NONLINEAR OPTICS COURSE

LECTURE 1: INTRODUCTION

$\underset{\mathcal{E}(t)}{\rightsquigarrow}$ $\boxed{\text{Medium}}$ $\rightsquigarrow$ $\vec{P}(t)$: Macroscopic Polarization

↳ Response of the material to the $\mathcal{E}$-field excitation

LINEAR REGIME : $\vec{P}(t) = \chi^{(1)}\vec{\mathcal{E}}(t)$

Assuming a dielectric material.

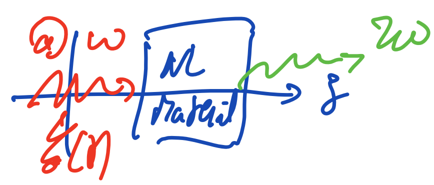
NONLINEAR REGIME → The response of the material is no longer LINEAR

$$\vec{P}(t) = \underline{\underline{\chi}}^{(NL)}(\underline{\underline{\vec{\mathcal{E}}}}) = \chi^{(1)}\vec{\mathcal{E}}(t) + \underbrace{\chi^{(2)}\vec{\mathcal{E}}\vec{\mathcal{E}}}_{\text{2nd order NL response}} + \underbrace{\chi^{(3)}\vec{\mathcal{E}}\vec{\mathcal{E}}\vec{\mathcal{E}}}_{\text{3rd order NL response}} + \dots$$

ILLUSTRATION (1)

Monochromatic optical field incident on a 2nd order NL material

$$\mathcal{E}(t) = A\cos(\omega t - kz)$$



⇒ 2nd order NL response

$$P^{(2)}(t) = \chi^{(2)}A^2\cos^2(\omega t - kz)$$

$$\boxed{P^{(2)}(t) = \frac{\chi^{(2)}}{2}A^2\left[\underbrace{1}_{\text{NL Response @ }\omega=0} + \underbrace{\cos(2\omega t - 2kz)}_{@\,2\omega}\right]}$$

OPTICAL RECTIFICATION

↳ 2nd ORIGIN of Harmonic Generation effect

ILLUSTRATION (2)

$\omega_1, \omega_2 \rightsquigarrow \boxed{\text{2nd order NL mat}} \rightsquigarrow P^{(2)}(t) = \chi^{(2)} \mathcal{E}\mathcal{E}$

$$\text{eR}_{C} = \mathcal{E}(t) = A_1 \cos(\omega_1 t + \varphi_1) + A_2 \cos(\omega_2 t + \varphi_2)$$

$$\text{Re}\ \mathcal{E}(t) = \underbrace{E(\omega_1)}_{} e^{-i\omega_1 t} + \underbrace{E(\omega_2)}_{} e^{-i\omega_2 t} + cc$$

complex amplitude

$$P^{(2)}(t) = \chi^{(2)} \mathcal{E}^2(t)$$

$$\text{Re}\ P^{(2)}(t) = P(0) e^{i(0)t} + P(2\omega_1) e^{-2i\omega_1 t} + P(2\omega_2) e^{-2i\omega_2 t} + P(\omega_1+\omega_2) e^{-i(\omega_1+\omega_2)t} + P(\omega_1-\omega_2) e^{-i(\omega_1-\omega_2)t} + cc$$

with

$$P(0) = 2\chi^{(2)} \left[E(\omega_1) E(-\omega_1) + E(\omega_2) E(-\omega_2) \right]$$

with $E(-\omega) = E^*(\omega) =$ complex conjugation

$$P(2\omega_{1,2}) = \chi^{(2)} E(\omega_{1,2}) E(\omega_{1,2})$$

$$P(\omega_1 \pm \omega_2) = 2\chi^{(2)} E(\omega_1) E(\pm\omega_2)$$

CONCLUSIONS

↳ we understand that the interaction between 2 waves @ ω_1 and ω_2 through a 2nd order NL material can lead to the generation of waves:

@ $\omega = 0$ $\Rightarrow$ generation of a STATIC field in the material.

@ $2\omega_1$ and $2\omega_2$ $\Rightarrow$ SHG

@ $\omega_3 = \omega_1 + \omega_2$ $\Rightarrow$ SUM FREQ. Generation

@ $\omega_3 = \omega_1 - \omega_2$, $\omega_2 - \omega_1$ $\Rightarrow$ DIFFERENCE freq. Generation.

↳ The magnitude of the NL response is proportional to

- $\chi^{(2)}$: NL response of the material
- $E(\omega_1)E(\omega_2)$

$\Rightarrow$ NONLINEAR EFFECTS are governed by the magnitudes of the ELECTRIC FIELDS

Intensity $\propto |E|^2$

$\boxed{\text{NL OPTICS is driven by FIELD INTENSITY}}$