Photonics

Lecture 8-9

Nonlinear optical effect

The optical frequency Kerr effect

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Nonlinear Optics $\rightarrow$ light-matter interactions when material's response is a non-linear function of the applied electric-field.
For a nonlinear material, the electric polarization field will depend on the electric field:

$$\mathbf{P} = \epsilon_0 \chi^{(1)} \mathbf{E} + \epsilon_0 \chi^{(2)} \mathbf{E}\mathbf{E} + \epsilon_0 \chi^{(3)} \mathbf{E}\mathbf{E}\mathbf{E} + \cdots,$$

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The i-th component for the vector **P**:

$$P_i = \varepsilon_0 \sum_{j=1}^{3} \chi_{ij}^{(1)} E_j + \varepsilon_0 \sum_{j=1}^{3} \sum_{k=1}^{3} \chi_{ijk}^{(2)} E_j E_k + \varepsilon_0 \sum_{j=1}^{3} \sum_{k=1}^{3} \sum_{l=1}^{3} \chi_{ijkl}^{(3)} E_j E_k E_l + \cdots$$

$\chi^{(n)}$: n-th order electric susceptibility

Electro-optical Kerr effect

Polarizations in x and y directions are

$$
\begin{aligned}
\hat{P}_x(\omega) &= 3\epsilon_0 \chi^K_{xyyx}(\omega; 0, 0, \omega) E_y^2(0) \hat{E}_x(\omega) \\
&= 3\epsilon_0 \chi^K_4 E_y^2(0) \hat{E}_x(\omega) \\
\hat{P}_y(\omega) &= 3\epsilon_0 \chi^K_{yyyy}(\omega; 0, 0, \omega) E_y^2(0) \hat{E}_y(\omega) \\
&= 3\epsilon_0 \chi^K_1 E_y^2(0) \hat{E}_y(\omega).
\end{aligned}
$$

The DC field creates a refractive index difference between the two polarizations given by

$$
n_\parallel - n_\perp \simeq \frac{3(\chi^K_1 - \chi^K_4) E_y^2(0)}{2n} = \frac{3\chi^K_2 E_y^2(0)}{n},
$$

The Kerr constant K of a medium is defined by

$$
\Delta n \equiv n_\parallel - n_\perp = \lambda_0 K E^2(0),
$$

Optical Kerr effect

A strong wave at frequency ω_2 changes the refractive index of a weak probe wave at ω_1. The operative term in the polarization is

$$\hat{P}_x(\omega_1) = \frac{3}{2}\epsilon_0 \chi^{OK}_{xxxx}(\omega_1;\ \omega_2, -\omega_2, \omega_1)|\hat{E}_x(\omega_2)|^2 \hat{E}_x(\omega_1),$$

which implies that the refractive index of the weak wave is changed by

$$\Delta n_x \cong \frac{3\chi^{OK}_{xxxx} I(\omega_2)}{2n(\omega_1)n(\omega_2)c\epsilon_0}.$$

Let's consider an electric field: $\tilde{E}(t) = E(\omega)e^{-i\omega t} + c.c$

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Kerr effect: $P(\omega) \cong \epsilon_0 \chi^{(1)} E(\omega) + 3\epsilon_0 \chi^{(3)} |E(\omega)|^2 E(\omega) \equiv \epsilon_0 \chi_{\text{eff}} E(\omega)$

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Refractive index of many materials: $n = n_0 + \bar{n}_2 \left\langle \tilde{E}^2 \right\rangle$

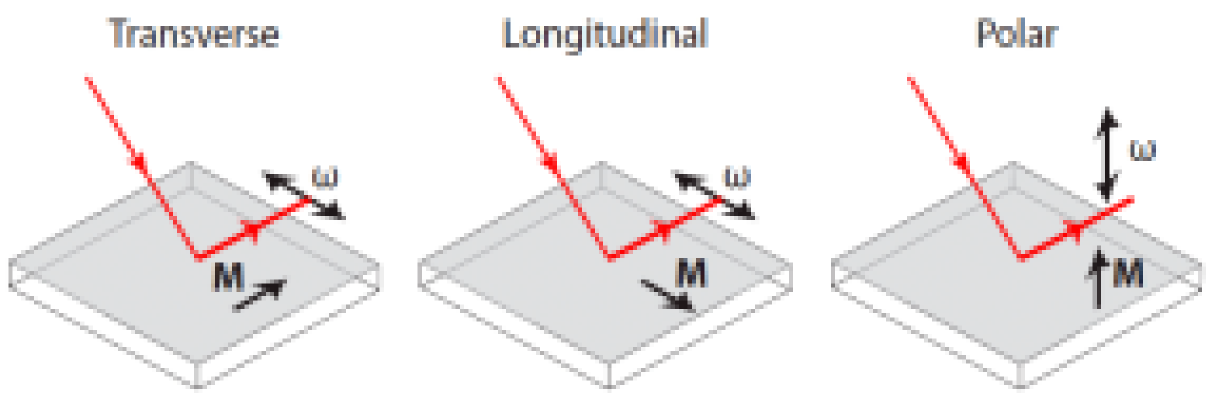
$n^2 = 1 + \chi_{\text{eff}}$

$$n_0 = (1 + \chi^{(1)})^{1/2}$$

$$\bar{n}_2 = \frac{3\chi^{(3)}}{2n_0}.$$

Magneto-optical Kerr effect

Magneto-optical Kerr effect (MOKE): light reflected from a magnetized material has a slightly rotated plane of polarization.



It is used in materials science research in devices such as the Kerr microscope, to investigate the magnetization structure of materials.
Thanks to its high accuracy, high temporal and spatial resolution and very fast response, the MOKE is a powerful method to study the magnetic properties of ultrathin and multilayer films.