Materiais Elétricos e Magnéticos para Engenharia

Professor: Marcus V. Batistuta

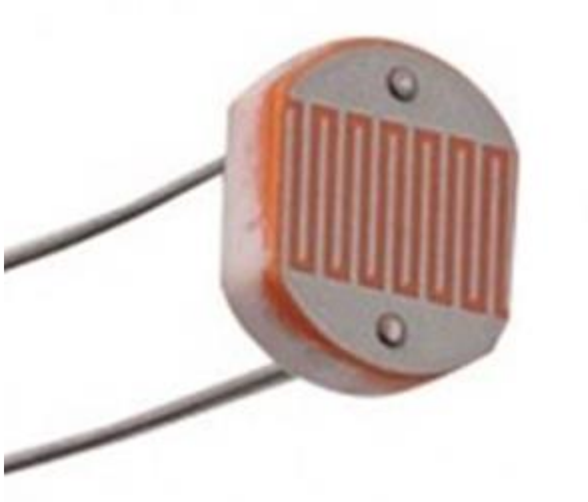
Laboratório #4

LDR

1º Semestre de 2018

FGA - Universidade de Brasília

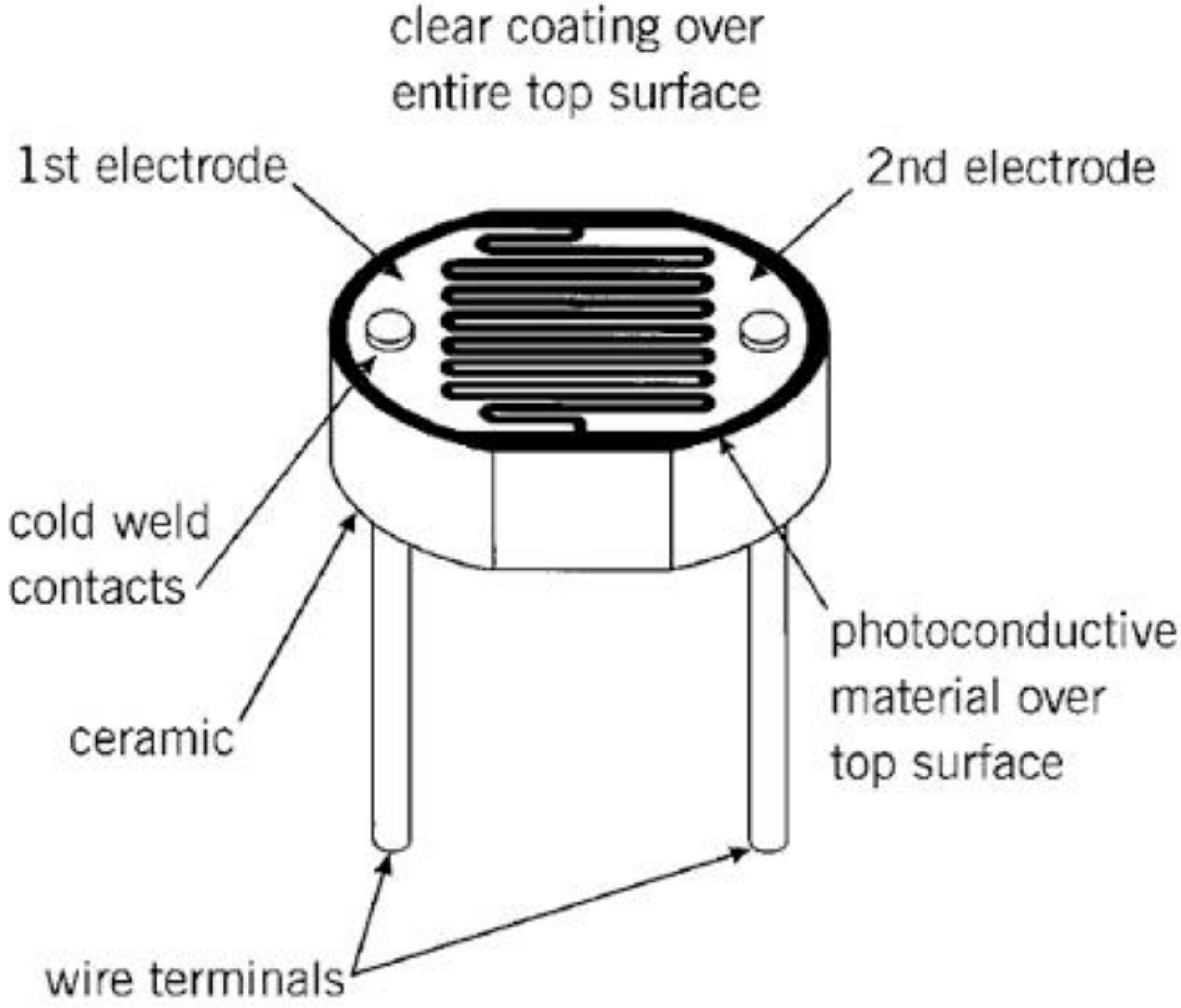
LDR: *Light Dependent Resistor*

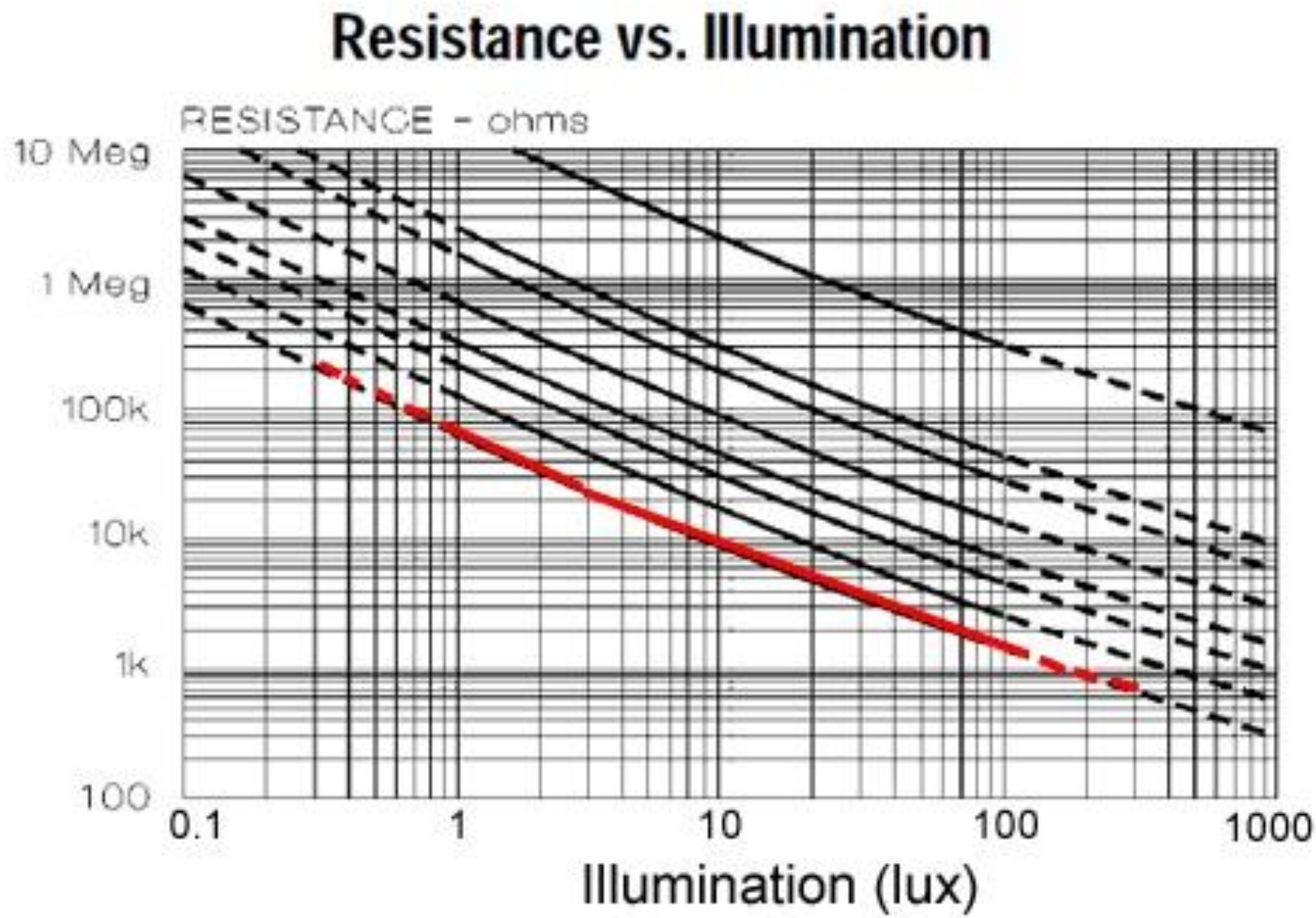


Semicondutor	Tipo	E_g, eV 0 K	E_g, eV 300 K
CdS	*d*	2,582	2,42
CdSe	*d*	1,840	1,74

Restriction of Hazardous Substances Directive (RoHS): CdS e CdSe

LDR: *Light Dependent Resistor*





1 lux = 1 lúmen/m^2

Fotometria

Quantity		Unit		Dimension	Notes
Name	Symbol[nb 1]	Name	Symbol	Symbol	
Luminous energy	Q_v [nb 2]	lumen second	lm⋅s	**T⋅J** [nb 3]	Units are sometimes called *talbots*.
Luminous flux / luminous power	Φ_v [nb 2]	lumen (= cd⋅sr)	lm	**J** [nb 3]	Luminous energy per unit time.
Luminous intensity	I_v	candela (= lm/sr)	cd	**J** [nb 3]	Luminous power per unit solid angle.
Luminance	L_v	candela per square metre	cd/m^2	$\mathbf{L}^{-2}\cdot\mathbf{J}$	Luminous power per unit solid angle per unit *projected* source area. Units are sometimes called *nits*.
Illuminance	E_v	lux (= lm/m^2)	lx	$\mathbf{L}^{-2}\cdot\mathbf{J}$	Luminous power *incident* on a surface.
Luminous exitance / luminous emittance	M_v	lux	lx	$\mathbf{L}^{-2}\cdot\mathbf{J}$	Luminous power *emitted* from a surface.
Luminous exposure	H_v	lux second	lx⋅s	$\mathbf{L}^{-2}\cdot\mathbf{T}\cdot\mathbf{J}$	
Luminous energy density	ω_v	lumen second per cubic metre	$lm\cdot s\cdot m^{-3}$	$\mathbf{L}^{-3}\cdot\mathbf{T}\cdot\mathbf{J}$	
Luminous efficacy	η [nb 2]	lumen per watt	lm/W	$\mathbf{M}^{-1}\cdot\mathbf{L}^{-2}\cdot\mathbf{T}^{3}\cdot\mathbf{J}$	Ratio of luminous flux to radiant flux or power consumption, depending on context.
Luminous efficiency / luminous coefficient	V			1	
See also: SI · Photometry · Radiometry					

Fotômetro Analógico

$$P_{(\mathrm{W})} = \Phi_{\mathrm{v}(\mathrm{lm})} \,/\, \eta_{(\mathrm{lm/W})}$$

Luminous efficacy table

Light type	Typical luminous efficacy (lumens/watt)
Tungsten incandescent light bulb	12.5-17.5 lm/W
Halogen lamp	16-24 lm/W
Fluorescent lamp	45-75 lm/W
LED lamp	30-90 lm/W
Metal halide lamp	75-100 lm/W
High pressure sodium vapor lamp	85-150 lm/W
Low pressure sodium vapor lamp	100-200 lm/W
Mercury vapor lamp	35-65 lm/W

Lumens to watts table

Lumens	Incandescent light bulb watts	Fluorecent / LED watts
375 lm	25 W	6.23 W
600 lm	40 W	10 W
900 lm	60 W	15 W
1125 lm	75 W	18.75 W
1500 lm	100 W	25 W
2250 lm	150 W	37.5 W
3000 lm	200 W	50 W

Examples	
Illuminance	**Surfaces illuminated by:**
0.0001 lux	Moonless, overcast night sky (starlight)[3]
0.002 lux	Moonless clear night sky with airglow[3]
0.27–1.0 lux	Full moon on a clear night[3][4]
3.4 lux	Dark limit of civil twilight under a clear sky[5]
50 lux	Family living room lights (Australia, 1998)[6]
80 lux	Office building hallway/toilet lighting[7][8]
100 lux	Very dark overcast day[3]
320–500 lux	Office lighting[9][10][11]
400 lux	Sunrise or sunset on a clear day.
1000 lux	Overcast day;[3] typical TV studio lighting
10 000–25 000 lux	Full daylight (not direct sun)[3]
32 000–100 000 lux	Direct sunlight

Criação e Recombinação de Pares Elétron-Buraco

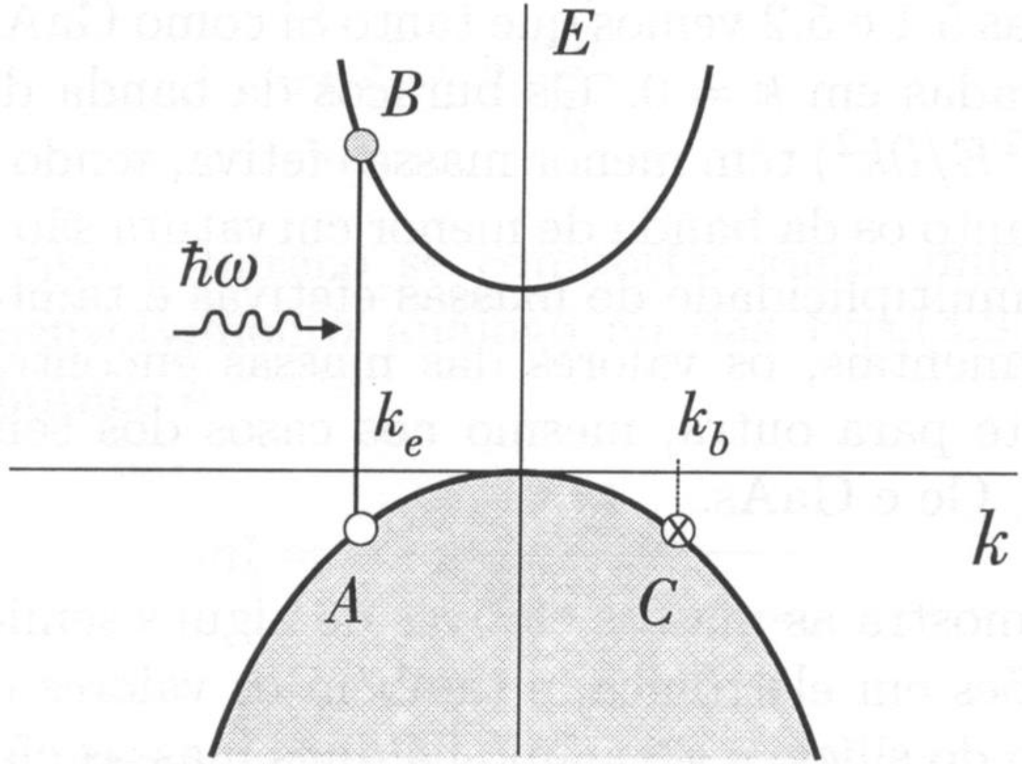


Figura 5.5: Absorção de um fóton de energia $\hbar\omega$ e vetor de onda desprezível acompanhada da criação de um par elétron-buraco em semicondutor de gap direto.

$$J = (\sigma_n + \sigma_p)\mathcal{E} = \sigma\mathcal{E}$$

$$\sigma = e(n_0\,\mu_n + p_0\,\mu_p)$$

LDR: Resposta Espectral

Errado

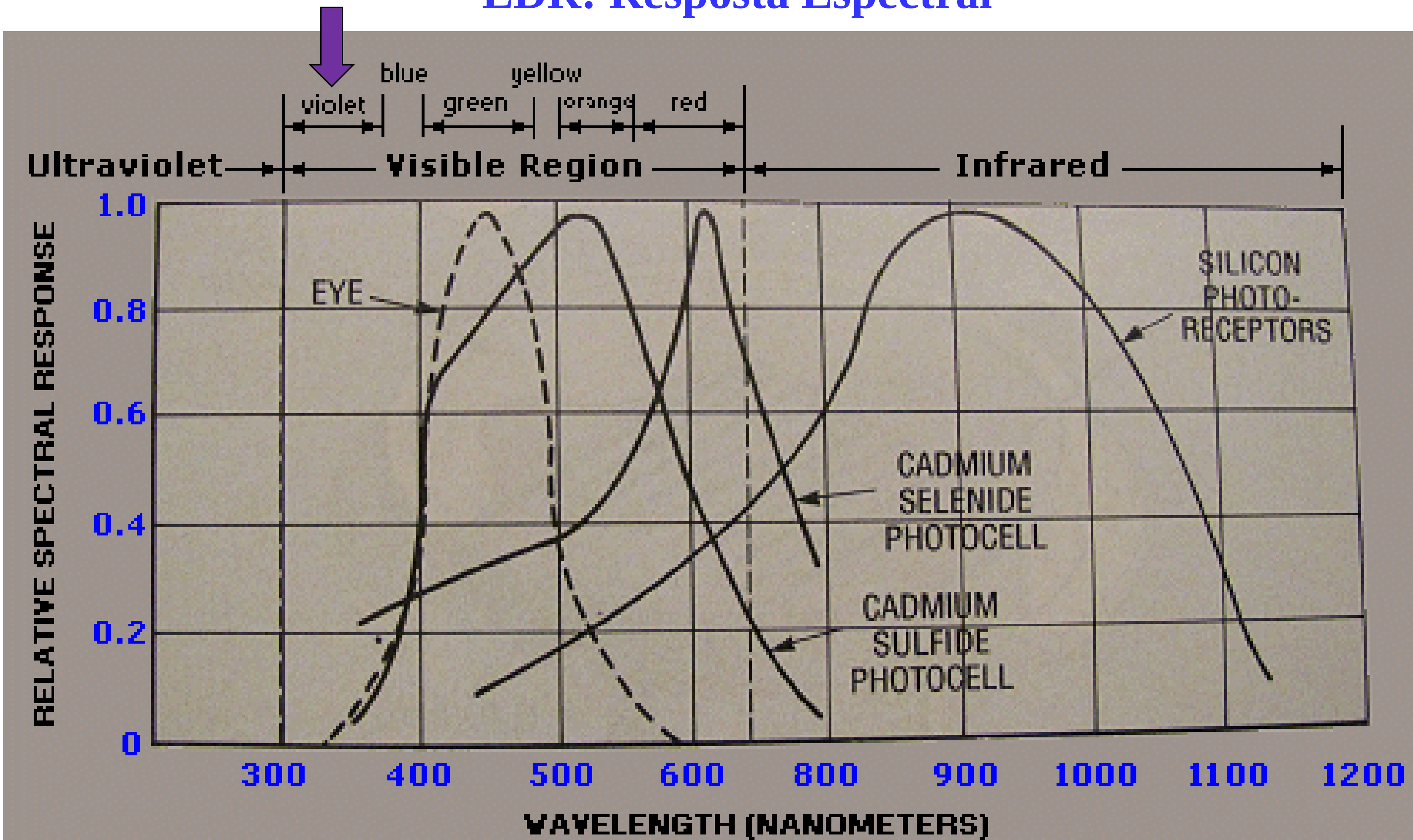
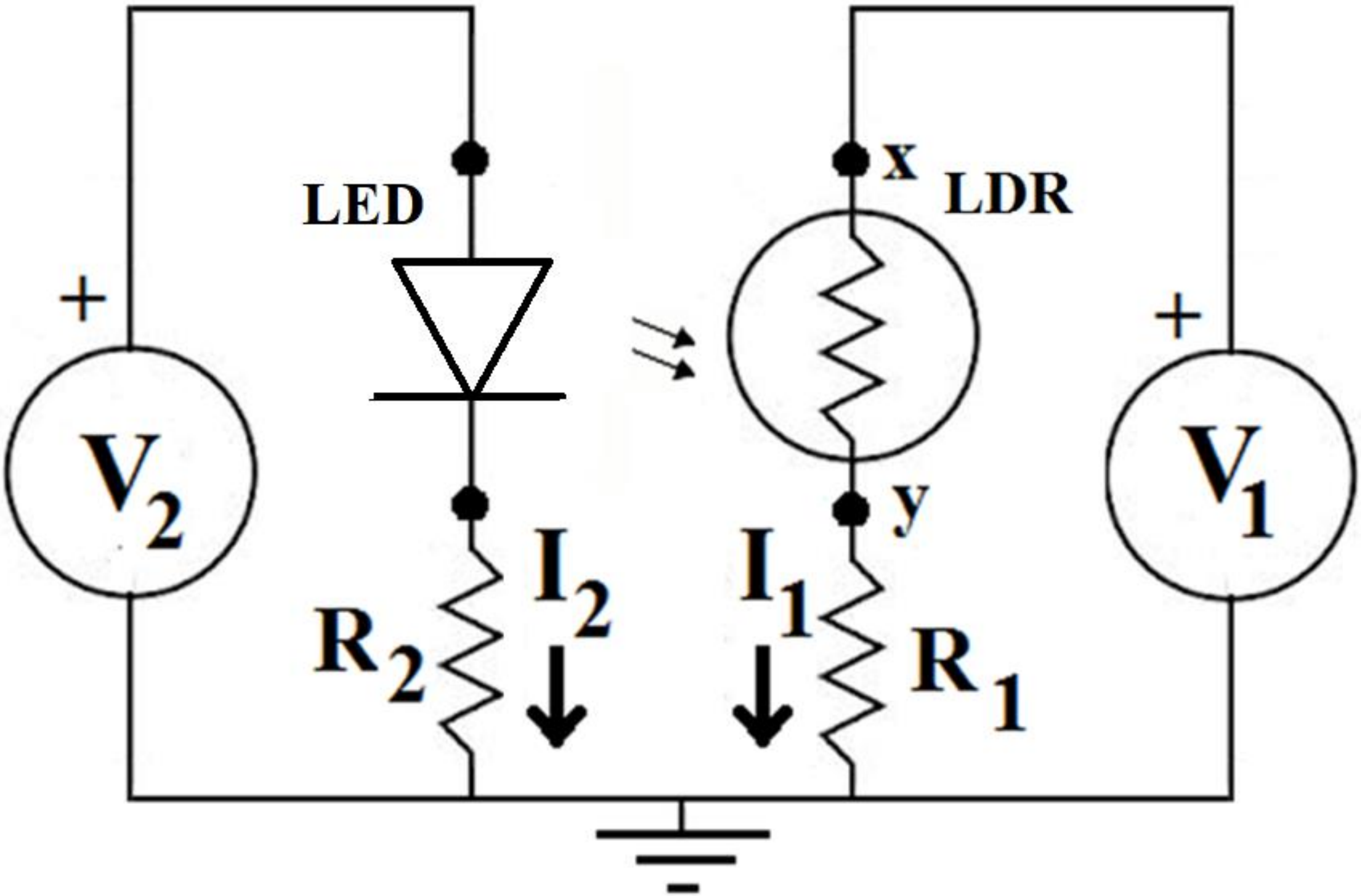
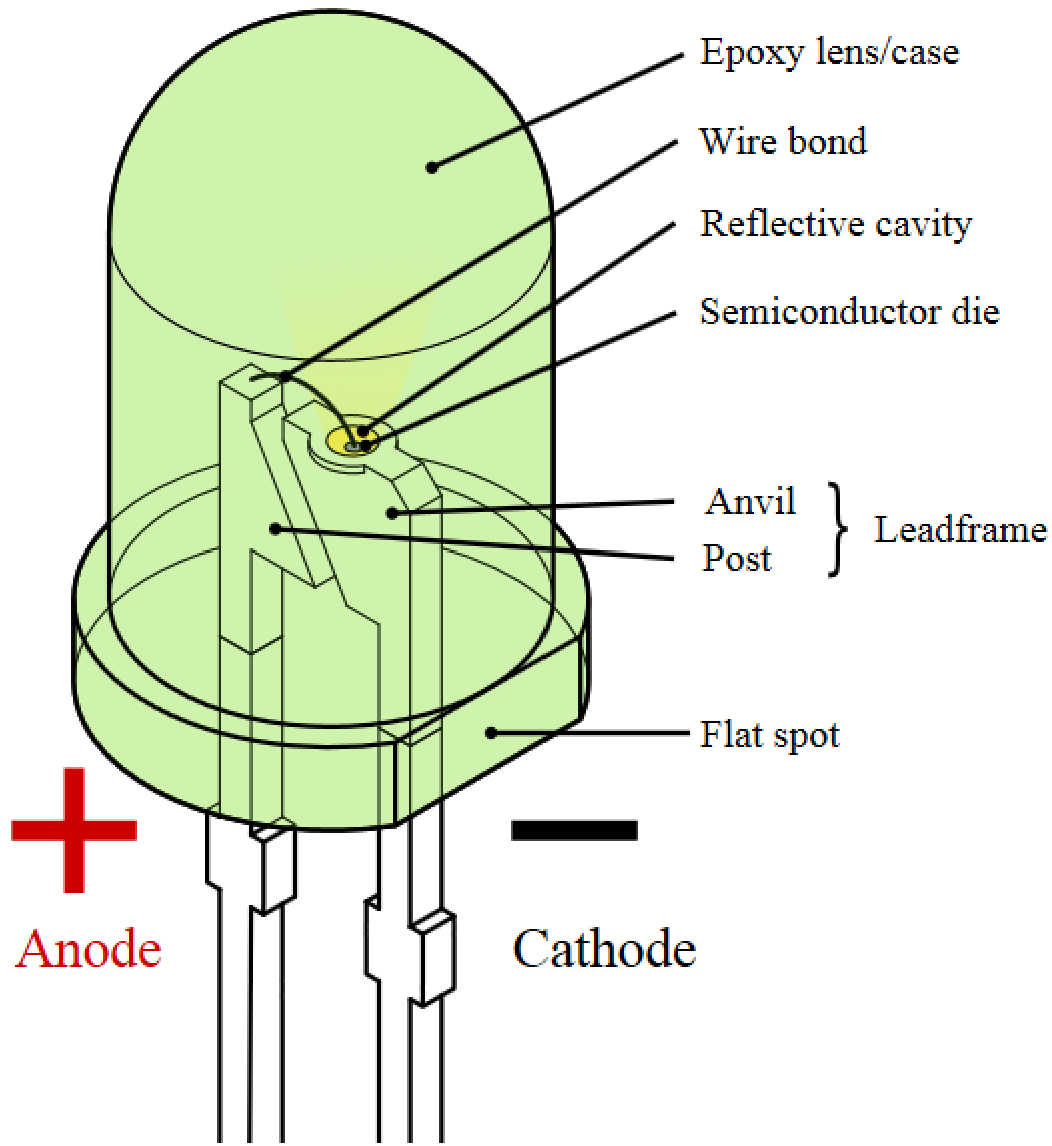


Fig. 3--Characteristic curves of photosensitive devices compared with the response curve of the human eye.

Montagem Experimental



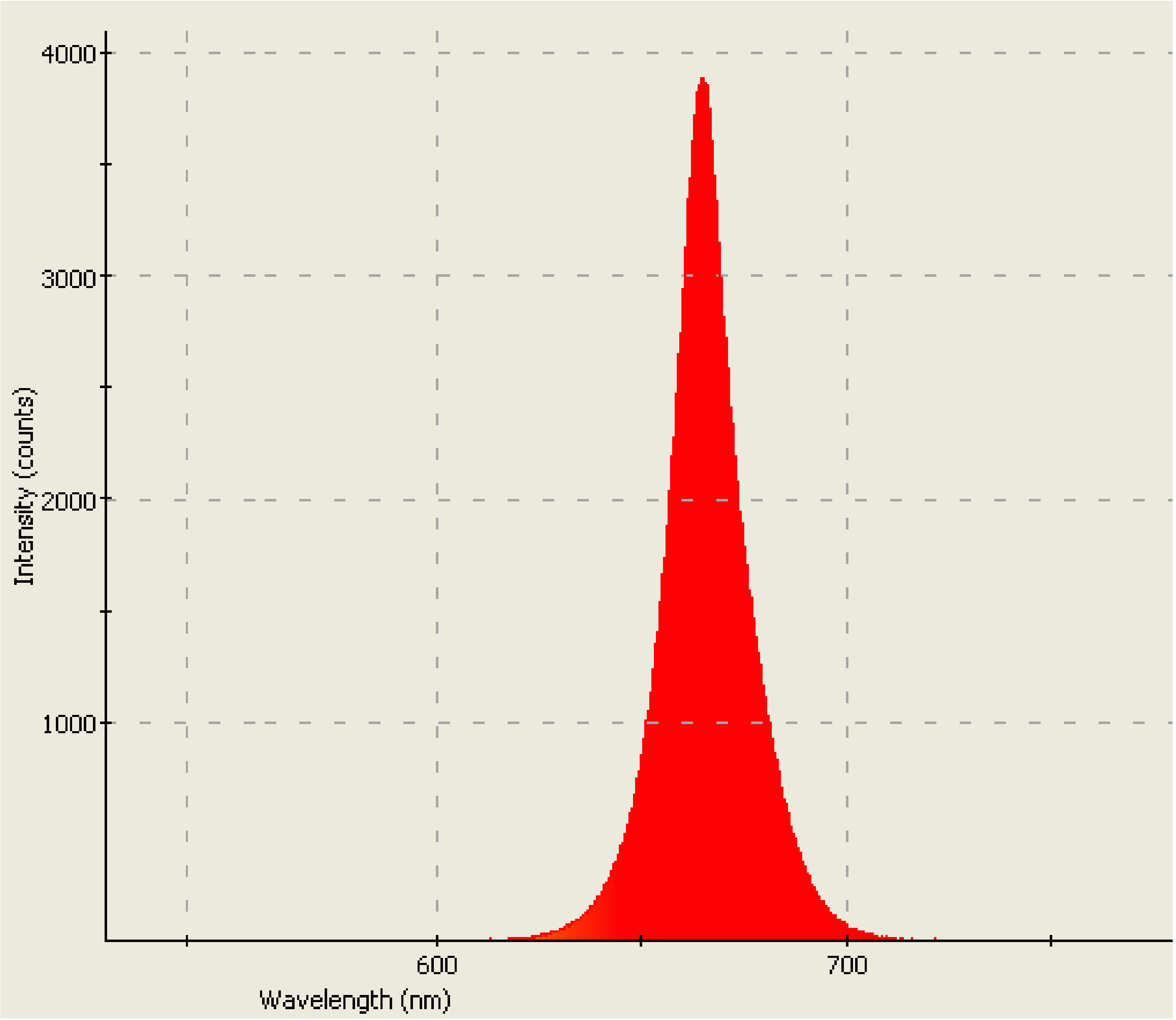
LED – Light Emitting Diode



Potência Irradiada:

$$I_0 \approx k.I_{LED}$$

Espectro de LED Vermelho



http://ledmuseum.candlepower.us/specx101.htm

Optoeletrônica - Fotoresistor

$$I(x,\lambda) = I_0 e^{-\alpha(\lambda).x} [W/m^2]$$

$$\alpha \approx 10^6 [m^{-1}]$$

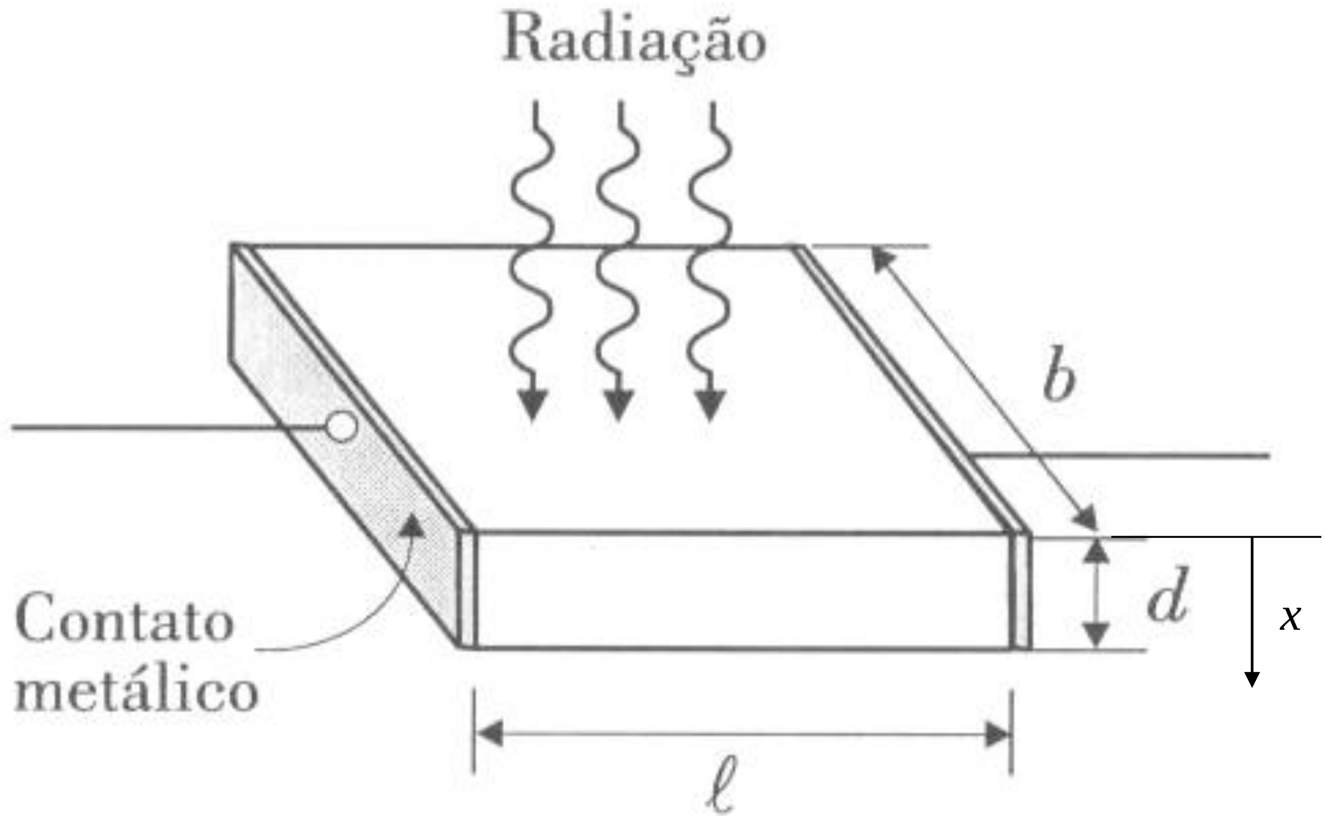


Figura 8.16: Estrutura simples de um foto-resistor, ou LDR.

Geração de Pares Elétron-Lacuna

$$\frac{\partial \delta p}{\partial t} = \frac{\partial \delta n}{\partial t} = g = \frac{\eta I_0}{\hbar \omega d}$$

g – Taxa de Geração de pares elétron-lacuna [$m^{-3}s^{-1}$]

d – Espessura do Semicondutor (Profundidade) [m]

I_0 – Radiação Incidente com ABSORÇÃO UNIFORME [W/m^2]

η – Eficiência de geração de pares elétron-lacuna

ω – Frequência Média dos Fótons [rad/s]

Semicondutor Intrínseco:

$$n_0 = p_0 = n_i$$

$$\begin{cases} p = p_0 + \delta p & [m^{-3}] \\ n = n_0 + \delta n & [m^{-3}] \end{cases}$$

Geração e Recombinação de Pares Elétron-Lacuna

$$\begin{cases} \dfrac{\partial \delta n}{\partial t} = g - r = \dfrac{\eta I_0}{\hbar \omega d} - \dfrac{\delta n}{\tau_r} \\[2ex] \dfrac{\partial \delta p}{\partial t} = g - r = \dfrac{\eta I_0}{\hbar \omega d} - \dfrac{\delta p}{\tau_r} \end{cases}$$

τ_r – Tempo de Recombinação [s]

r – Taxa de Recombinação [$1/m^3.s$]

Regime Estacionário: $g = r \Longrightarrow \boxed{\dfrac{\partial}{\partial t} = 0}$

Semicondutor Intrínseco: $\boxed{\delta p = \delta n = g\,\tau_r = \dfrac{\eta I_0 \tau_r}{\hbar \omega d}}$

Geração e Recombinação de Pares Elétron-Lacuna

$$\sigma = n.e.\mu_n + p.e.\mu_p = (n_0 + \delta n).e.\mu_n + (p_0 + \delta p).e.\mu_p$$

σ – Condutividade [S/m]

μ – Mobilidades de Elétrons e Lacunas

$$\sigma = n.e.\mu_n + p.e.\mu_p = (n_i + \Delta)e(\mu_n + \mu_p)$$

$$\boxed{\Delta = \frac{\eta I_0 \tau_r}{\hbar \omega d} = C.I_0}$$

$$I_0 \approx k.I_{LED}$$

$$\sigma = (n_i + C.I_0)e(\mu_n + \mu_p)$$

Concentração Intrínseca vs. Temperatura

$$n_i = p_i = \sqrt{n_i p_i} = (N_c N_v)^{1/2}\, \mathrm{e}^{-E_g/2k_B T}$$

$$n = N_c\, \mathrm{e}^{-(E_c - E_F)/k_B T} \qquad p = N_v\, \mathrm{e}^{-(E_F - E_v)/k_B T}$$

$$N_c = 2\left(\frac{m_c^*\, k_B T}{2\pi\, \hbar^2}\right)^{3/2} \qquad N_v = 2\left(\frac{m_v^*\, k_B T}{2\pi\, \hbar^2}\right)^{3/2}$$

Assumindo Invariante: Temperatura ~ 300 K

Corrente vs. Tensão no LDR

$$\sigma = (n_i + C.I_0).e(\mu_n + \mu_p)$$

$$I = G.V \qquad \frac{1}{R} = G = \frac{A\sigma}{l} \qquad I = \frac{A\sigma}{l}V$$

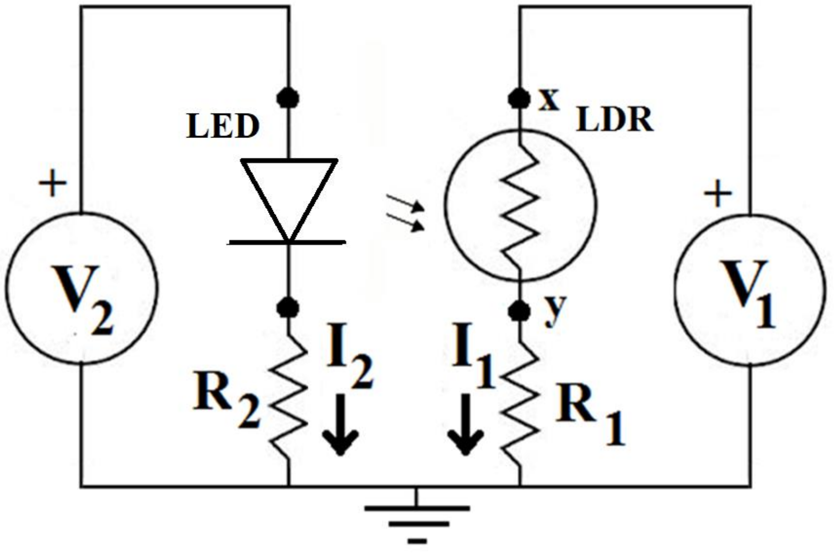
$$I = \frac{A\sigma}{l}V = \left[\frac{A}{l}(n_i + C.I_0).e(\mu_n + \mu_p)\right].V$$

$$I = \left[\frac{A}{l}(n_i + C.k.I_{LED}).e(\mu_n + \mu_p)\right].V$$

$$\boxed{I_{LDR} = \left[C_1.I_{LED} + C_2\right].V_{LDR}}$$

Desafio: Ganho de Corrente, Tensão e Potência

$$I_{LDR} = \left[C_1 . I_{LED} + C_2 \right] . V_{LDR}$$



1) Possível ? $i_{LDR} > i_{LED}$

$$G_i = i_{LDR}/i_{LED}$$

2) Possível ? $v_{LDR} > v_{LED}$

$$G_v = v_{LDR}/v_{LED}$$

3) Possível ? $i_{LDR}v_{LDR} > i_{LED}v_{LED}$

$$G = (i_{LDR}v_{LDR})/(i_{LED}v_{LED})$$

Pequenos sinais em regime permanente senoidal.