

Propiedades Ópticas de Aislantes



Ricardo E. Marotti

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* e-mail: khamul@fing.edu.uy

Instituto de Física
Facultad de Ingeniería
Universidad de la República
Montevideo, URUGUAY

Clasificación de Materiales por su Conducción Eléctrica

➤ **“Superconductor”:**

$$\rho \approx 0$$

($T < T_c$ + efecto Meissner)

➤ **Metal:**

$$\rho \approx 1 - 100 \mu\Omega \text{ cm}$$

➤ **Aislante:**

$$\rho > 10 \text{ G}\Omega \text{ cm}$$

➤ **Semiconductor ($T=300\text{K}$):**

$$\rho \approx 1 \text{ m}\Omega \text{ cm} - 1 \text{ M}\Omega \text{ cm}$$

Ley de Ohm:

$$\vec{J} = \sigma \vec{E}$$

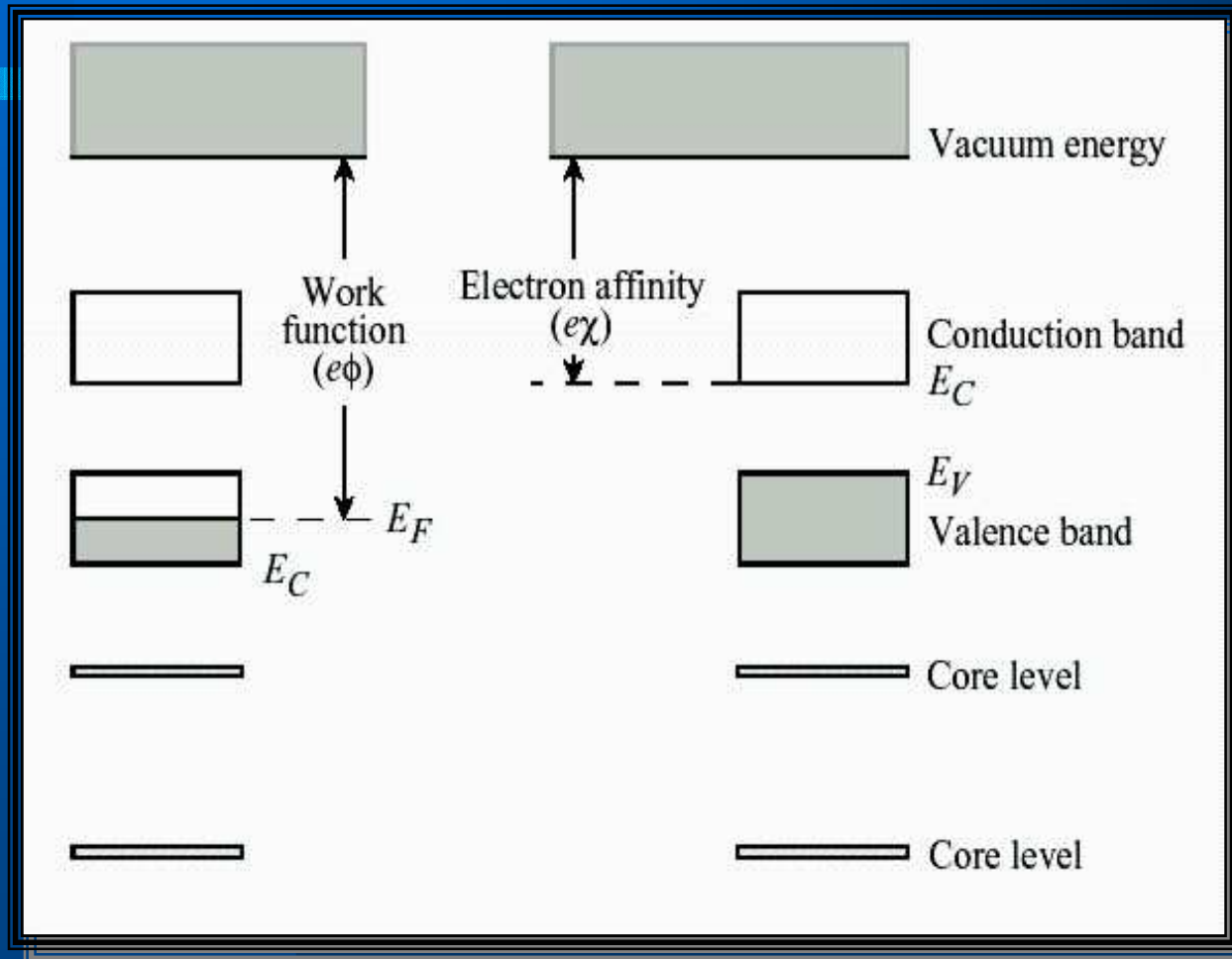
\vec{J} \mapsto Densidad de Corriente Eléctrica

\vec{E} \mapsto Campo Eléctrico

σ \mapsto Conductividad Eléctrica

$$\rho = \frac{1}{\sigma} \mapsto \text{Resistividad Eléctrica}$$

Estructura Electrónica de Bandas “Chatas”



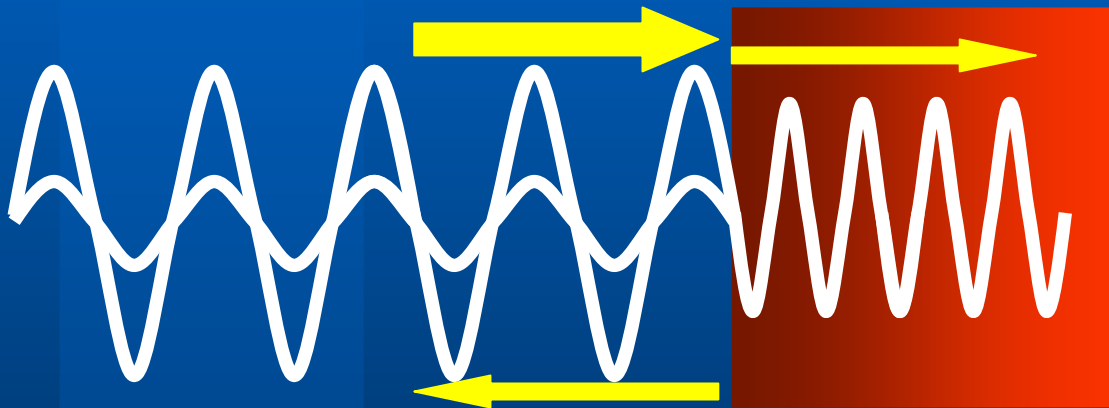
Metal

Aislante o Semiconductor

Propiedades Ópticas

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

$\eta \rightarrow$ Índice de Refracción



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

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

Velocidad de la luz :

$v \rightarrow$ en el medio,

$c \rightarrow$ en el vacío,

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

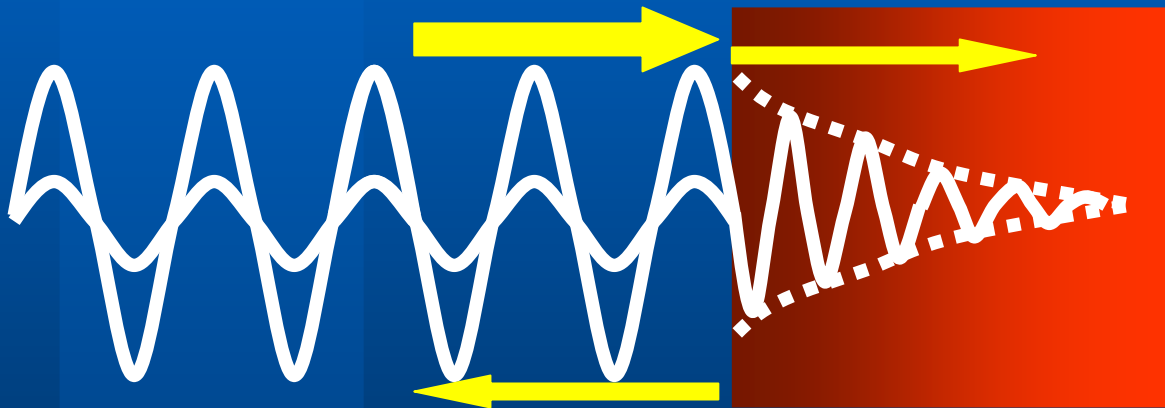
$$\omega = 2\pi\nu = \frac{2\pi}{T} \rightarrow \text{Frecuencia Óptica}$$

Propiedades Ópticas

Materiales **NO** Transparente,

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

$\eta_c \rightarrow$ Índice de Refracción COMPLEJO



$$\eta_c = n + iq$$

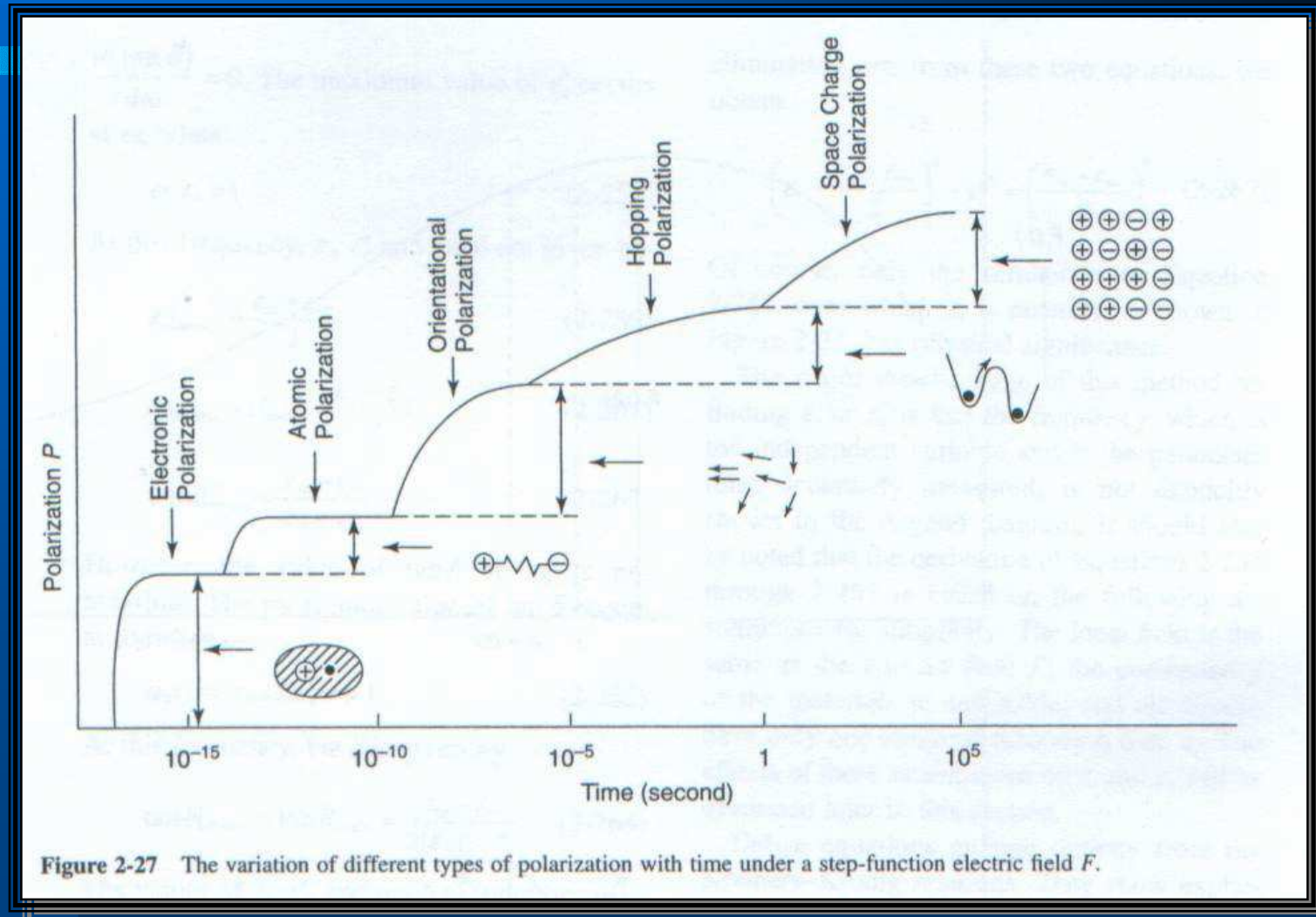
$n = \text{Re}(\eta_c) \rightarrow$ índice de refracción,

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

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

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

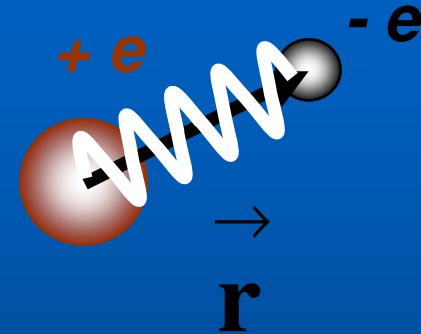
Origen Interacción Radiación - Materia



Modelo clásico de Lorentz

- Oscilador Armónico Amortiguado:

$$\langle \vec{F} \rangle = -e \vec{E} - \frac{m_e}{\tau} \vec{v} - m_e \omega_0^2 \vec{r}$$



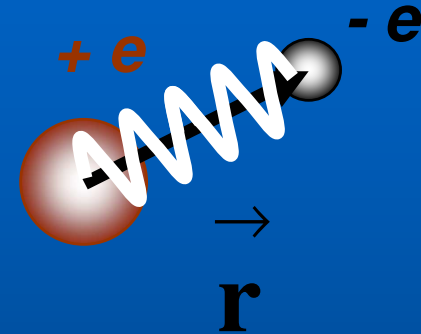
Fuerza media
sobre electrón
de carga **-e**

Fuerza impuesta
por un campo eléctrico **E**

Modelo clásico de Lorentz

- Oscilador Armónico Amortiguado:

$$\langle \vec{F} \rangle = -e \vec{E} - \frac{m_e}{\tau} \vec{v} - m_e \omega_0^2 \vec{r}$$



Fuerza Disipativa:

m_e : masa electrónica

v : velocidad media

τ : Tiempo Característico



Fuerza Restitutiva

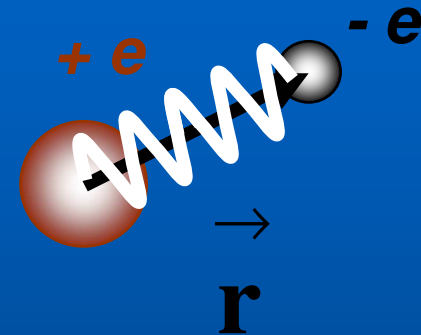
ω_0 : Frecuencia de

Resonancia

Modelo clásico de Lorentz

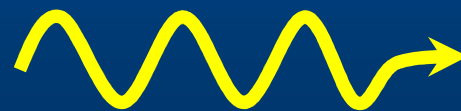
- Oscilador Armónico Amortiguado:

$$\langle \vec{F} \rangle = -e \vec{E} - \frac{m_e}{\tau} \vec{v} - m_e \omega_0^2 \vec{r}$$



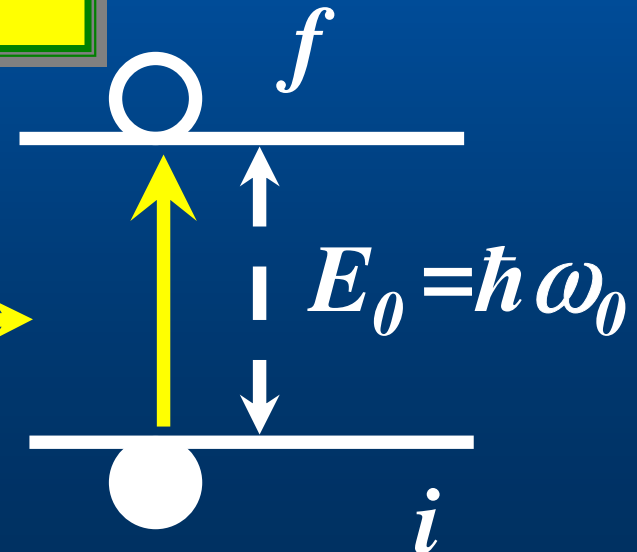
- Sistema Cuántico Equivalente:

τ : constante de tiempo



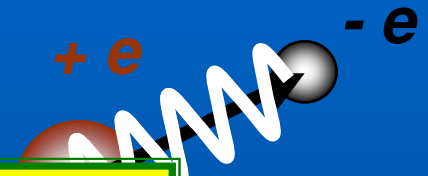
$$\frac{1}{\tau} \approx \frac{1}{\tau_{\text{vida}}} + \frac{1}{\tau_{\text{colisiones}}}$$

$$E_{ph} = h\nu = \hbar\omega$$



Modelo clásico de Lorentz

- Oscilador Armónico Amortiguado:



$$-m_e \omega^2 \vec{r} = -e \vec{E} + i\omega \frac{m_e}{\tau} \vec{r} - m_e \omega_0^2 \vec{r}$$

$$\vec{E} = \vec{E}_0 \exp(-i\omega t)$$

$$\dot{\vec{v}} = \dot{\vec{r}} = -i\omega \vec{r}$$

$$\vec{r} = \vec{r}_0 \exp(-i\omega t)$$

$$\vec{a} = \dot{\vec{v}} = -i\omega \vec{v} = -\omega^2 \vec{r}$$

ética.
torio,

τ/T .

Modelo clásico de Lorentz

- Oscilador Armónico Amortiguado:



$$-m_e \omega^2 \vec{r} = -e \vec{E} + i\omega \frac{m_e}{\tau} \vec{r} - m_e \omega_0^2 \vec{r}$$

$$\vec{r} = \frac{e \vec{E} / m_e}{(\omega^2 - \omega_0^2) + i\omega / \tau}$$

$$\vec{P} = -eN \vec{r}$$

P: Polarización Eléctrica,
N: electrones por volumen

Modelo clásico de Lorentz

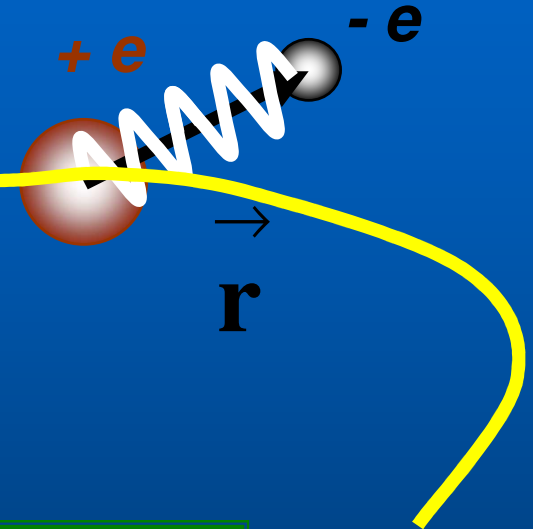
- Oscilador Armónico Amortiguado:

$$\vec{P} = -\frac{e^2 N}{m_e} \frac{\vec{E}}{(\omega^2 - \omega_0^2) + i\omega/\tau}$$

$$\vec{r} = \frac{e \vec{E} / m_e}{(\omega^2 - \omega_0^2) + i\omega/\tau}$$

$$\vec{P} = -eN \vec{r}$$

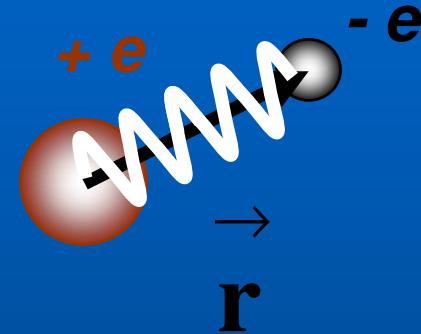
P: Polarización Eléctrica,
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Modelo clásico de Lorentz

- Oscilador Armónico Amortiguado:

$$\vec{P} = - \frac{e^2 N}{m_e} \frac{\vec{E}}{(\omega^2 - \omega_0^2) + i\omega/\tau}$$



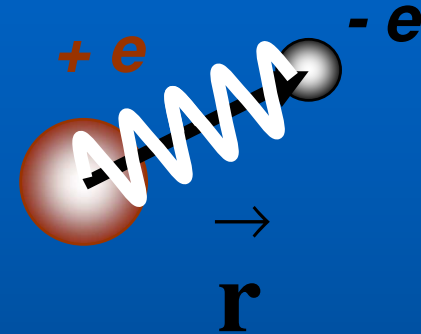
$$\vec{D} = \epsilon_0 \vec{E} + \vec{P}$$

D: Desplazamiento dieléctrico.

ϵ_0 : Permitividad del vacío

Modelo clásico de Lorentz

- Oscilador Armónico Amortiguado:



$$\vec{P} = - \frac{e^2 N}{m_e} \frac{\vec{E}}{(\omega^2 - \omega_0^2) + i\omega/\tau}$$

$$\vec{D} = \epsilon \vec{E}$$

$$\eta_c^2 = \frac{\epsilon}{\epsilon_0}$$

$$\epsilon = \epsilon_1 + i\epsilon_2$$

$$\eta_c = n - ik$$

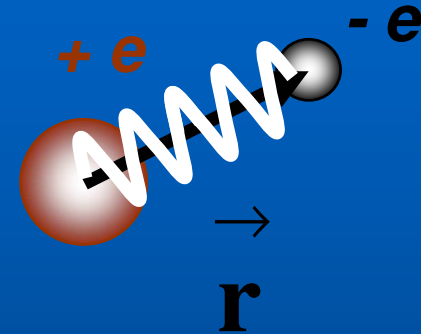
(M)

$$\eta_c^2 = 1 - \frac{\omega_p^2}{(\omega^2 - \omega_0^2) + i\omega/\tau}$$

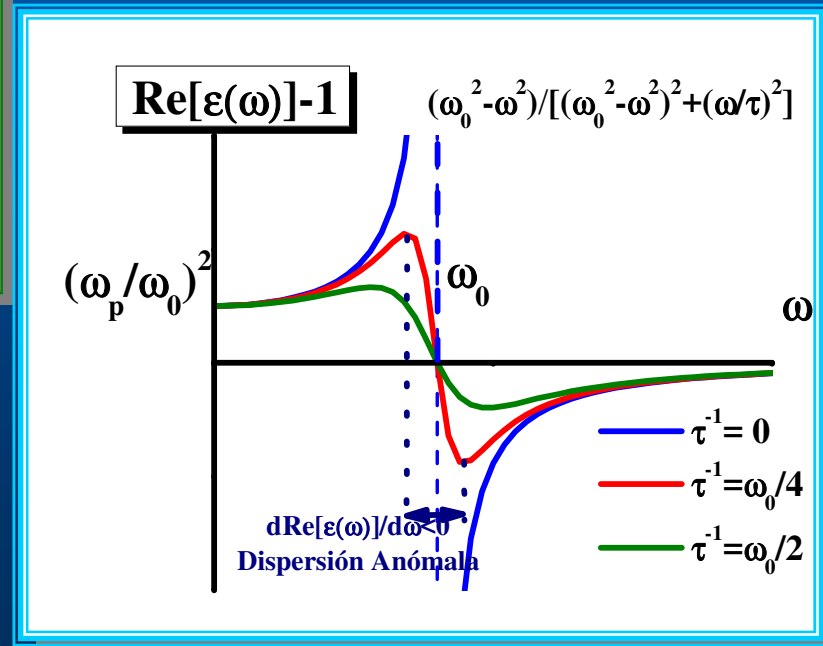
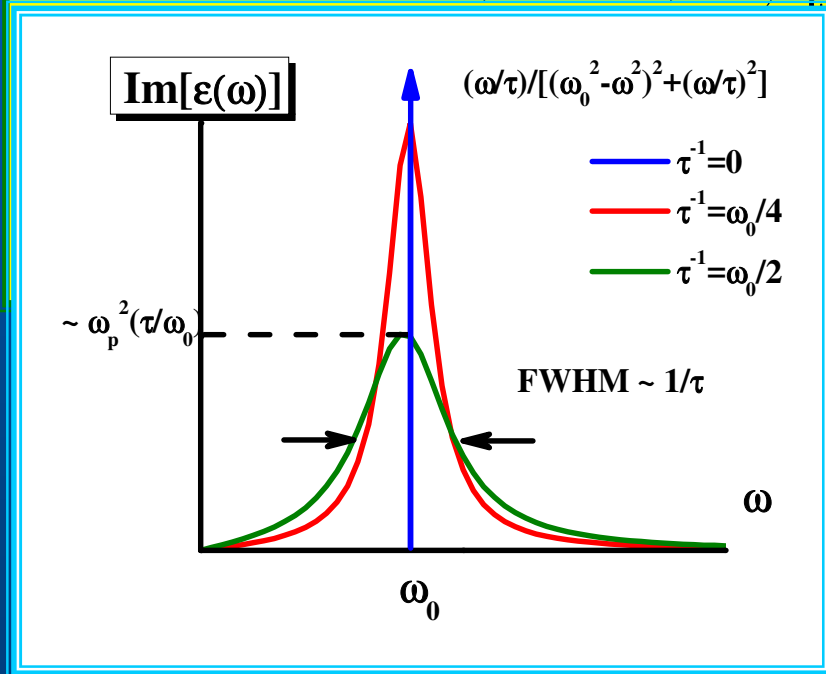
$$\omega_p^2 = \frac{e^2 N}{\epsilon_0 m_e}$$

Modelo clásico de Lorentz

- Oscilador Armónico Amortiguado:



$$\eta_c^2 = \epsilon_1 + i\epsilon_2 = 1 - \frac{\omega_p^2}{(\omega^2 - \omega_0^2) + i\omega/\tau}$$



Modelo clásico de Lorentz

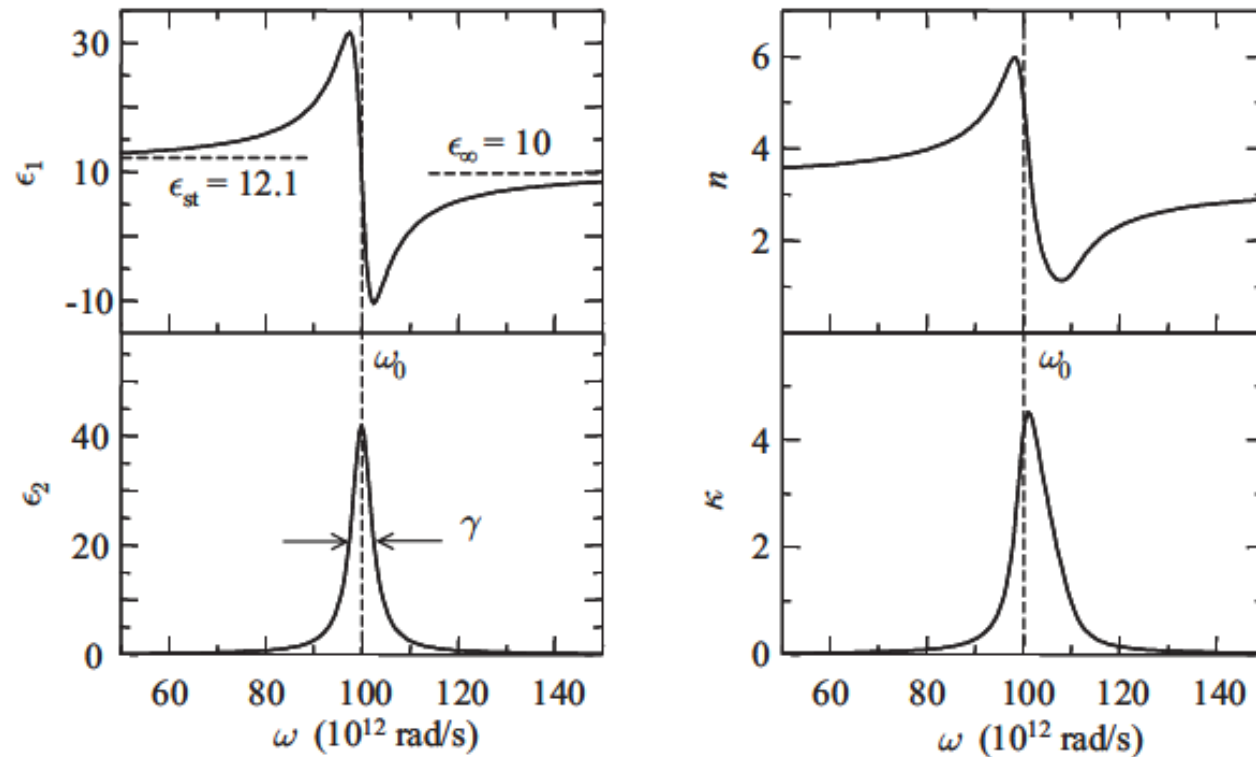


Fig. 2.4 Frequency dependence of the real and imaginary parts of the complex dielectric constant of a dipole oscillator at frequencies close to resonance. The graphs are calculated for an oscillator with $\omega_0 = 10^{14}$ rad/s, $\gamma = 5 \times 10^{12}$ s $^{-1}$, $\epsilon_{st} = 12.1, 0$ and $\epsilon_\infty = 10$. Also shown is the real and imaginary part of the refractive index calculated from the dielectric constant.

Origen Interacción Radiación - Materia

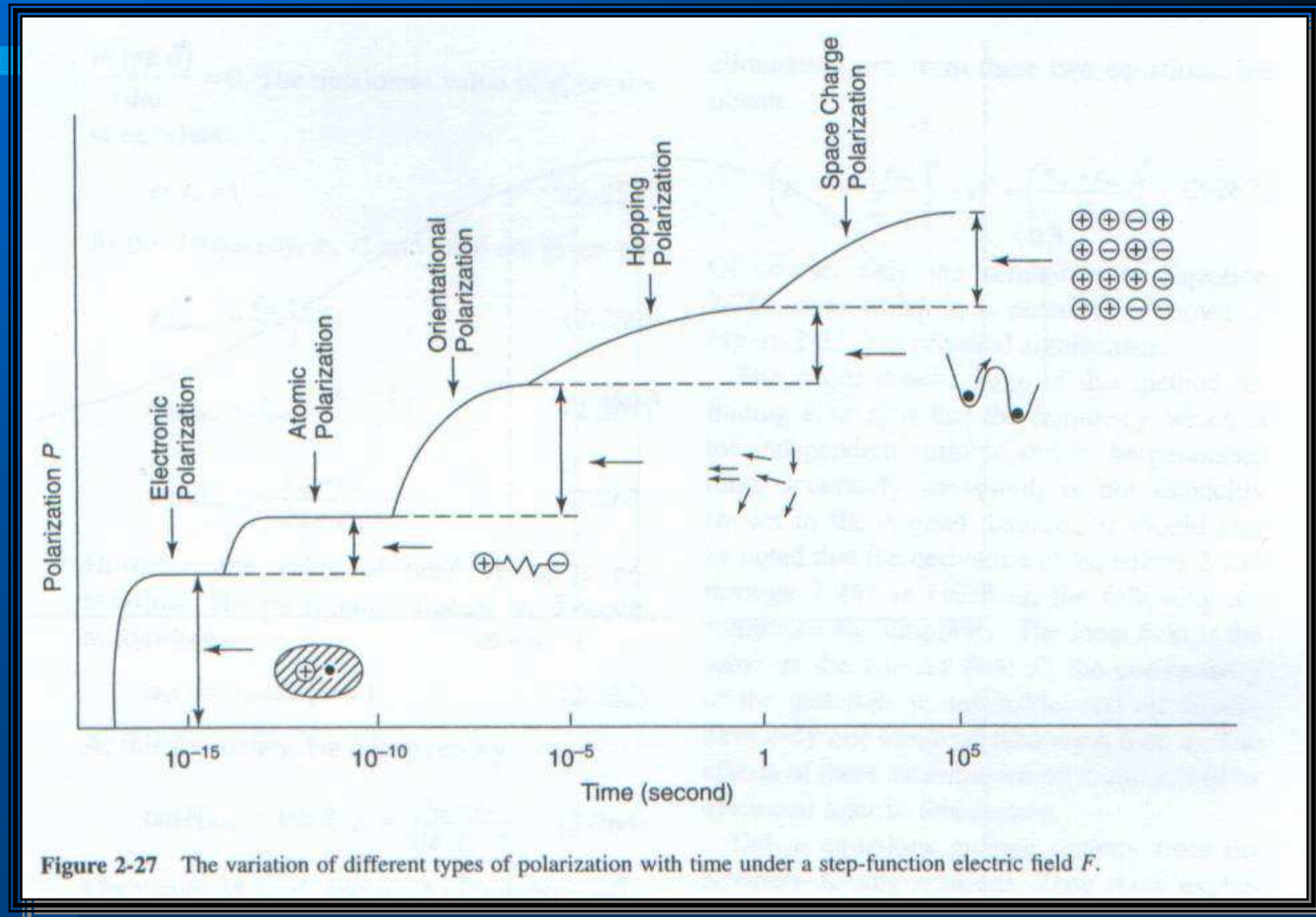


Figure 2-27 The variation of different types of polarization with time under a step-function electric field F .

Generalidades

- Energía del Fotón:

$$E = h\nu = hc/\lambda = \hbar\omega$$

- Sistemas “Homogéneos”:

Todos los electrones tienen una única resonancia: ω_0

- Sistemas “Inhomogéneos”:

Existen distribuciones de resonancias: $\omega_0(p)$

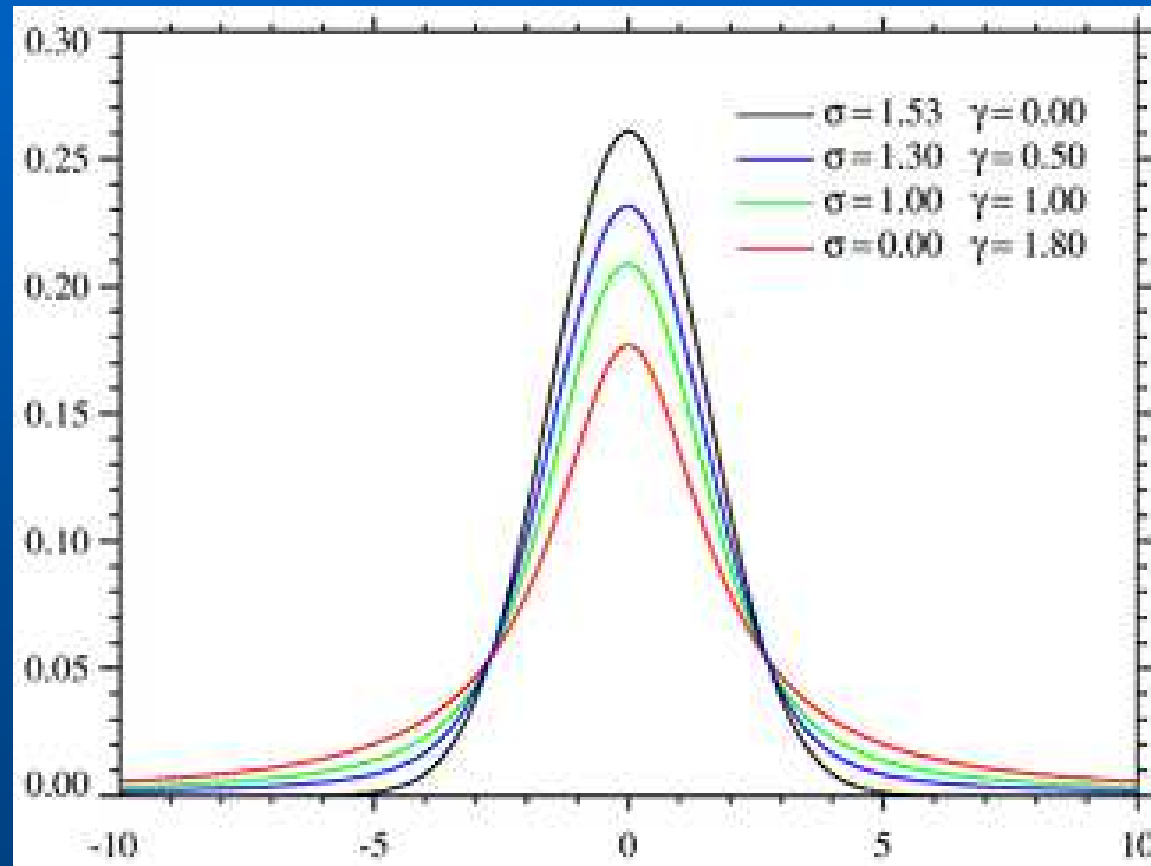
- Kramers-Kronig:

Por causalidad:

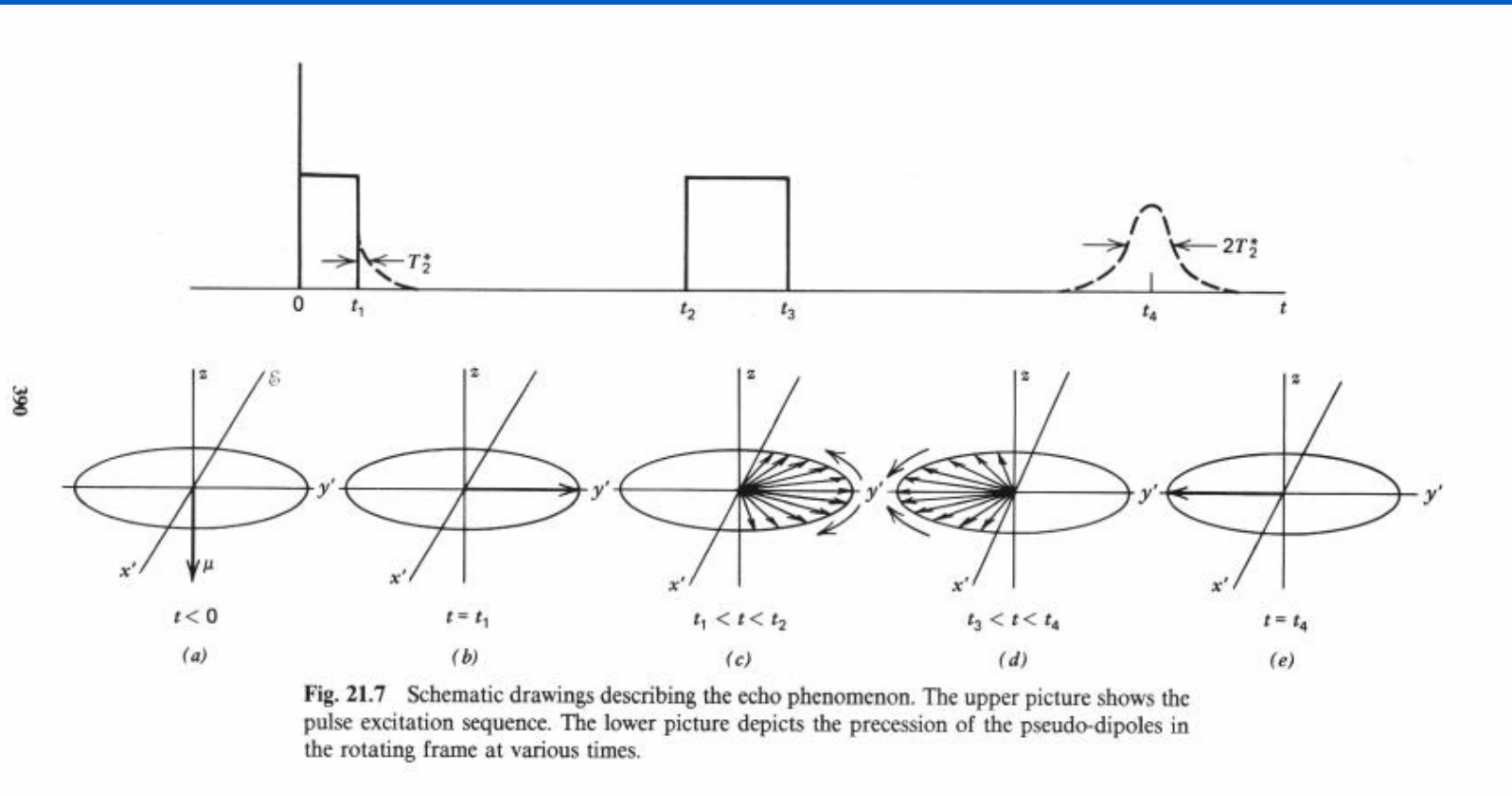
$$P\int_0^{\infty} = \lim_{\varepsilon \rightarrow 0} \left(\int_0^{h\nu - \varepsilon} + \int_{h\nu + \varepsilon}^{\infty} \right)$$

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

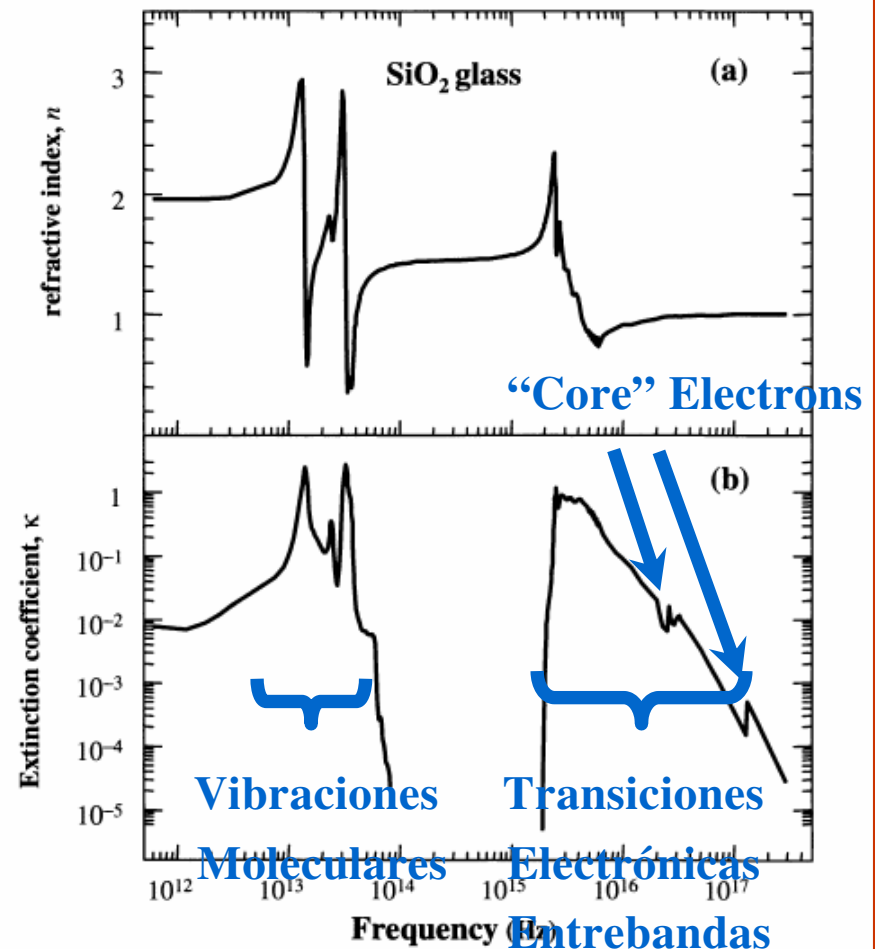
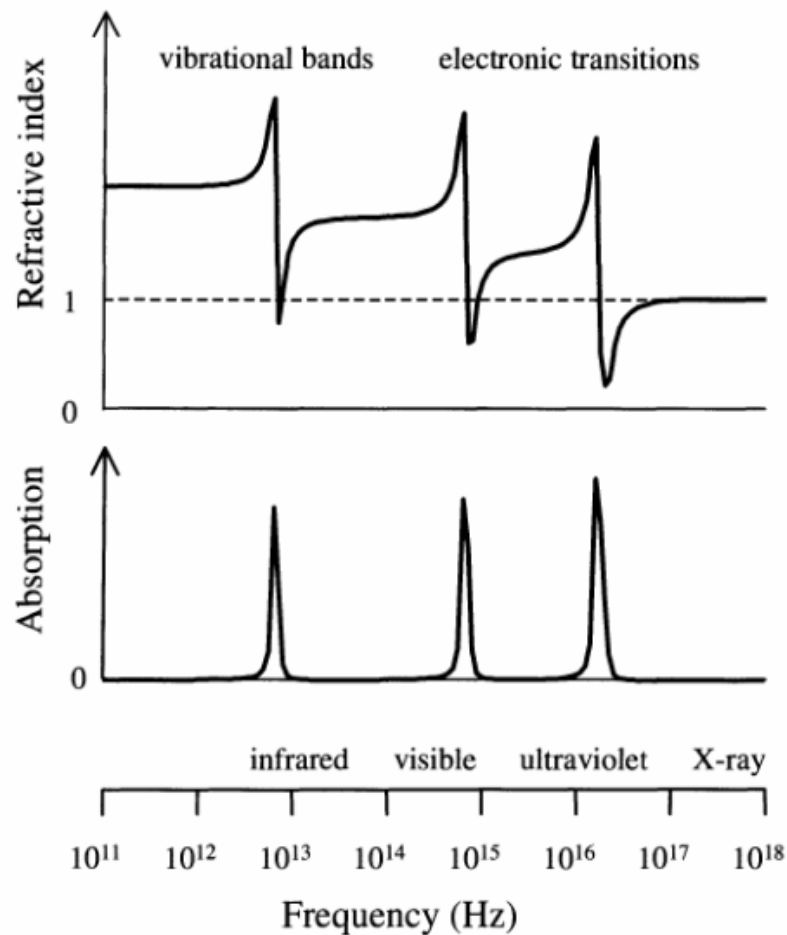
Formas de líneas homogéneas vs. inhomogéneas



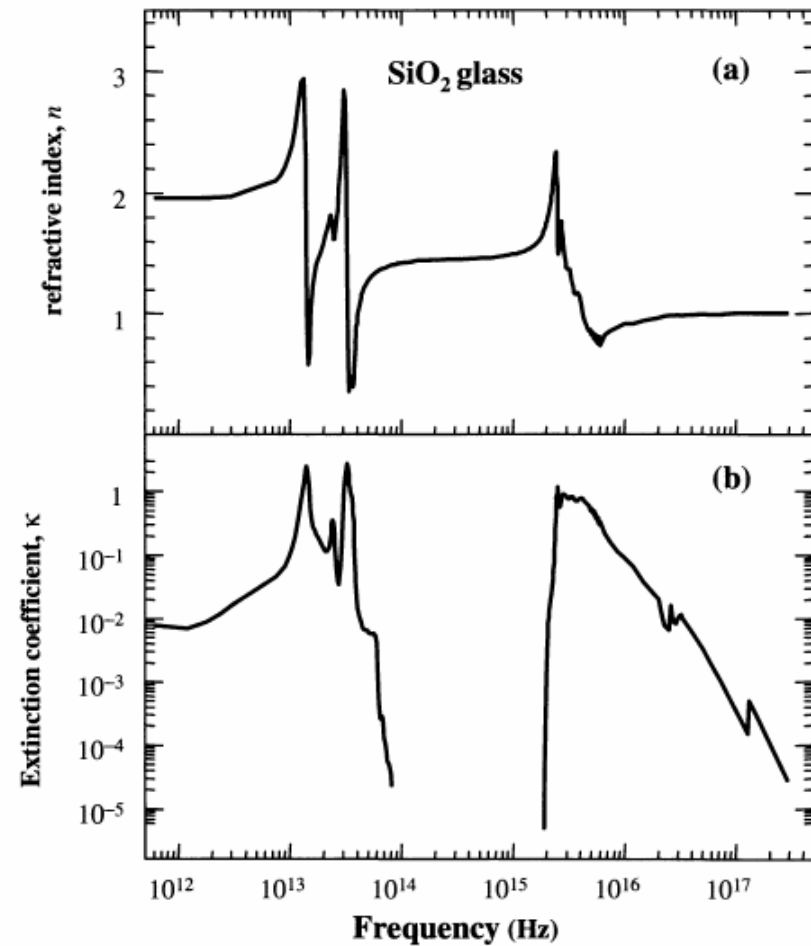
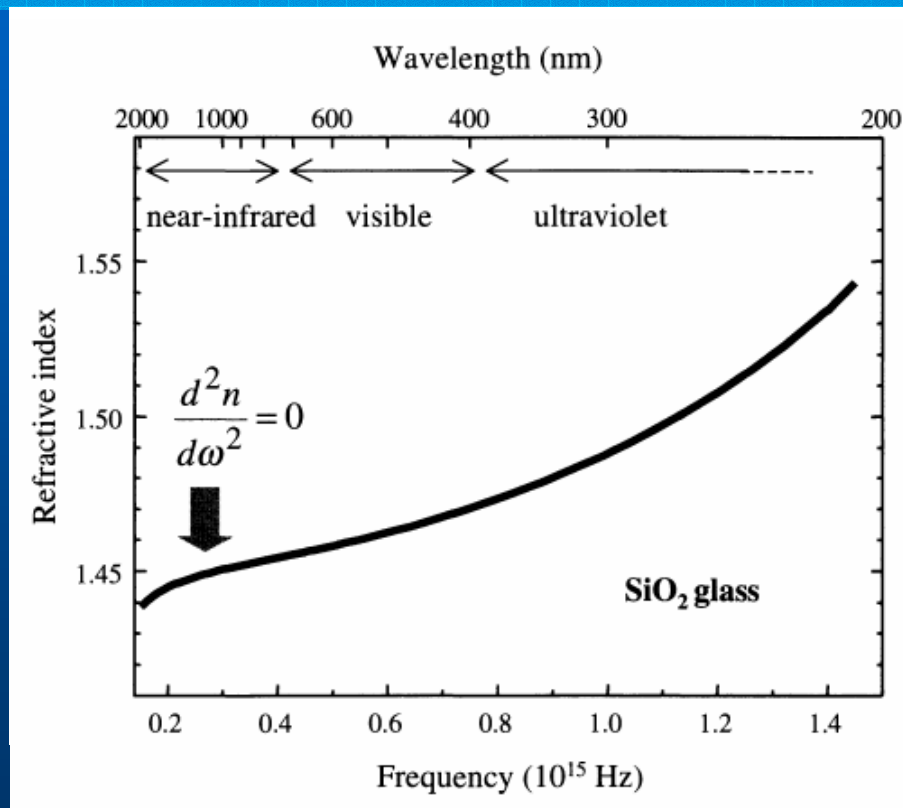
Eco de Fotones



Índice de Refracción y Coeficiente de Extinción



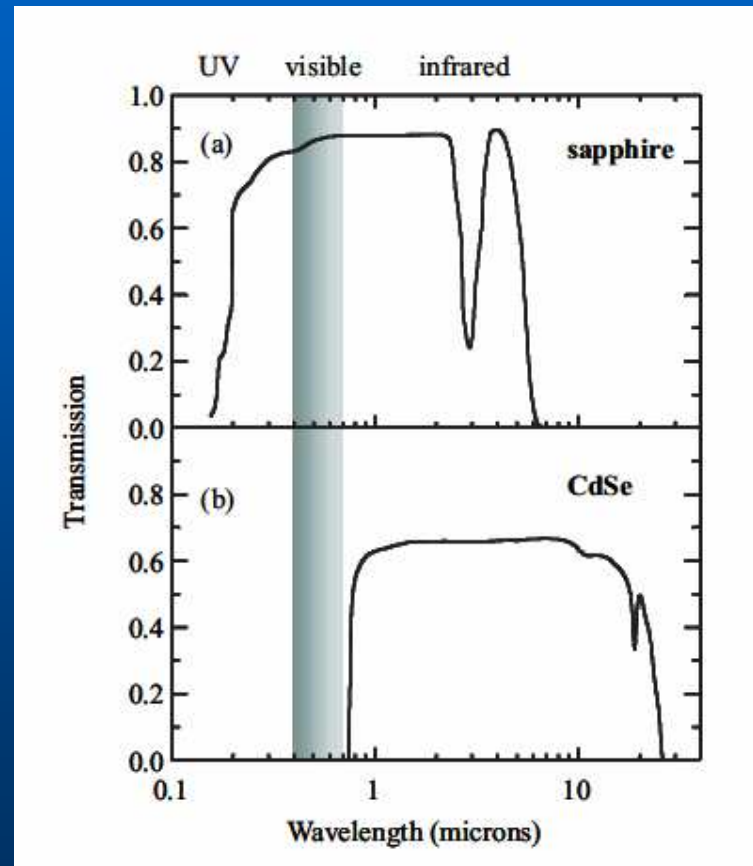
Índice de Refracción y Coeficiente de Extinción



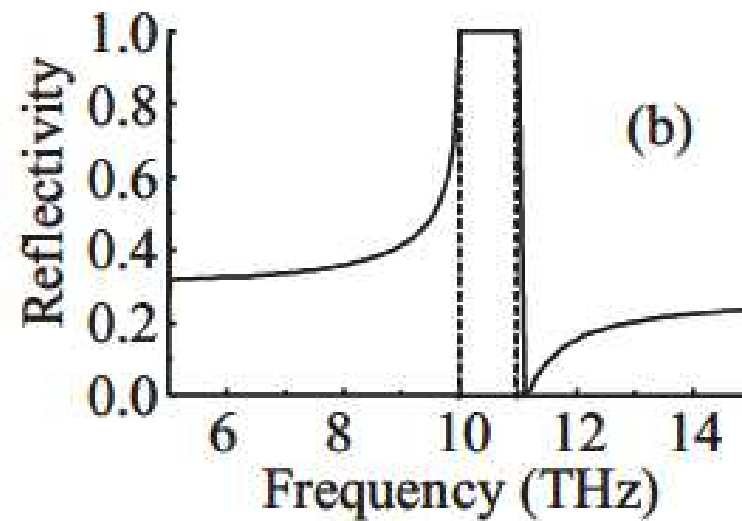
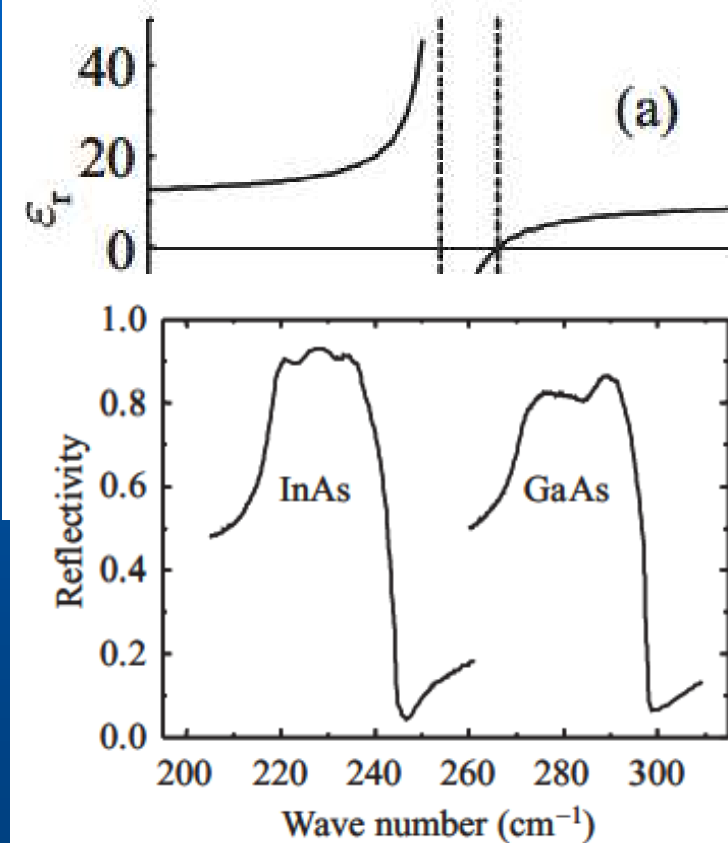
Dispersión de Velocidad de Grupo:

$$\text{GVD}' \equiv \frac{d}{d\omega} \left(\frac{1}{v_g} \right) \approx \frac{\omega}{c} \frac{d^2n}{d\omega^2}$$

Absorción Infrarroja



Banda Retstrahl (rayo residual)



Mezclas

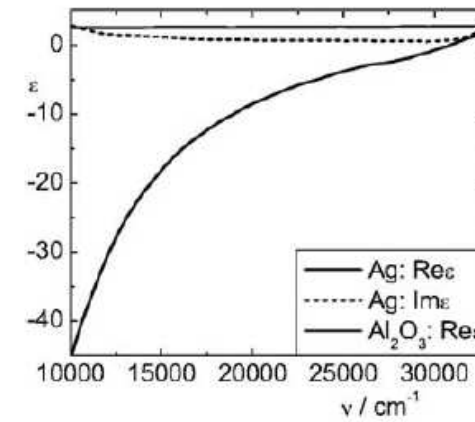
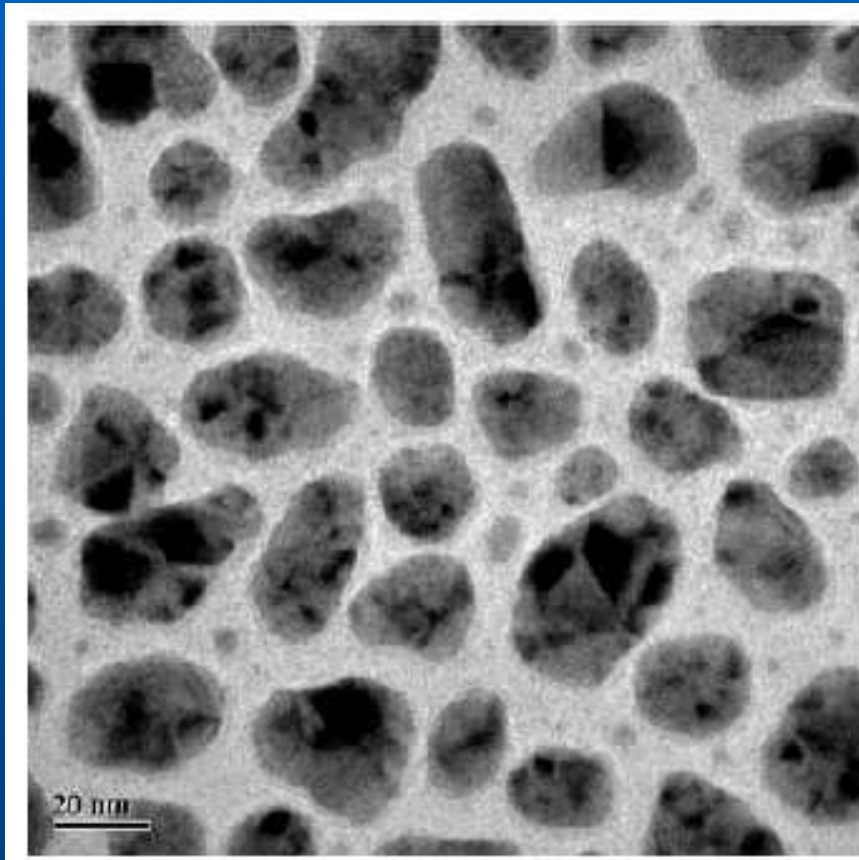


Fig. 4.4. Dielectric functions of Ag and Al₂O₃

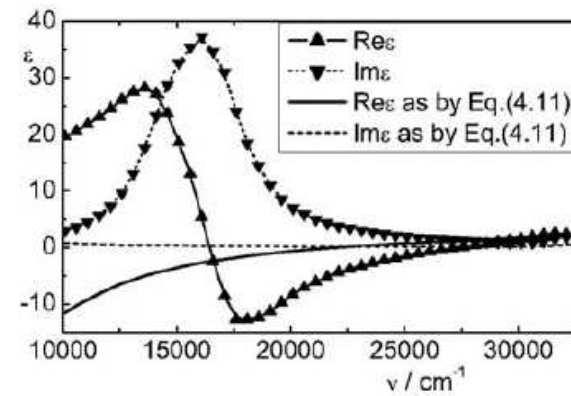
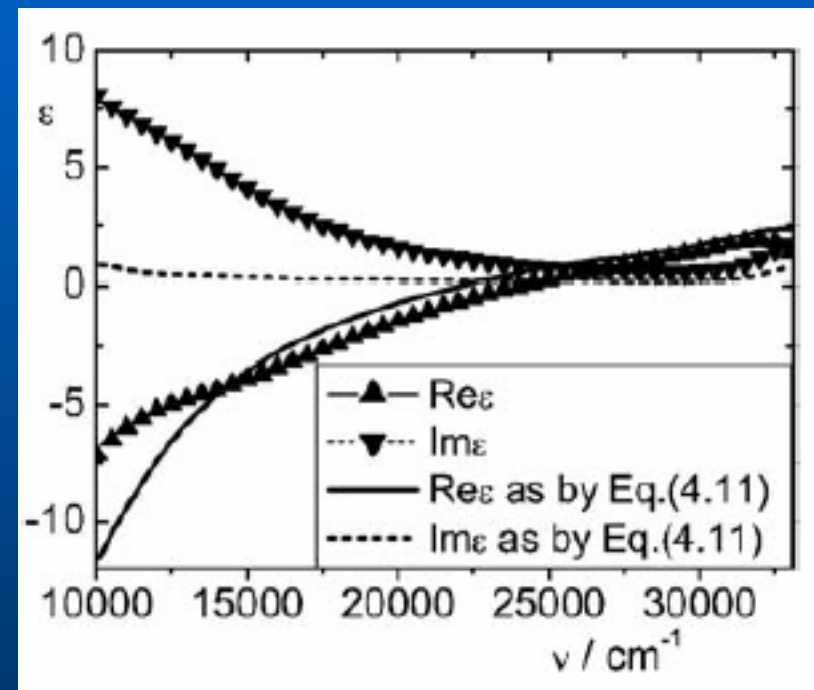
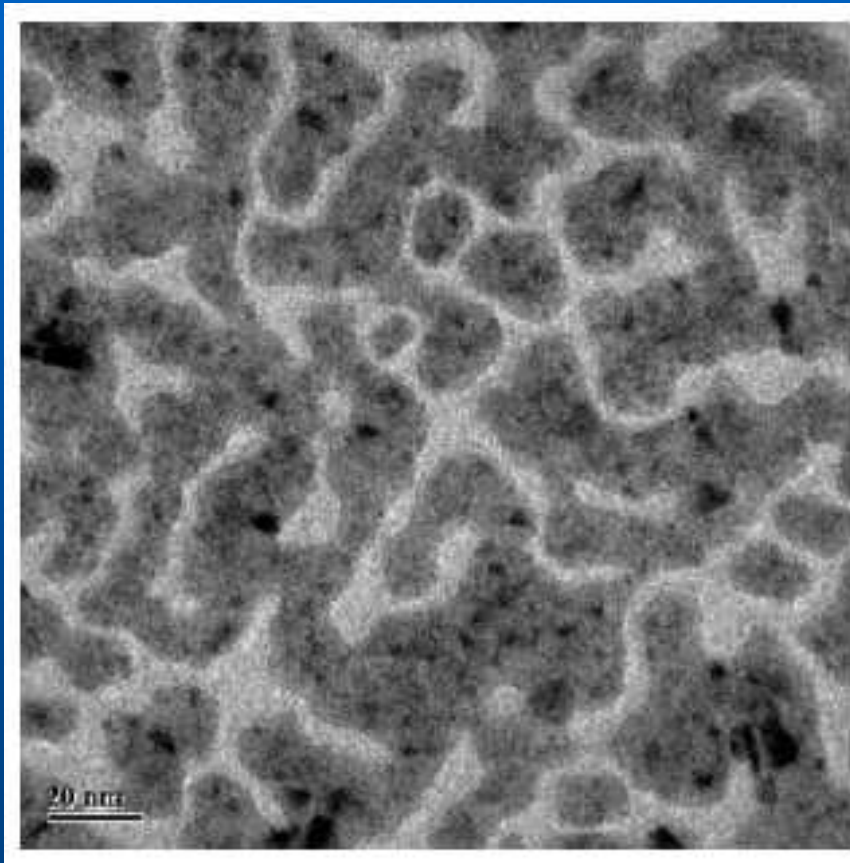
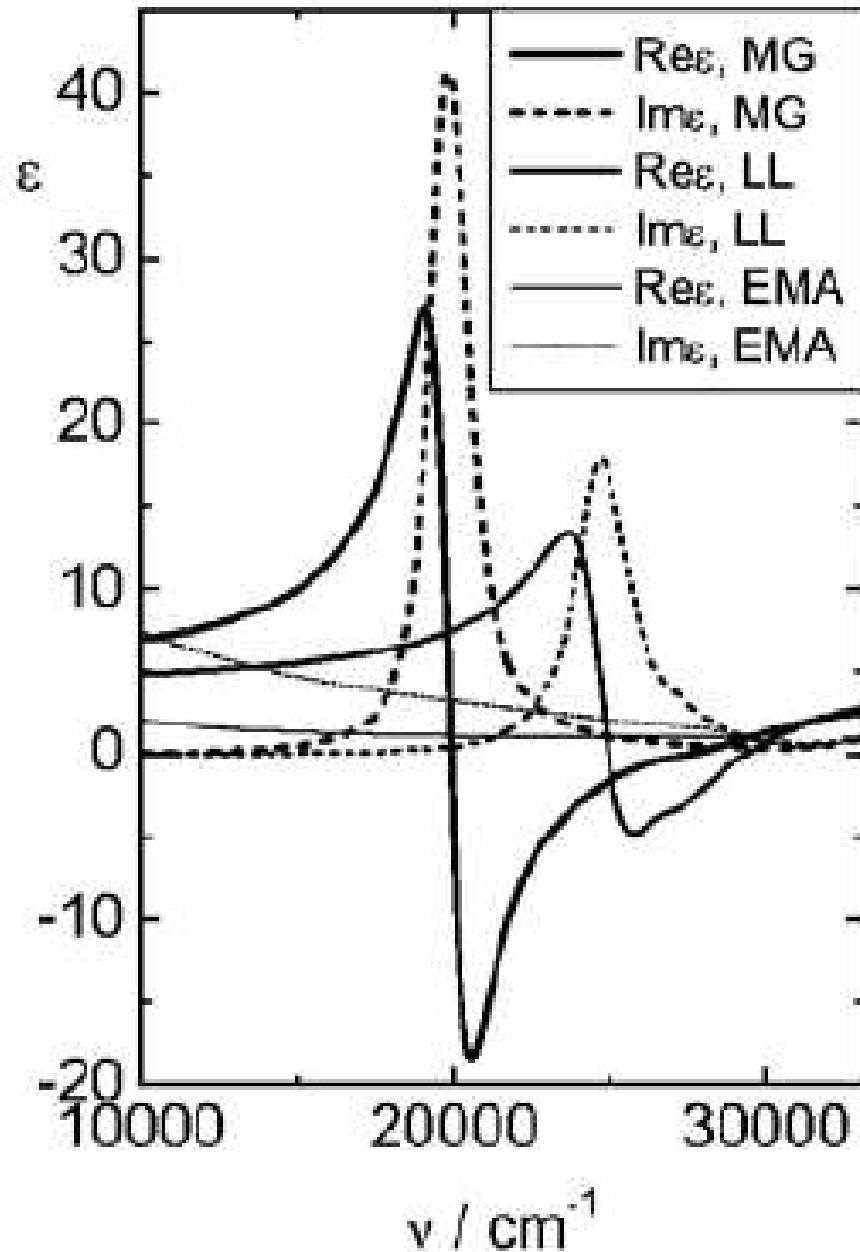


Fig. 4.5. Dielectric function of the composite material

Mezclas

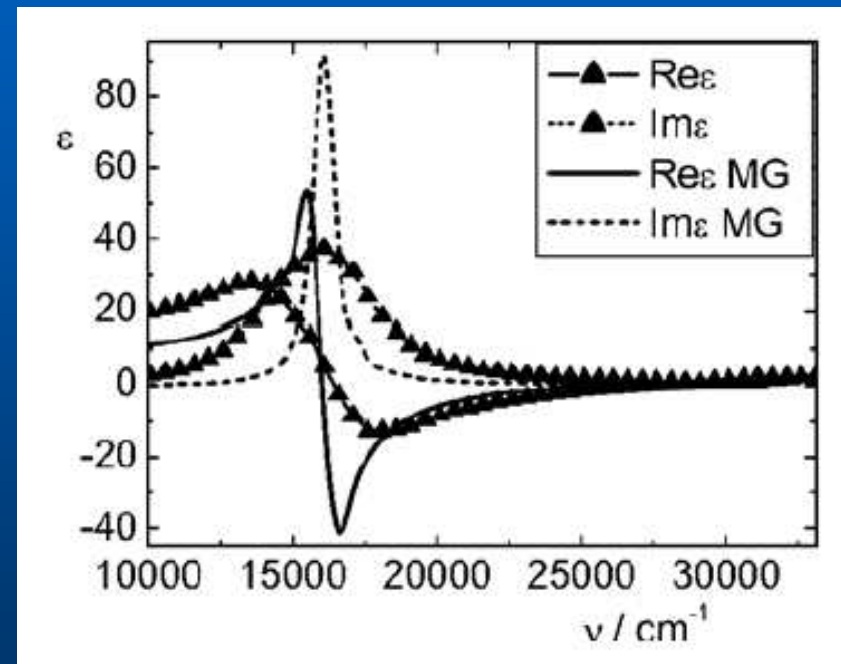
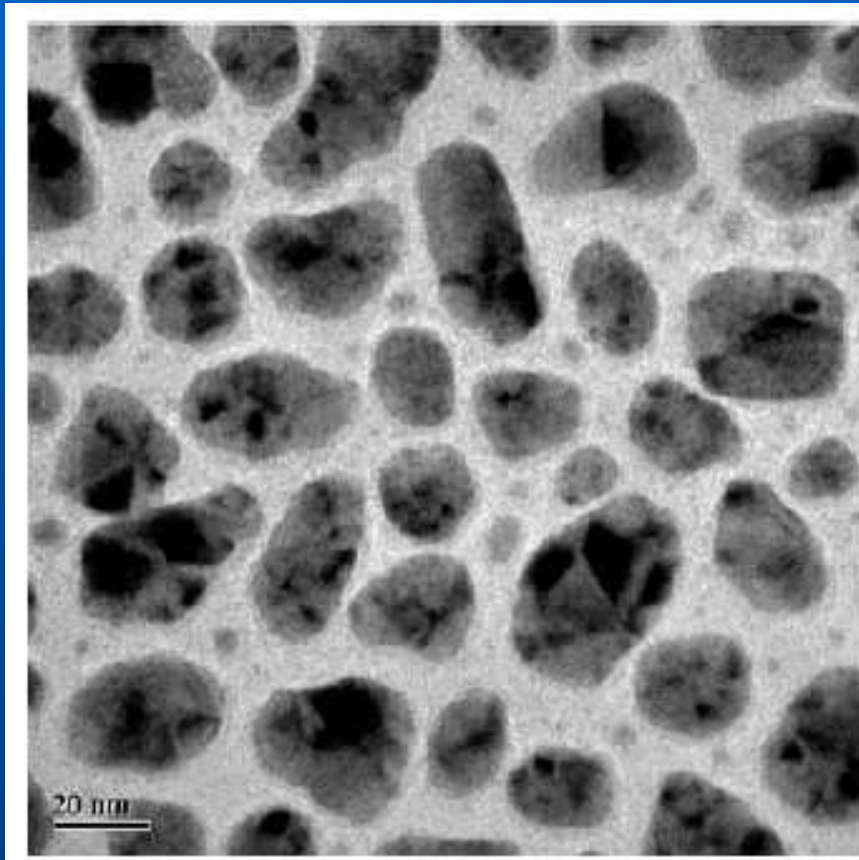


Mezclas



MG: Maxwell–Garnett
LL: Lorentz–Lorenz
EMA: Effective
Medium
Approximation of
Bruggeman

Mezclas



$$L = 0.21$$

Plasmones

➤ Volumétrico:

$$\omega = \omega_p$$

➤ Superficial:

$$\omega = \frac{\omega_p}{\sqrt{2}}$$

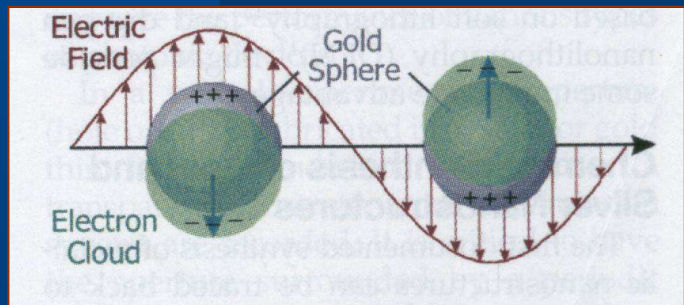
➤ Esférico:

$$\omega = \frac{\omega_p}{\sqrt{3}}$$

Interface Metal –
Dieléctrico (ϵ_m):

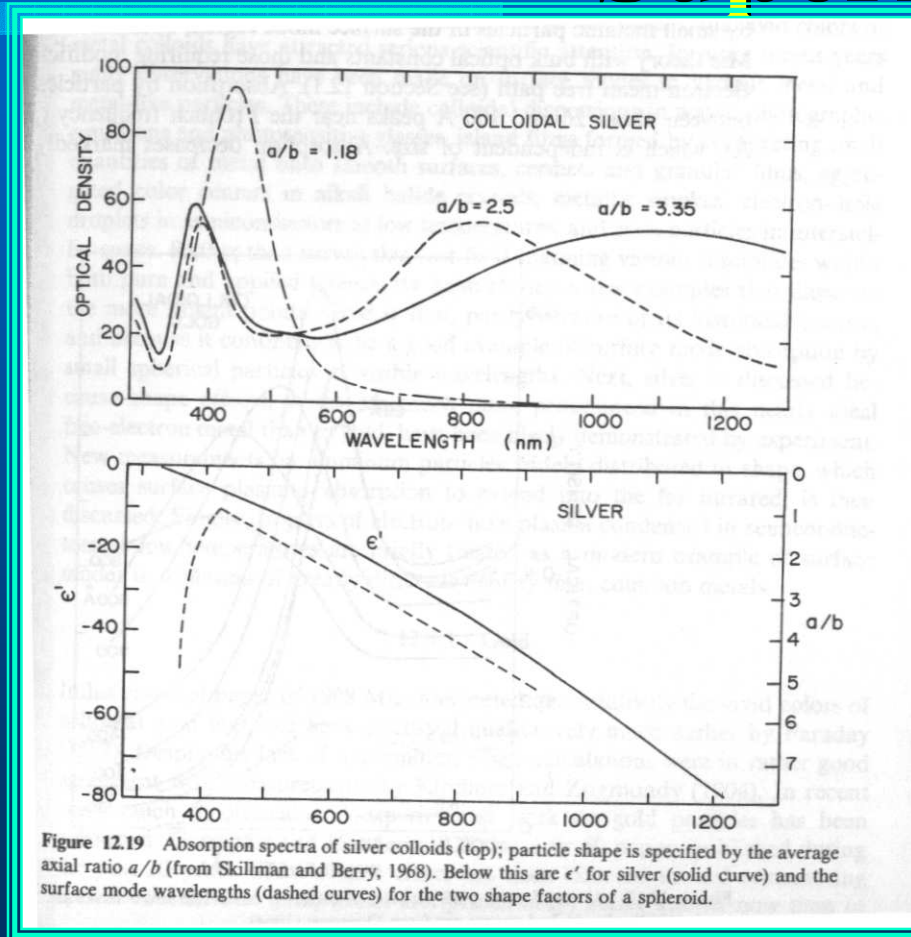
$$\omega = \frac{\omega_p}{\sqrt{1 + \epsilon_m / \epsilon_0}}$$

$$\omega = \frac{\omega_p}{\sqrt{1 + 2\epsilon_m / \epsilon_0}}$$



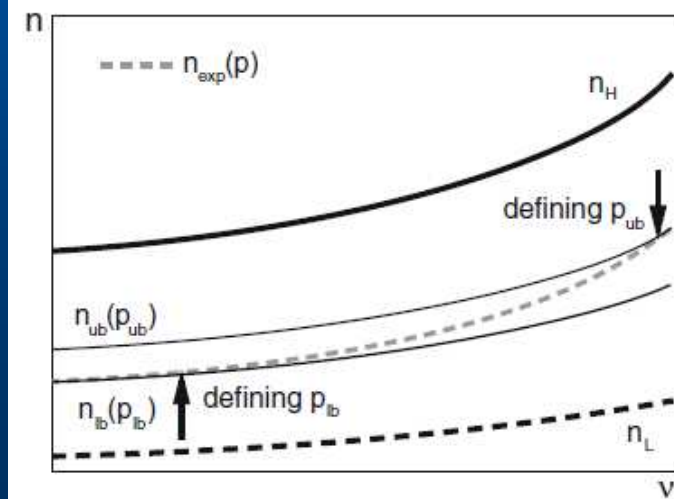
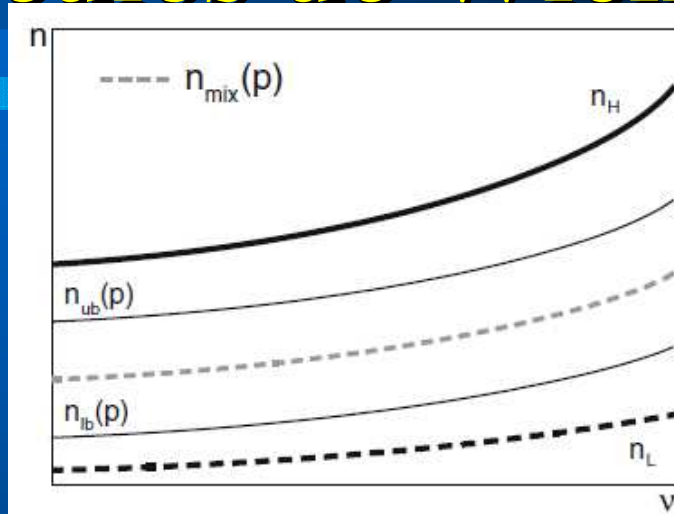
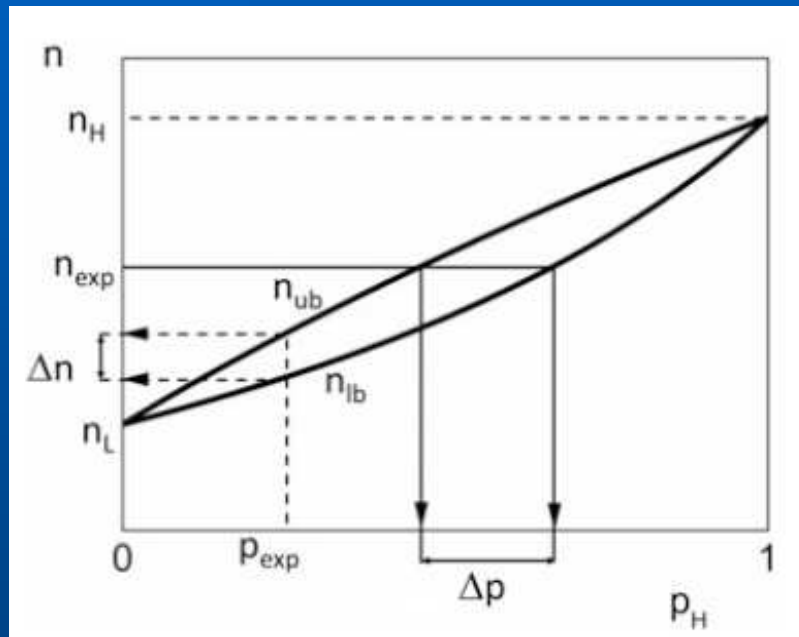
$$R \ll \lambda$$

SPR: Resonancia Plasmones Superficiales

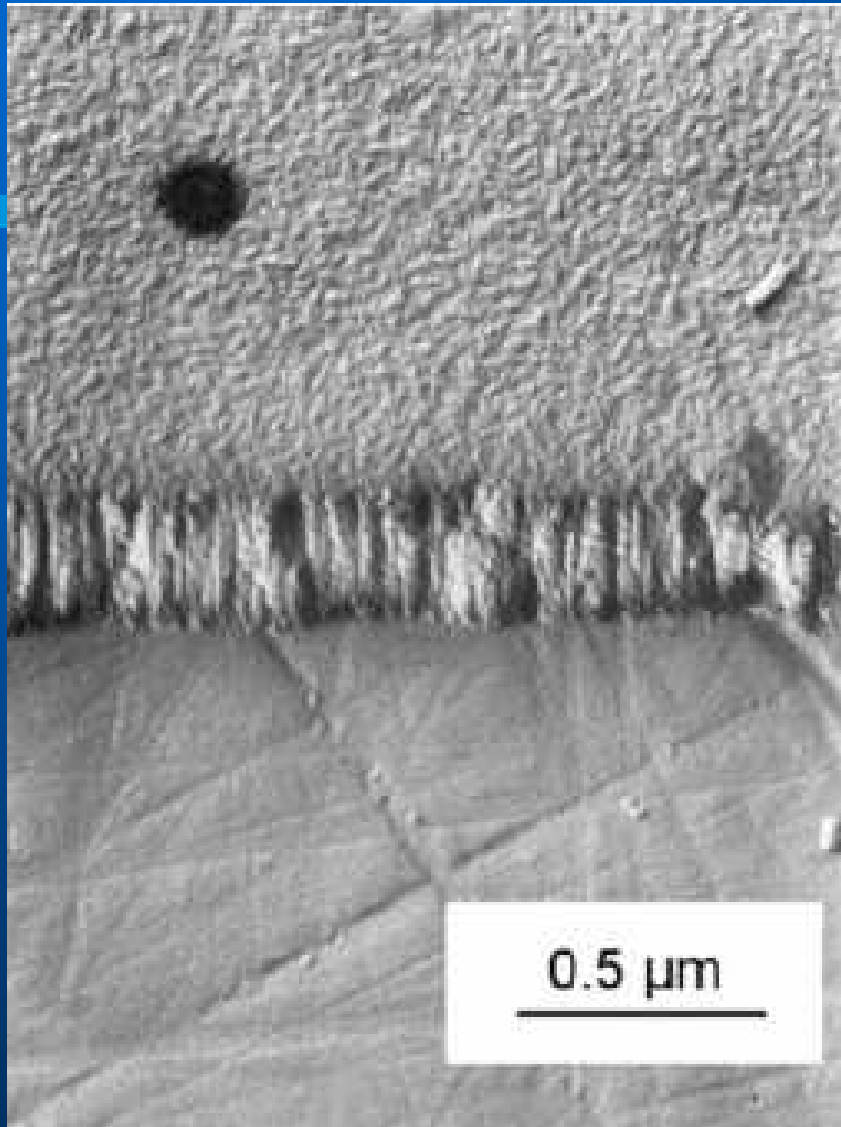


Plata

Vínculos de Wiener



Materiales Porosos



0.5 μm