

Caracterización Óptica de Materiales.

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Origen Interacción Radiación - Materia

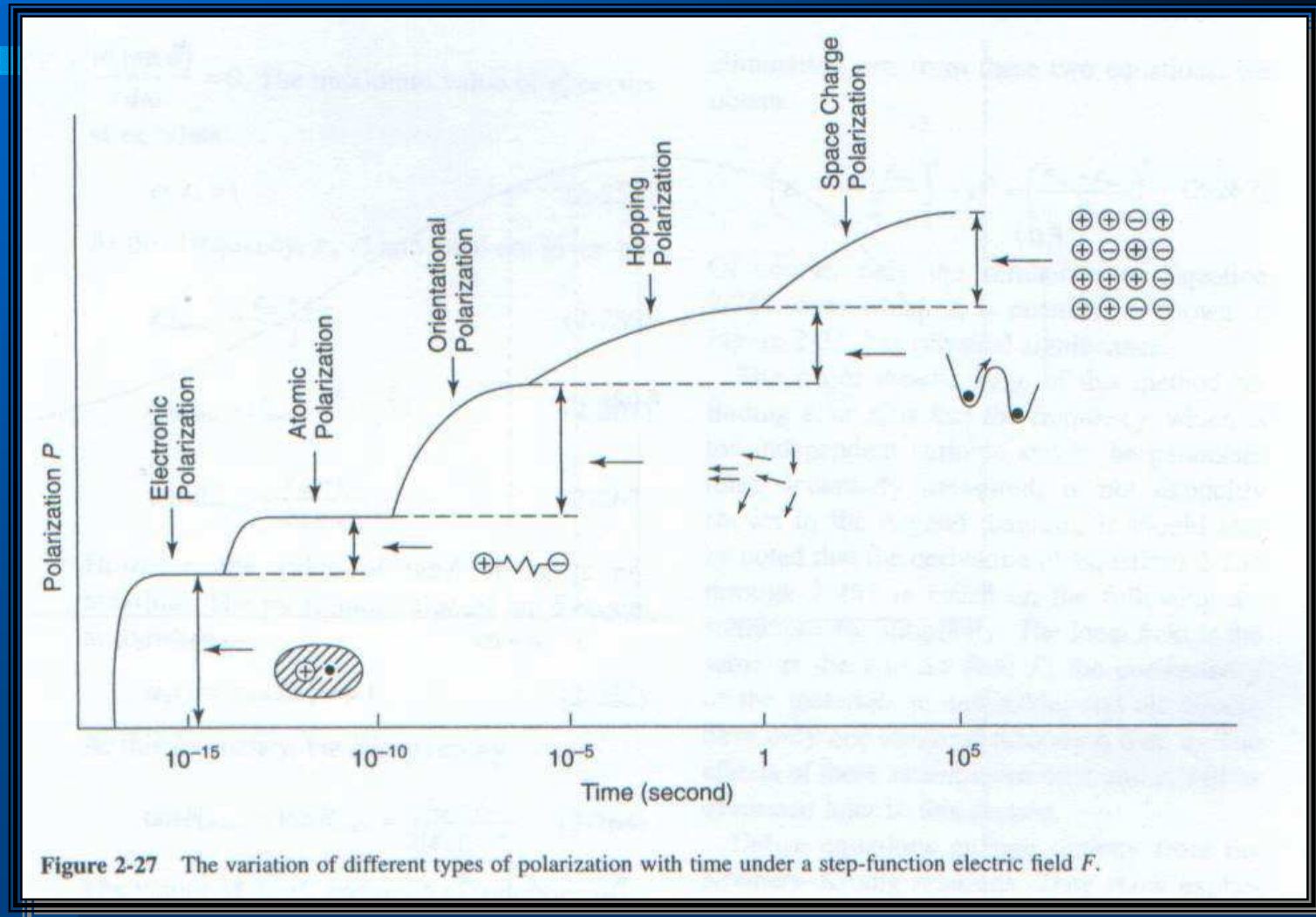
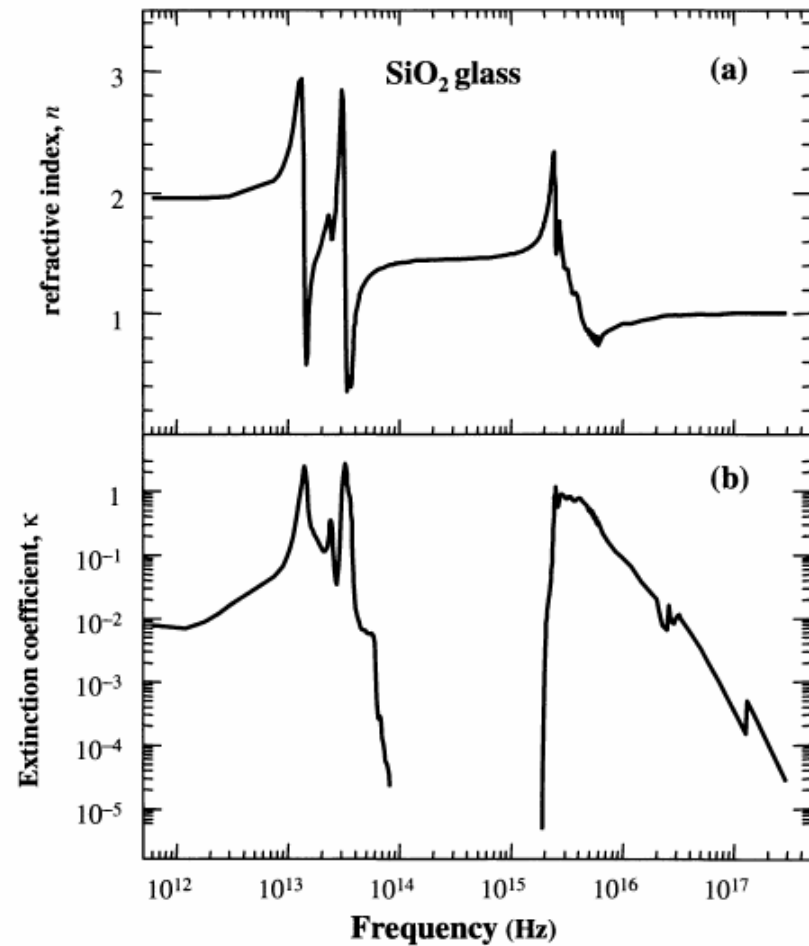
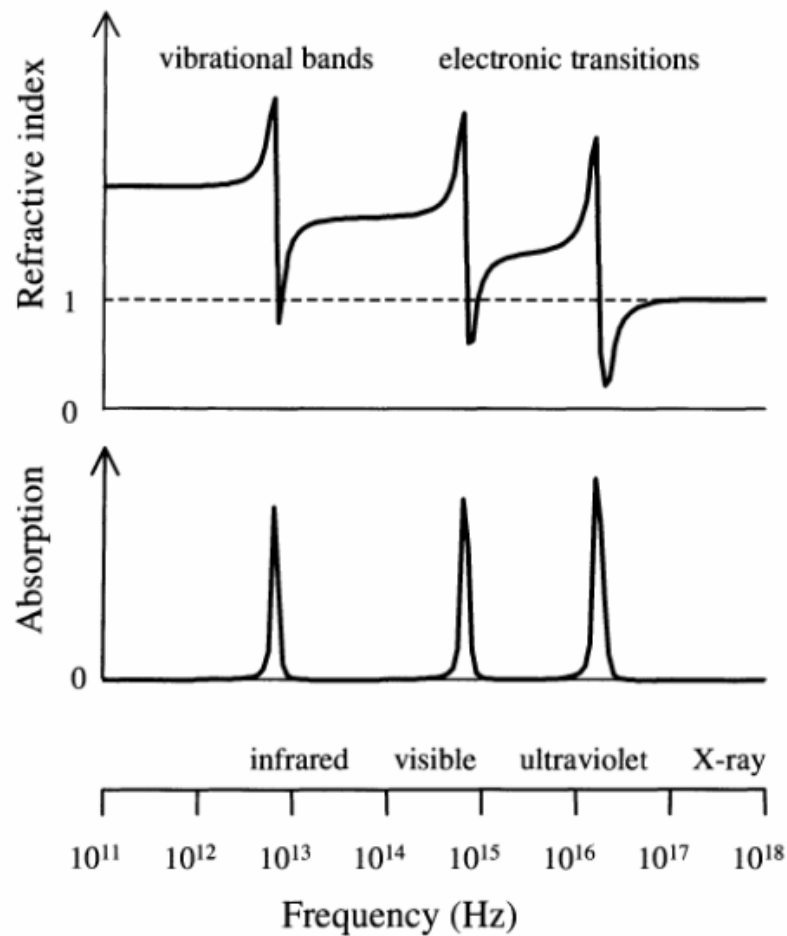


Figure 2-27 The variation of different types of polarization with time under a step-function electric field F .

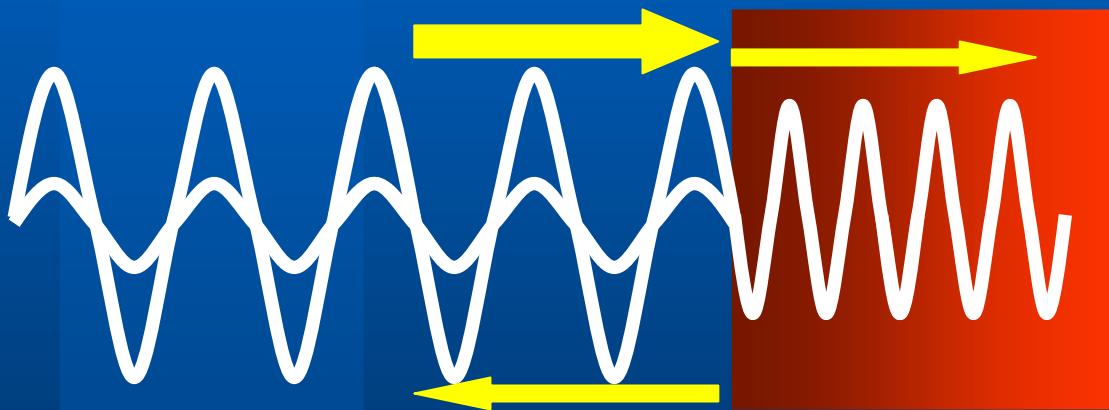
Índice de Refracción y Coeficiente de Extinción



Propiedades Ópticas

Materiales Transparentes
(En Semicond: Caso $h\nu < E_g$):

$\eta \rightarrow$ Índice de Refracción



$$\vec{E} \propto \exp[i(kx - \omega t)] = \exp\left[i\omega\left(\eta \frac{x}{c} - t\right)\right]$$

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

$$v = \frac{c}{\eta} = \frac{\omega}{k} = v\lambda$$

Velocidad de la luz :

$v \rightarrow$ en el medio,

$c \rightarrow$ en el vacío,

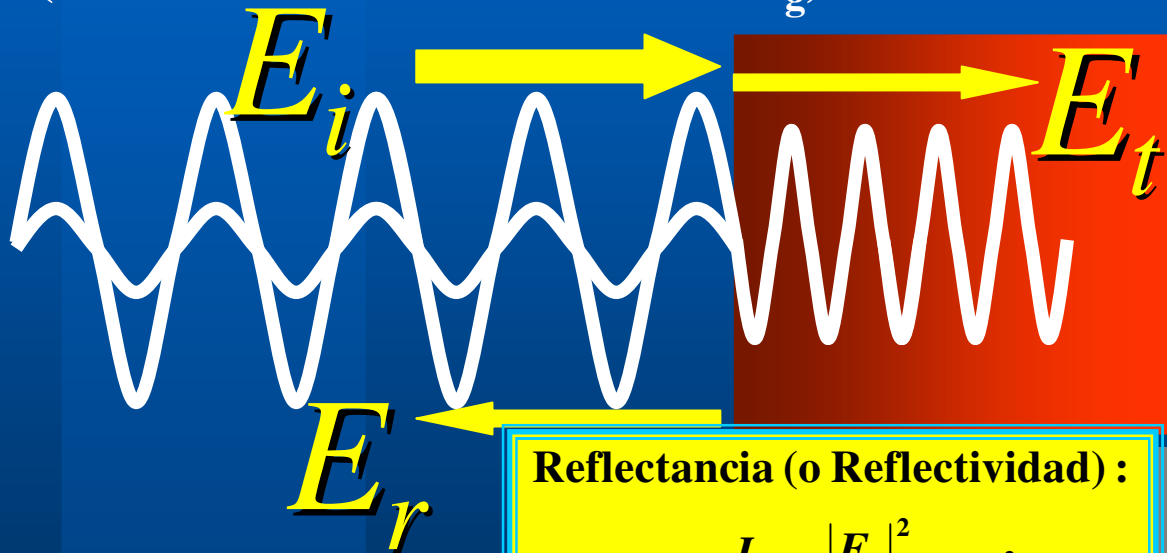
$$k = \frac{2\pi}{\lambda} \rightarrow \text{Número de Onda} \left(k = \omega \frac{c}{\eta} \right)$$

$$\omega = 2\pi\nu = \frac{2\pi}{T} \rightarrow \text{Frecuencia Óptica}$$

Interfaz Plana 1 - 2

Materiales Transparentes
(En Semicond: Caso $h\nu < E_g$):

$$m = \frac{n_2}{n_1} \rightarrow \text{Relación entre índices de Refracción.}$$



Coefficiente de Reflexión :

$$r = \frac{E_r}{E_i}$$

Coefficiente de Transmisión :

$$t = \frac{E_t}{E_i}$$

Reflectancia (o Reflectividad) :

$$R = \frac{I_r}{I_i} = \frac{|E_r|^2}{|E_i|^2} = |r|^2$$

Incidencia Normal : $R = \left| \frac{m-1}{m+1} \right|^2$

Transmitancia (o Transmitividad) :

$$T = \frac{I_t}{I_i} = m \frac{|E_t|^2}{|E_i|^2} = m |t|^2$$

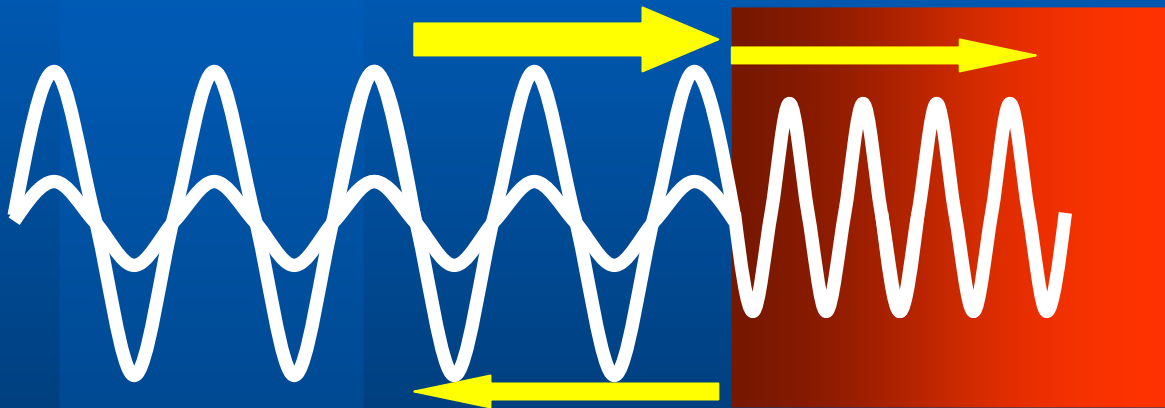
$$t = \frac{2}{1+m}$$

Idealmente : $T + R = 1$

Propiedades Ópticas

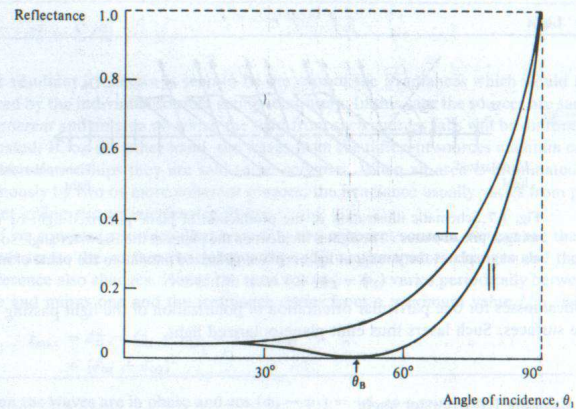
Materiales Transparentes

(En Semicond: Caso $h\nu < E_g$):

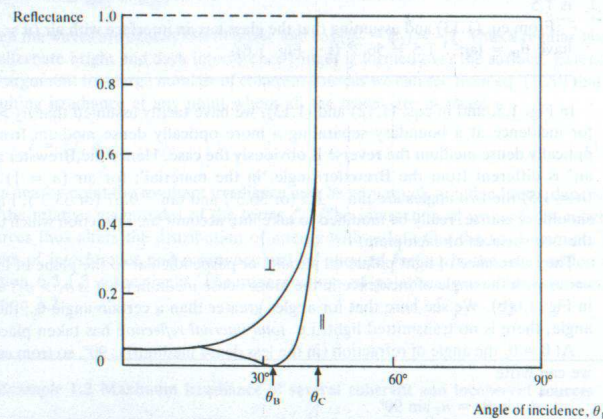


$$\vec{E} \propto \exp[i(kx - \omega t)] = \exp\left[i\omega\left(\eta\frac{x}{c} - t\right)\right]$$

Incidencia Oblicua: Coeficientes de Fresnel

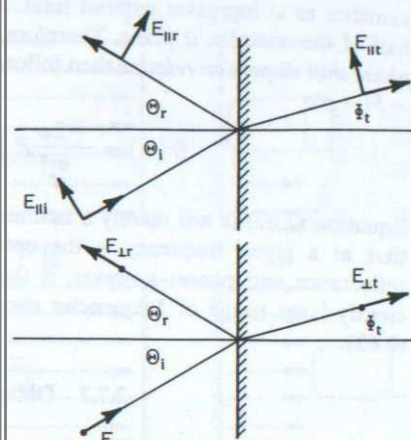


(a)



(b)

Fig. 1.6 Reflectance as a function of angle of incidence for light polarized parallel (∥) and perpendicular (⊥) to the plane of incidence incident on the interface from (a) the optically dense side and (b) the more optically dense side.

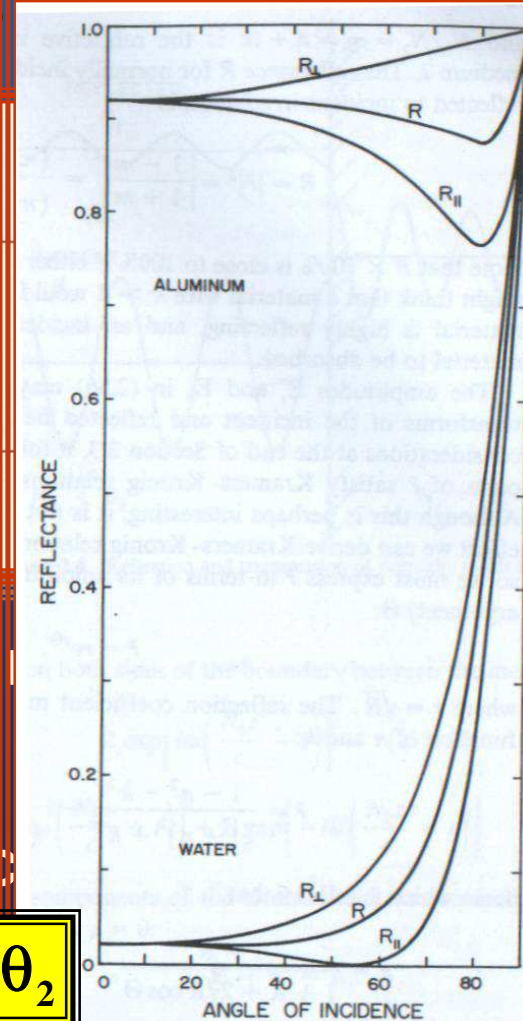


ley de Reflexión

$$\theta_r = \theta_i$$

de Snell (Refrac

$$n_1 \text{ sen} \theta_1 = n_2 \text{ sen} \theta_2$$

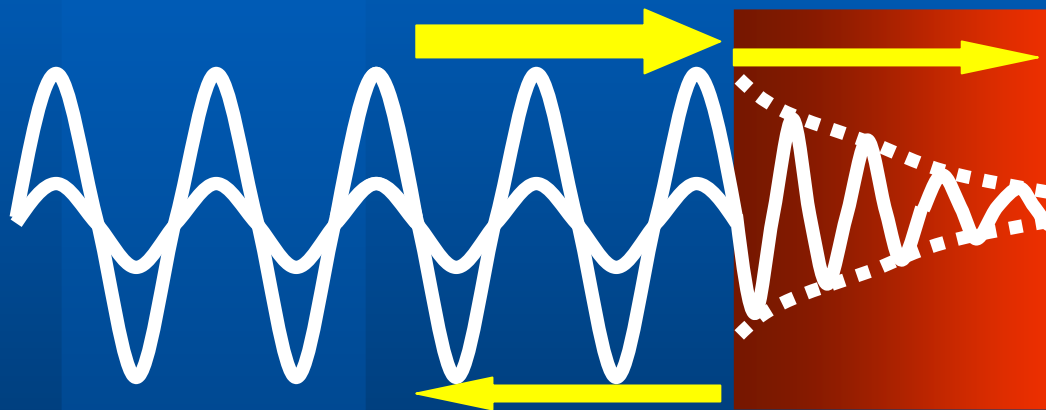


Propiedades Ópticas

Materiales **NO** Transparente,

Absorción de Luz (En Semicond: Caso $h\nu > E_g$):

$\eta_c \rightarrow$ Índice de Refracción COMPLEJO



$$\eta_c = n + iq$$

$n = \text{Re}(\eta_c) \rightarrow$ índice de refracción,

$q = \text{Im}(\eta_c) \rightarrow$ coeficiente de extinción,

$\alpha = \frac{2\omega q}{c} \rightarrow$ coeficiente de absorción

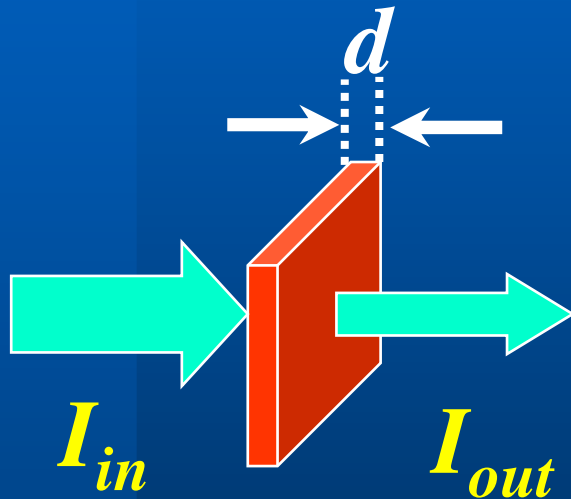
$$\vec{E} \propto \exp[i(kx - \omega t)] = \exp\left[i\omega\left(\eta_c \frac{x}{c} - t\right)\right] = \exp\left[i\omega\left(n \frac{x}{c} - t\right)\right] \exp\left(-\omega q \frac{x}{c}\right)$$

Coeficiente de Absorción

$$I \propto |\vec{\mathbf{E}}|^2 \Rightarrow I_{out} \approx I_{in} \exp\left(-2\omega q \frac{d}{c}\right)$$



$$\frac{I_{out}}{I_{in}} \approx \exp(-\alpha d)$$



$$\eta_c = n + iq$$

$n = \text{Re}(\eta_c) \rightarrow$ índice de refracción,
 $q = \text{Im}(\eta_c) \rightarrow$ coeficiente de extinción,

$\alpha = \frac{2\omega q}{c} \rightarrow$ coeficiente de absorción

$$\vec{\mathbf{E}} \propto \exp[i(kx - \omega t)] = \exp\left[i\omega\left(\eta_c \frac{x}{c} - t\right)\right] = \exp\left[i\omega\left(n \frac{x}{c} - t\right)\right] \exp\left(-\omega q \frac{x}{c}\right)$$

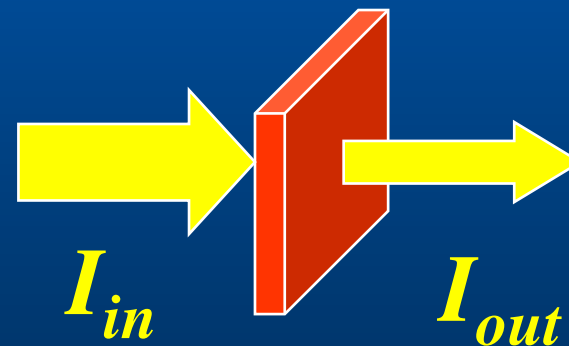
Espectroscopía de Absorción

Medida por Transmitancia

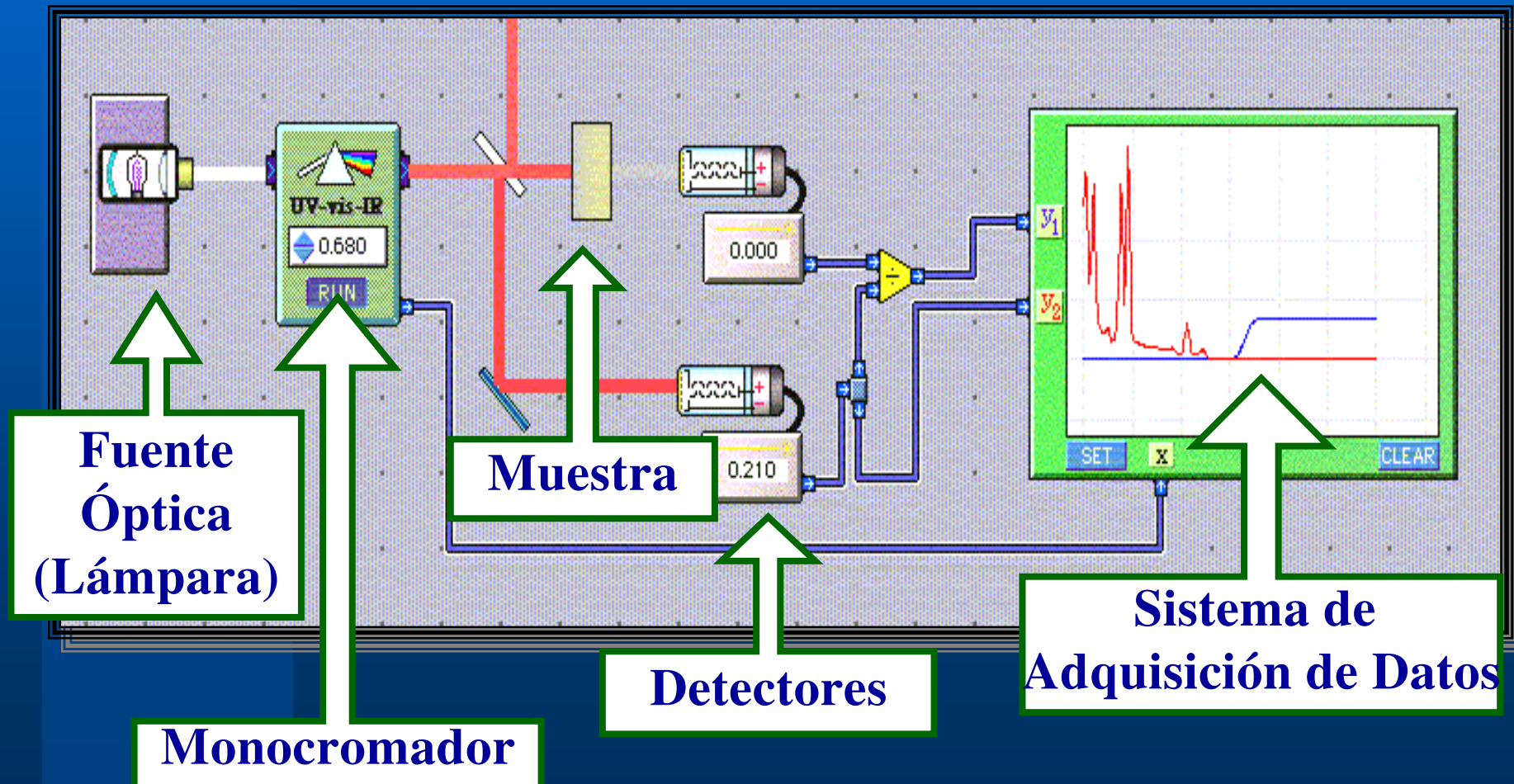
$$\frac{I_{out}}{I_{in}} \approx \exp(-\alpha d)$$

$$\text{Transmitancia: } T = \frac{I_{out}}{I_{in}}$$

$$\text{Coeficiente de Absorción: } \alpha \propto -\ln T$$



Transmisión Óptica



Caracterización Óptica - I

Monochromator
Control

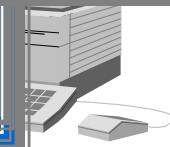
SPE

IRRADIANCE AT 0.5 m ($\text{mW m}^{-2}\text{nm}^{-1}$)

Spect

I_{in}
Coeficiente de Absorción: $\alpha \propto -\ln T$

CONDENSING
LENS
ASSEMBLY



Caracterización Óptica - I

Xe lamp
 $P_{\text{elect}} = 1000 \text{ W}$
 $\lambda \sim 260 - 2400 \text{ nm}$
(Flat $\sim 300 - 800 \text{ nm}$)

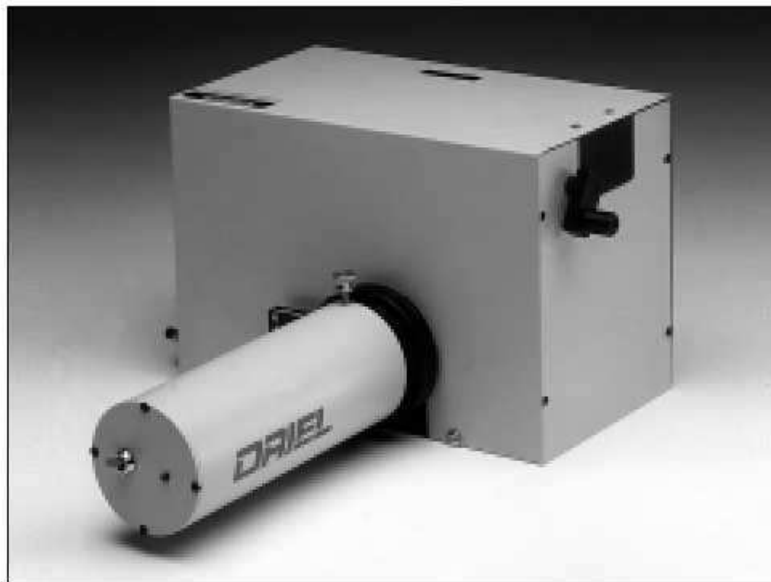


Chopper

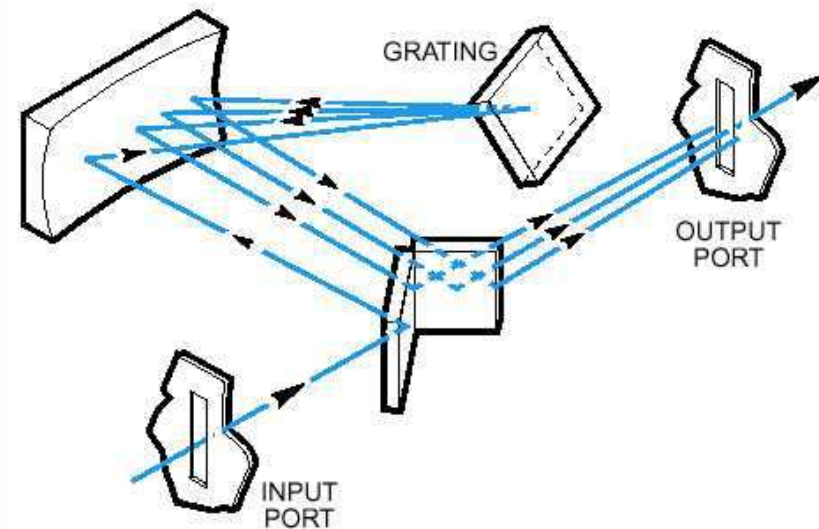
λ

Sample:
ZnO

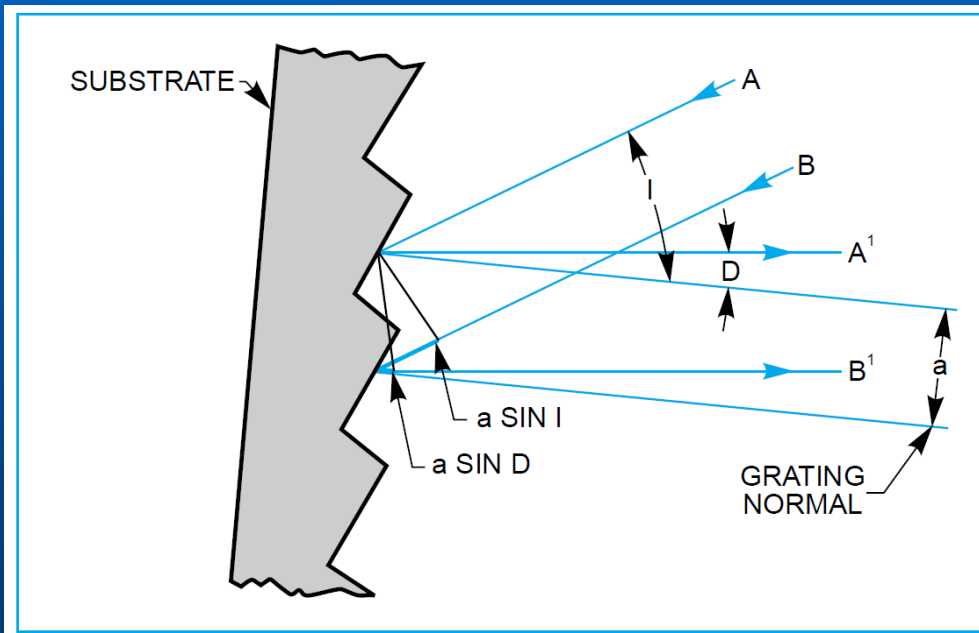
Monochromator
Control



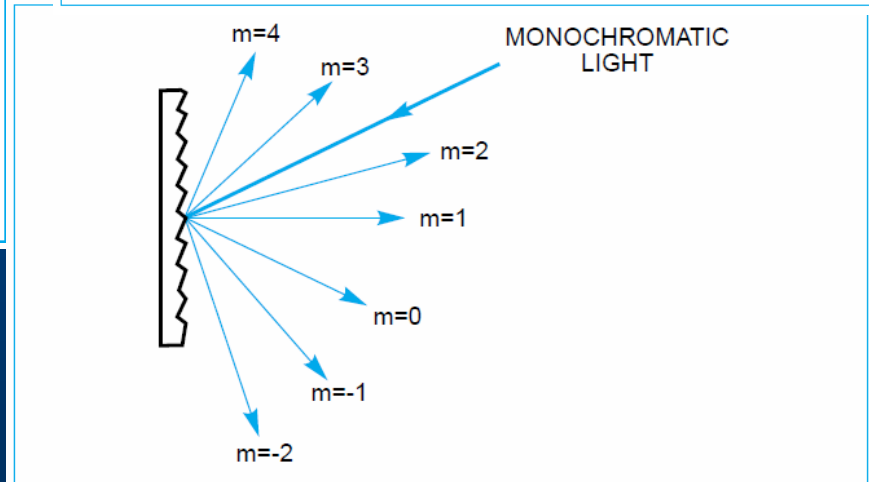
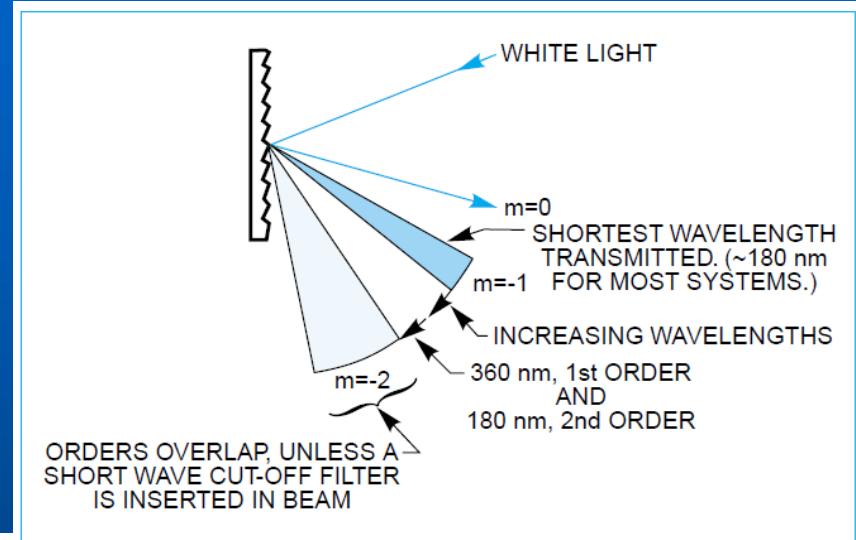
77250 1/8 m Monochromator with 6025 Hg(Ar) Spectral Calibration Lamp.



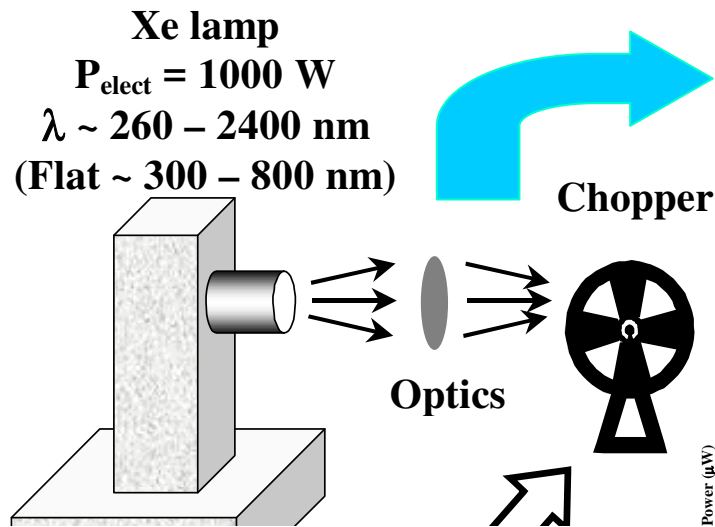
Red de Difracción



$$a[\text{sen}(I) + \text{sen}(D)] = m\lambda$$

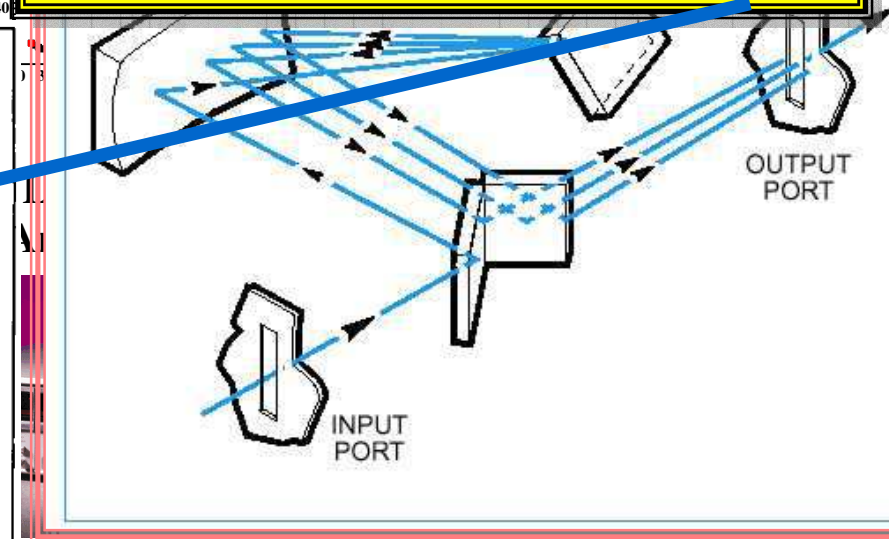
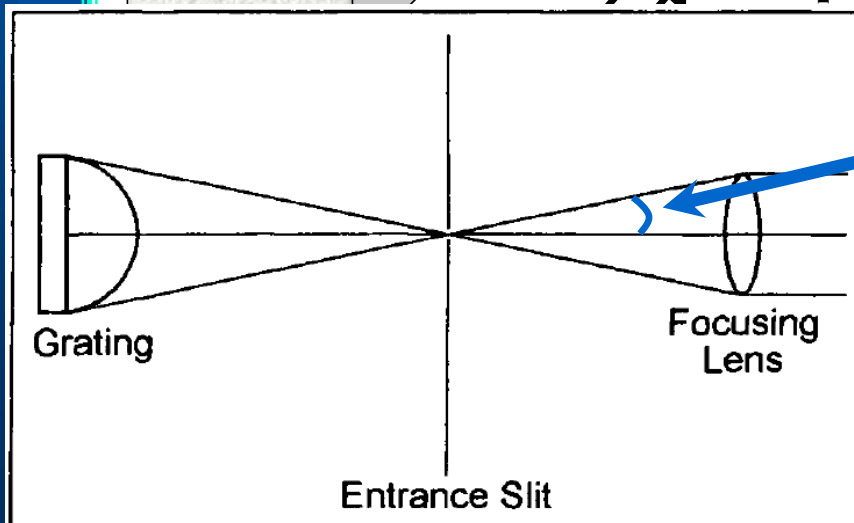


Caracterización Óptica - I



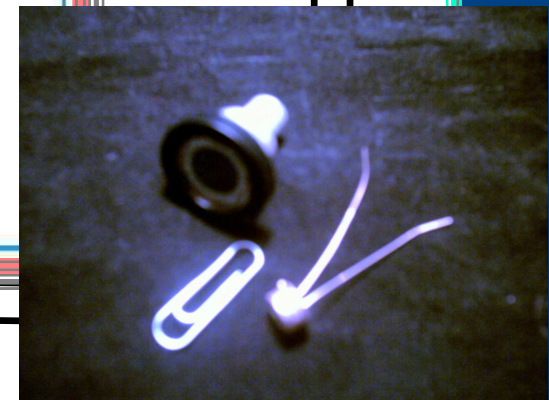
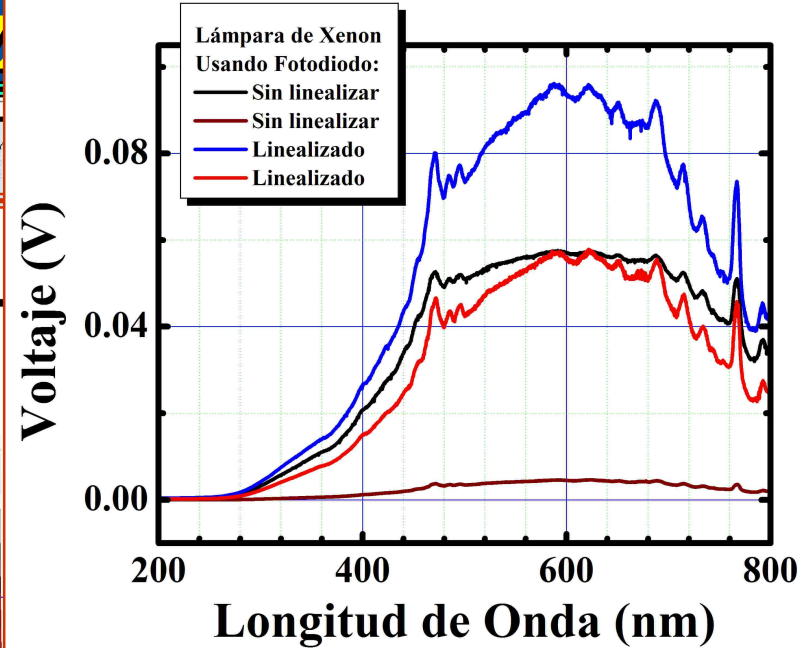
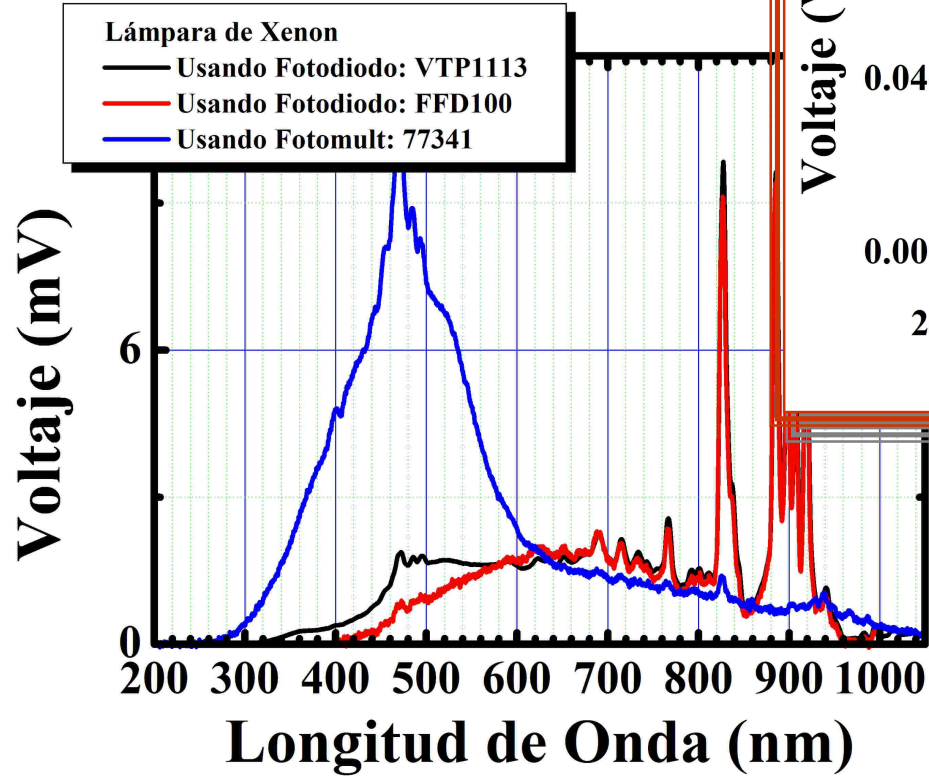
$$F\# = \frac{f}{D} = \frac{1}{2NA}$$

$F\#$: Número F,
 f : Distancia Focal,
 D : Diámetro Lente,
 NA : Apertura Numérica ($\text{sen}\theta$).

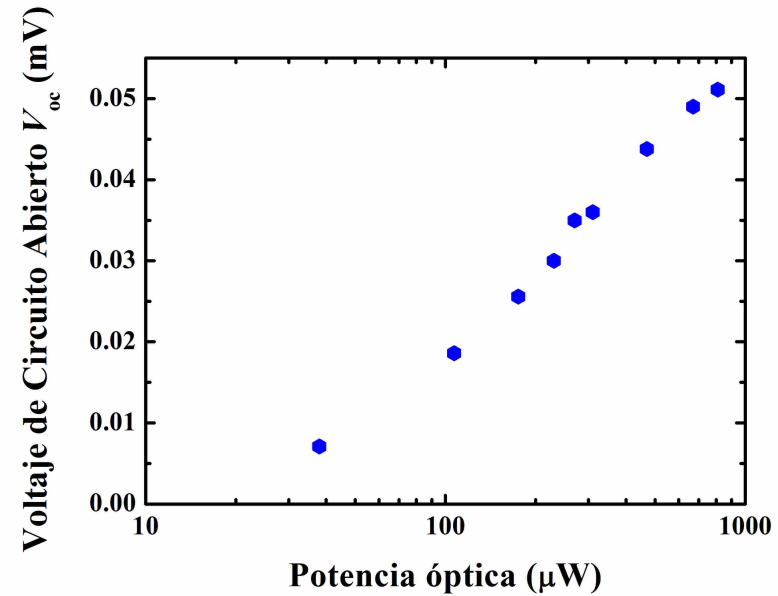
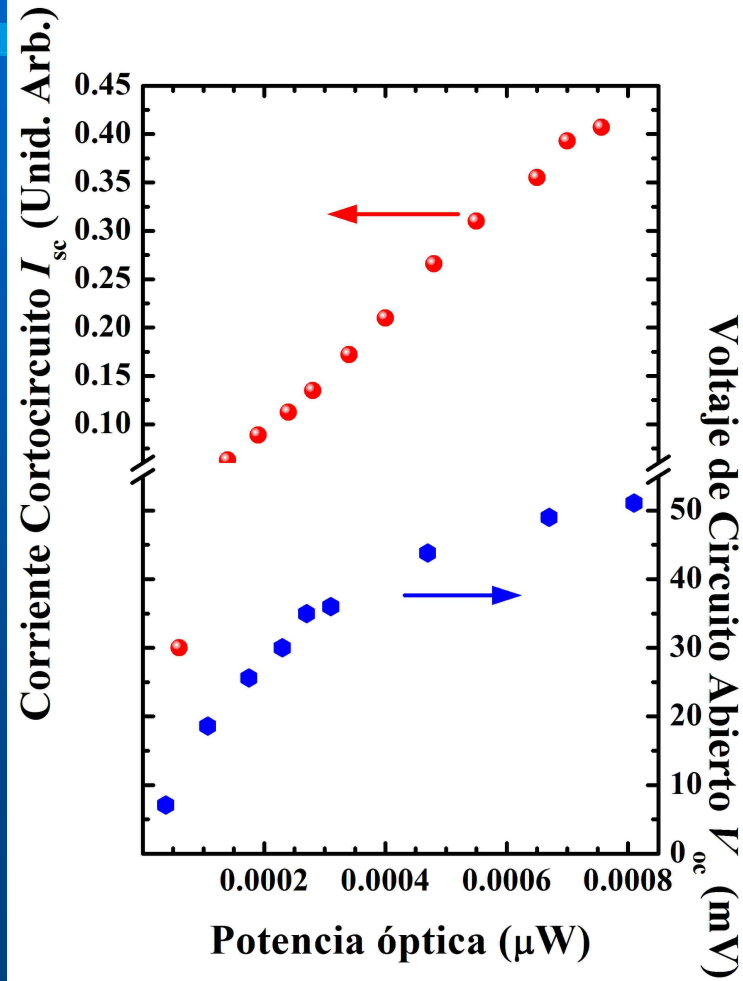


Caracteriz

Xe lamp
 $P_{\text{total}} = 1000 \text{ W}$

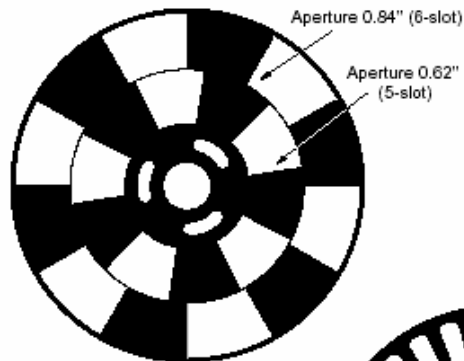


Respuesta Fotodiodos

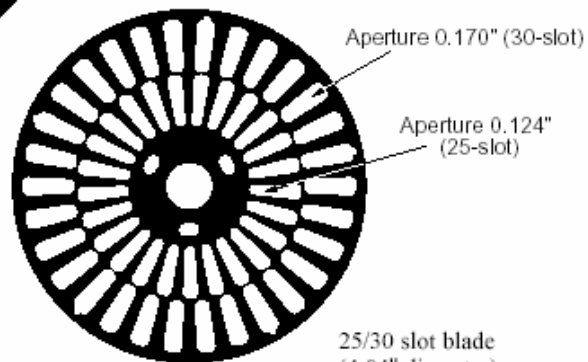


Caracterización Óptica - I

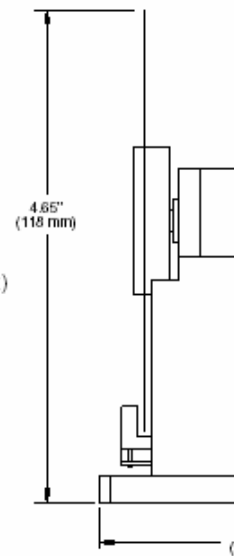
Xe lamp



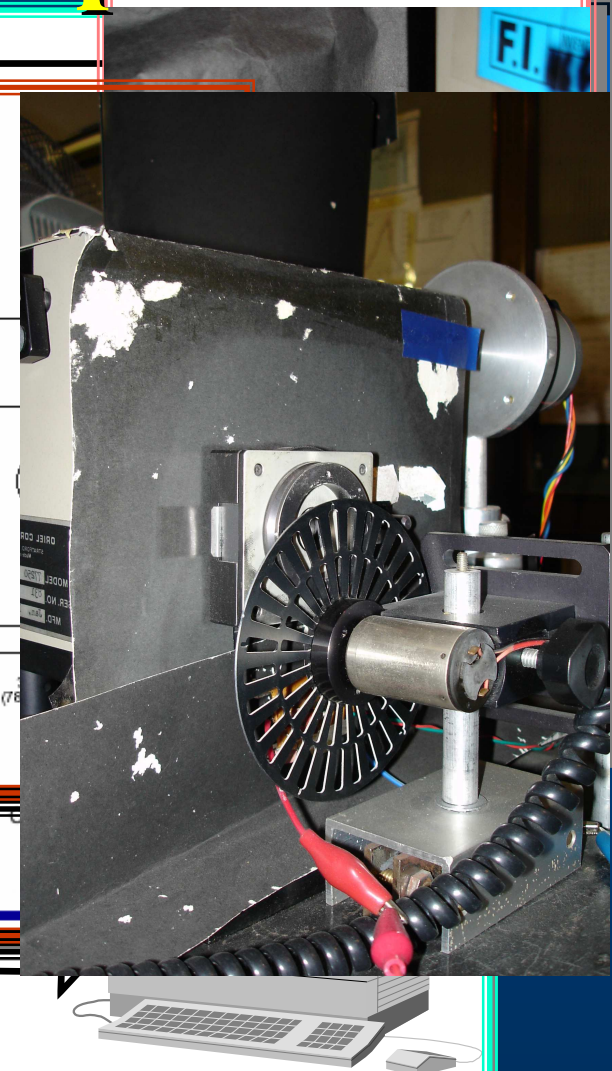
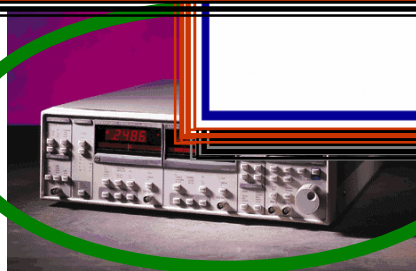
5/6 slot blade
(4.04" diameter)



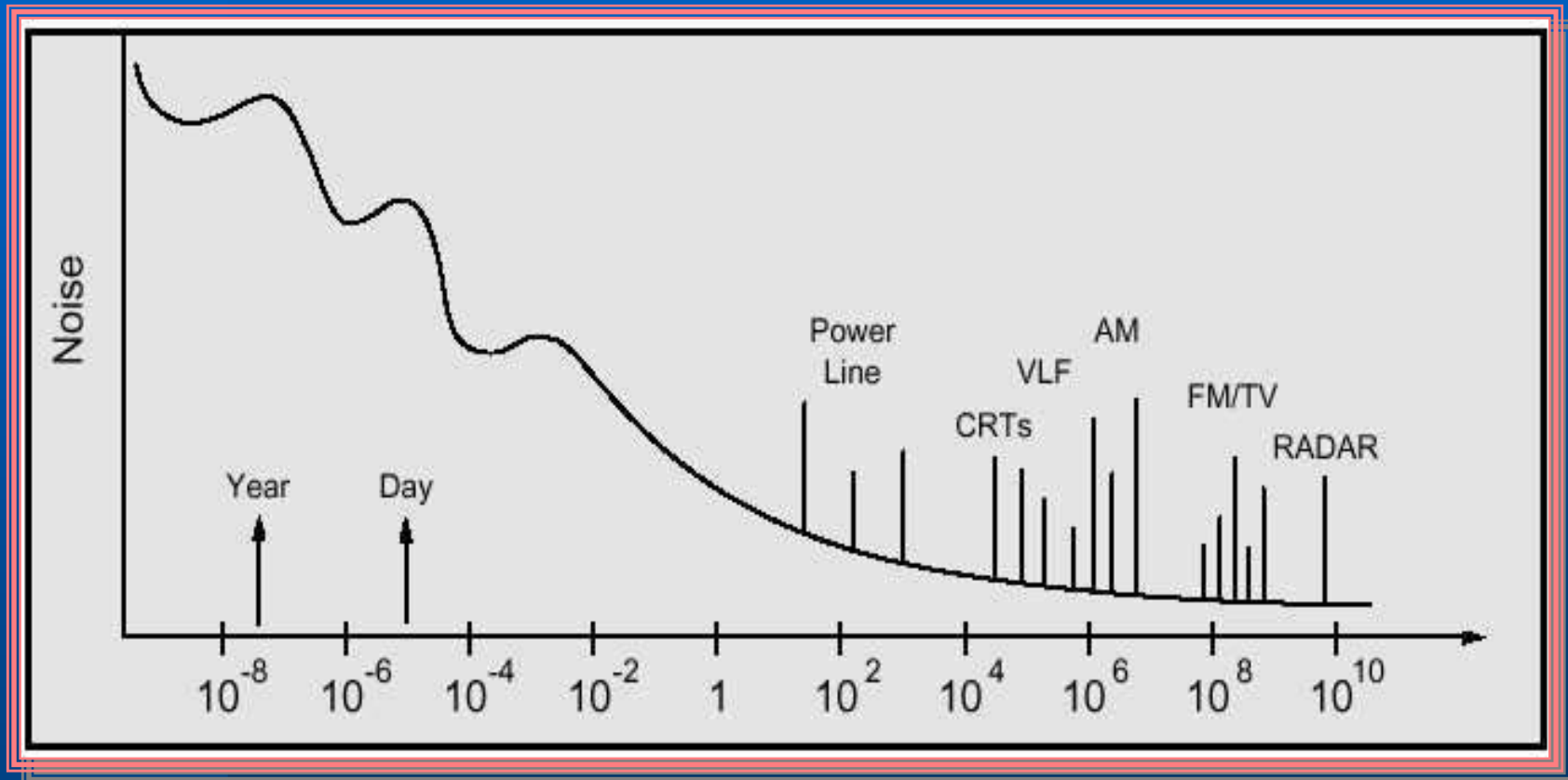
25/30 slot blade
(4.04" diameter)



Chopper
Motor
Control

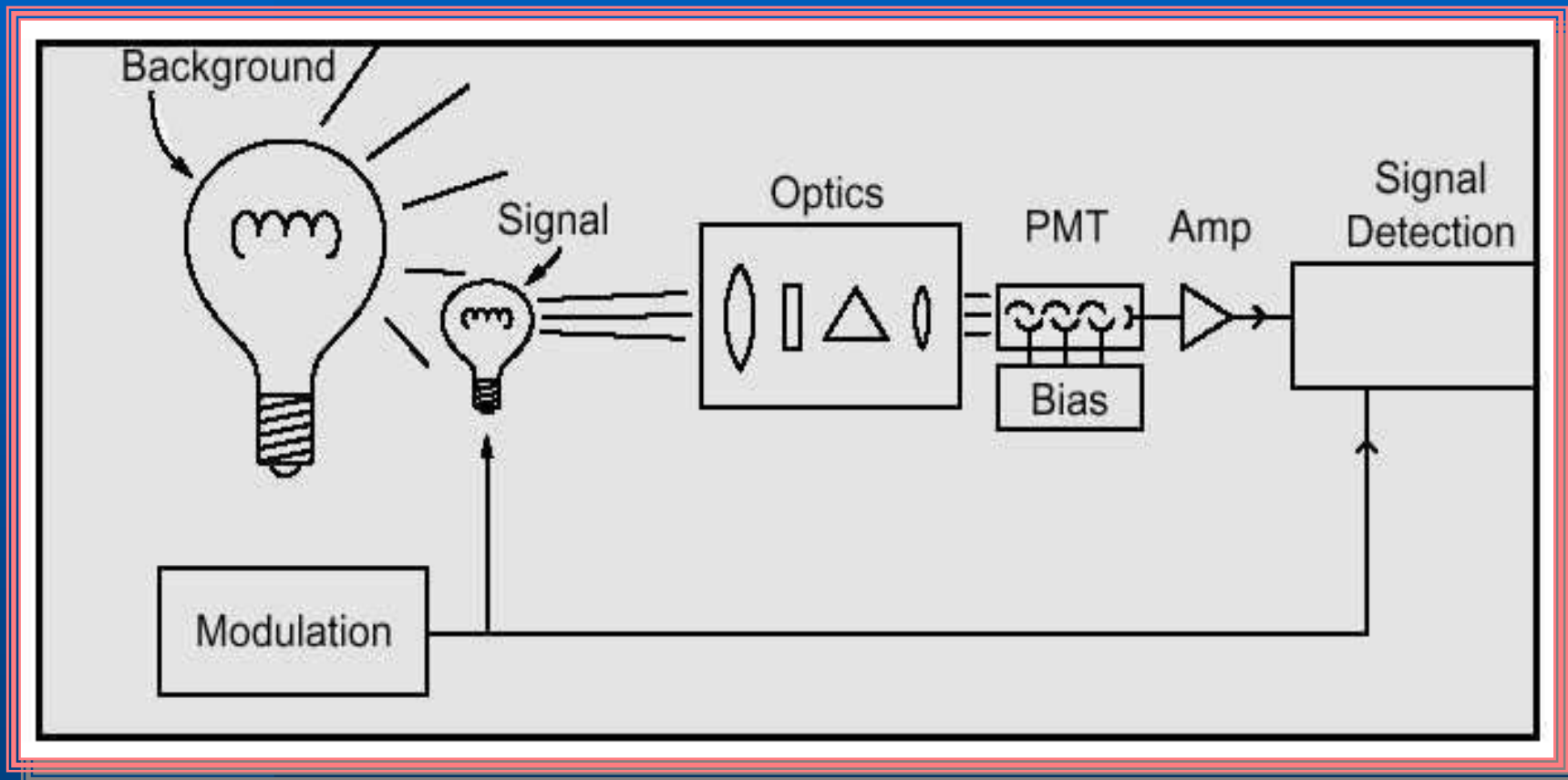


RUIDO: Fuentes de Ruido



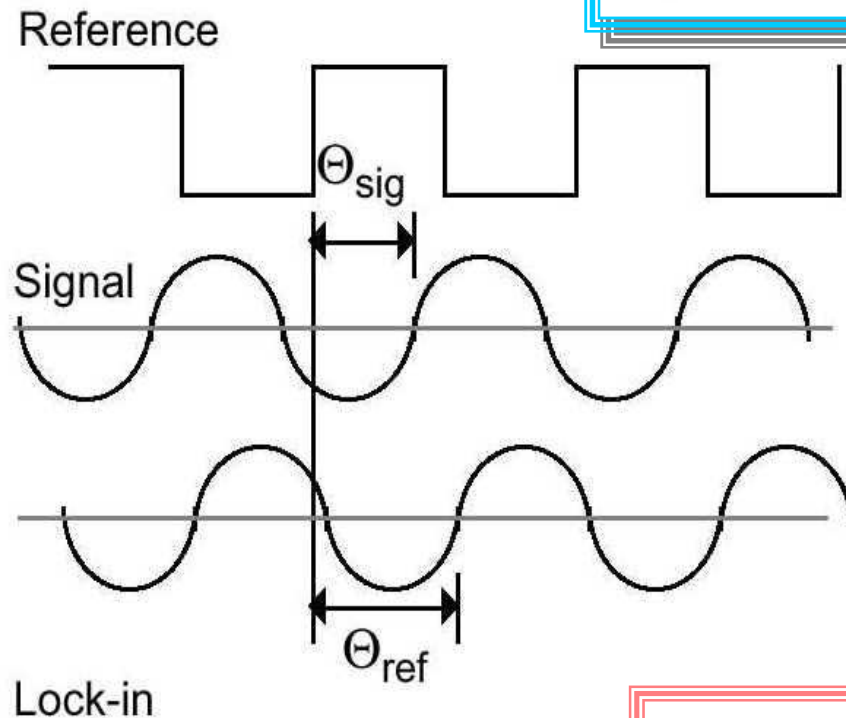
Frequency (Hz)

RUIDO: Modulación



RUIDO: Detección Sensible a la Fase

$$V_{psd} = V_{sig}V_L \sin(\omega_r t + \theta_{sig}) \sin(\omega_L t + \theta_{ref})$$



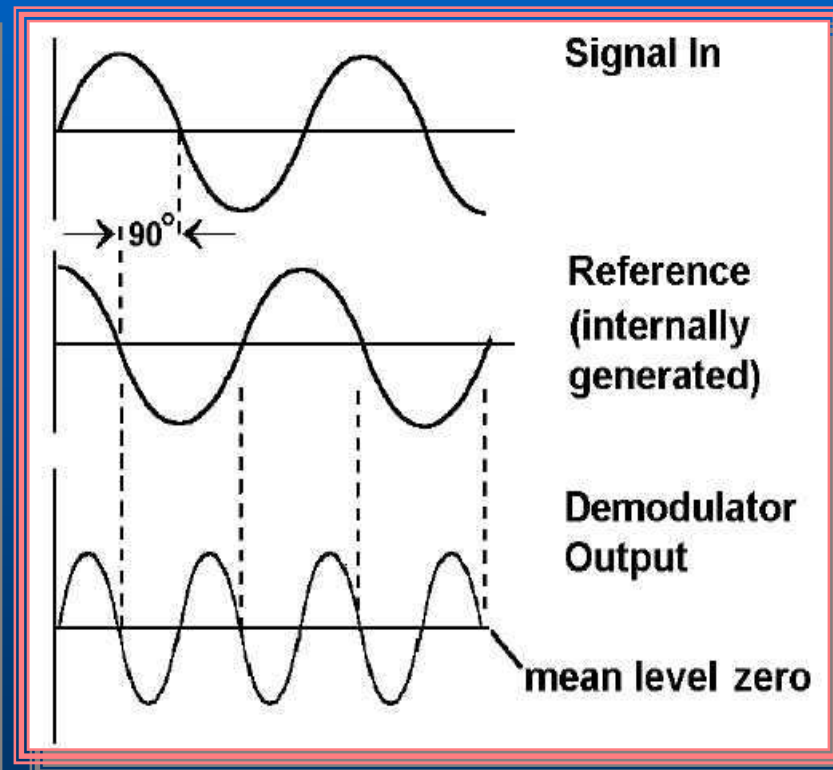
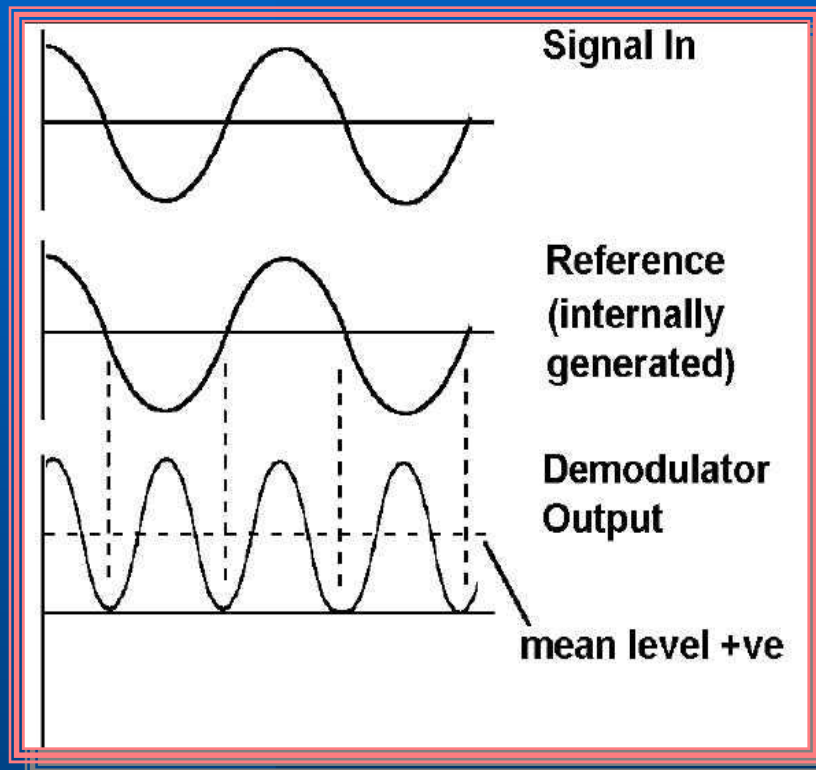
$$= \frac{1}{2} V_{sig} V_L \cos([\omega_r - \omega_L]t + \theta_{sig} - \theta_{ref}) - \frac{1}{2} V_{sig} V_L \cos([\omega_r + \omega_L]t + \theta_{sig} + \theta_{ref})$$

Tomando la
componente
de continua,
si $\omega_r = \omega_L$

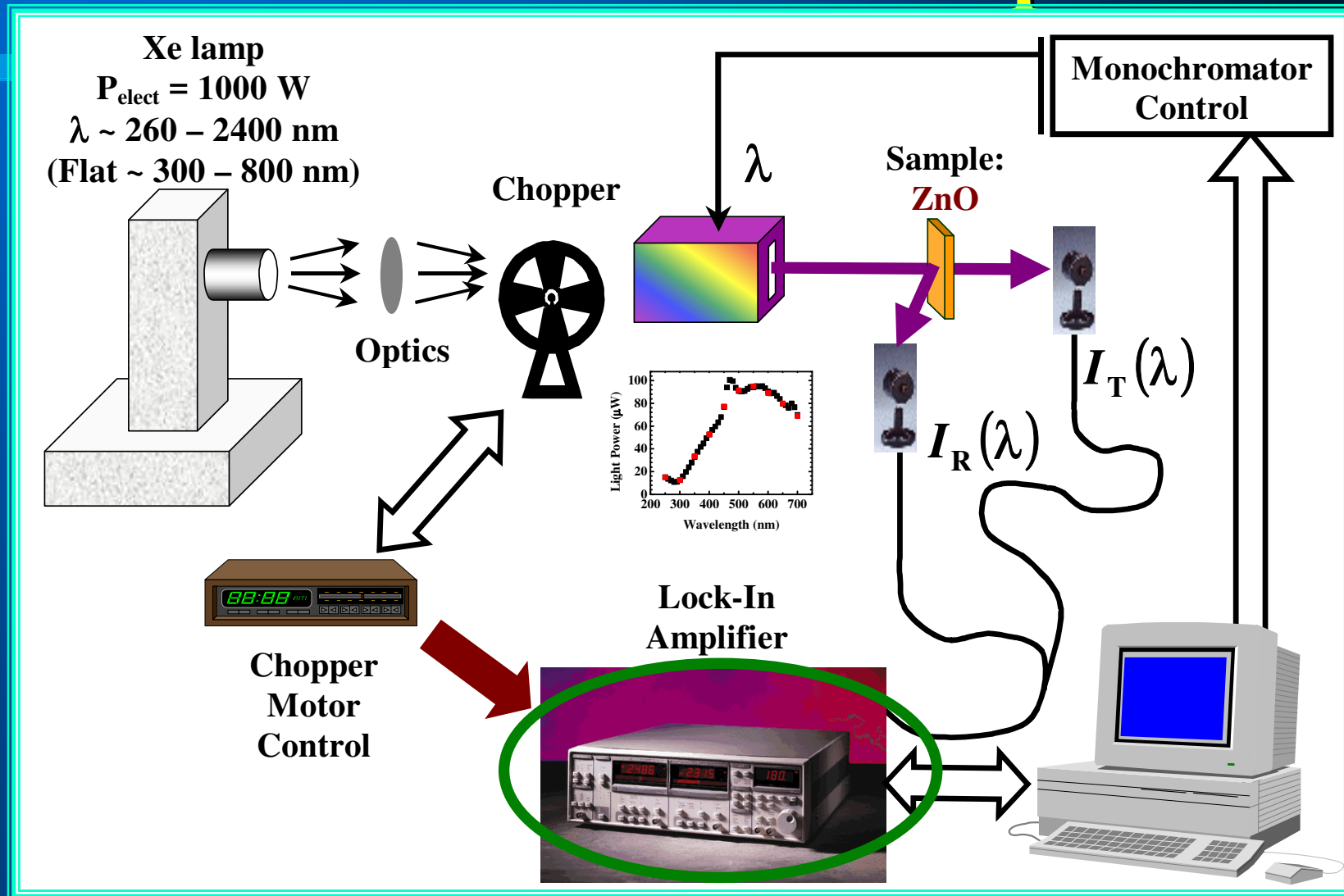
$$V_{psd} = \frac{1}{2} V_{sig} V_L \cos(\theta_{sig} - \theta_{ref})$$

RUIDO:

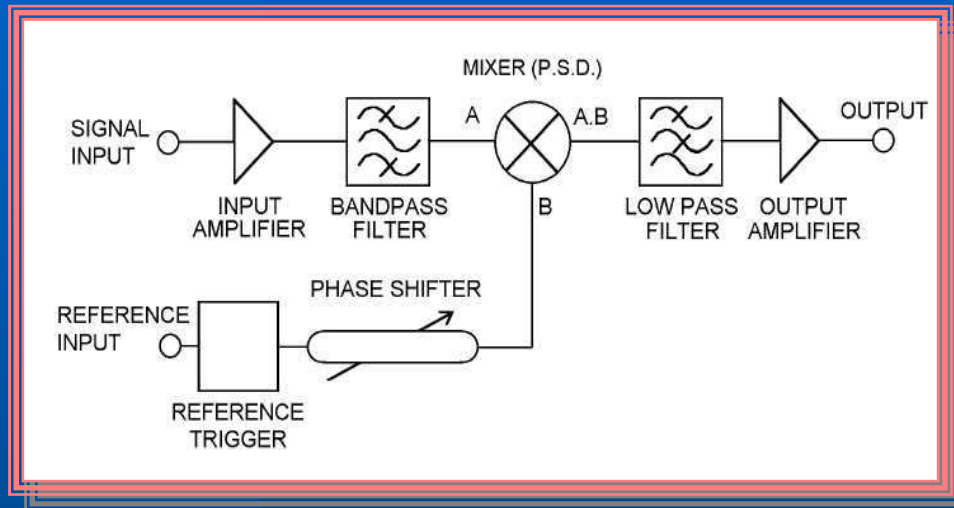
Detección Sensible a la Fase



Caracterización Óptica - I



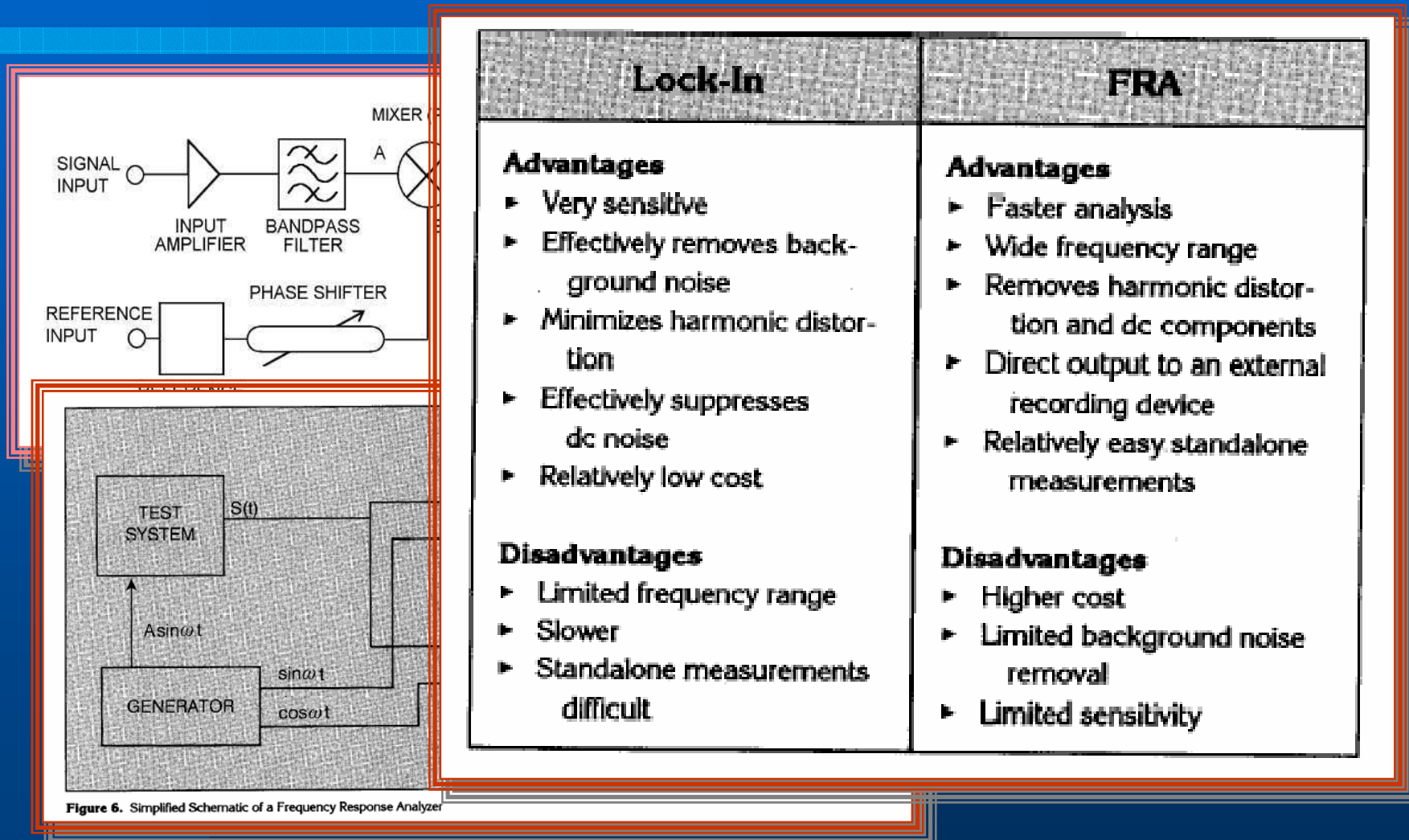
RUIDO: Detección Lock-In



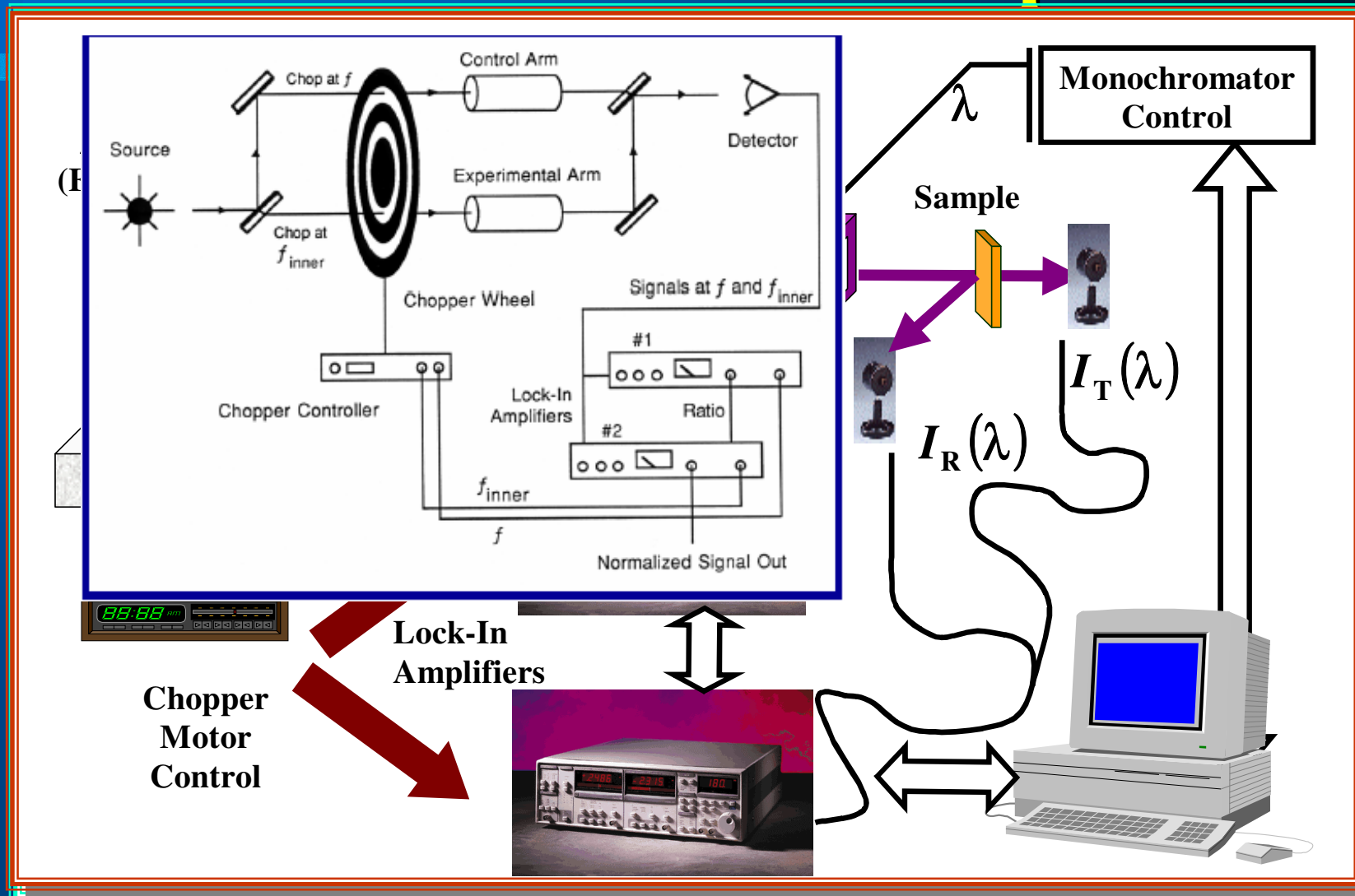
Reserva dinámica: Ganancia de los amplificadores se ajusta según nivel de ruido de la señal:

Ej. High Reserve: se usa cuando hay mucho ruido. Ganancia del amplificador de entrada es chica para que el ruido no sature el sistema.

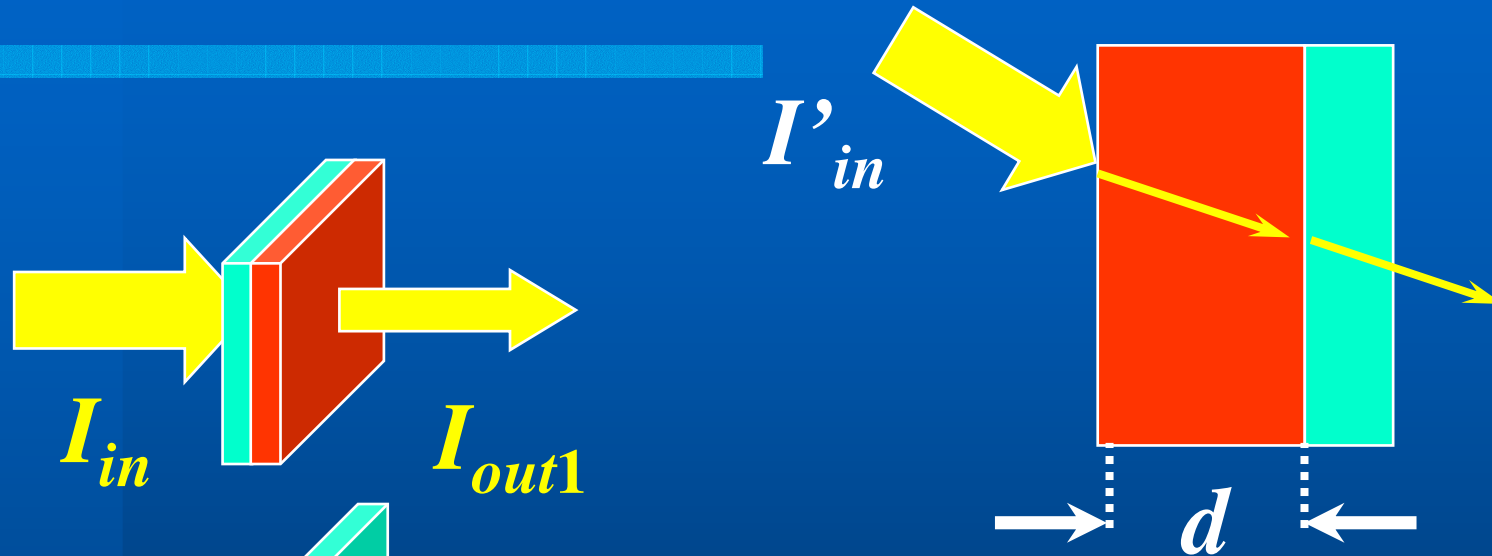
Lock-In vs FRA (Frequency Response Analyzer)



Caracterización Óptica - I



Transmitancia: Substrato Transparente



Transmitancia total: $T_{total} = \frac{I_{out1}}{I_{in}}$

Transmitancia substrato: $T_{subst} = \frac{I_{out2}}{I_{in}}$

Transmitancia del film: $T_{film} = \frac{I_{out1}}{I_{out2}}$

Transmitancia: Substrato Transparente

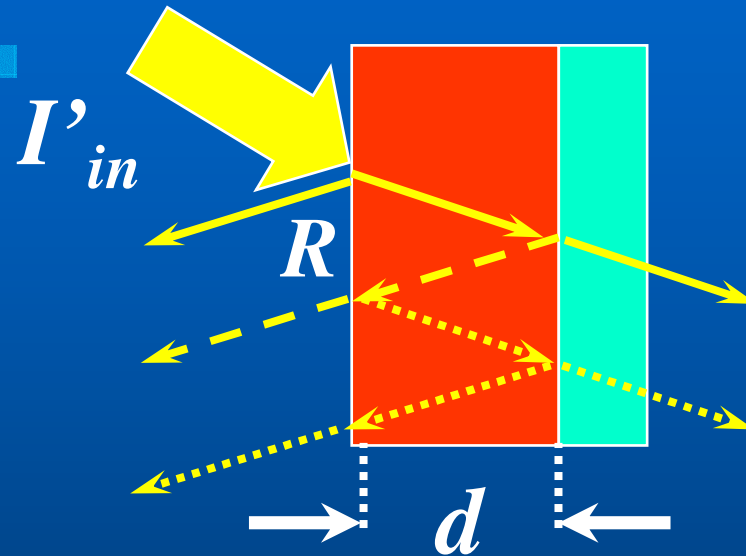
Reflectividad: R

$$T = \frac{(1 - R)^2 \exp(-\alpha d)}{1 - R^2 \exp(-2\alpha d)}$$

$$R < 0.3$$

$$T \approx (1 - R)^2 \exp(-\alpha d)$$

$$\Rightarrow \alpha \propto -\ln T$$



Transmitancia: Substrato Transparente

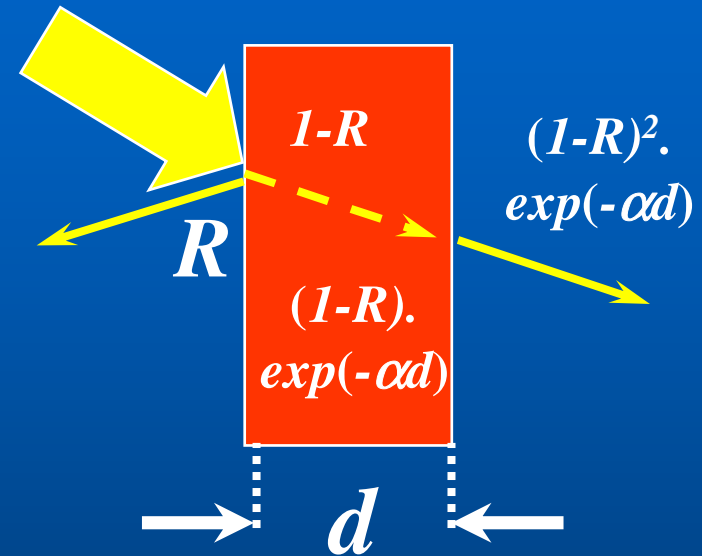
Reflectividad: R

$$T = \frac{(1-R)^2 \exp(-\alpha d)}{1 - R^2 \exp(-2\alpha d)}$$

$R < 0.3$

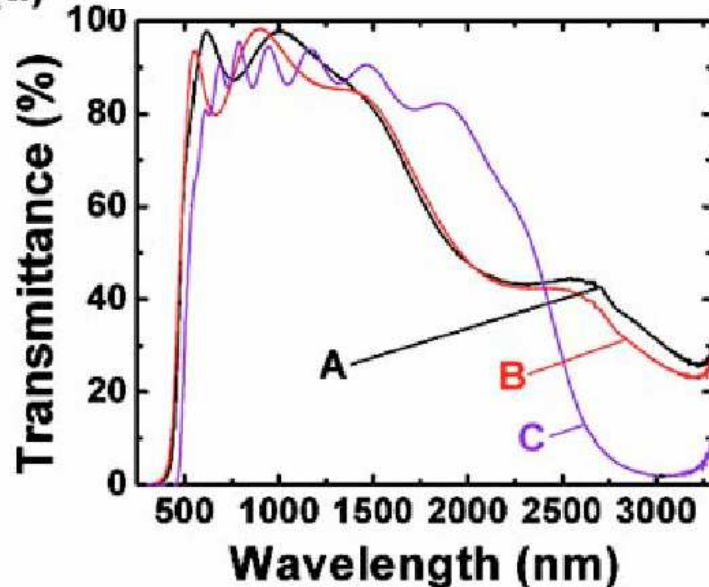
$$T \approx (1-R)^2 \exp(-\alpha d)$$

$$\Rightarrow \alpha \propto -\ln T$$



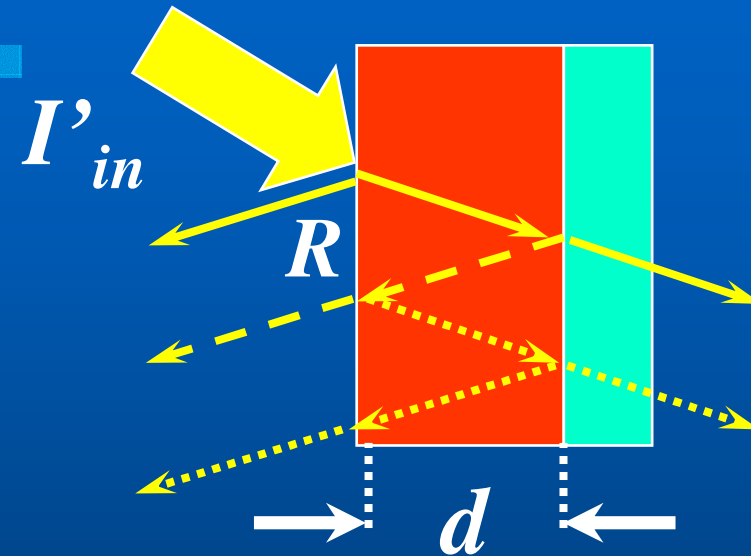
Transmitancia: Substrato Transparente

(a) Appl. Phys. Lett. **88**, 162115 (2006)



$$I \approx (1 - K) \exp(-\alpha d)$$

$$\Rightarrow \alpha \approx -\ln T$$



➤ Películas muy finas (d chico): Interferencia.

➤ n :

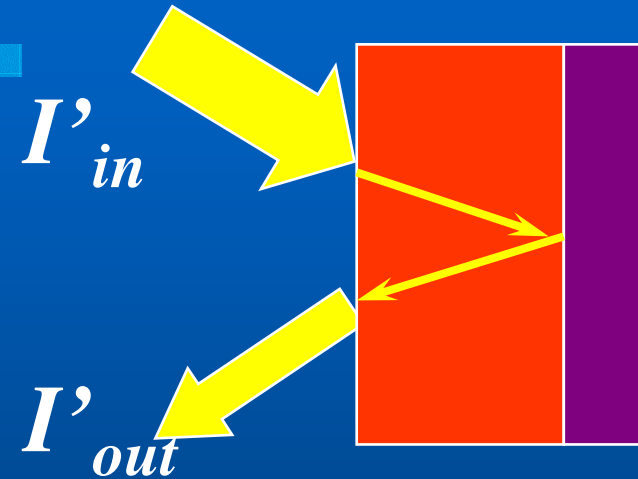
$$n = \frac{1}{\left(\frac{1}{\lambda_{\max 1}} - \frac{1}{\lambda_{\max 2}} \right) 2d}$$

Substrato Opaco

- Un método:

$$\text{Reflectancia: } R = \frac{I'_{out}}{I'_{in}}$$

$$\alpha(h\nu) \propto \ln\left(\frac{R_{max} - R_{min}}{R(h\nu) - R_{min}}\right)$$



$\lambda \rightarrow$ Longitud de Onda

$$\lambda_g = hc/E_g$$

- Más “fácil”:

$$R(\lambda) = f(n(\lambda), k(\lambda))$$

- Kramers-Kronig:

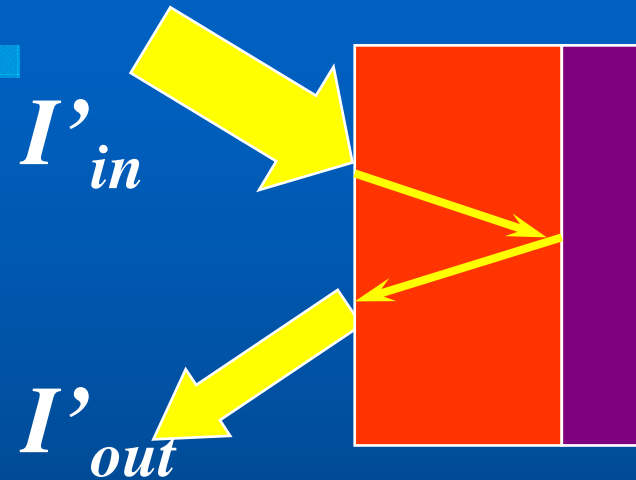
$$n(h\nu) - 1 = \frac{hc}{2\pi^2} P \int_0^{\infty} \frac{\alpha(E)}{E^2 - (h\nu)^2} dE$$

Substrato Opaco

- Un método:

$$\text{Reflectancia: } R = \frac{I'_{out}}{I'_{in}}$$

$$\alpha(h\nu) \propto \ln\left(\frac{R_{\max} - R_{\min}}{R(h\nu) - R_{\min}}\right)$$



$\lambda \rightarrow$ Longitud de Onda

$$\lambda_g = hc/E_g$$

- Más “fácil”:

Gap Directo

$$\frac{dR}{d\lambda}(\lambda_g) \rightarrow \infty$$

Gap Indirecto

$$\frac{dR}{d\lambda}(\lambda_g) \rightarrow 0$$

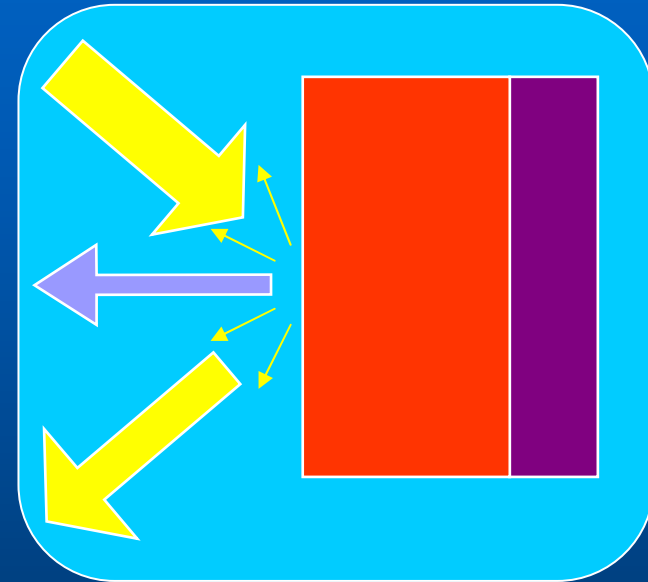
Reflectancia Difusa

$$DRS \equiv \frac{I_{muestra}}{I_{substrato}}$$

$$DRS = \frac{T^2}{1 - r_{substrato} R}$$

$$T = \frac{(1 - r)^2 \exp(-\alpha d)}{1 - r^2 \exp(-2\alpha d)}$$

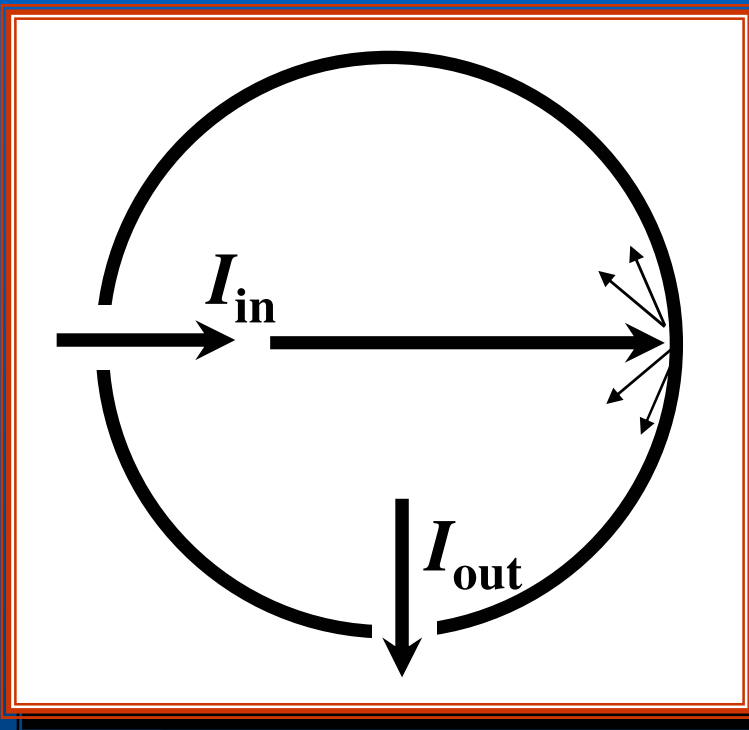
$$R = r \left[1 + \frac{(1 - r)^2 \exp(-2\alpha d)}{1 - r^2 \exp(-2\alpha d)} \right]$$



$$\exp[2\alpha(h\nu)d] \propto f(DRS(h\nu), r, r_{substrato})$$

Esfera Integradora

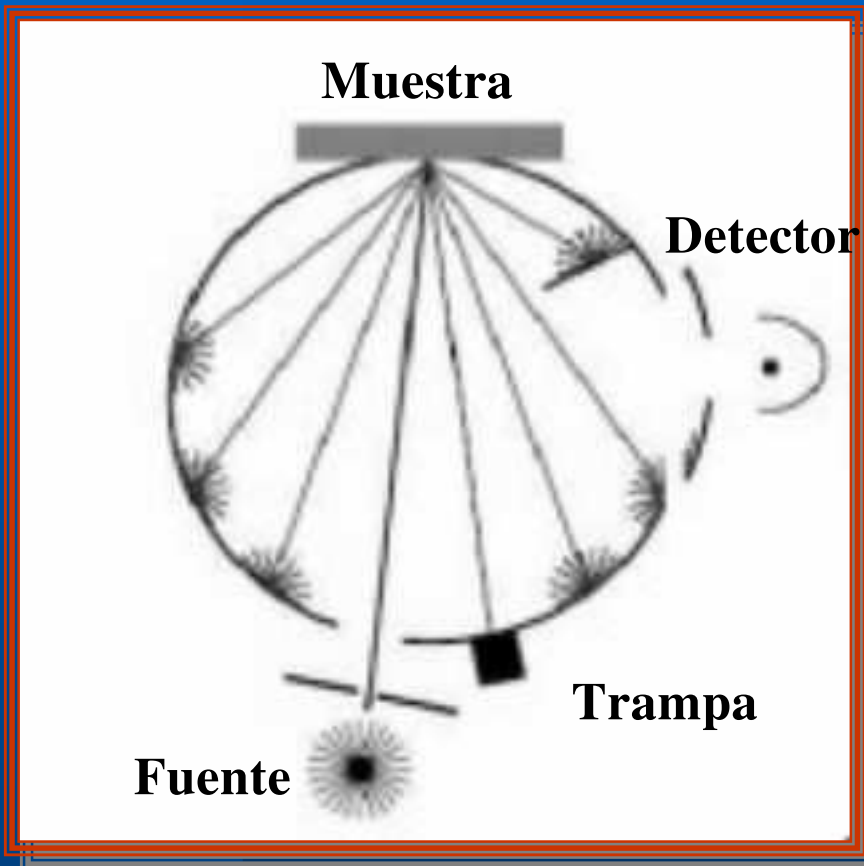
Para medida de Irradiancia (LEDs):



$$I_{out} \propto I_{in}$$

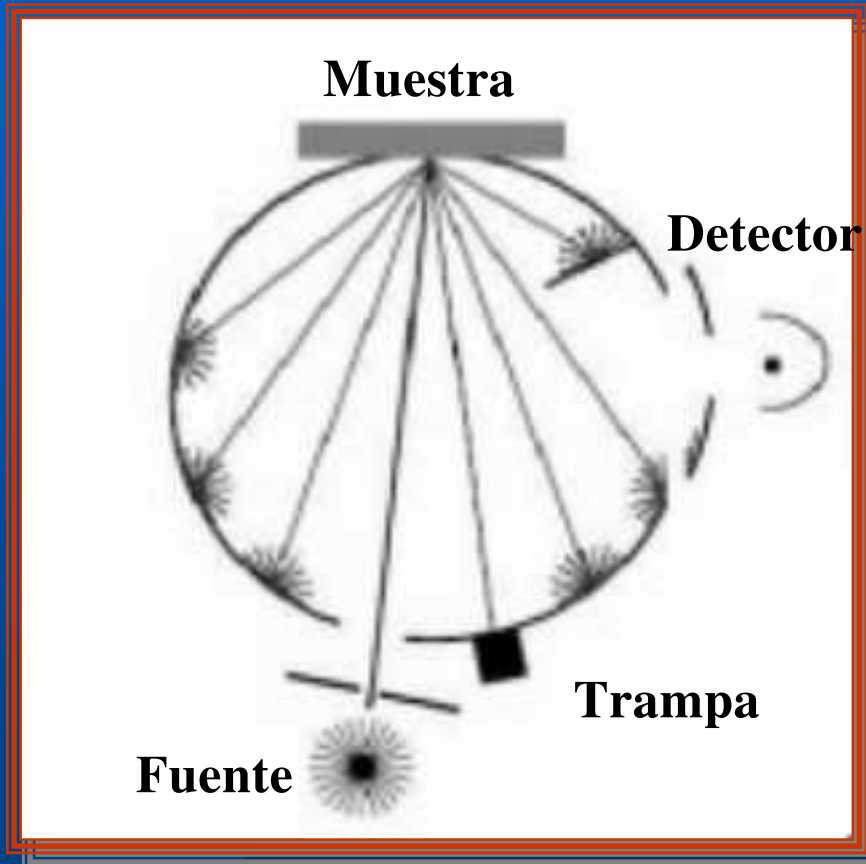
Esfera Integradora

Para medida de Reflectancia Difusa o Total:



Esfera Integradora

Para medida de Reflectancia Difusa o Total:



Trampa abierta:
Se excluye reflexión
“especular” (I_{exc}).

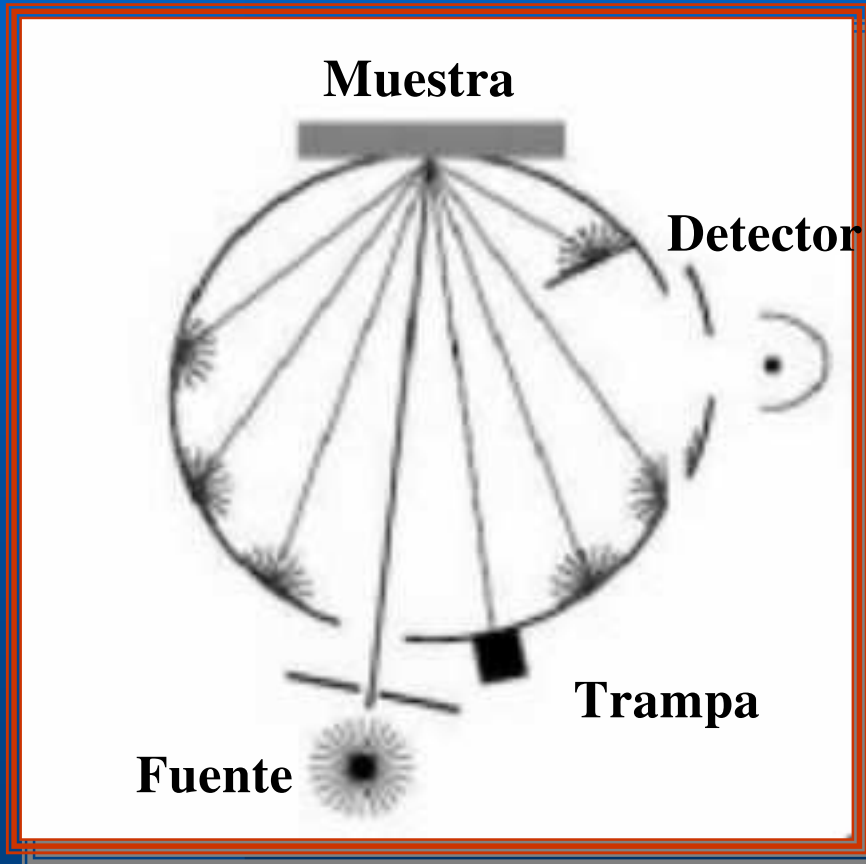
Trampa cerrada:
Se incluye reflexión
“especular” (I_{inc}).

“Glossines”

$$G = \frac{I_{inc}}{I_{exc}} \geq 1$$

Esfera Integradora

Para medida de Reflectancia Difusa o Total:



I_{exc} es una medida de reflectancia “difusa”.

$$R_{dif} \equiv \frac{I_{exc}}{I_{ref}} \Rightarrow F = \frac{(1 - R)^2}{2R}$$

I_{ref} misma medida en “blanco” de referencia.

$F \equiv$ Función de Kubelka-Munk.

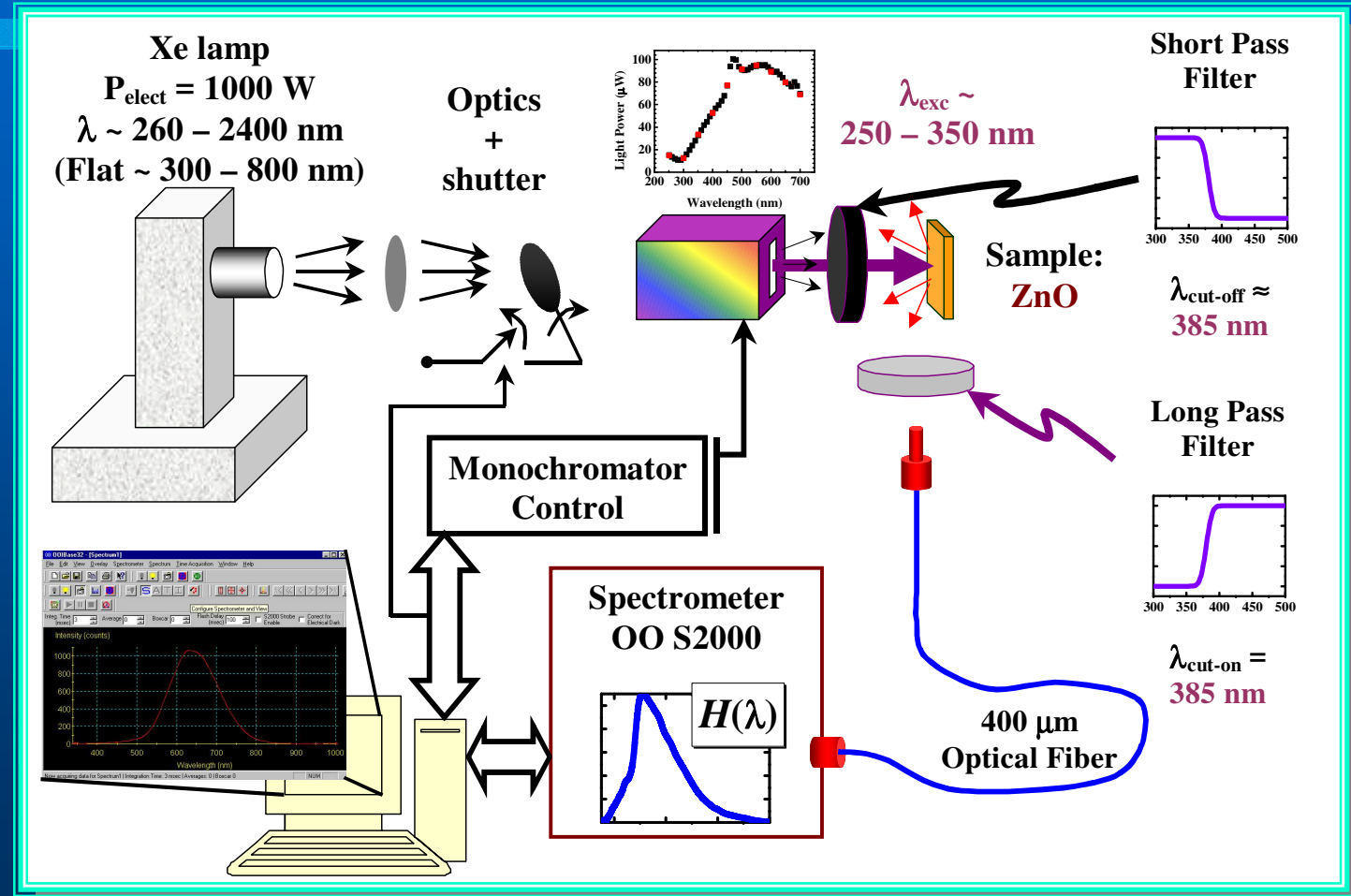
$$F \approx \frac{\alpha}{\sigma}$$

α : absorción.

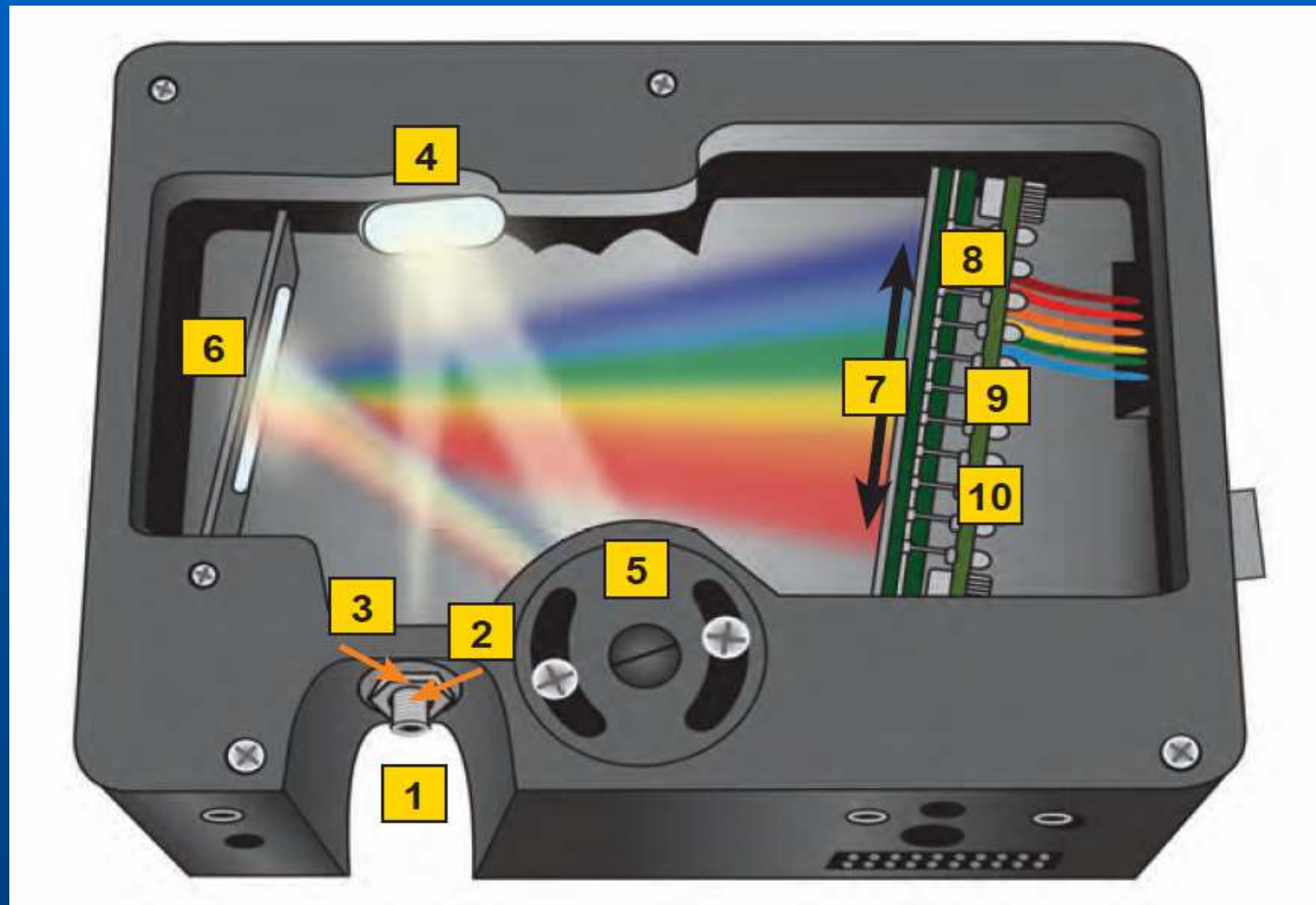
σ : dispersión.

Caracterización Óptica - II

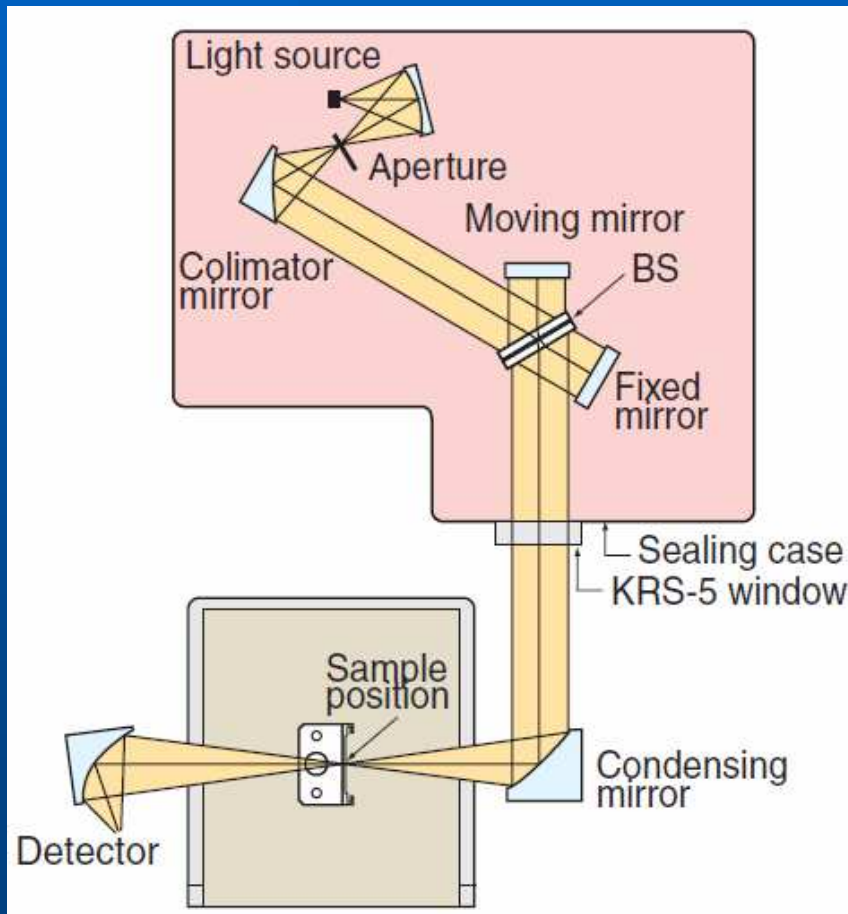
Detalles del
Montaje
Experimental
para Estudio
de Emisión
de Luz.



Espectrómetro o Espectrógrafo



FTIR: Fourier Transform Infrared Spectroscopy.



$$I(p, \tilde{\nu}) = I(\tilde{\nu})[1 + \cos(2\pi\tilde{\nu}p)]$$

$I(\tilde{\nu})$: Espectro Fuente (a medir).
 p : Posición Interferómetro.

Señal en el detector :

$$I(p) = \int_0^{\infty} d\tilde{\nu} I(\tilde{\nu})[1 + \cos(2\pi\tilde{\nu}p)] =$$

$$= I_0 + \frac{1}{2} \mathfrak{S}(I(\tilde{\nu}))$$

$\mathfrak{S}(I(\tilde{\nu}))$: Transformada de Fourier.

$$I(\tilde{\nu}) = 2\mathfrak{S}^{-1}(I(p) - I_0)$$