Optoelectronică, structuri şi tehnologii

Curs 3

2013/2014

Orar

- Curs
  - marti, 17-20, P4
  - 2C ⇨ 3C
    - $14*2/3 \approx 9.33$
    - $9 \div 10$ C

Lumina ca undă electromagnetică

Capitolul 2

Parametri, dependenta de mediu

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

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

$n = 1$

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

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

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

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

$n = \sqrt{\varepsilon_r}$

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

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

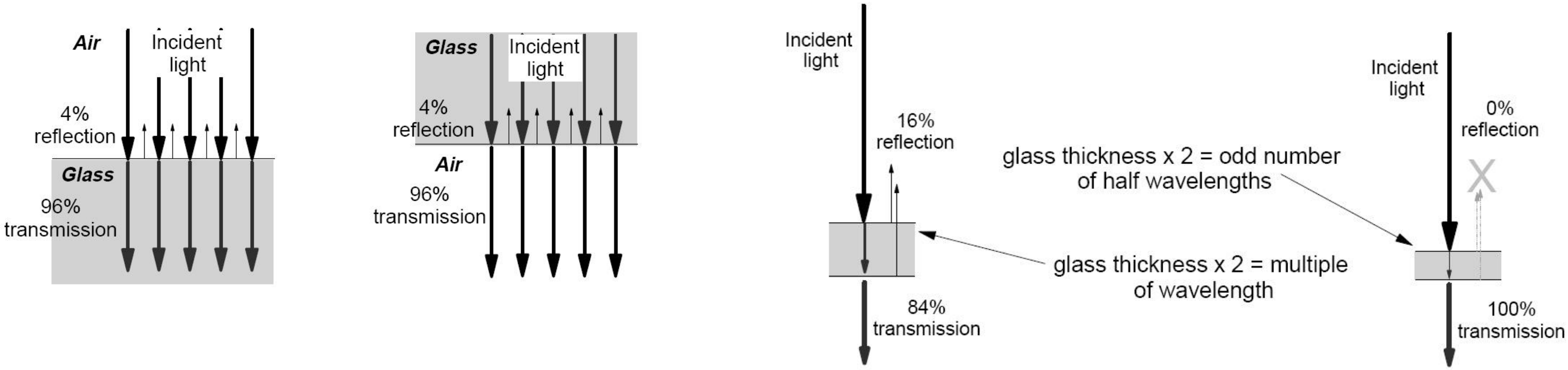
ITU G.692

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

SI

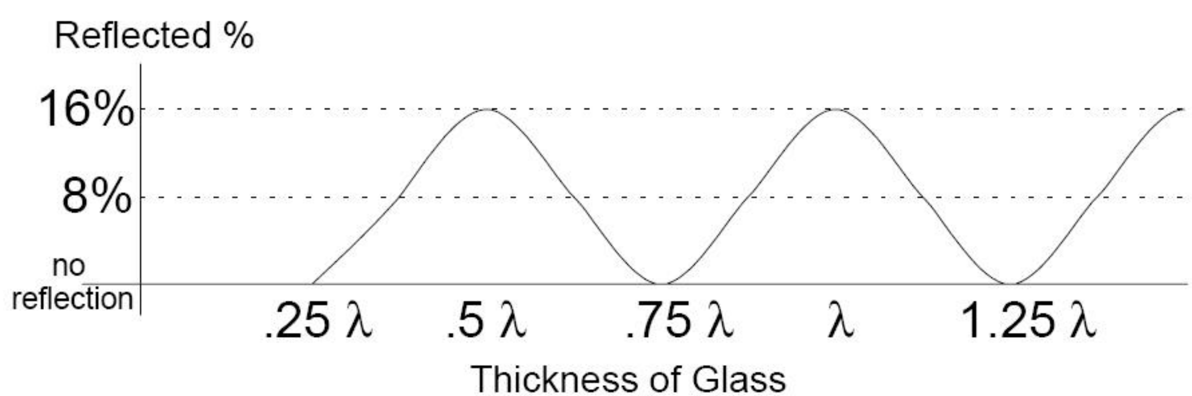
"a source that emits monochromatic radiation of frequency $540 \cdot 10^{12}$ Hz"

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



Optică geometrică

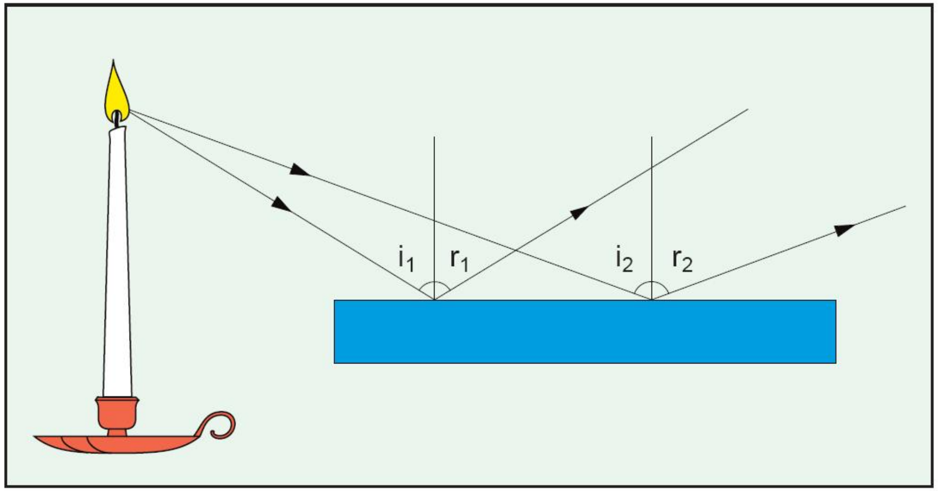
Capitolul 3

Reflexia luminii

- la suprafata de separatie dintre doua medii, (o parte din) lumina se intoarce in mediul de incidenta
- unghiul facut de raza incidenta cu normala (ϕ_i) este egal cu unghiul facut de raza reflectata cu normala (ϕ_r)

- Legea reflexiei

$$\phi_i = \phi_r$$

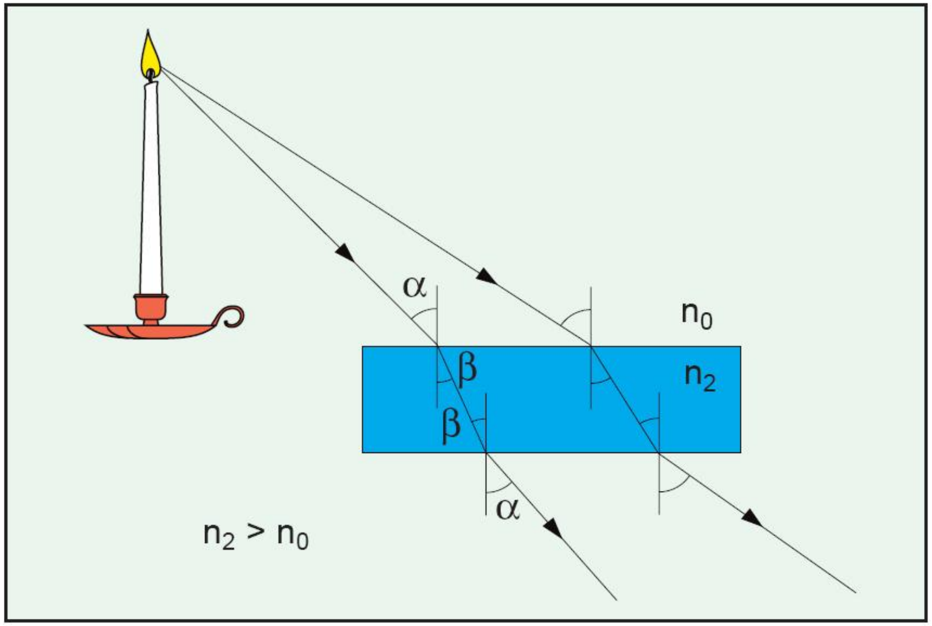


Refractia luminii

- la suprafata de separatie dintre doua medii, (o parte din) lumina se (poate) propaga in mediul de transmisie sub un unghi diferit de unghiul incident
- la trecerea in medii mai “dense” (optic) lumina se apropie de normala
- Legea lui Snell (a refractiei)

$$n_1 \cdot \sin \phi_i = n_2 \cdot \sin \phi_R$$

ϕ_i – unghi incident
ϕ_R – unghi de refractie



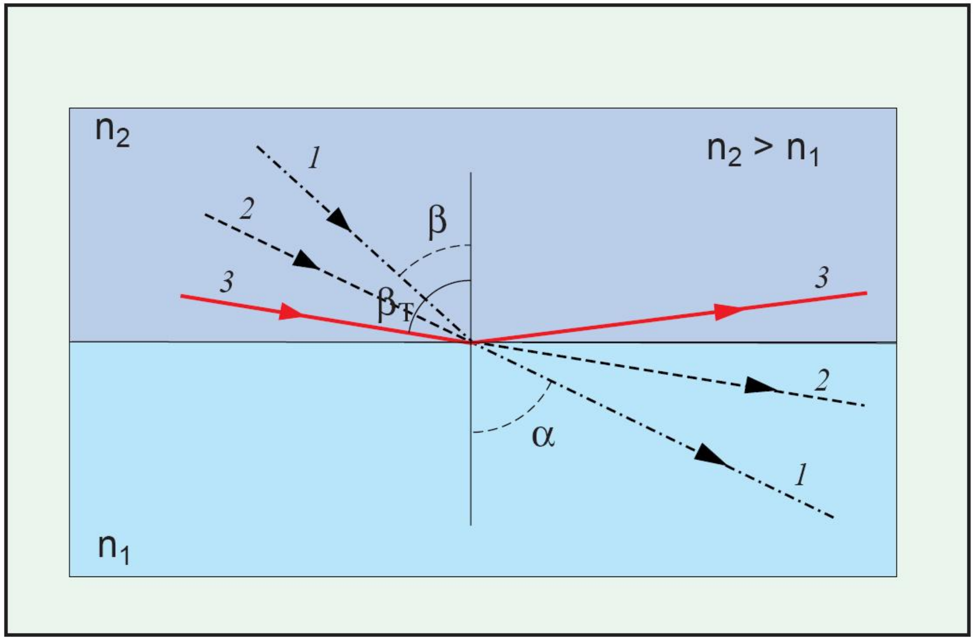
Reflexia totala

- Apare **numai când** lumina se propaga dintr-un mediu mai dens optic intr-un mediu mai putin dens
- La intersectia luminii cu suprafata de separatie a doua medii se intalnesc in general raze reflectate **si** raze refractate
- Pentru un unghi de incidenta numit **unghi critic**, raza refractata se obtine in lungul suprafetei de separatie
- Pentru orice unghi mai mare decât unghiul critic exista numai raza reflectata

$$n_1 > n_2; \quad \phi_R = 90°$$

$$n_1 \cdot \sin\phi_C = n_2$$

$$\phi_C = \arcsin\left(\frac{n_2}{n_1}\right)$$



Fotometrie şi radiometrie

Capitolul 4

O alta dualitate

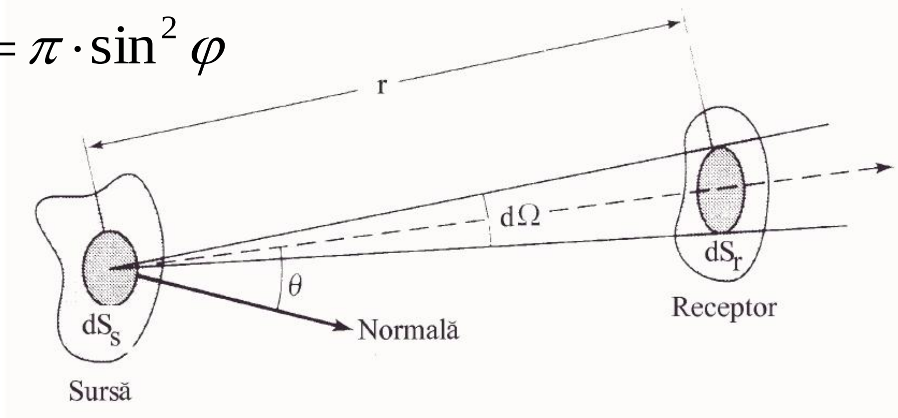
- In optoelectronica lumina poate fi privita din doua puncte de vedere
  - energetic (efect asupra dispozitivului)
  - uman (efect asupra ochiului)
- Dualitatea marimilor implicate
  - energetice
  - luminoase
- Candela (cd) este una din cele 7 marimi fundamentale ale SI
  - Cd = intensitatea luminoasa a unei surse ce emite o radiatie monocromatica cu frecventa $540 \cdot 10^{12}$ Hz (λ = 555nm <u>in vid</u>) si are o intensitate radianta de 1/683 W/sr

Flux energetic

- Flux energetic al luminii
  - viteza cu care energia trece printr-o suprafata
  - energie/unitatea de timp
  - unitatea SI - W

$$\Phi_e = \frac{dE}{dt} \quad [W]$$

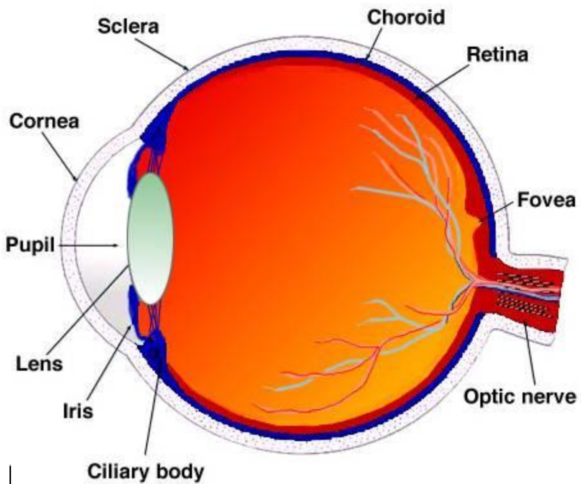
- Unghi solid
  - definitie $\Omega = \frac{A}{r^2} \quad [sr]$
  - valoarea maxima: $\Omega = 4\pi$ sr
  - pentru unghiuri mici $\Omega = \pi \cdot \sin^2 \varphi$

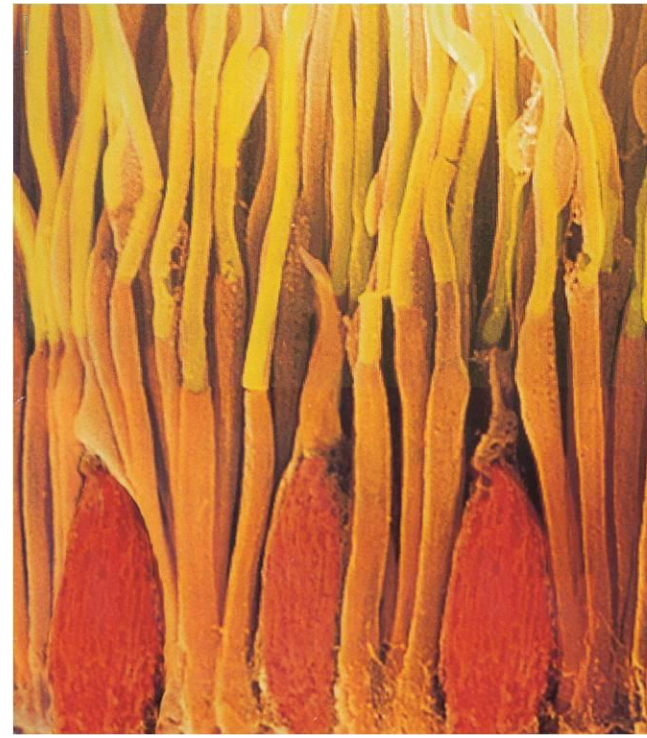


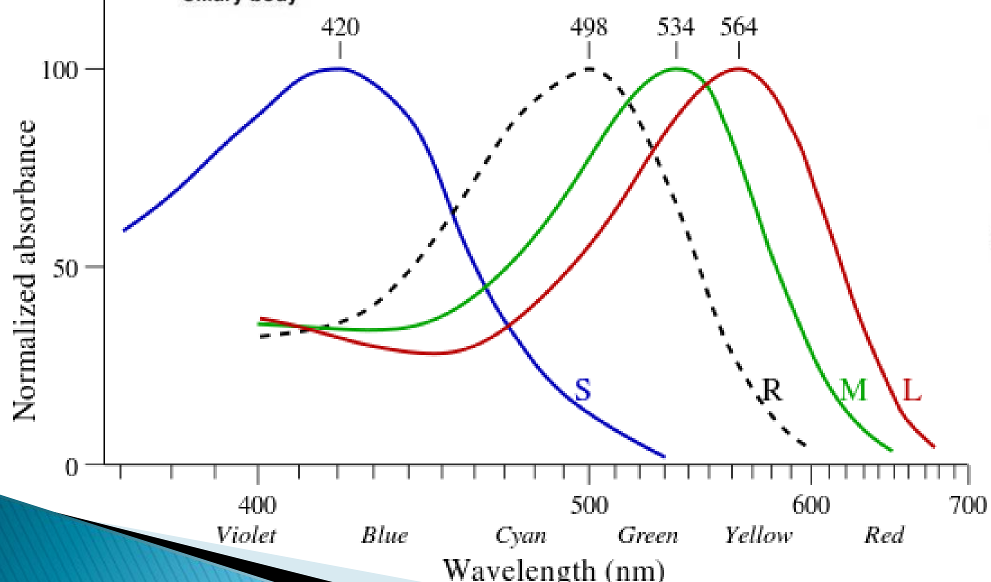
Flux luminos

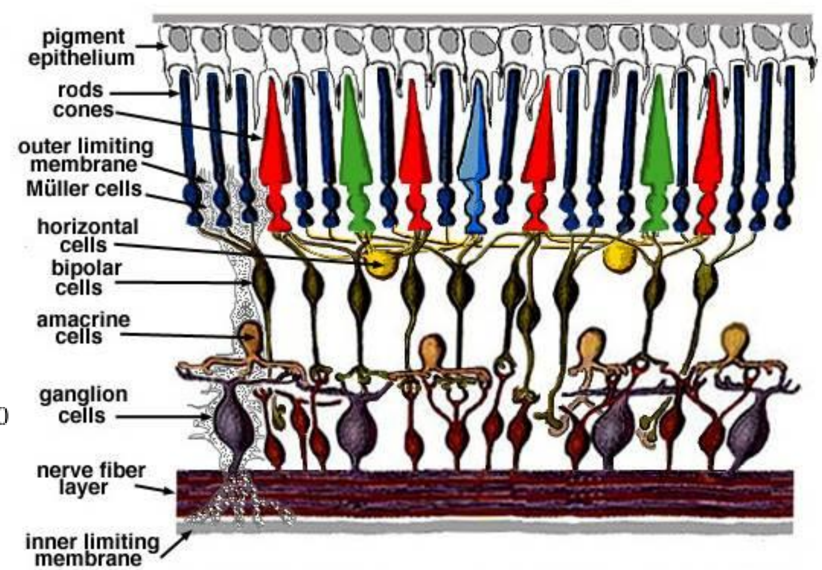
- Flux luminos, definitie
  - o masura a puterii luminoase percepute de om
- Unitate de masura – lm = lumen
  - In SI de unitati **lumenul** este definit ca fluxul luminos al unei surse luminoase punctiforme cu intensitatea luminoasa de o candela intr-un unghi solid egal cu 1 sr.
  - la λ = 555nm $\Phi_e = 1W \Leftrightarrow \Phi_v = 683 lm$
- Dualitate pentru toate marimile implicate
  - radiometrie – indice “e”
  - fotometri – indice “v”
- La alte lungimi de unda se tine cont de sensibilitatea relativa medie a ochiului uman

Ochiul uman


Sclera
Choroid
Retina
Cornea
Fovea
Pupil
Lens
Iris
Optic nerve
Ciliary body



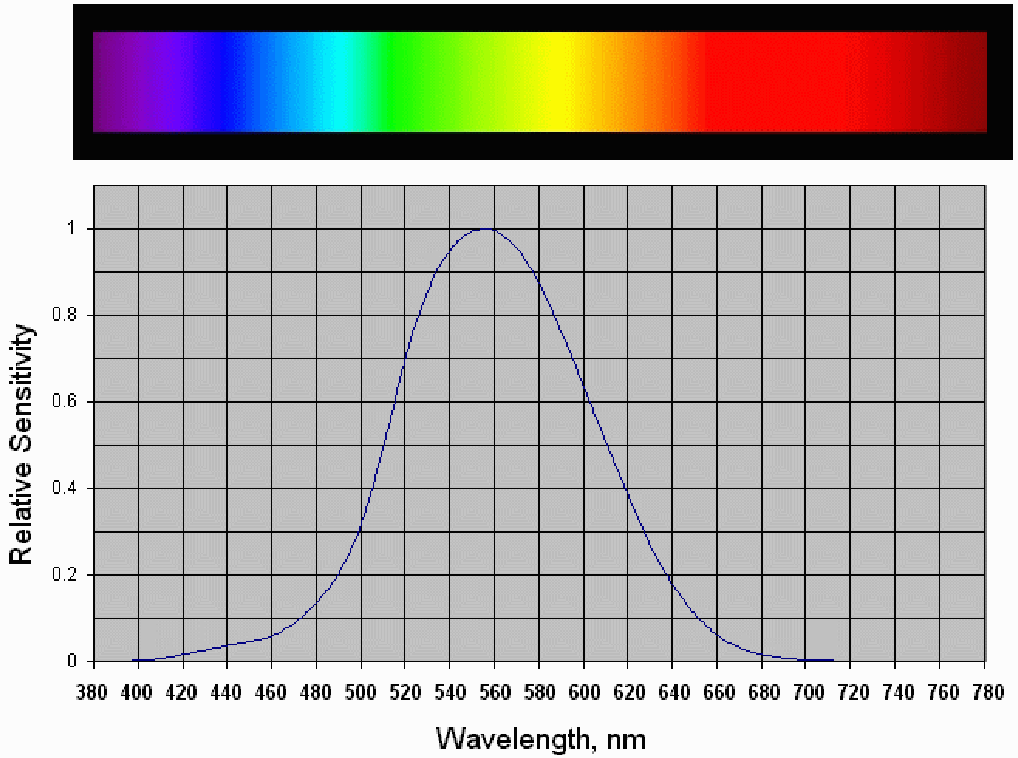

420
498
534
564
100
50
0
Normalized absorbance
S
R
M
L
400
500
600
700
Violet
Blue
Cyan
Green
Yellow
Red
Wavelength (nm)


pigment epithelium
rods
cones
outer limiting membrane
Müller cells
horizontal cells
bipolar cells
amacrine cells
ganglion cells
nerve fiber layer
inner limiting membrane

Standarde

- Se incearca definirea omului “standard”
- CIE – Commission Internationale de l'Éclairage
  - 1931 – luminozitatea relativa standard V(λ) – fotopic
  - 1951 – luminozitatea relativa standard V(λ) – scotopic
  - 1978 – Vos
  - 2005 – Sharpe, Stockman, Jagla, Jägle
- Sensibilitatea maxima a ochiului uman
  - vedere diurna (fotopic), λ=555 nm, η_v = 683 lm/W
  - vedere nocturna (scotopic), λ=507 nm , η_v = 1700 lm/W

CIE V(λ)



Response of Human Eye Versus Wavelength

(Data from the 1988 C.I.E. Photopic Luminous Efficiency Function)

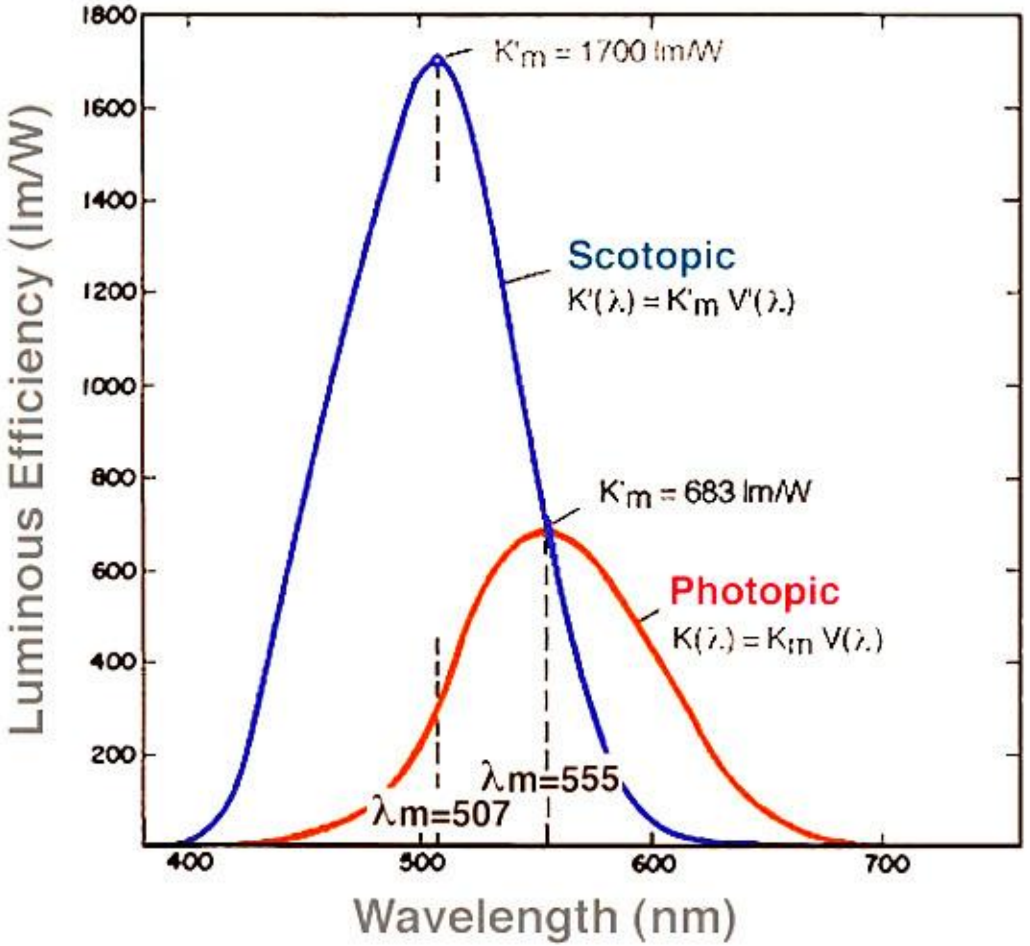


Figure 9. The scotopic and the photopic curves of spectral luminous efficacy (non-normalised values).

efect Purkinje

Curbe normalizate CIE

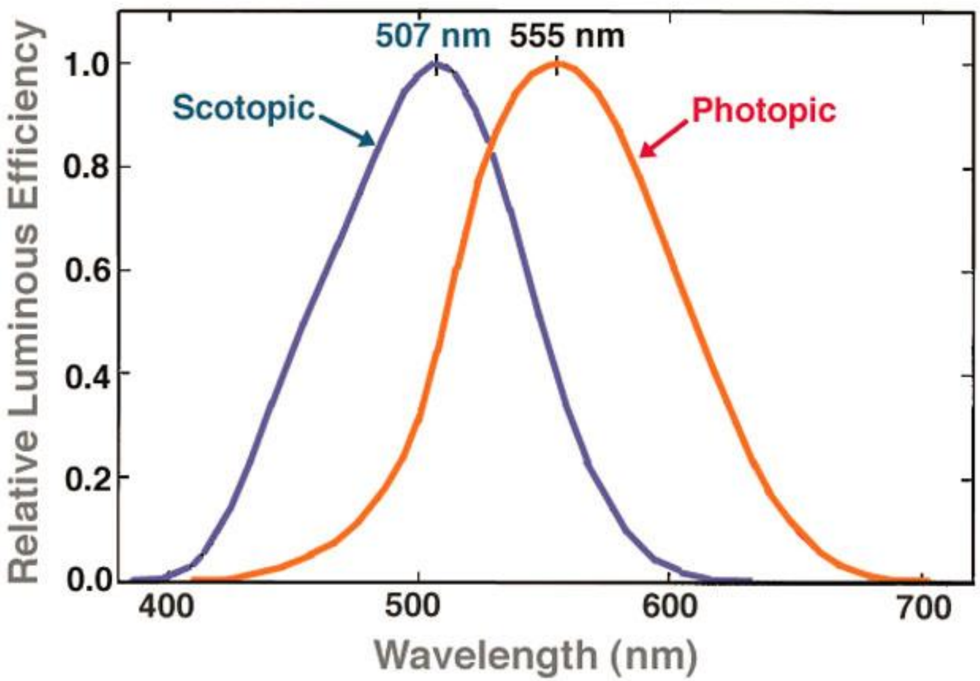


Figure 10. The scotopic and the photopic curves of relative spectral luminous efficiency as specified by the CIE (normalised values).

CIE V(λ)

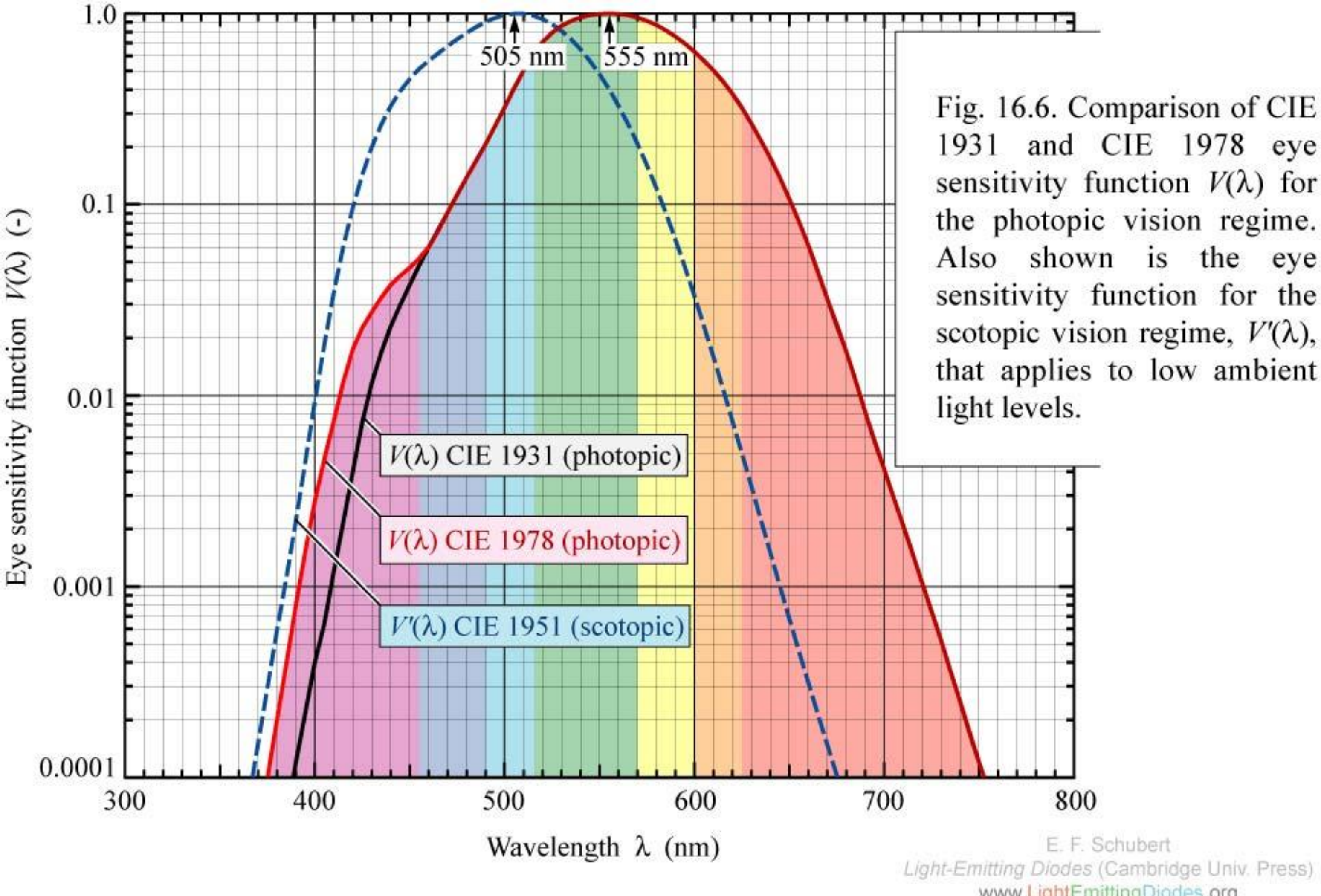


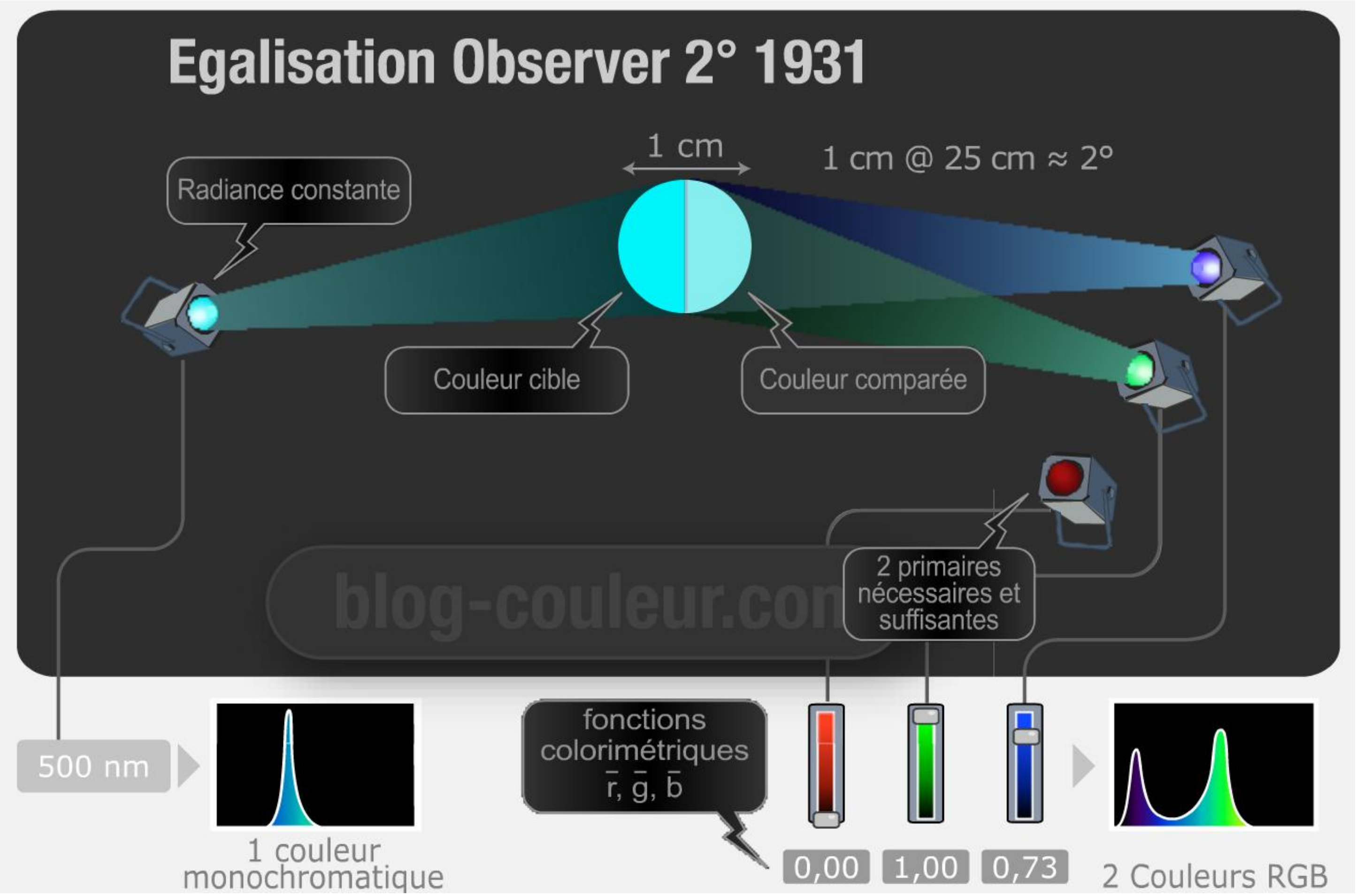
Fig. 16.6. Comparison of CIE 1931 and CIE 1978 eye sensitivity function $V(\lambda)$ for the photopic vision regime. Also shown is the eye sensitivity function for the scotopic vision regime, $V'(\lambda)$, that applies to low ambient light levels.

CIE V(λ) 1931

La Commission internationale de l'Éclairage recommande, pour l'usage général, les valeurs suivantes, comme valeurs provisoires pour le facteur de visibilité.

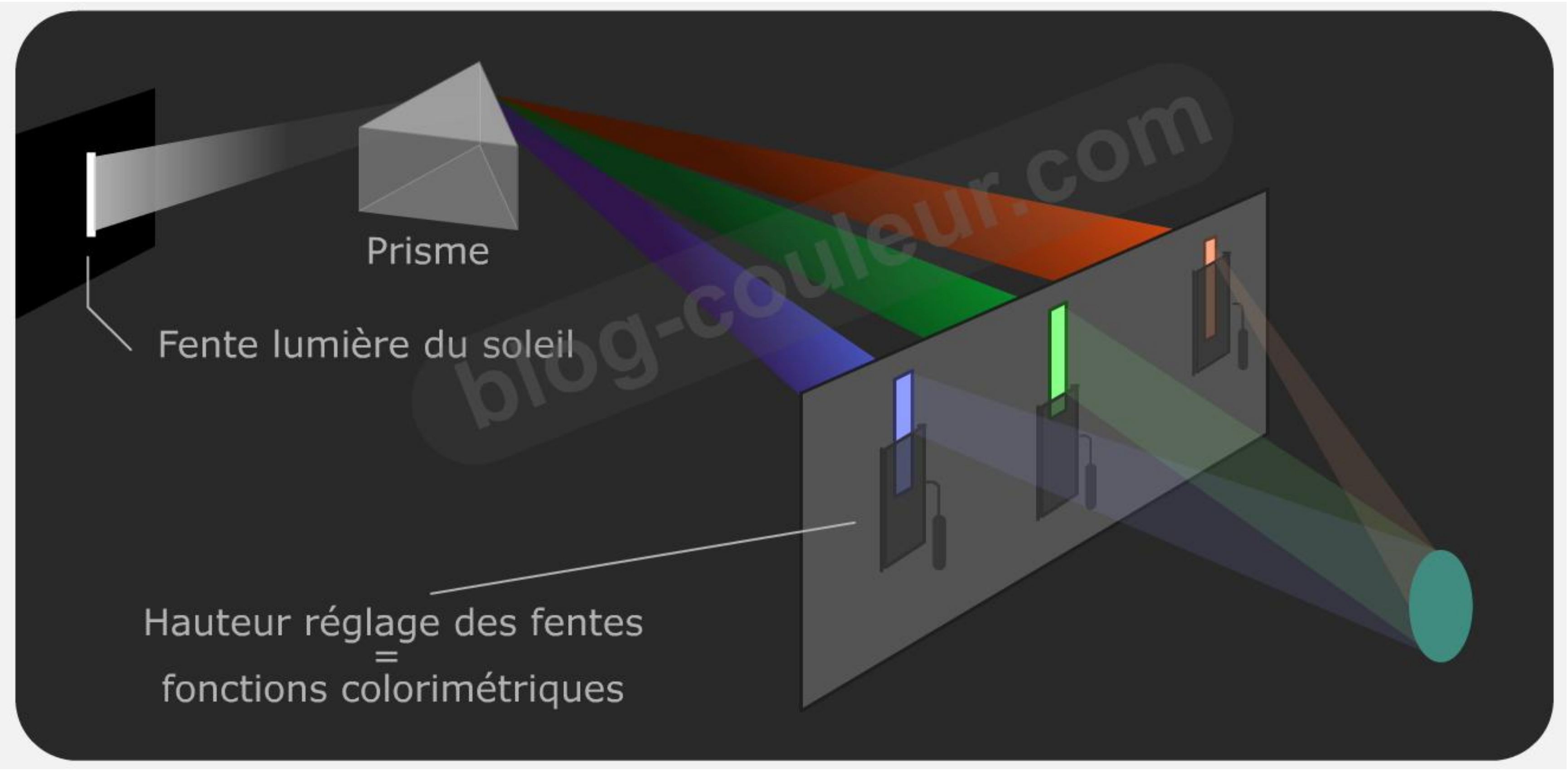
Longueur d'onde (mμ)	Facteur de Visibilité relative(mμ)	Longueur d'onde	Facteur de Visibilité relative	Longueur d'onde (mμ)	Facteur de Visibilité relative
400	0.0004	530	0.862	650	0.107
10	0012	40	954	60	061
20	0040	550	995	70	032
30	0116	60	995	80	017
40	023	70	952	90	0082
450	038	80	870	700	0041
60	060	90	757	10	0021
70	091	600	631	20	00105
80	139	10	503	30	00052
90	208	20	381	40	00025
500	323	30	265	750	00012
10	503	40	175	60	00006
20	710				

CIE xy 1931



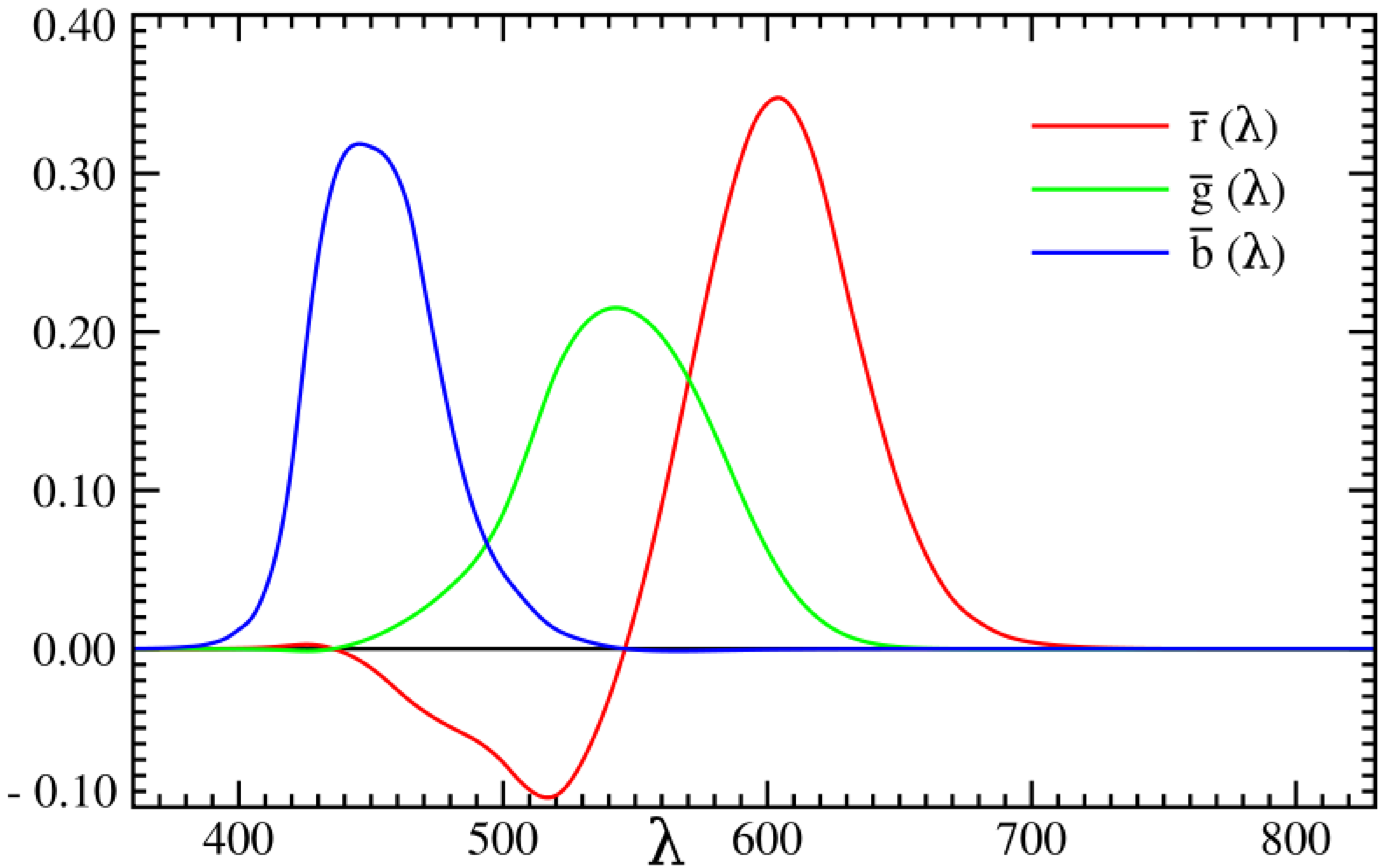
Egalisation Observer 2° 1931
1 cm
1 cm @ 25 cm ≈ 2°
Radiance constante
Couleur cible
Couleur comparée
blog-couleur.com
2 primaires nécessaires et suffisantes
500 nm
1 couleur monochromatique
fonctions colorimétriques r̄, ḡ, b̄
0,00
1,00
0,73
2 Couleurs RGB

CIE xy 1931

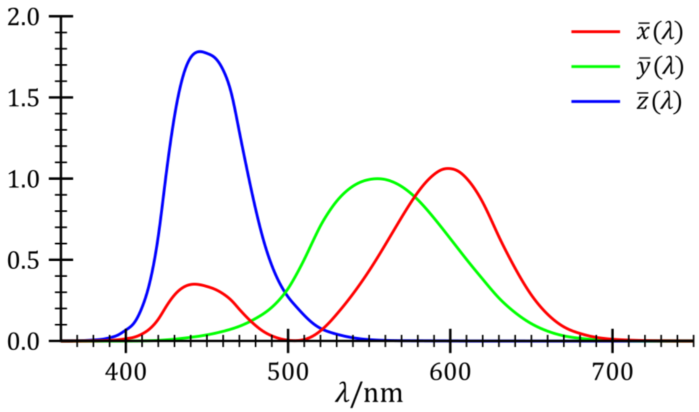


Prisme
Fente lumière du soleil
Hauteur réglage des fentes
=
fonctions colorimétriques
blog-couleur.com

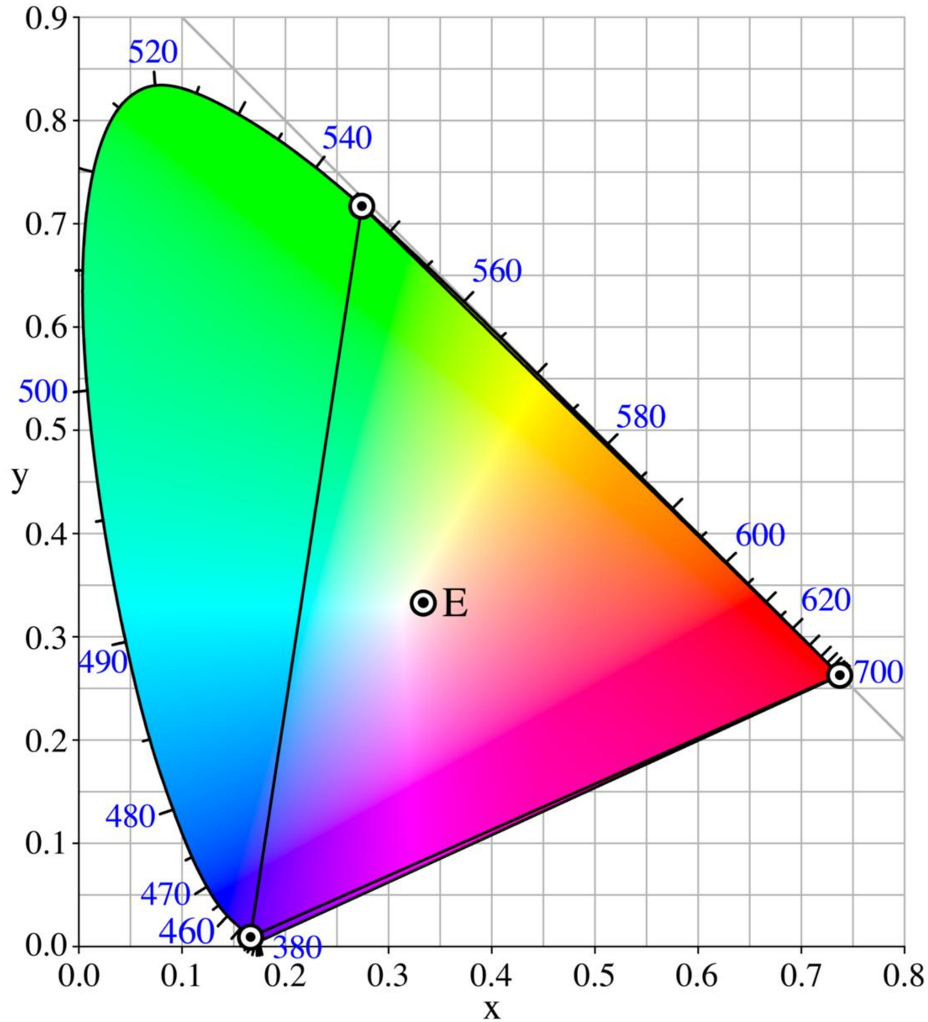
Cantitatea din culorile primare pentru aceeasi senzatie de culoare



CIE xy 1931



2.0
1.5
1.0
0.5
0.0
400
500
600
700
λ/nm
x̄(λ)
ȳ(λ)
z̄(λ)



0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
y
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x
520
540
560
580
600
620
700
500
490
480
470
460
380
E

Interpretarea standard a culorilor

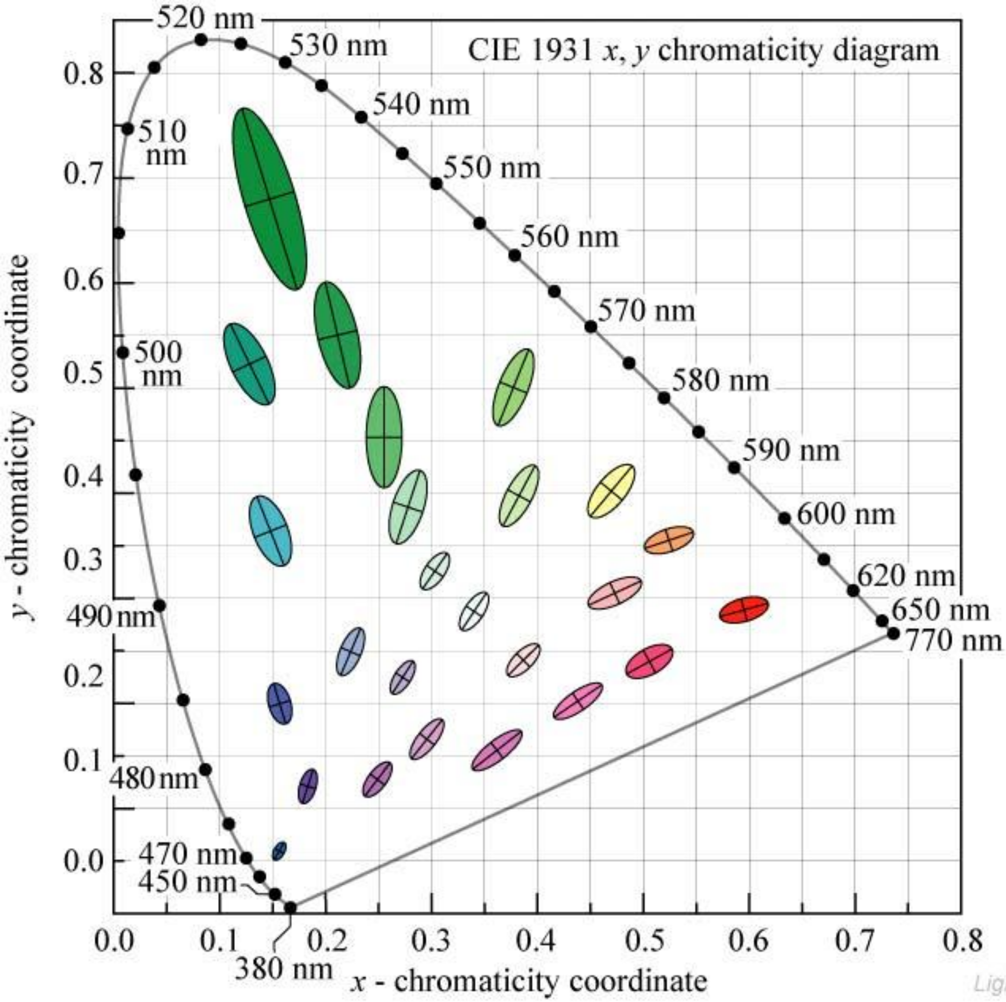
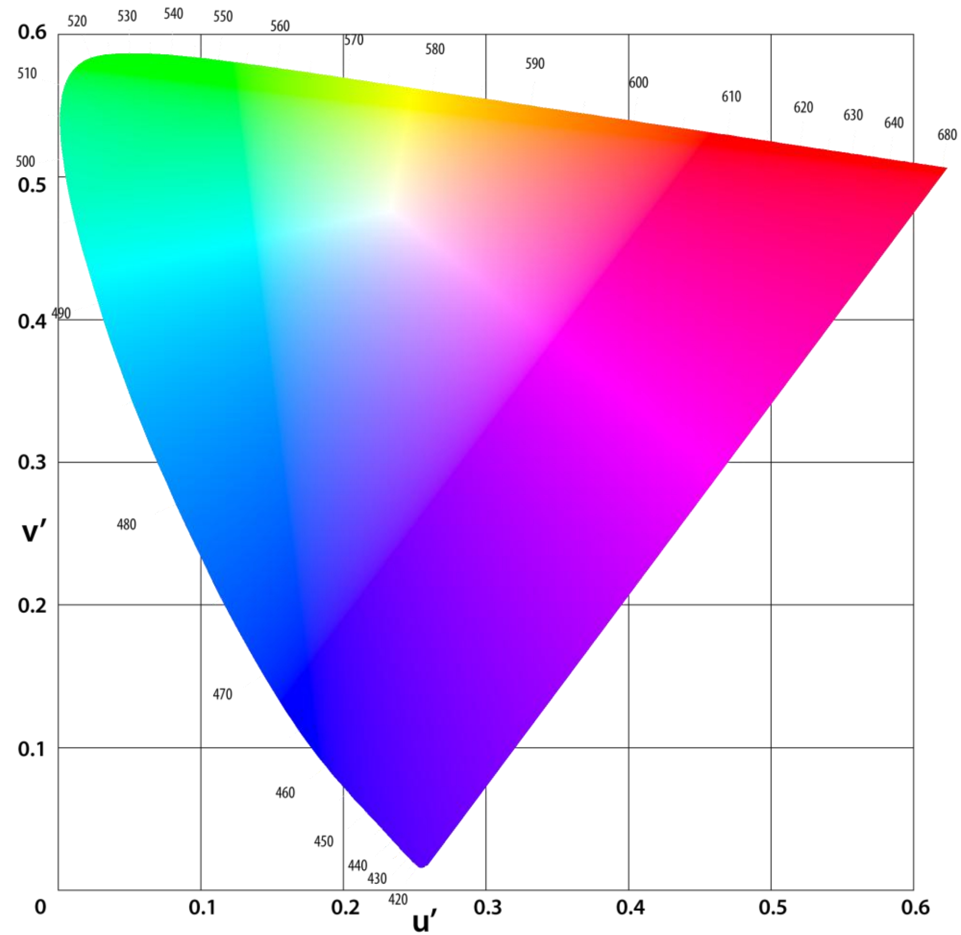


Fig. 17.5. MacAdam ellipses plotted in the CIE 1931 (*x*, *y*) chromaticity diagram. The axes of the ellipses are ten times their actual lengths (after MacAdam, 1943; Wright, 1943; MacAdam, 1993).

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

CIELUV 1976

- uniformitatea perceptiei, a "diferentei de culoare"

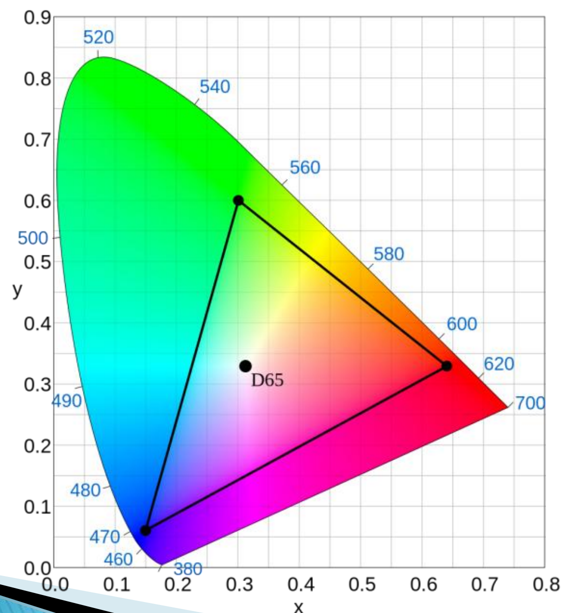


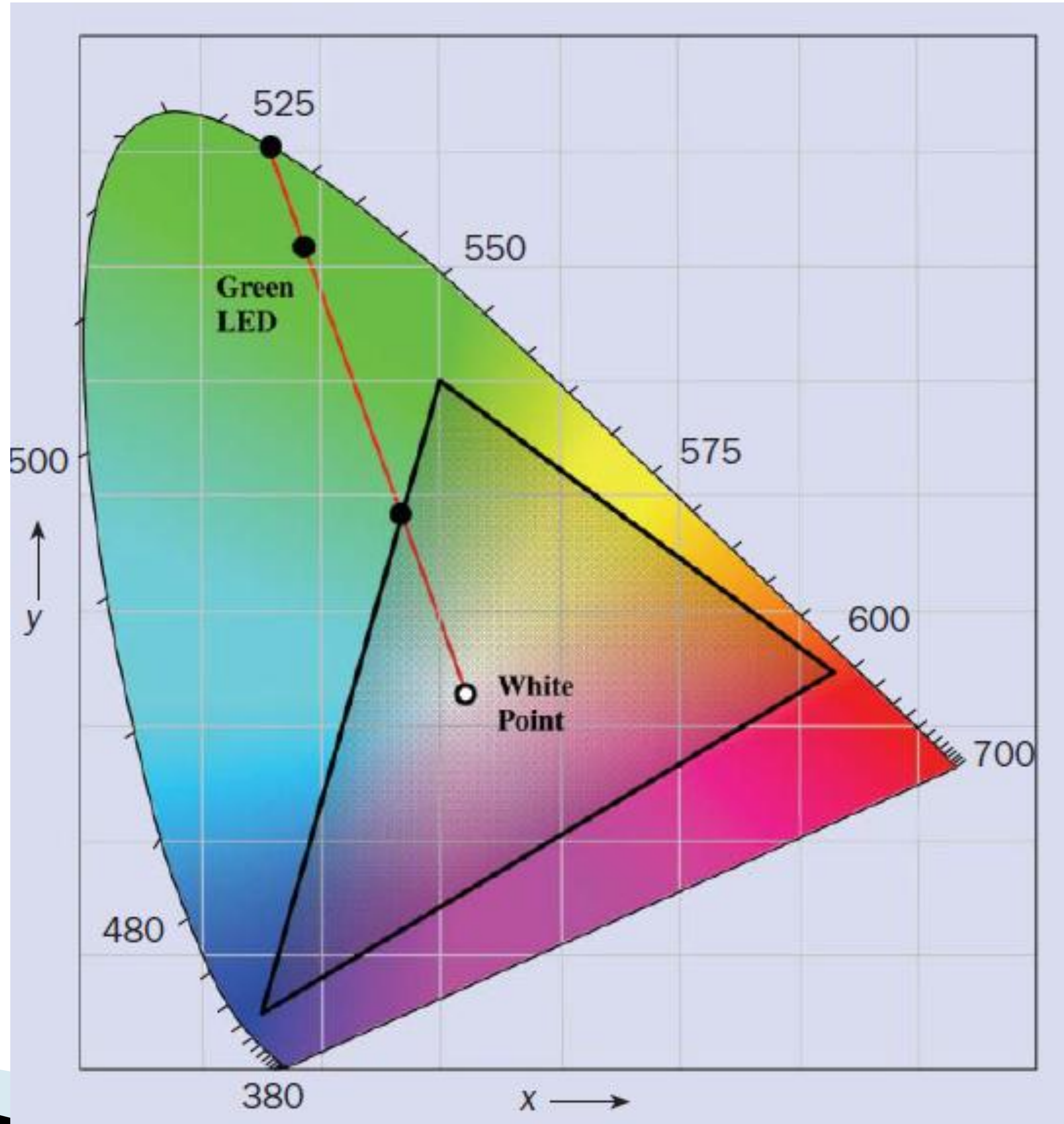
ITU-R BT.709

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].





Determinarea lungimii de unda dominante

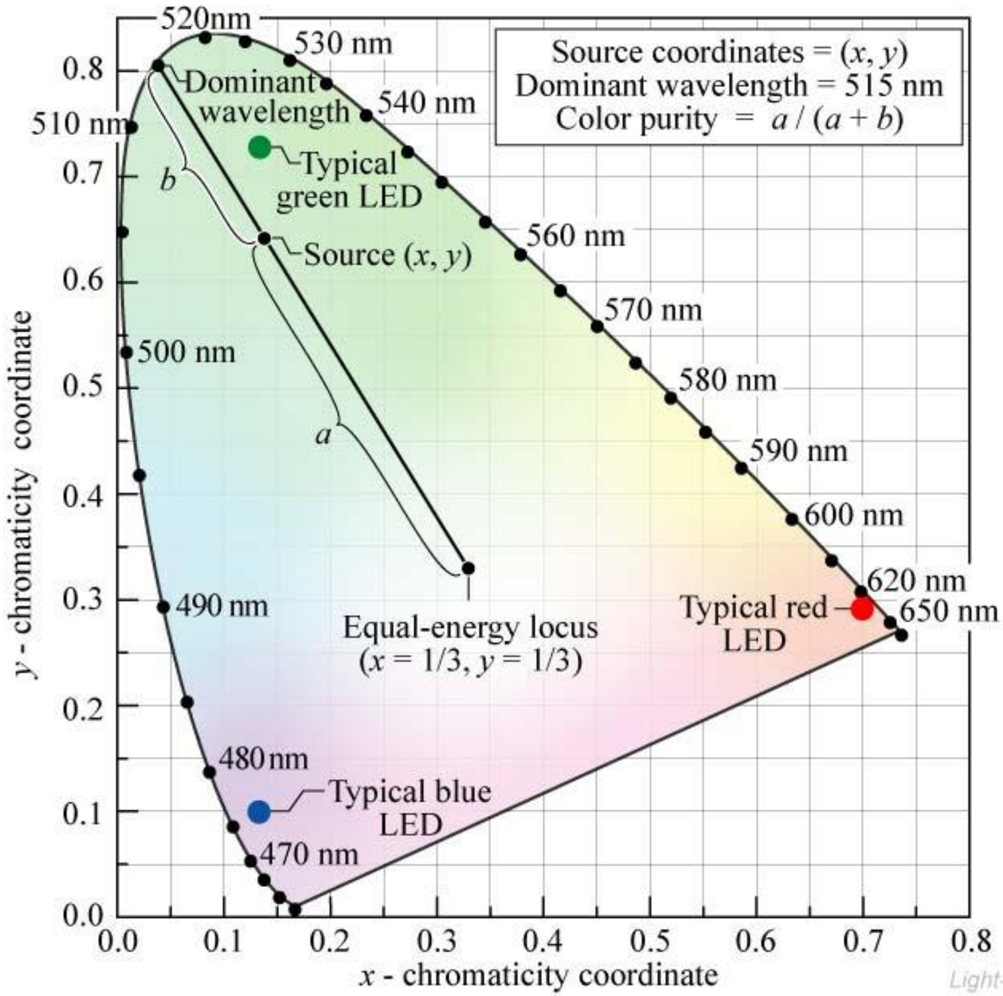
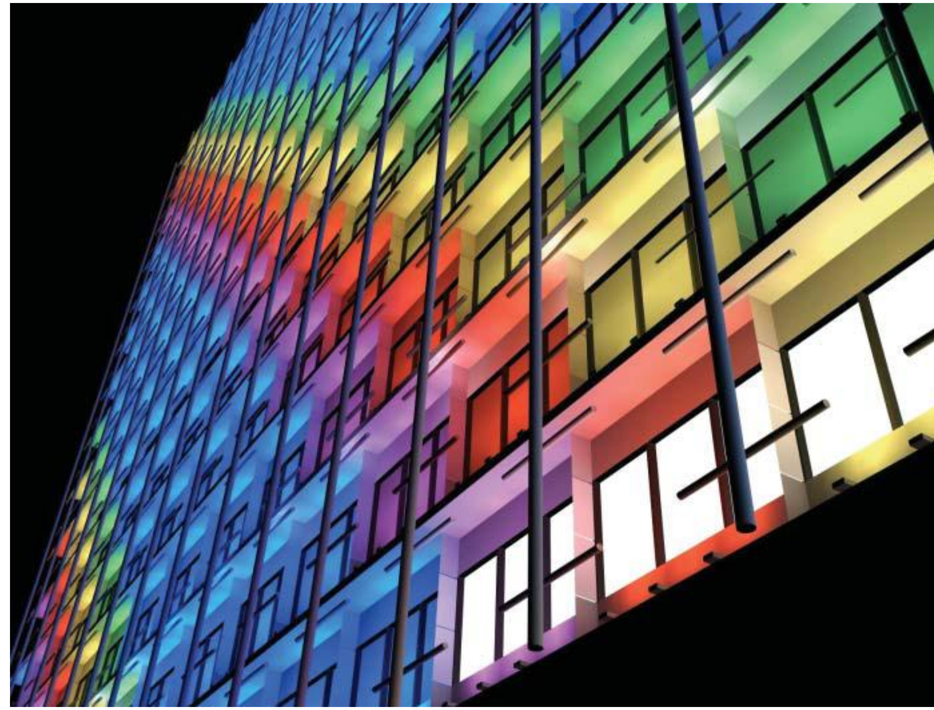


Fig. 17.8. Chromaticity diagram showing the determination of the *dominant color* and *color purity* of a light source with chromaticity coordinates (x, y) using the equal-energy locus ($x = 1/3$, $y = 1/3$) as the white-light reference. Also shown are typical locations of blue, green, and red LEDs.

ITU-R BT.709

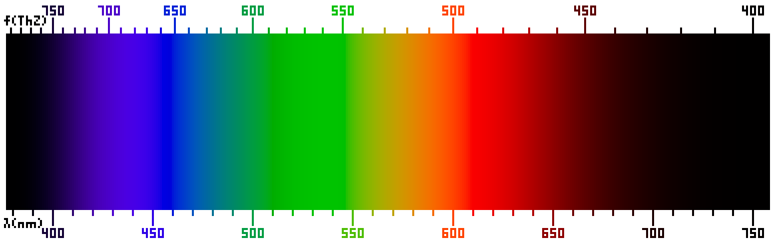


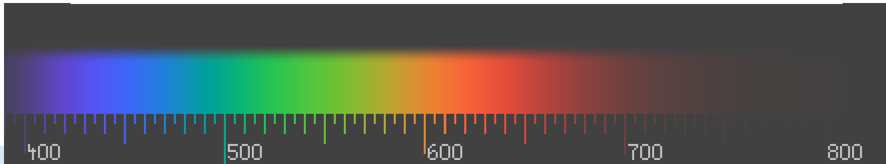
RGB values for Luxeon LEDs

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

Culori – lungime de unda (dominante)

Culoare	Lungime de unda	Frecventa
Rosu	~ 700–630 nm	~ 430–480 THz
Portocaliu	~ 630–590 nm	~ 480–510 THz
Galben	~ 590–560 nm	~ 510–540 THz
Verde	~ 560–490 nm	~ 540–610 THz
Albastru	~ 490–450 nm	~ 610–670 THz
Violet	~ 450–400 nm	~ 670–750 THz





Interpretarea standard a culorilor

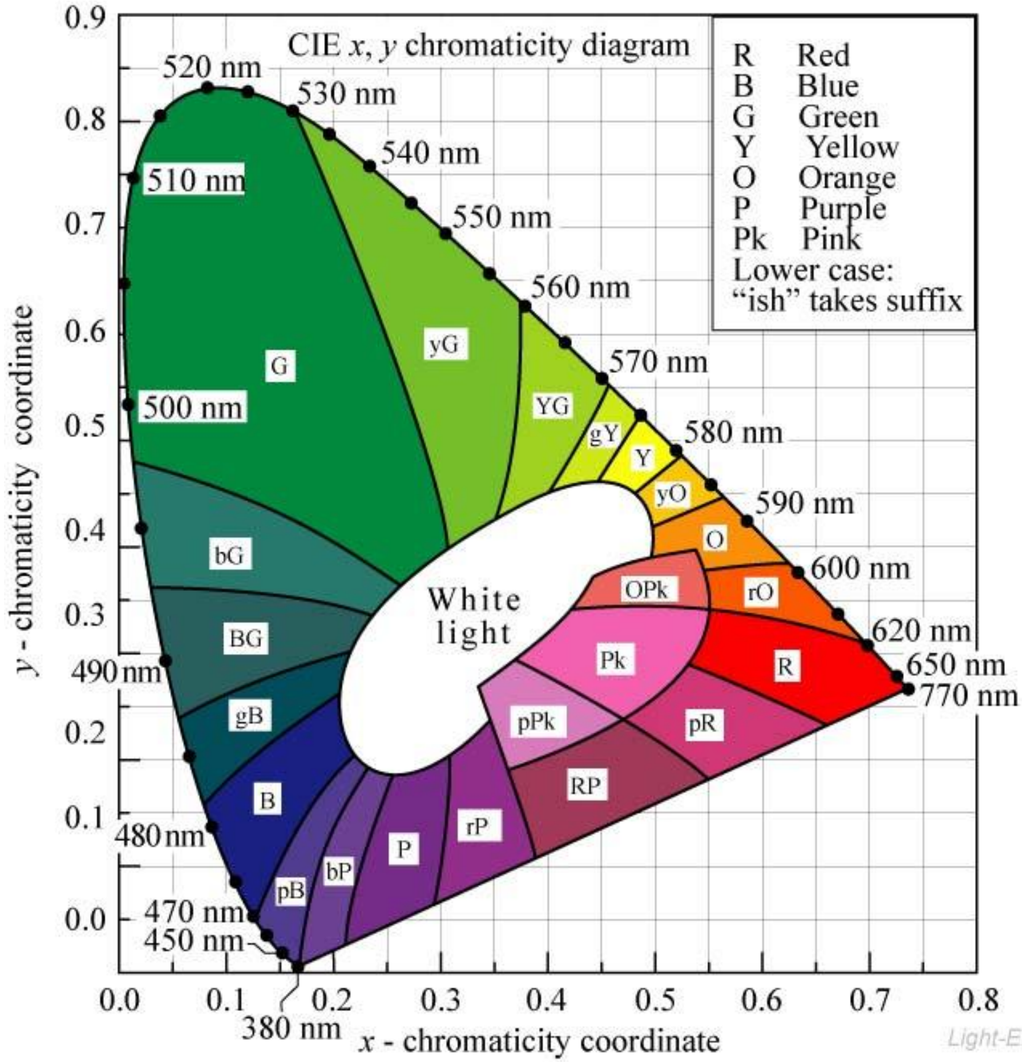


Fig. 17.3. 1931 CIE chromaticity diagram with areas attributed to distinct colors (adopted from Gage *et al.*, 1977).

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Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Temperatura de culoare

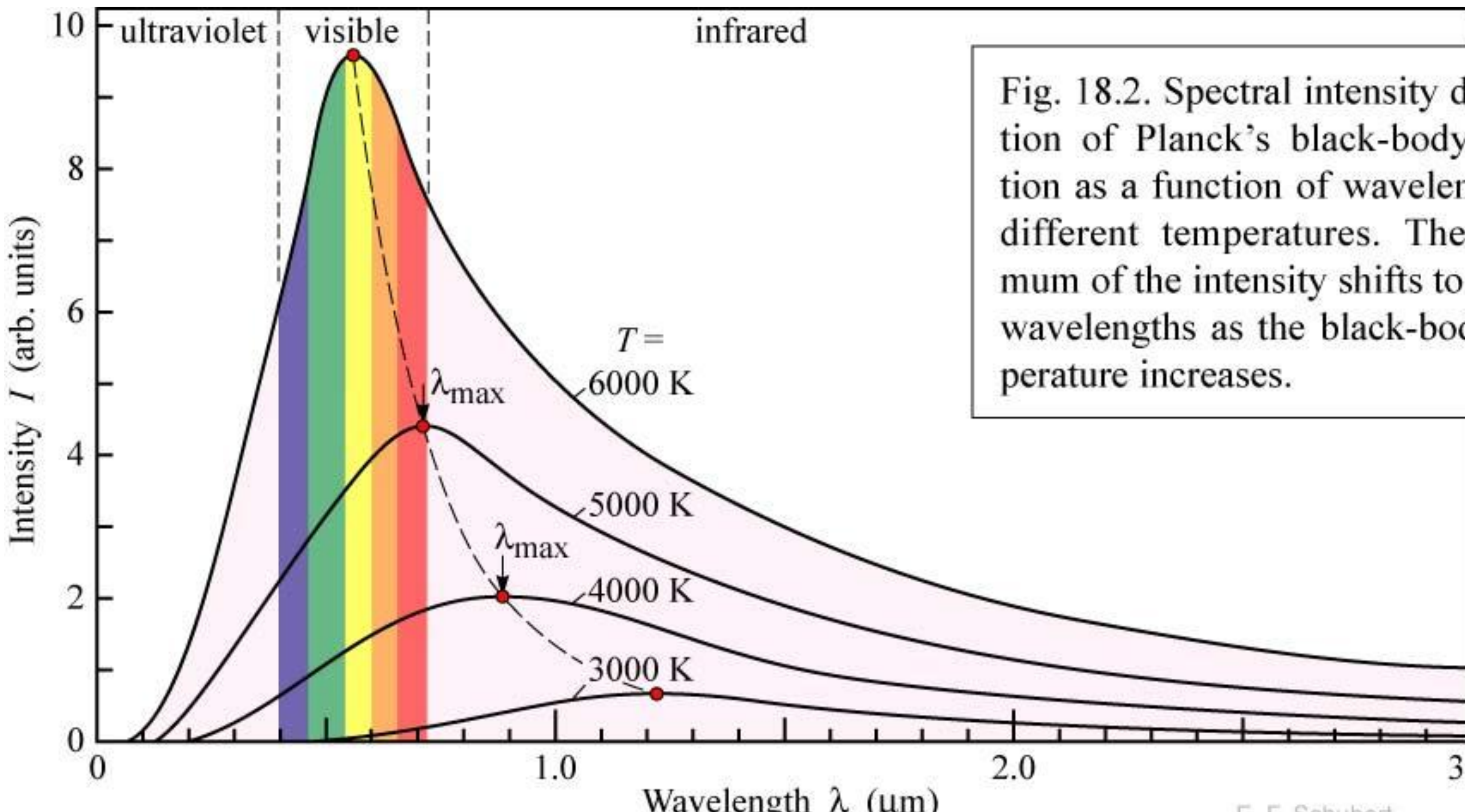

Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

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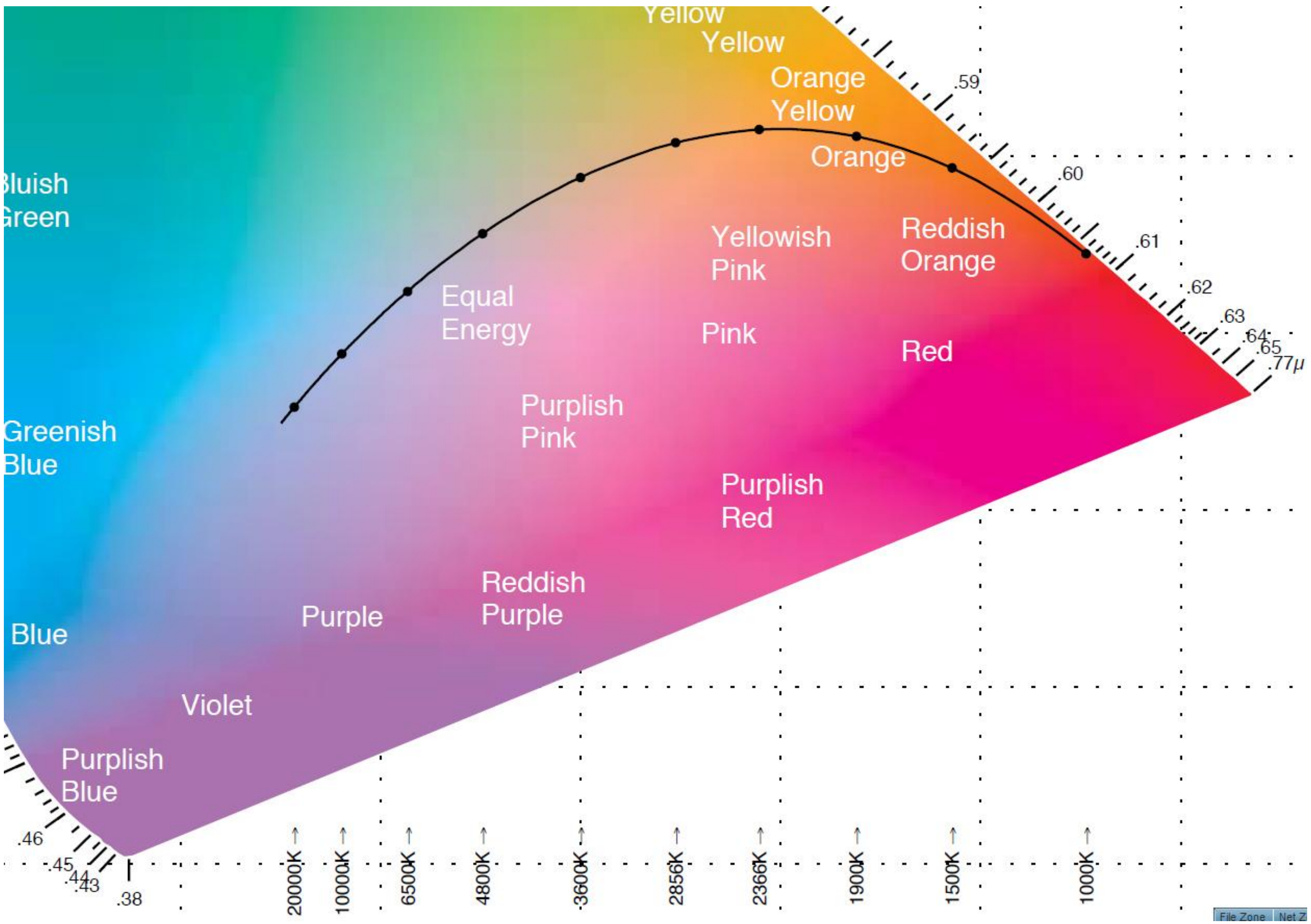
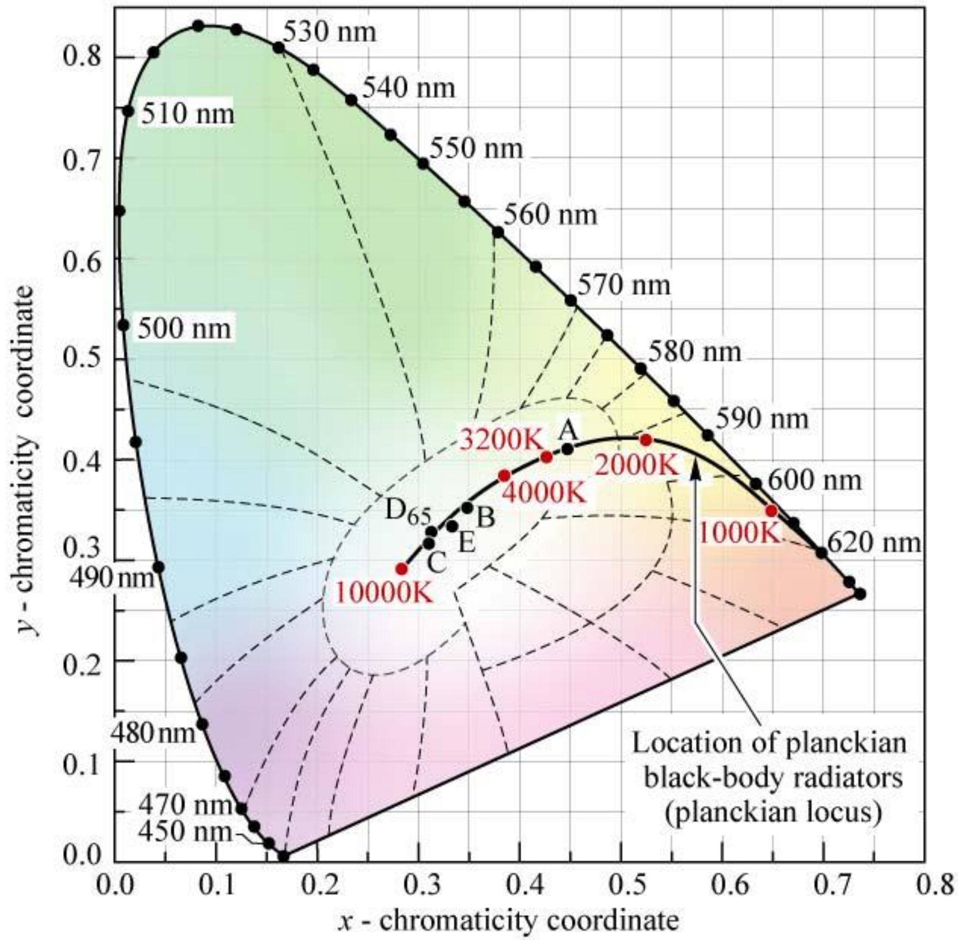
CIE xy 1931



Yellow
Yellow
Orange Yellow
Orange
Bluish Green
Yellowish Pink
Reddish Orange
Equal Energy
Pink
Red
Greenish Blue
Purplish Pink
Purplish Red
Reddish Purple
Purple
Blue
Violet
Purplish Blue
.59
.60
.61
.62
.63
.64
.65
.77μ
.46
.45
.44
.43
.38
20000K
10000K
6500K
4800K
3600K
2856K
2366K
1900K
1500K
1000K

Temperatura de culoare



Illuminant A
$(x, y) = (0.4476, 0.4074)$
(Incandescent source, $T = 2856$ K)

Illuminant B
$(x, y) = (0.3484, 0.3516)$
(Direct sunlight, $T = 4870$ K)

Illuminant C
$(x, y) = (0.3101, 0.3162)$
(Overcast source, $T = 6770$ K)

Illuminant D_{65}
$(x, y) = (0.3128, 0.3292)$
(Daylight, $T = 6500$ K)

Illuminant E (equal-energy point)
$(x, y) = (0.3333, 0.3333)$

Fig. 18.3. Chromaticity diagram showing planckian locus, the standardized white Illuminants A, B, C, D_{65}, and E, and their color temperature (after CIE, 1978).

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Lungimi de unda tipice – LED

Wavelength (nm)	Color Name
940	Infrared
880	Infrared
850	Infrared
660	Ultra Red
635	High Eff. Red
633	Super Red
620	Super Orange
612	Super Orange
605	Orange
595	Super Yellow
592	Super Pure Yellow
585	Yellow
4500K	"Incandescent" White
6500K	Pale White
8000K	Cool White
574	Super Lime Yellow
570	Super Lime Green
565	High Efficiency Green
560	Super Pure Green
555	Pure Green
525	Aqua Green
505	Blue Green
470	Super Blue
430	Ultra Blue

Relatie radiometrie/fotometrie

- Pentru radiatii monocromatice

$$\Phi_v = 683\frac{lm}{W}\cdot\Phi_e[W]\cdot V(\lambda)\quad [lm]$$

- Pentru radiatii complexe:

$$\Phi_v = 683\frac{lm}{W}\int_0^{\infty}\frac{d\Phi_e}{d\lambda}\cdot V(\lambda)d\lambda = 683\frac{lm}{W}\int_{390nm}^{830nm}\frac{d\Phi_e}{d\lambda}\cdot V(\lambda)d\lambda\quad [lm]$$

- Eficienta luminoasa

$$\eta_v = \frac{\Phi_v[lm]}{\Phi_e[W]}\quad \left[\frac{lm}{W}\right]$$

Relatie radiometrie/fotometrie

- Eficienta luminoasa maxima
  - scotopic: K_m' = 1700lm/W @ 505nm
  - fotopic: K_m = 683 lm/W @555nm
    - 683.002lm/W; $540 \cdot 10^{12}$ Hz (λ = 555.016nm)
- Eficienta luminoasa

$$\eta_v = \frac{\Phi_v[lm]}{\Phi_e[W]} = K_m \cdot V(\lambda) = 683 \frac{lm}{W} \cdot V(\lambda)$$

$$\eta_v' = \frac{\Phi_v[lm]}{\Phi_e[W]} = K_m' \cdot V'(\lambda) = 1700 \frac{lm}{W} \cdot V'(\lambda)$$

- Functiile de sensibilitate luminoasa sunt normalizate (valoarea 1 pentru sensibilitate maxima)

Radiometrie/fotometrie

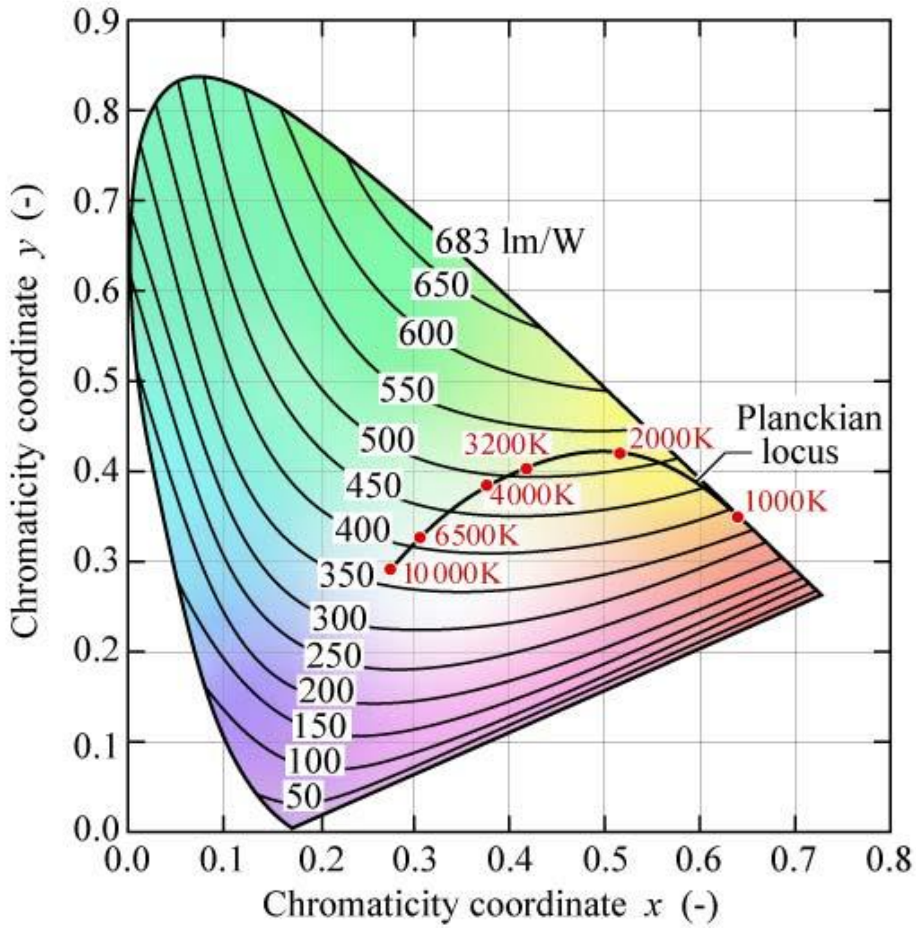


Fig. 16.8. Relation of maximum possible luminous efficacy (lumens per optical Watt) and chromaticity in the CIE 1931 *x*, *y* chromaticity diagram (adopted from MacAdam, 1950).

Eficienta luminoasa

	λ	fotopic CIE 1924	Sharpe 2005	scotopic CIE 1951
Violet	400	0	2	16
Indigo	445	20	40	668
Albastru	475	77	108	1248
Verde	510	344	361	1695
Galben	570	650	659	353
Portocaliu	590	517	541	111
Rosu	650	73	77	1

Marimi luminoase

- Intensitatea
  - raportul dintre fluxul care părăseşte sursa şi se propagă într-un element de unghi solid ce conţine direcţia de propagare şi elementul de unghi solid.
  - o masura a puterii emise de o sursa intr-un element de unghi solid

Intensitatea			
Fotometrie		Radiometrie	
$I_v = \dfrac{d\Phi_v}{d\Omega}$	SI: cd	$I_e = \dfrac{d\Phi_e}{d\Omega}$	SI: W/sr

Marimi luminoase

- Iluminarea
  - raportul dintre fluxul primit de un element de suprafaţă conţinînd punctul şi aria acestui element (definita într-un punct al unei suprafeţe la **receptie**):
  - o masura a intensitatii luminii incidente pe o suprafata

Iluminarea			
Fotometrie		Radiometrie	
$E_v = \frac{d\Phi_v}{dS}$	SI: lx	$E_e = \frac{d\Phi_e}{dS}$	SI: W/m^2

Marimi luminoase

- Excitanţa
  - raportul dintre fluxul care părăseşte un element de suprafaţă conţinînd punctul şi aria elementului de suprafaţă (definita într-un punct al unei suprafeţe la **emisie**):
  - o masura a intensitatii luminii emise de o suprafata

Excitanţa			
Fotometrie		Radiometrie	
$M_v = \frac{d\Phi_v}{dS}$	SI: lm/m^2	$M_e = \frac{d\Phi_e}{dS}$	SI: W/m^2

Marimi luminoase

- Luminanţa
  - raportul dintre fluxul care părăseşte, atinge sau traversează un element de suprafaţă şi care se propagă în direcţii conţinute într-un con elementar, dΩ, conţinînd direcţia dată, şi produsul dintre unghiul solid al conului şi aria proiecţiei ortogonale a elementului de suprafaţă pe un plan perpendicular pe direcţia dată, dS (definita într-o direcţie, într-un punct de pe suprafaţa unei surse sau unui receptor, sau într-un punct pe traiectul unui fascicol):
  - o masura a densitatii de intensitate luminoasa intr-o anumita directie

Luminanţa			
Fotometrie		Radiometrie	
$L_v = \dfrac{d^2\Phi_v}{d\Omega \cdot dS}$	SI: cd/m^2	$L_e = \dfrac{d^2\Phi_e}{d\Omega \cdot dS}$	SI: $W/m^2/sr$

Probleme

- Panoul unui dispozitiv conţine două LED-uri de semnalizare, unul de culoare verde şi unul roşu standard. Doriţi ca ambele să ofere aceeaşi luminozitate relativă şi cât mai mare posibilă. Dacă ambele LED-uri acceptă un curent maxim de 50 mA, calculaţi curentul prin cele două LED-uri.
- Rezolvari: http://rf-opto.etti.tuiasi.ro

Probleme

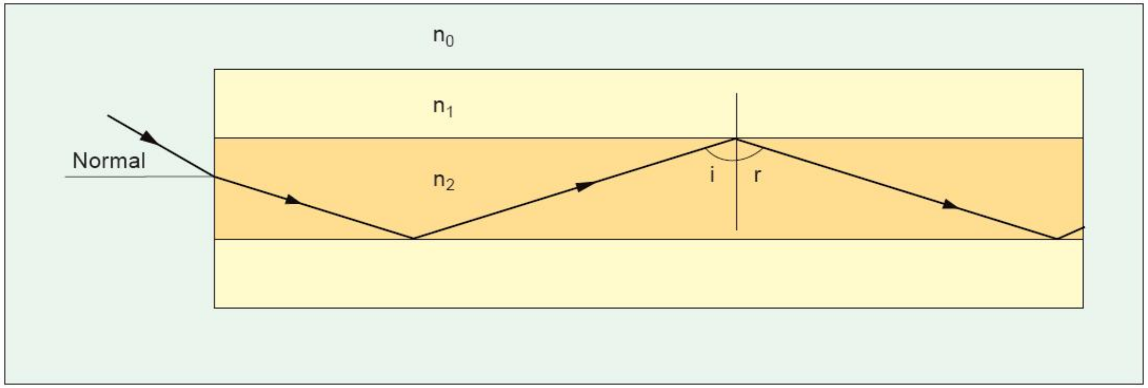
- Trebuie să proiectaţi un semafor cu LED-uri. LED-urile care intră în componenţa sa sunt caracterizate de eficienţă cuantică egală (aceeaşi tehnologie), iar parametrii de catalog pentru LED-ul roşu sunt …
- Proiectaţi semaforul, pentru a obţine o iluminare la 5m, pe direcţie normală, de 50 lx pe timp de zi şi 2 lx pe timp de noapte.
- Cerinţe: luminozitate egală pentru cele 3 culori, alegerea numărului de LED-uri (considerente electronice/practice), necesităţile de curent ale fiecărui LED, parametrii pentru sursa de alimentare, parametrii unui sistem de control a intensităţii luminoase pentru reglare zi/noapte.
- Rezolvari: http://rf-opto.etti.tuiasi.ro

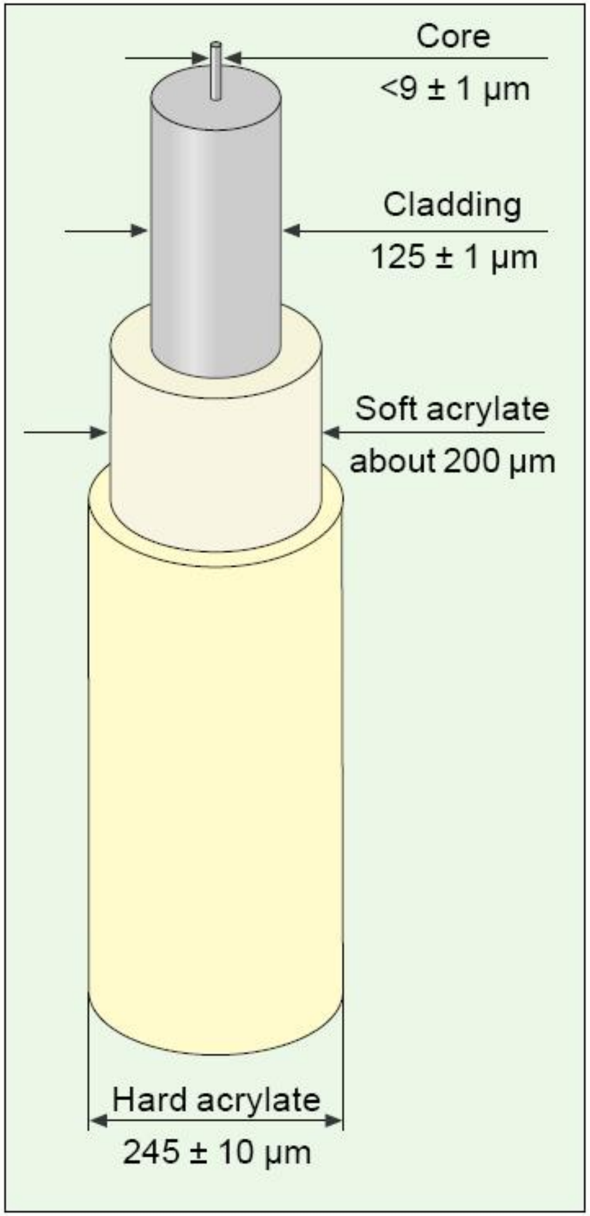
Fibra optică

Capitolul 5

Fibra optica

- un ghid de unda dielectric
  - miez
  - teaca





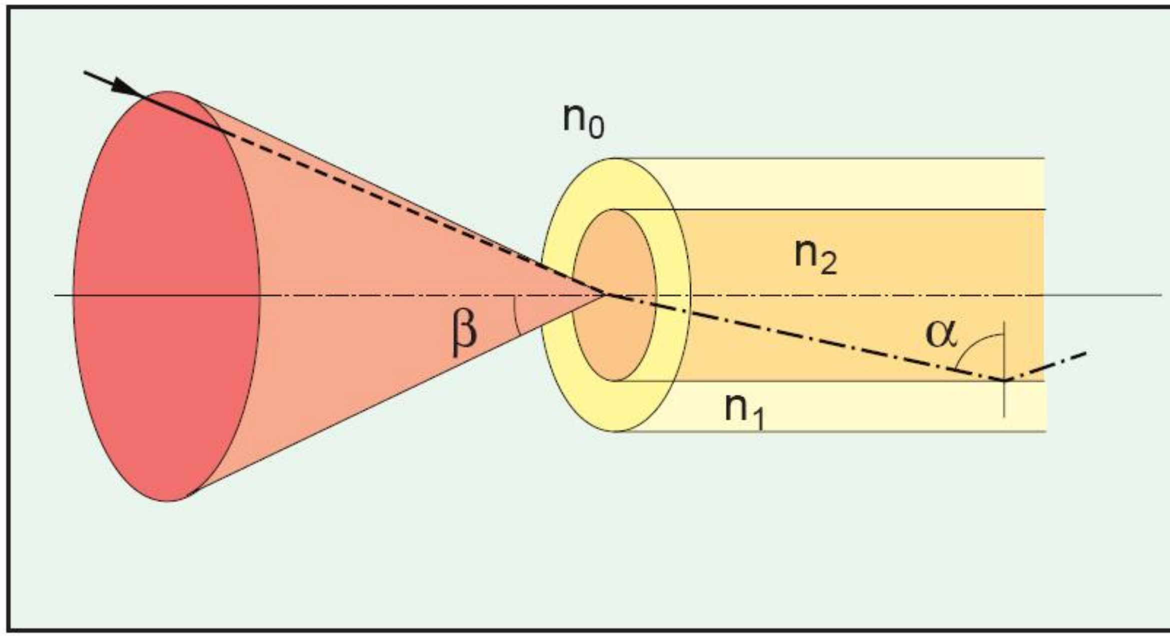
Unghi de acceptanta, apertura numerica

- Unghi de acceptanta

$$n_0 \cdot \sin\theta_{ACC} = n_1 \cdot \sin\phi_c$$

- Apertura numerica

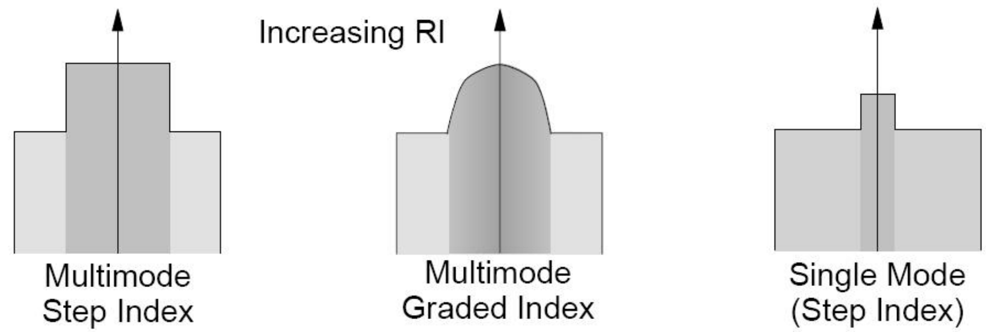
$$NA = n_0 \cdot \sin\theta_{ACC}$$

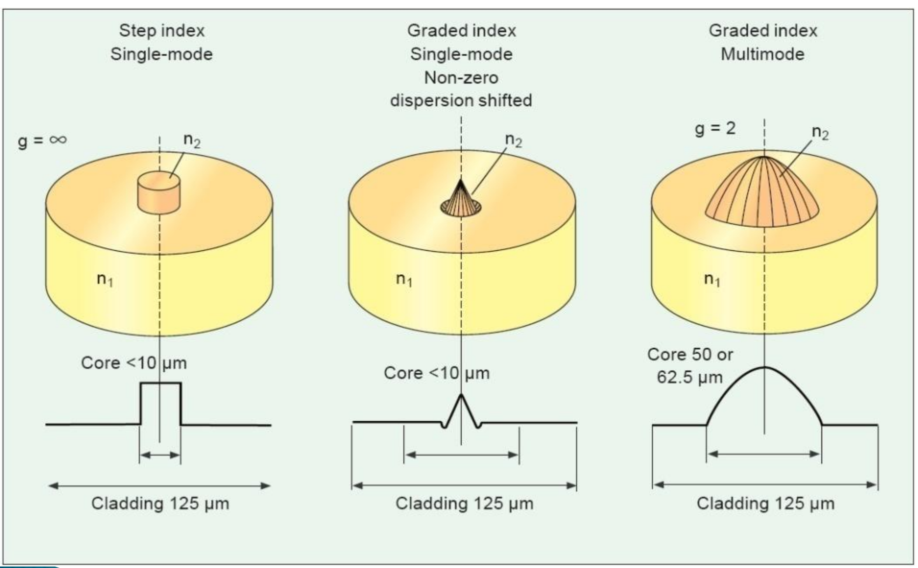


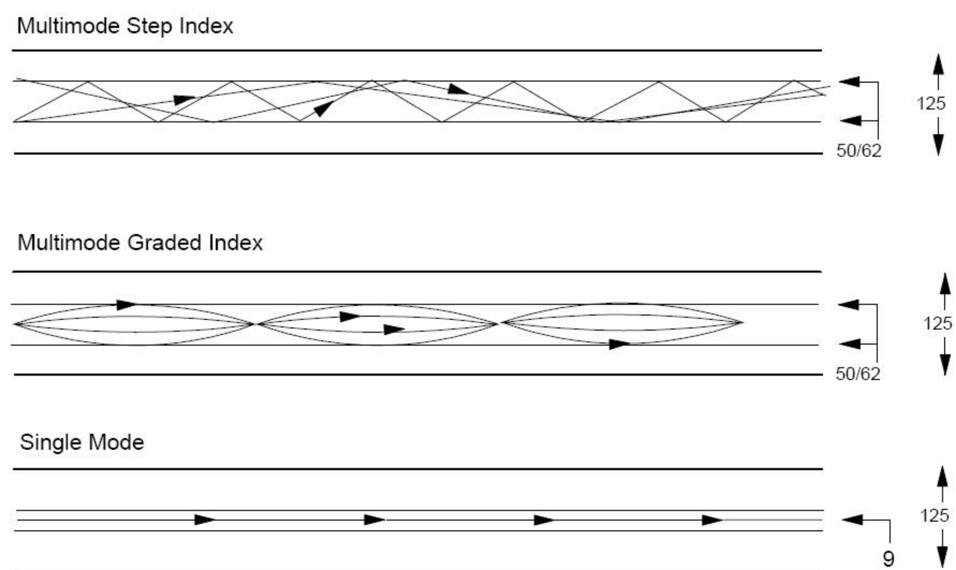
$$NA = n_2\sqrt{\frac{n_2^2 - n_1^2}{n_2^2}} = \sqrt{n_2^2 - n_1^2}$$

Tipuri de fibra

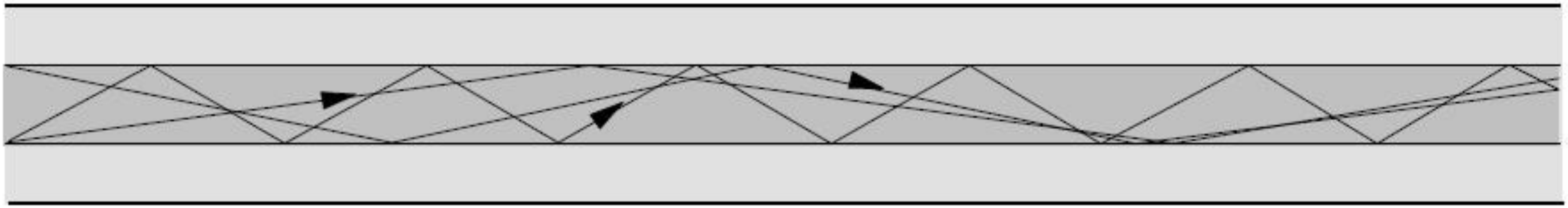
- Monomod
- Multimod
  - cu salt de indice
  - cu indice gradat



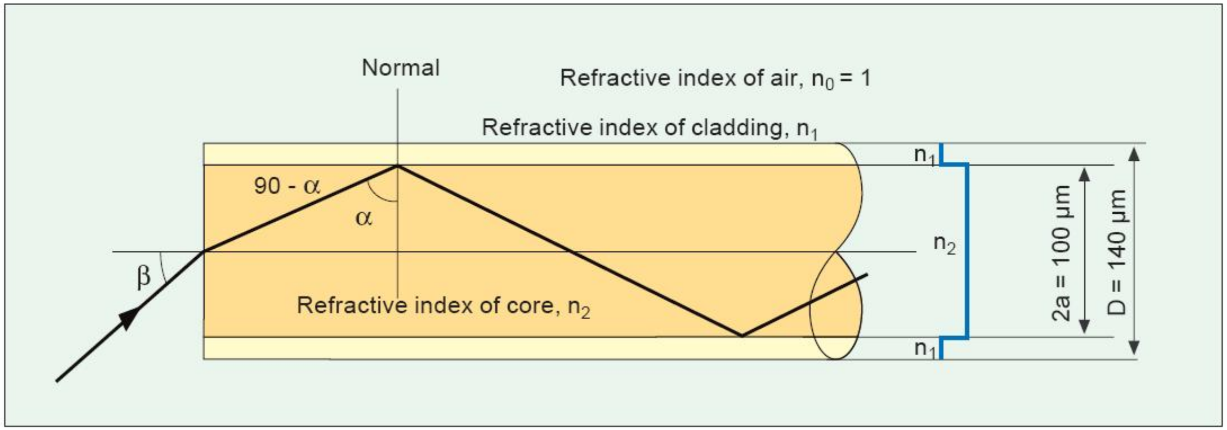




Fibre multimod cu salt de indice

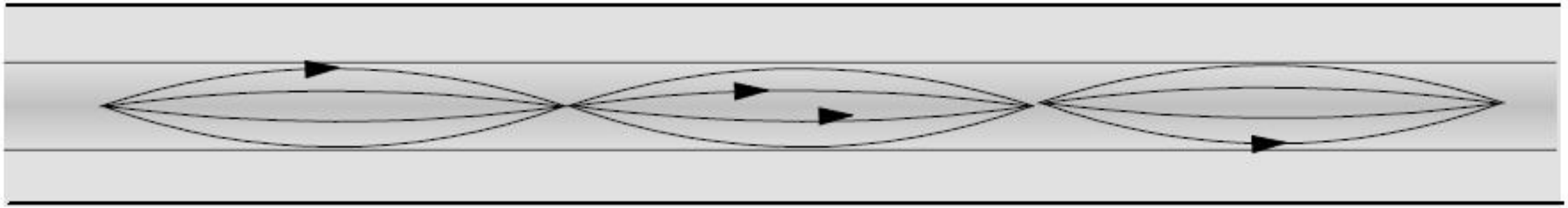


- 50/125 sau 62.5/125 (µm)
- 15-50 MHz km

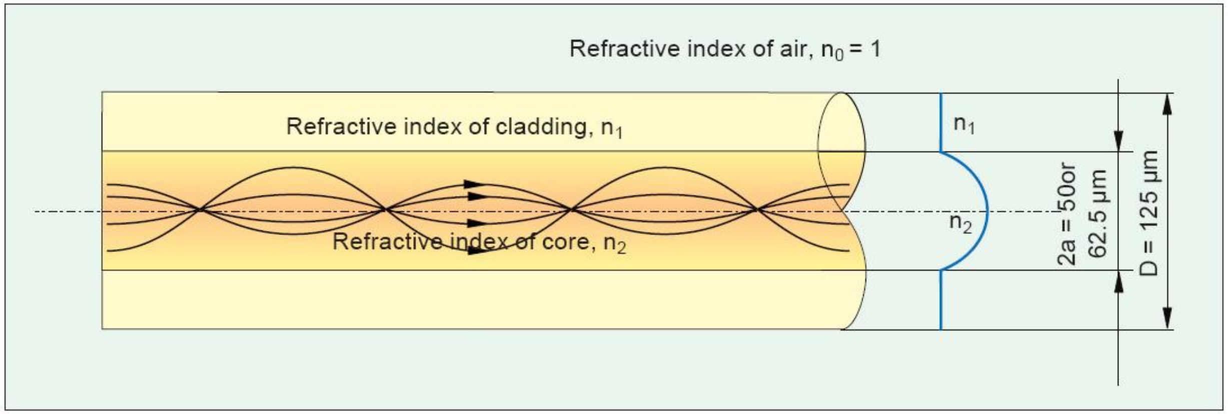


	glass	plastic
core diameter 2a	100 µm	980 µm
cladding diameter D	140 µm	1000 µm
core refractive index n_2	1.48	
cladding refractive index n_1	1.45	

Fibre multimod cu indice gradat

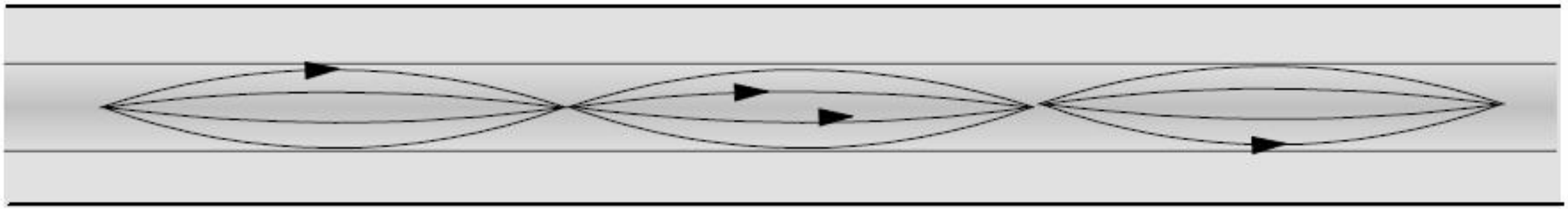


- 50/125 sau 62.5/125 (µm)
- 700-1200 MHz km



Core diameter 2a	50 or 62.5 µm
Cladding diameter D	125 µm
Maximum refractive index, core	1.46
Relative differential refractive index	0.010

Fibre multimod cu indice gradat

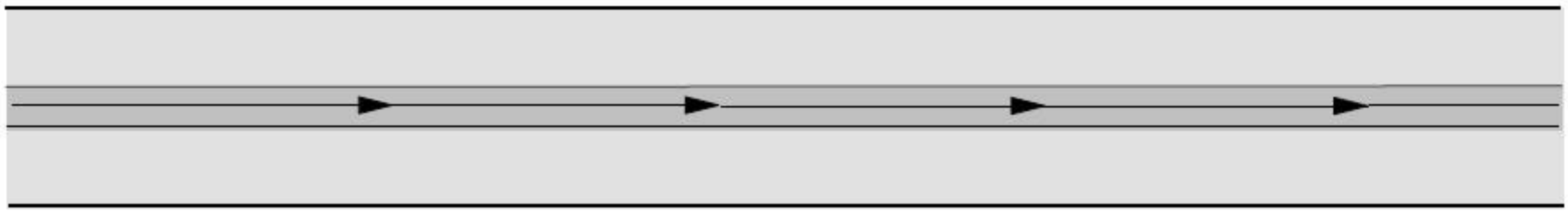


$$n(r) = n_2\left[1 - \Delta\left(\frac{r}{a}\right)^g\right]$$

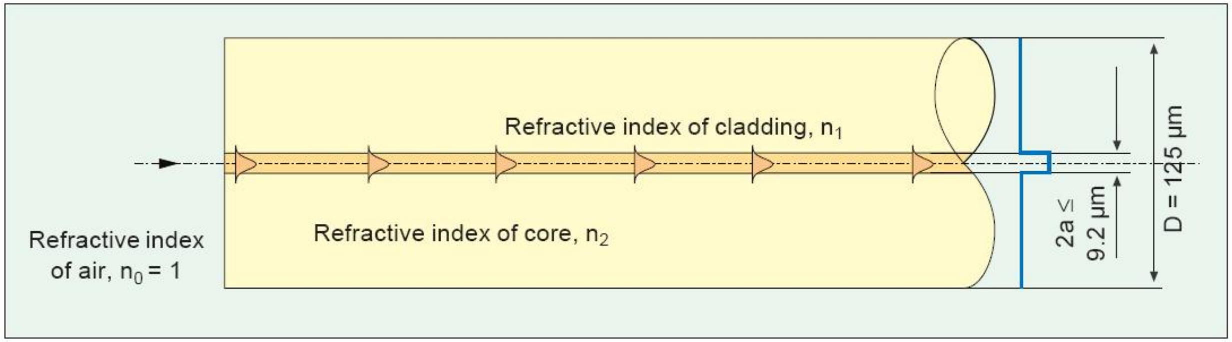
$$\Delta = \frac{NA^2}{2n_2^2} = \frac{n_2^2 - n_1^2}{2n_2^2} \approx \frac{n_2 - n_1}{n_2} \approx \frac{\Delta n}{n} \quad \text{for } \Delta << 1$$

- g = 1 – indice gradat triunghiular
- g = 2 – indice gradat parabolic
- g = ∞ – salt de indice

Fibre monomod



- 6-8/125 (µm)
- MHz km nerelevant
- MFD – Mode Field Diameter



Cladding diameter D	125 µm
Core refractive index n_2	1.4485
Cladding refractive index n_1	1.4440
Refractive index differential	0.003 = 0.3%

Frecventa normalizata

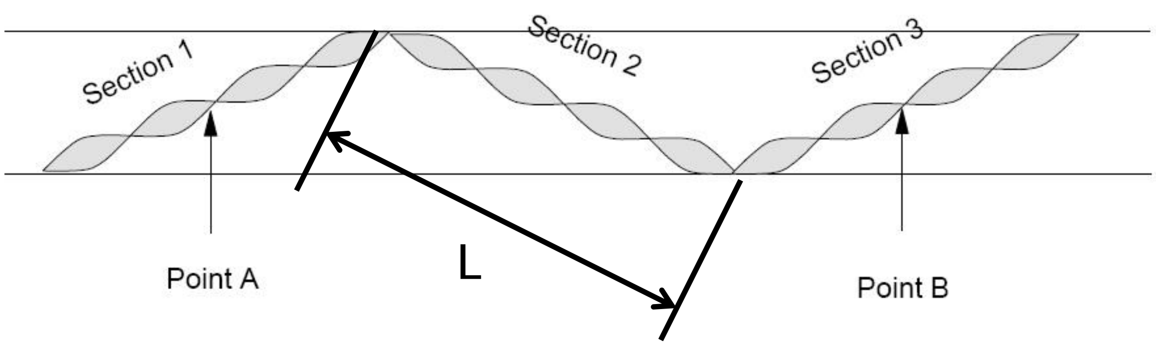
- Frecventa normalizata

$$V = 2\pi \frac{a}{\lambda} NA = k \cdot a \cdot NA$$

a – raza miezului

$$k = \frac{2\pi}{\lambda}$$

- Numar de moduri



$$L = m \cdot \lambda$$

$$N \approx \frac{V^2}{2} \cdot \frac{g}{g+2}$$

Frecventa normalizata

- Numar de moduri
  - Multimod cu salt de indice

$$g = \infty \quad \Rightarrow \quad N \approx \frac{V^2}{2}$$

  - Multimod cu indice gradat

$$g = 2 \quad \Rightarrow \quad N \approx \frac{V^2}{4}$$

  - Monomod

$V \le V_C = 2.405$ exista un singur mod (solutii fc. Bessel)

Exemplu

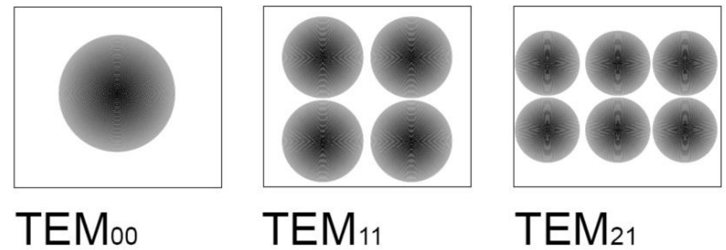
- fibra tipica multimod
  - g=2
  - 2a = 50μm -> a = 25μm
  - NA = 0.2 la λ = 1μm

$$V = 2\pi \frac{a}{\lambda} NA = 2\pi \frac{25}{1} 0.2 = 2 \cdot \pi \cdot 5 \approx 31.4$$

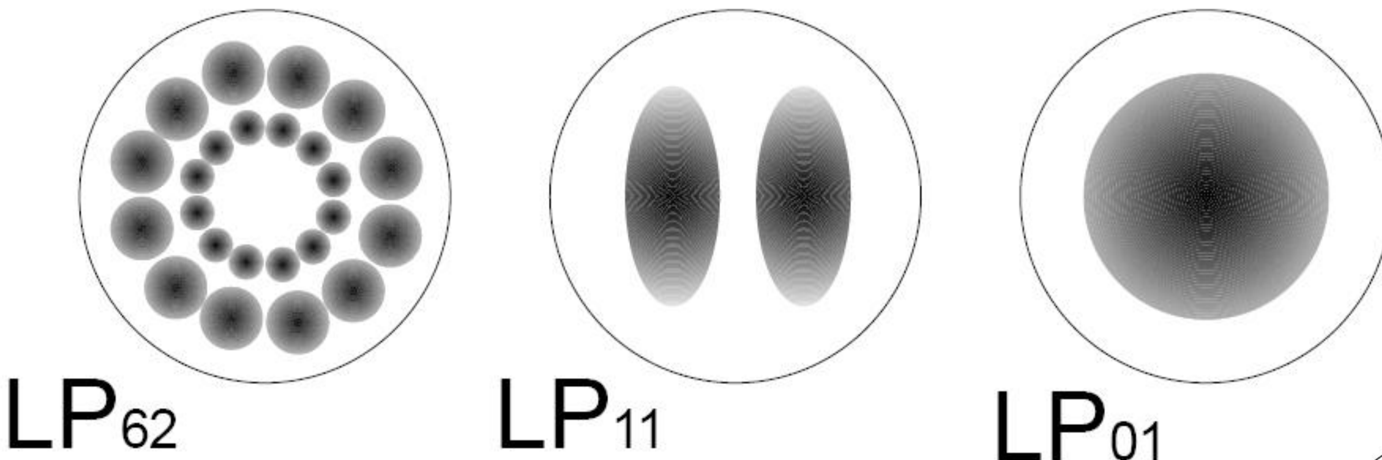
$$g = 2 \quad \Rightarrow \quad N = \frac{V^2}{4} = \frac{31.4^2}{4} = 247$$

Moduri in fibra

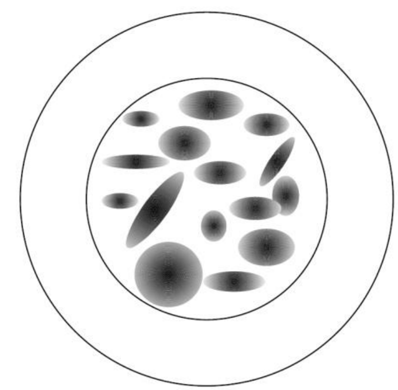
- Moduri in ghid rectangular



- Moduri linear polarizate in fibra

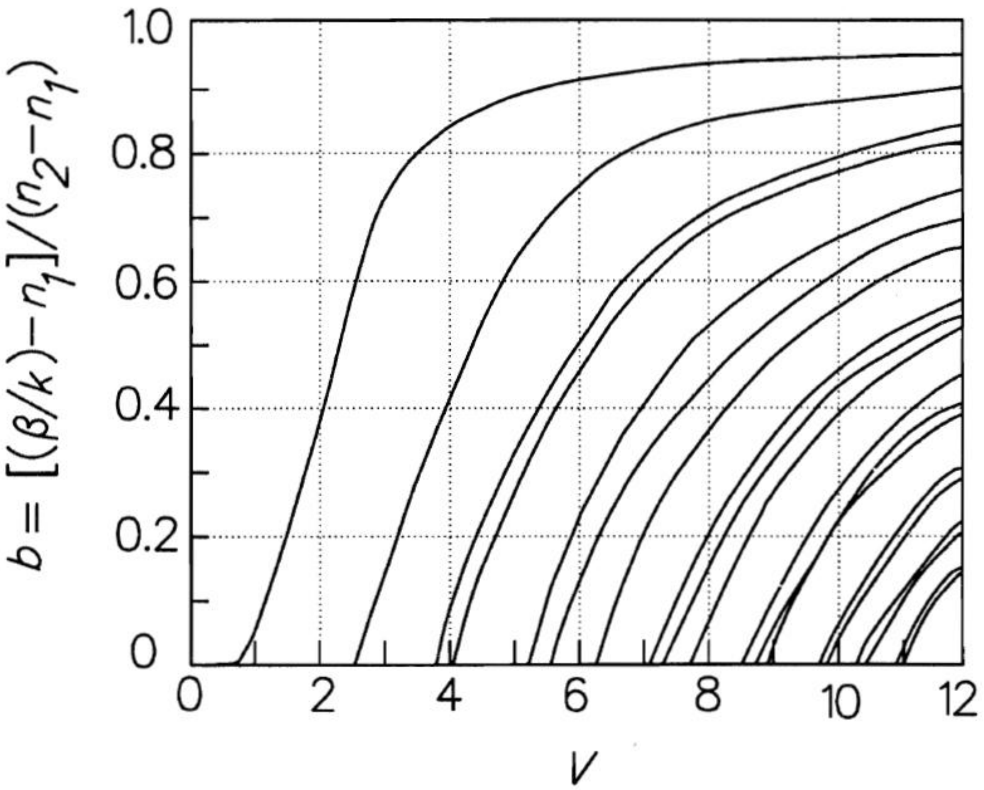


“Sparkle” pattern



Frecventa normalizata – monomod

- Fibre monomod



b – coeficient de propagare modal relativ

$$V \le V_C = 2.405$$

exista un singur mod (solutii fc. Bessel)

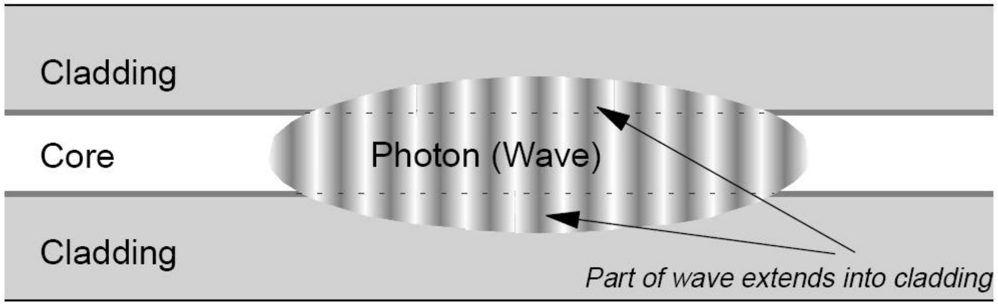
$$\lambda \ge \lambda_C = \pi \frac{2a}{V_C} NA = \pi \frac{2a}{2.405} NA$$

Exemplu:
2a = 8.5μm
NA = 0.11

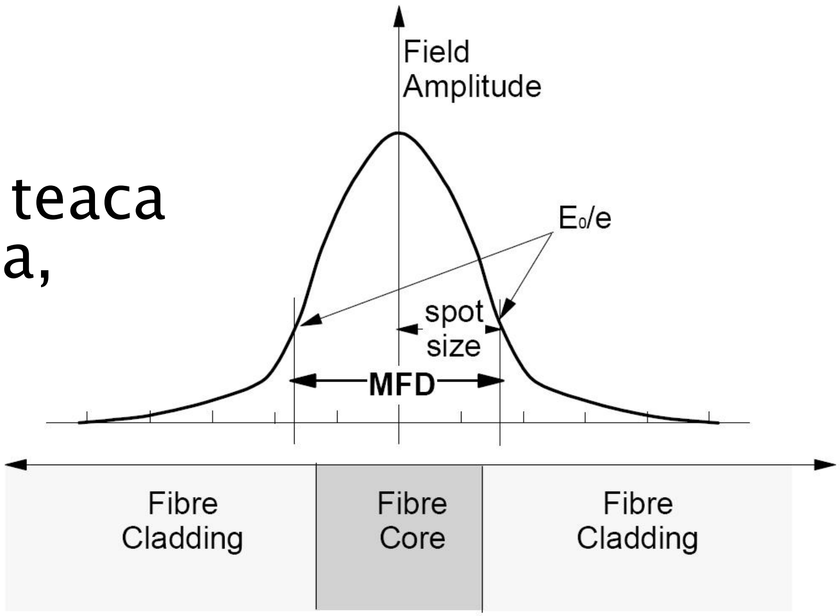
$$\lambda_C = \pi \frac{8.5}{2.405} 0.11 = 1210\text{nm}$$

Propagarea in fibra monomod

- Propagarea luminii poate fi explicata doar prin teoria electromagnetica



- Energia campului se extinde in teaca (diametrul efectiv al spotului luminos – MFD, Mode Field Diameter)
- MFD > 2a
- Adancimea de patrundere in teaca depinde de lungimea de unda, generand dispersia de ghid



Contact

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