Óptica No Lineal

Generalidades y algunas aplicaciones

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IB - GCO

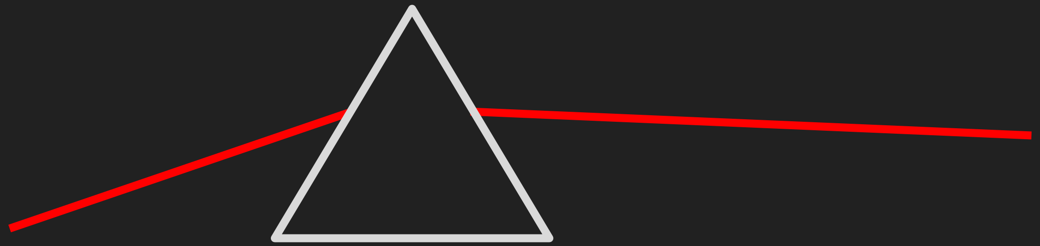
ONL

¿Dónde la encontramos?
¿Qué procesos posibilita?
¿Qué condiciones la favorecen?

Óptica

Estudia el comportamiento y las propiedades de la luz, incluyendo su interacción con la materia.

Óptica Lineal



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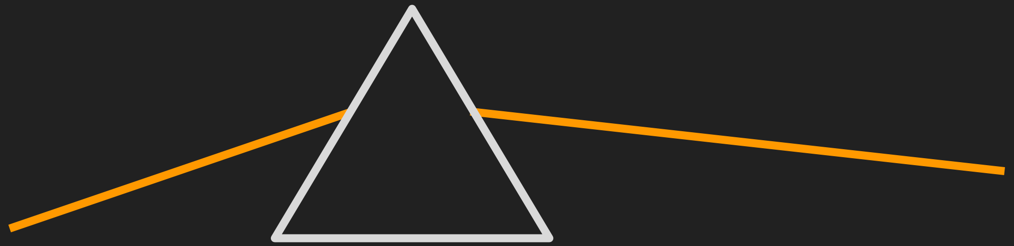

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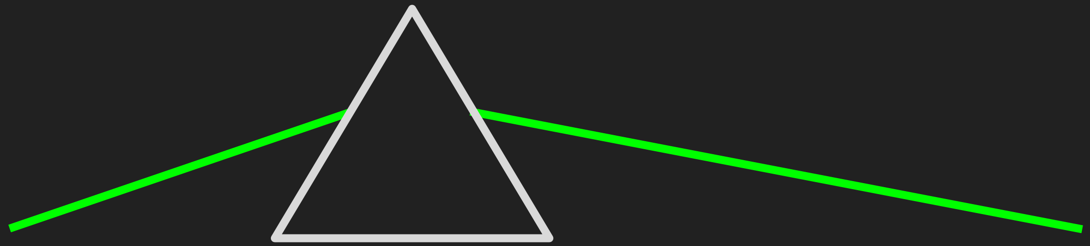

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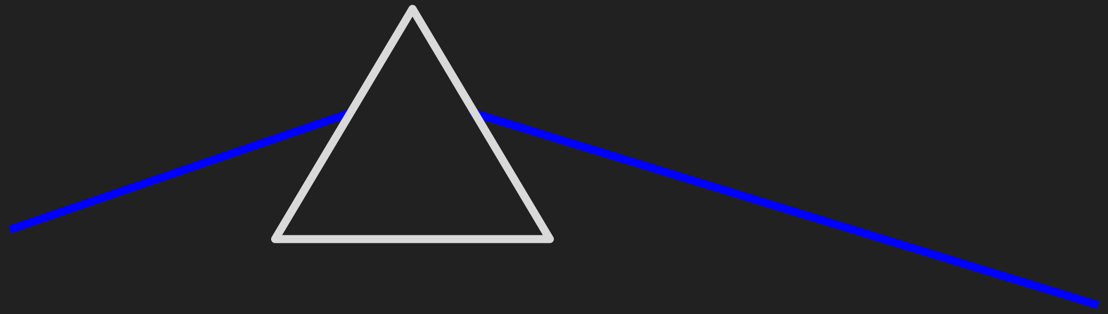

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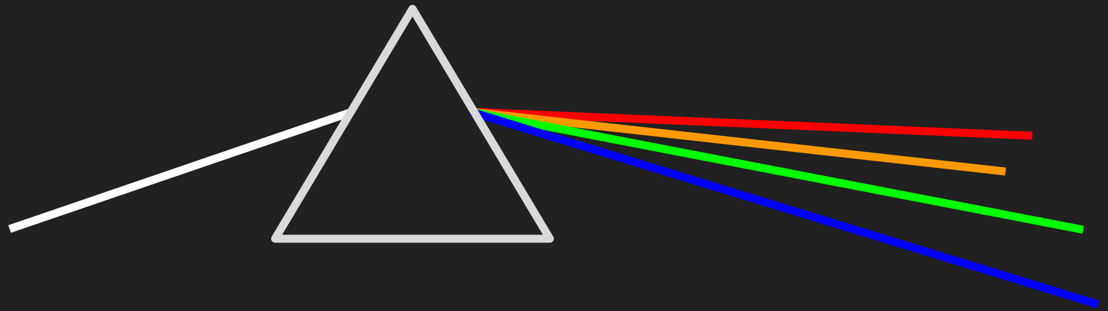

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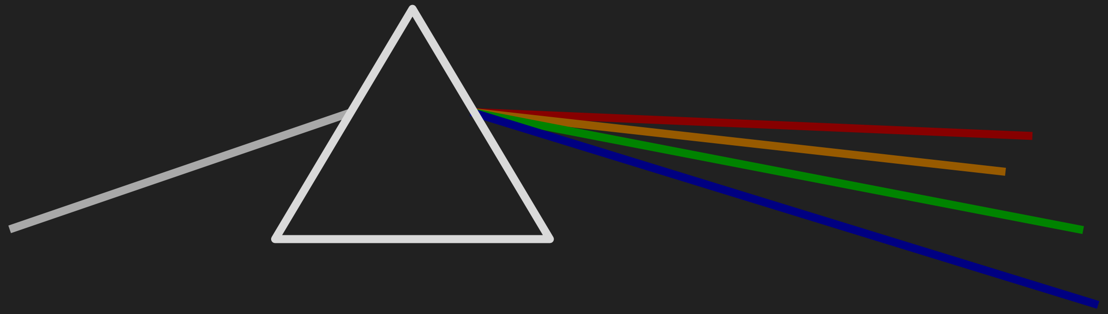

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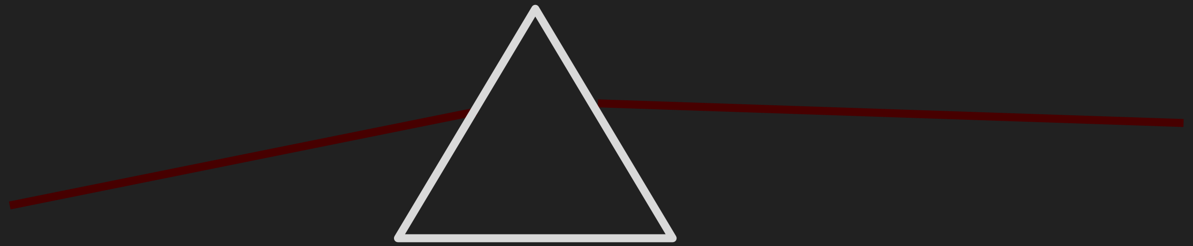

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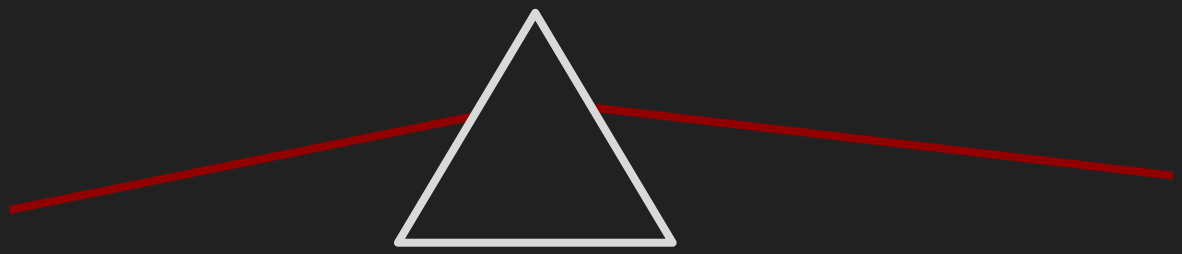

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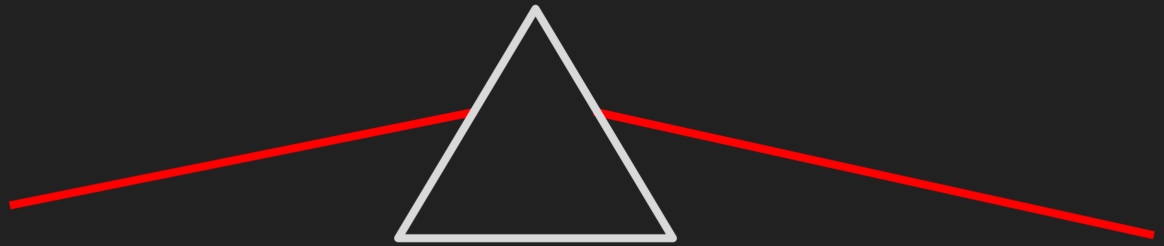
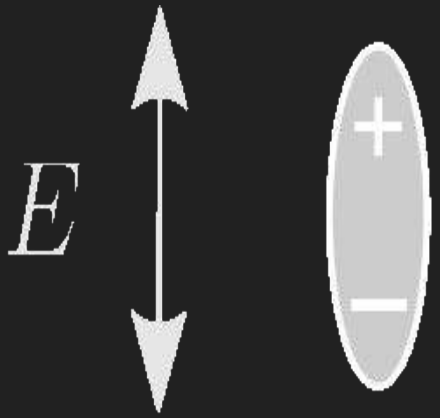


¿Cómo se manifiesta?

$$D = \varepsilon_0 E + P = \varepsilon_0 (1 + \chi^{(1)}) E$$



¿Cómo se manifiesta?

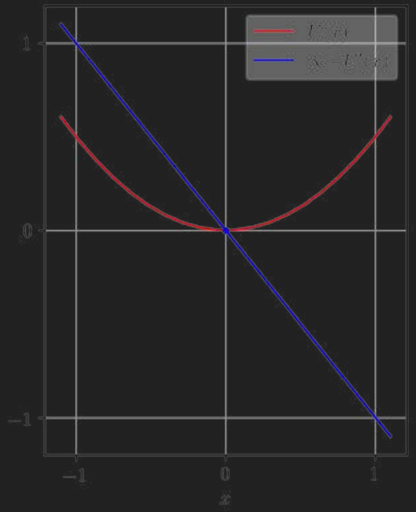
$$P_{\mathrm{L}}$$

$$D = \varepsilon_0 E + \boxed{\varepsilon_0(\chi^{(1)} E +}$$

$$\boxed{+\chi^{(2)} E^2 + \chi^{(3)} E^3 + \ldots)}$$

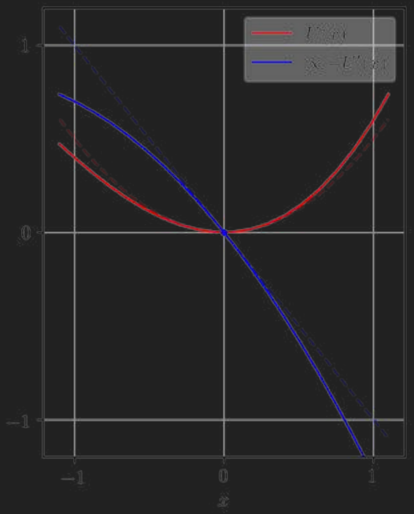
$$P_{\mathrm{NL}}$$

Modelo simple



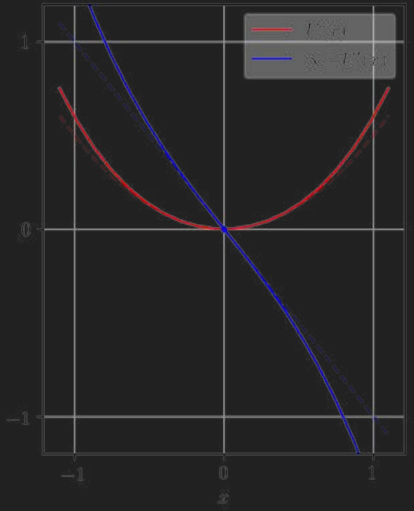
$$P = \varepsilon_0 \chi^{(1)} E$$

Consideraciones de simetría



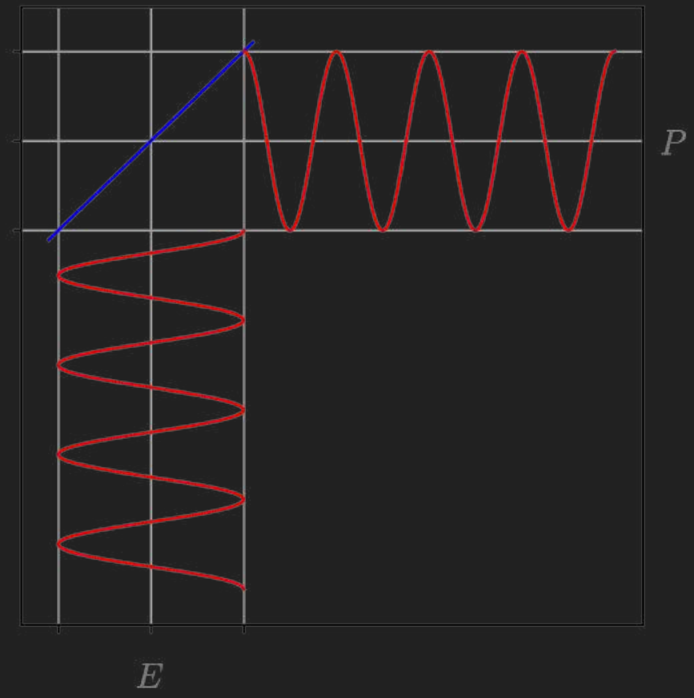
$$P = \varepsilon_0(\chi^{(1)}E + \chi^{(2)}E^2)$$

Consideraciones de simetría



$$P = \varepsilon_0(\chi^{(1)}E + \chi^{(3)}E^3)$$

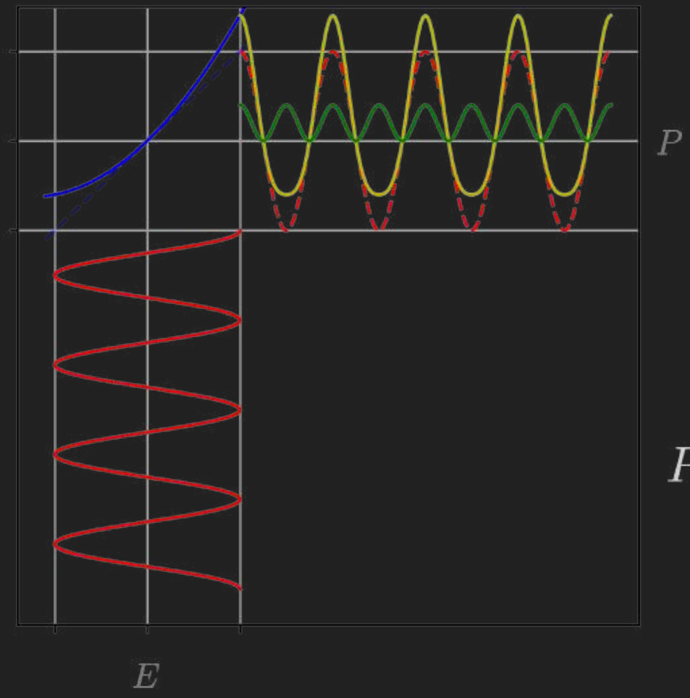
P lineal



$$E = A\cos(\omega t)$$

$$P = \varepsilon_0 \chi^{(1)} A\cos(\omega t)$$

P no lineal



$$E = A\cos(\omega t)$$

$$P = \varepsilon_0(\chi^{(1)}E + \chi^{(2)}E^2)$$

$$P = \varepsilon_0\left(\chi^{(1)}A\cos(\omega t) + \frac{1}{2}\chi^{(2)}A^2[1+\cos(2\omega t)]\right)$$

¿Cuándo?

$$\chi^{(1)} \sim 1$$

$$\chi^{(2)} \sim \frac{1}{E_{\text{at}}}$$

$$E_{\text{at}} = \frac{1}{4\pi\varepsilon_0}\frac{e}{r_{\text{Bohr}}^2}$$

$$\boxed{\chi^{(2)} \sim 10^{-12}\ \text{m/V}}$$

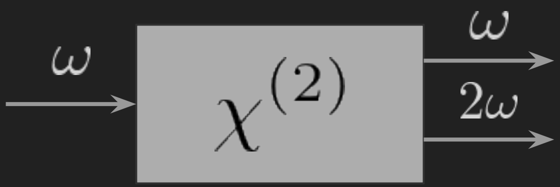
+ sobre la susceptibilidad

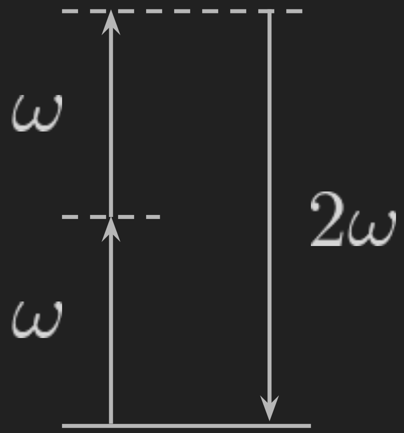
- En general son de carácter tensorial.
- En general, dependientes de la frecuencia.

$$\chi^{(2)}_{ijk}(\omega_i, \omega_j, \omega_k)$$

Algunos procesos de la ONL

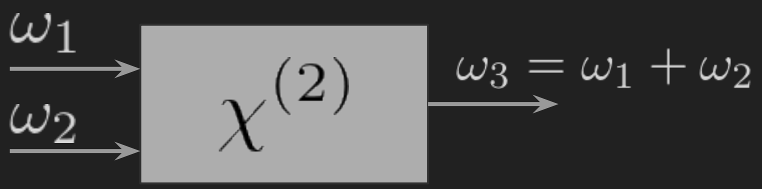
SHG ("Second Harmonic Generation")

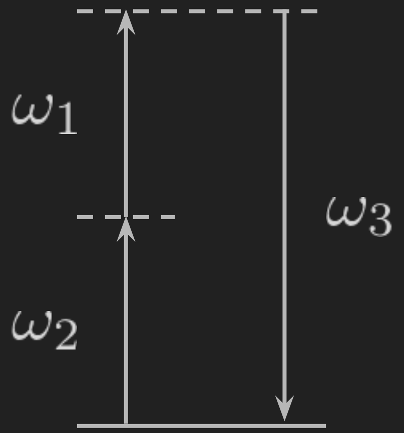




Algunos procesos de la ONL

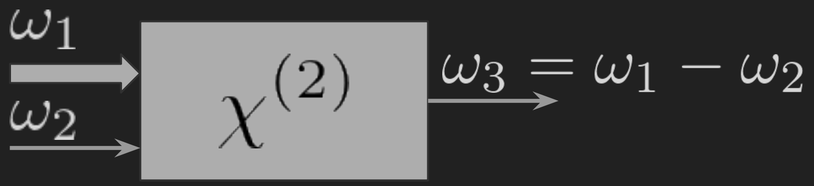
SFG (“Sum Frequency Generation”)

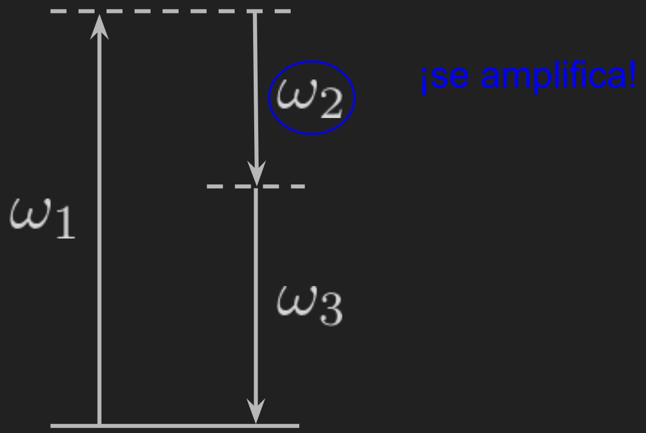




Algunos procesos de la ONL

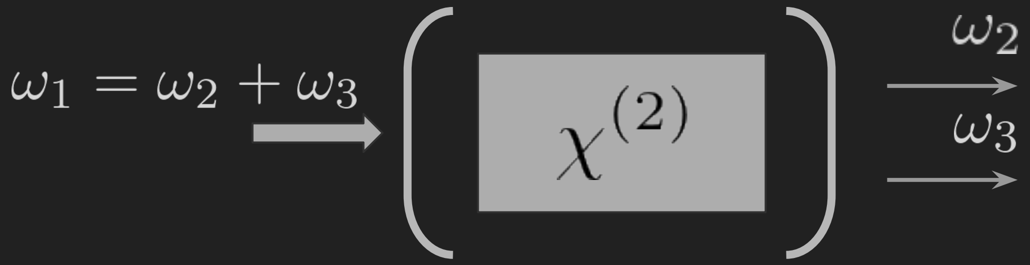
DFG (“Difference Frequency Generation”)





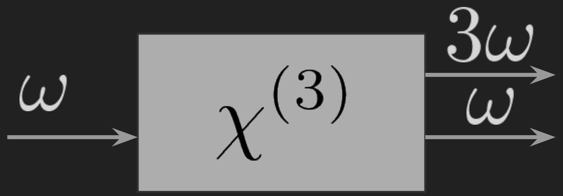
Algunos procesos de la ONL

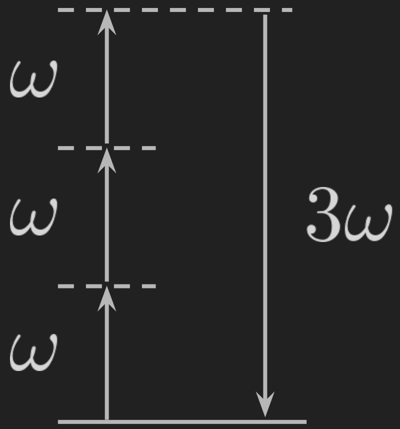
OPO ("Optical Parametric Oscillator")



Algunos procesos de la ONL

THG (“Third Harmonic Generation”)

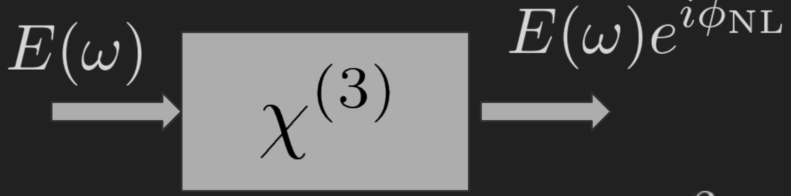




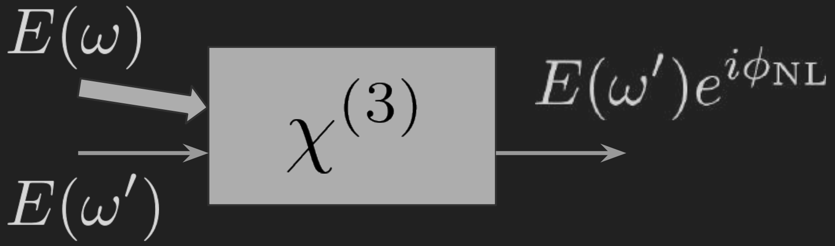
Algunos procesos de la ONL

SPM/XPM (“Self/Cross Phase Modulation”)

$$n = n_0 + n_2 I$$



$$n_2 = \frac{3}{4n_0^2\varepsilon_0 c}\chi^{(3)}$$



Phase Matching

$$\nabla^2 \mathbf{E} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{E}}{\partial t^2} + \mu_0 \frac{\partial^2 \mathbf{P}}{\partial t^2}$$

$$\nabla^2 \mathbf{E} - \frac{n^2}{c^2} \frac{\partial^2 \mathbf{E}}{\partial t^2} = \mu_0 \frac{\partial^2 \mathbf{P}_{\mathrm{NL}}}{\partial t^2} \qquad n = \sqrt{(1 + \chi^{(1)})}$$

Phase Matching

$$E_1 = A_1 \cos(k_1 z - \omega t), \quad k_1 = n_1 \omega / c$$

$$P_2 = \frac{1}{2} \varepsilon_0 \chi^{(2)} A_1^2 \cos(2k_1 z - 2\omega t)$$

$$E_2 = A_2 \cos(k_2 z - 2\omega t), \quad k_2 = n_2 2\omega / c$$

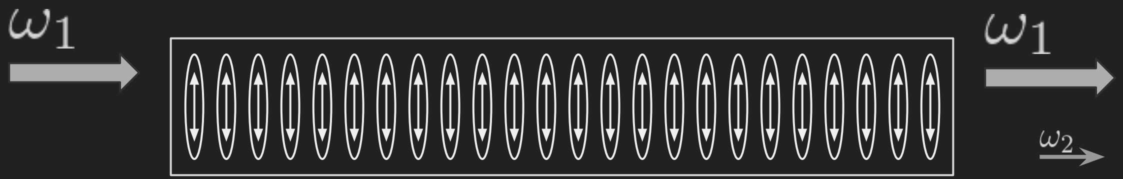
Phase Matching

$$2k_1 = k_2 \longrightarrow n_1 = n_2$$

$$L_c = \frac{\pi}{|\Delta k|} = \frac{\lambda}{4|n_1 - n_2|}$$

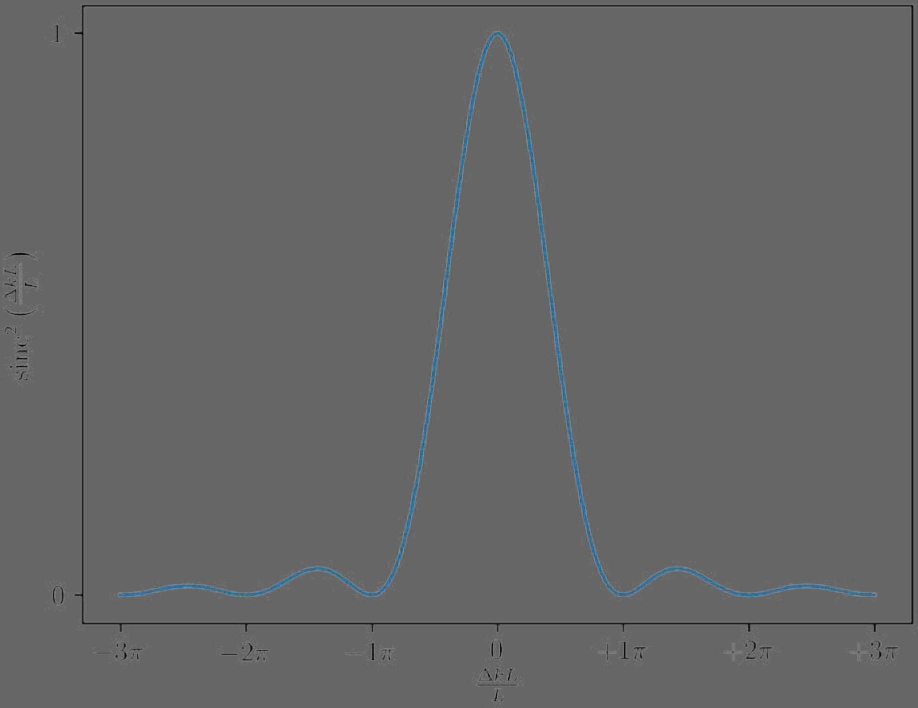
Phase Matching

Ejemplo: *SHG* aproximación de baja *depleción*

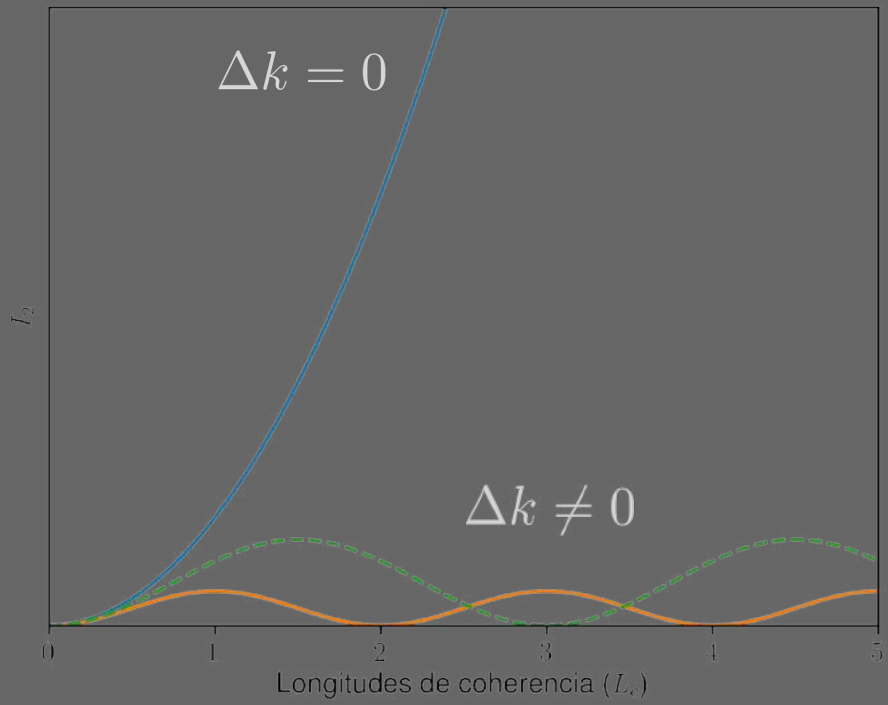


$$I_2(L) = \frac{(\omega_2 \chi^{\mathrm{SHG}} I_1)^2}{8\varepsilon_0 c^3 n_2 n_1^2} L^2 \mathrm{sinc}^2\left(\frac{\Delta k L}{2}\right)$$

Phase Matching



Phase Matching



Phase Matching

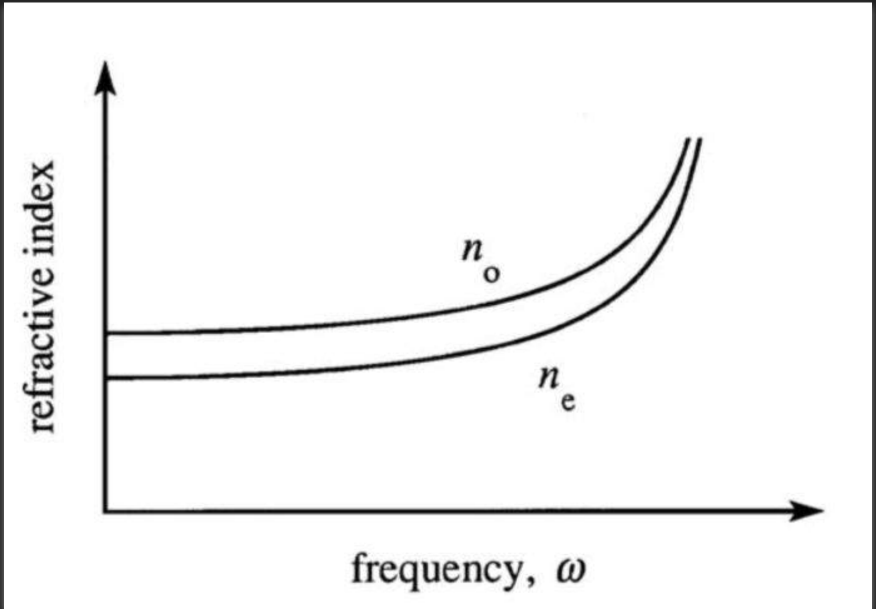
Problema:

$$n(\omega_1) < n(\omega_2) \text{ para } \omega_1 < \omega_2 \quad \text{(disp. normal)}$$

Algunas soluciones posibles:

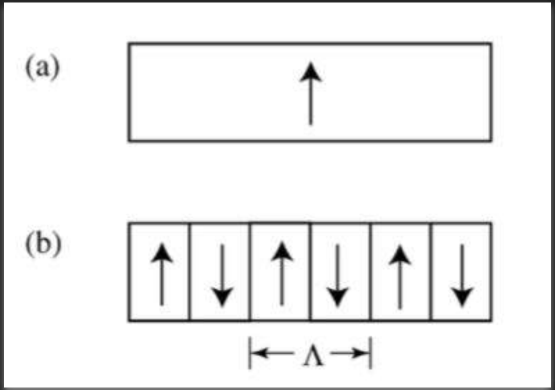
- BPM (*Birefringent Phase Matching*)
- QPM (Quasi-phase Matching)

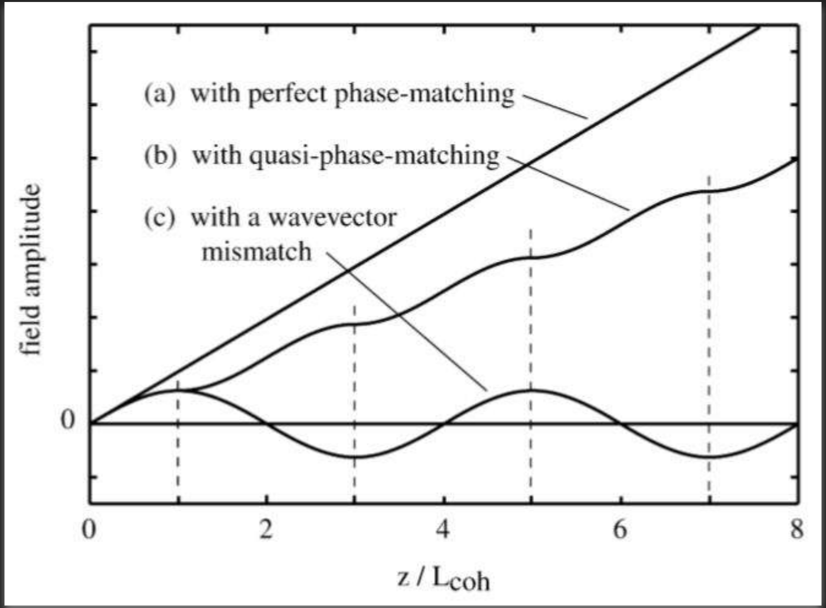
Phase Matching: BPM



Fuente: R.W. Boyd, *Nonlinear Optics* (3ra Ed.)

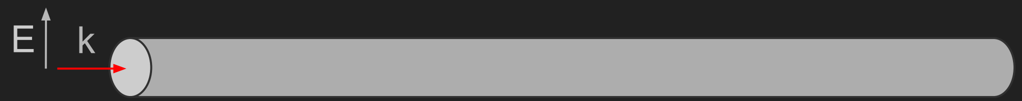
Phase Matching: QPM





Fuente: R.W. Boyd, *Nonlinear Optics* (3ra Ed.)

ONL en Fibras



$$\mathbf{E}(\mathbf{r},t) = \frac{1}{2}\mathbf{x}[E(\mathbf{r},t)e^{-i\omega_0 t} + c.c.]$$

$$\tilde{E}(x,y,z,t) = F(x,y,\omega)\boxed{\tilde{A}(z,\omega-\omega_0)}e^{i\beta_0 z}$$

ONL en fibras: Generalized Nonlinear Schrödinger Equation

Lineal — No Lineal

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A + i\left(\sum_{k\geq 2}\frac{i^k}{k!}\beta_k\frac{\partial^k A}{\partial T^k} + \gamma\left(1 + i\tau_{\text{shock}}\frac{\partial}{\partial T}\right)\cdot\left[(R * |A|^2)A\right]\right)$$

$$\frac{\partial \tilde{A}}{\partial z} = i\left(\beta(\omega)\tilde{A} + \gamma(\omega)\mathcal{F}\{|A|^2 A\}\right)$$

ONL en fibras: solo dispersión $(\gamma = 0)$

$$\frac{\partial \tilde{A}}{\partial z} = i\beta(\omega)\tilde{A} \quad \Longrightarrow \quad \tilde{A}(z,\omega) = \tilde{A}(0,\omega)e^{i\beta(\omega)z}$$

$$|\tilde{A}(z,\omega)| = |\tilde{A}(0,\omega)|$$

ONL en fibras: solo NL $(\beta(\omega) = 0)$

$$\frac{\partial A}{\partial z} = i\gamma_0 |A|^2 A$$

$$A(z,T) = A(0,T)e^{i\phi_{\mathrm{NL}}(z,T)}$$

$$\phi_{\mathrm{NL}}(z,T) = \gamma_0 |A(0,T)|^2 z$$

$$|A(z,T)| = |A(0,T)|$$

ONL en fibras

- Solitones Ópticos
- Inestabilidad Modulacional
- Supercontínuo

¡Muchas gracias!
¿Preguntas?