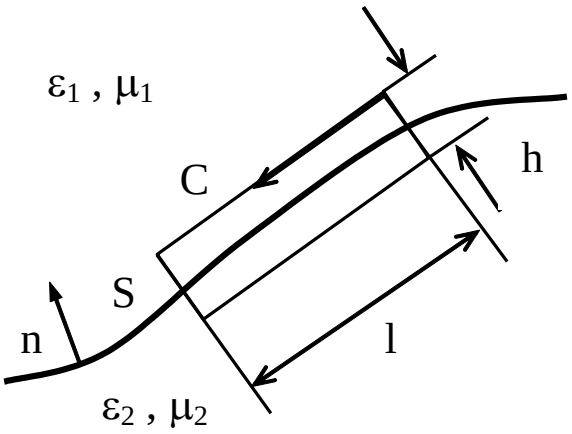
- Dispersia se exprima de obicei in ps/nm/km si permite aflarea intarzierilor aparute intre "moduri" (latirea impulsurilor) pentru o anumita latime spectrala si o anumita distanta parcursa

$$\Delta\tau = D \cdot \Delta\lambda \cdot L$$

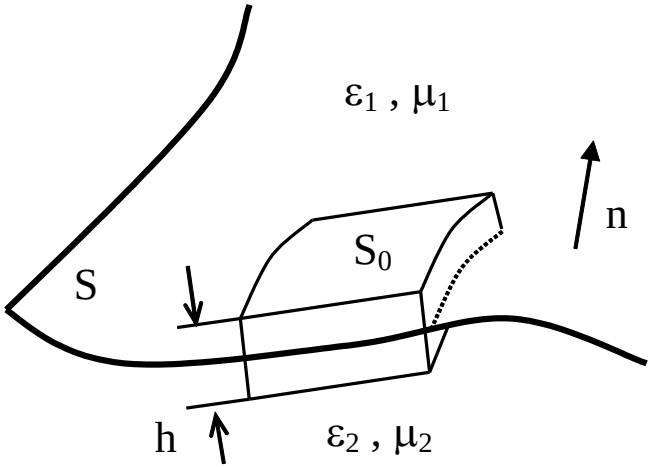
Dispersie


> 50 km Single-mode step index
< 10 km Multimode graded index
< 1 km Multimode step index
Transmission:
Well-defined pulses but not absolutely monochromatic.
Typical spectal width < 0.8 nm
Reception:
Pulse broadening caused by the laser's spectral width and the difference between the refractive indices of the red and blue ends of the light pulse.

Condiţii la limita de separaţie între două medii



a)



b)

$$n \times (E_1 - E_2) = 0$$

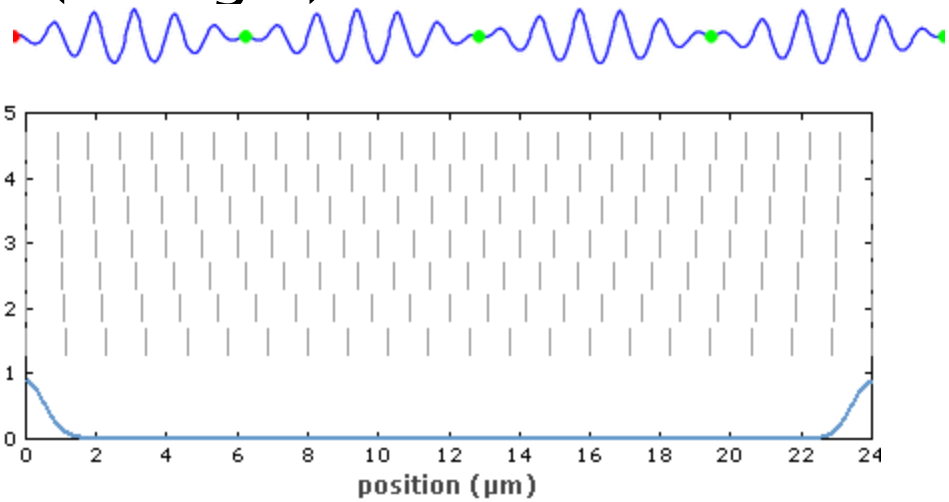
$$n \times (H_1 - H_2) = J_S$$

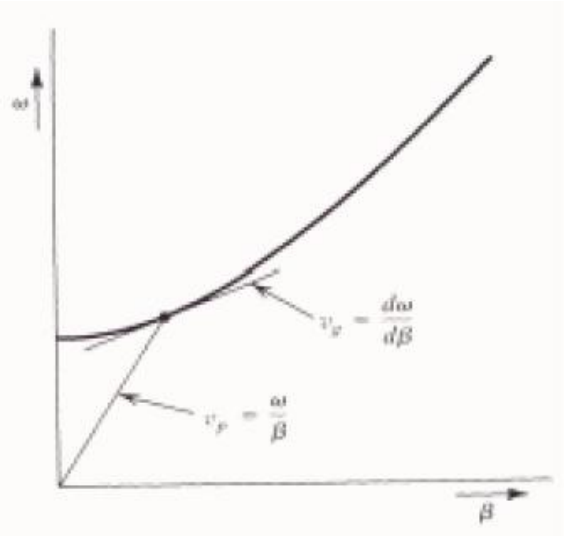
$$n \cdot (D_1 - D_2) = \rho_S$$

$$n \cdot (B_1 - B_2) = 0$$

Viteze de grup si faza

- Viteza de faza – viteza virtuala cu care circula punctul cu o anumita faza
- Viteza de grup – viteza cu care circula informatia (energia)

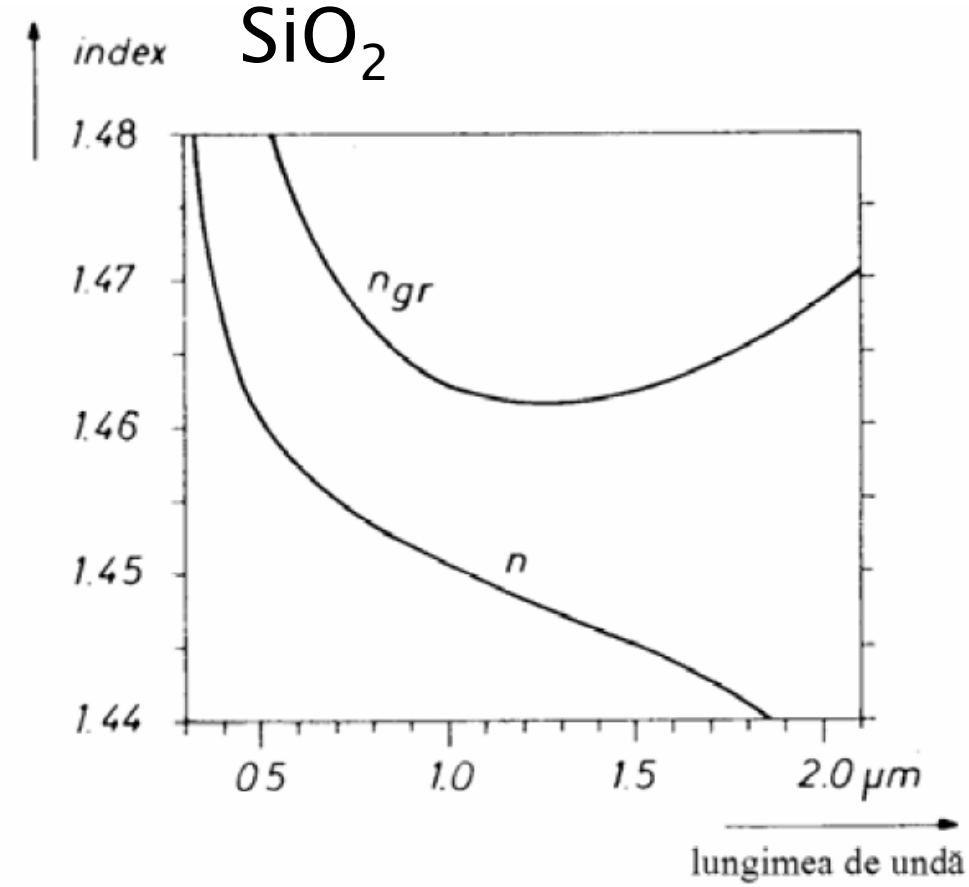




Dispersie normala

$$n_{gr} = n - \lambda \frac{dn}{d\lambda}$$

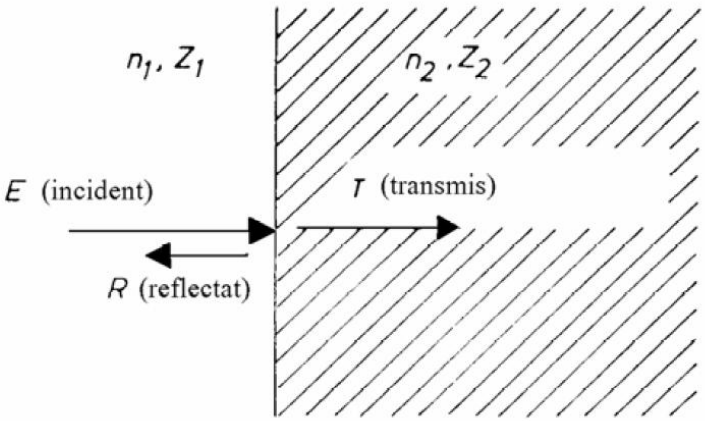
$$D = \frac{d\tau}{d\lambda} = \frac{1}{c} \cdot \frac{dn_{gr}}{d\lambda}$$



Transmisia puterii intre medii

- incidenta normala
- reflexia in amplitudine

$$Z = \frac{Z_0}{n} \qquad \Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{n_1 - n_2}{n_1 + n_2}$$



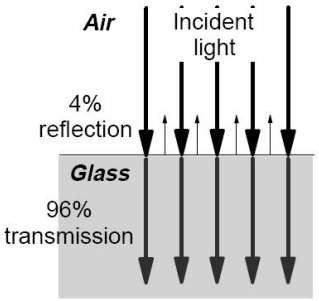
- densitatea de putere proportionala cu patratul amplitudinii câmpului

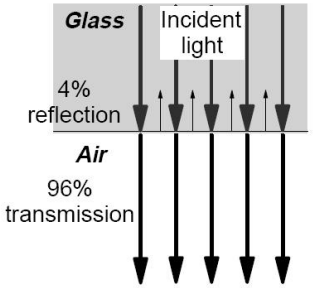
$$r = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \qquad t = \left(\frac{2n_1}{n_1 + n_2}\right)^2$$

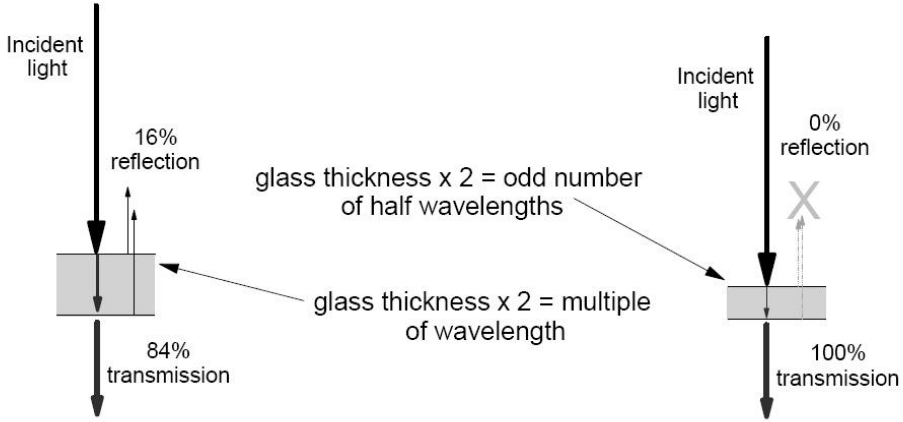
- interfata aer-sticla ($n_1 = 1$, $n_2 = 1.5$)

$$r = 0.04 = 4\%$$

Transmisia printr-o lamela

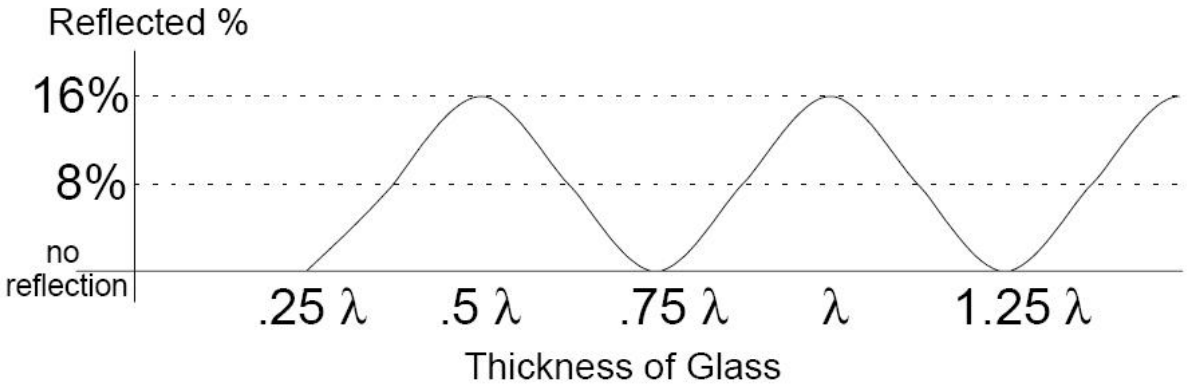






$$\Gamma = \frac{1.5-1}{1.5+1} = 0.2; \quad r = \Gamma^2 = 0.04 = 4\% \quad \Gamma_{max} = 0.2 + 0.2; \quad r_{max} = \Gamma_{max}^2 = 0.16 = 16\%$$

- apare interferenta intre diversele unde reflectate
- se aduna campurile nu puterile
- lamele antireflexive



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