

Nonlinear Optical Engineering

Parametric Processes (3)
(NFO 5th ed: 10.5 ~ 10.6)

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FWM Applications (1)

Wavelength conversion:

Modal birefringence: → FWM

$$\rightarrow \delta n = \Delta n_x - \Delta n_y$$

$$\begin{aligned}\rightarrow \Delta k_W &= [\Delta n_y(\omega_3 + \omega_4) - 2\Delta n_x\omega_1] / c \\ &= -2\omega_1(\delta n) / c\end{aligned}$$

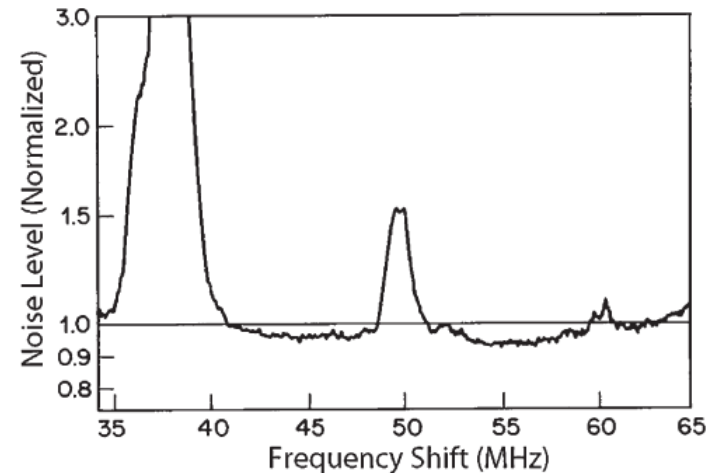
FWM Applications (2)

Squeezing:

Noise reduction by phase-sensitive conversion:

Limitation:

Inelastic scattering effects, e.g., SBS & SRS



G. P. Agrawal, Nonlinear Fiber Optics, 5th ed.

FWM Applications (3)

Phase conjugation:

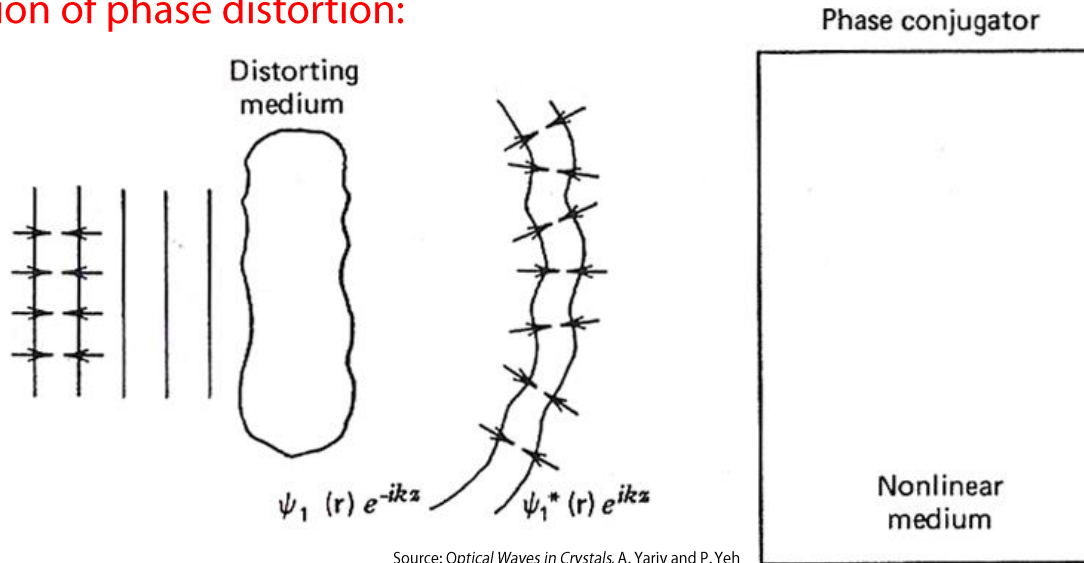
Undepleted-pump approximation:

$$\rightarrow A_1(z) = A_1(0) \exp(i\gamma P_1 z)$$

$$\rightarrow \frac{dA_3}{dz} = 2i\gamma P_1 A_3 + i\gamma [A_1(0)]^2 e^{-i\theta} A_4^* \quad \leftarrow \theta = (\Delta k - 2\gamma P_1)z$$

$$\rightarrow \frac{dA_4^*}{dz} = -2i\gamma P_1 A_4^* - i\gamma [A_1^*(0)]^2 e^{i\theta} A_3 \quad \rightarrow A_3 \Leftrightarrow A_4^*$$

Cancellation of phase distortion:



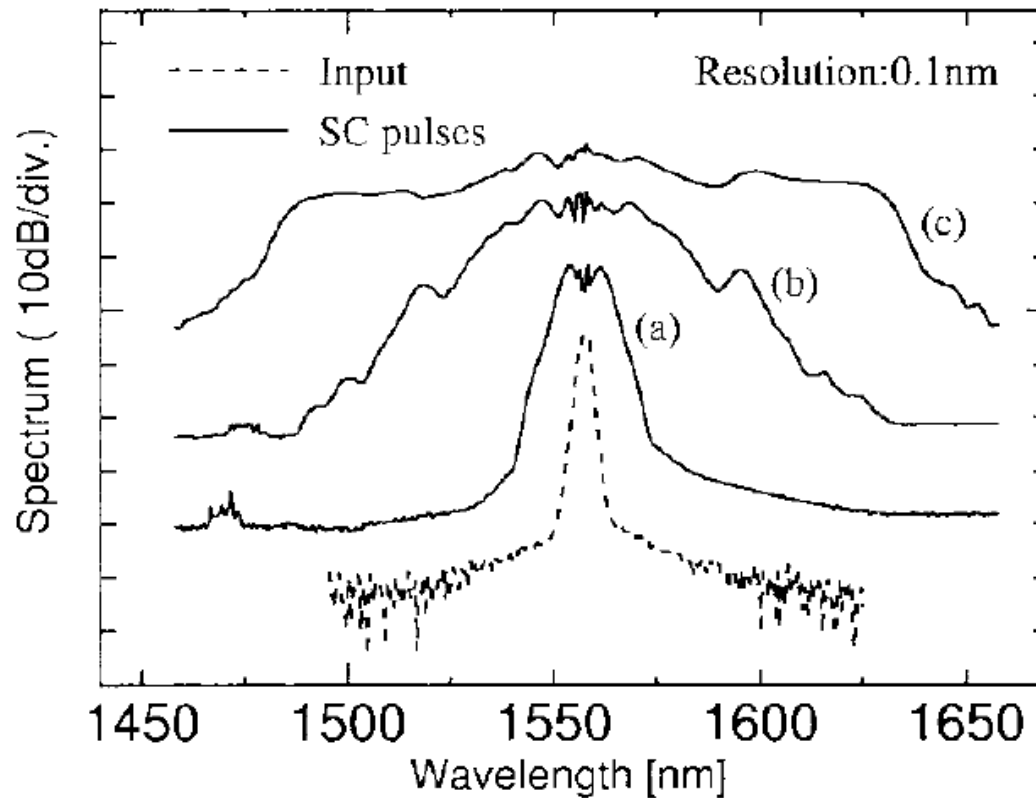
Source: Optical Waves in Crystals, A. Yariv and P. Yeh

$$\rightarrow e^{i\Delta\phi_{\Delta L}} = \prod_{j=1}^N e^{i\Delta\phi_j} \rightarrow e^{-i\Delta\phi_{\Delta L}} \prod_{j=1}^N e^{i\Delta\phi_j} = e^{j0}$$

FWM Applications (4)

Supercontinuum generation:

FWM + SPM + XPM + SRS + etc.:



G. P. Agrawal, Nonlinear Fiber Optics, 3rd ed.

Second-Harmonic Generation (1)

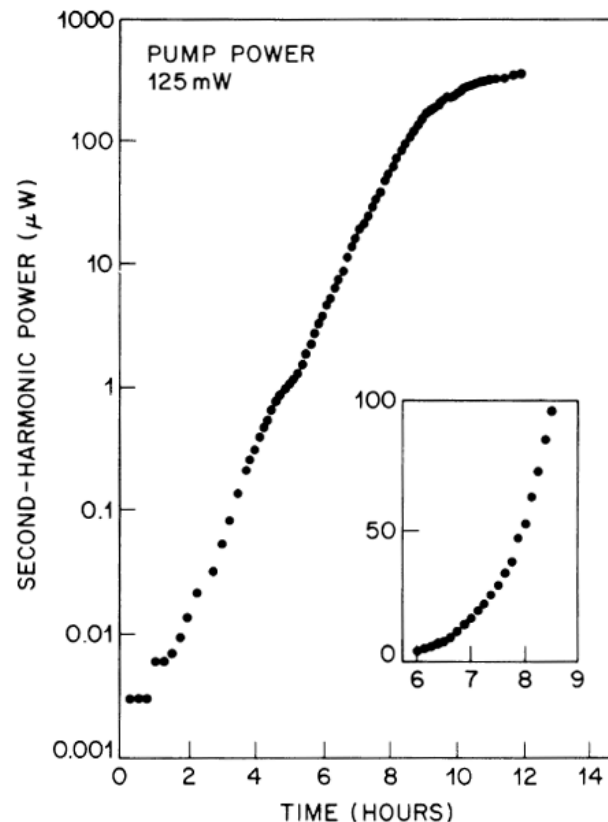
Physical mechanism:

Induced static polarization:

$$\rightarrow P_{dc} = (3\epsilon_0 / 4) \text{Re}[\chi^{(3)} E_p^* E_p^* E_{SH} \exp(i\Delta k_p z)] \quad \leftarrow \Delta k_p = [n(2\omega_p) - 2n(\omega_p)]\omega_p / c$$

Effective second-order nonlinearity:

$$\rightarrow \chi^{(2)} = \alpha_{SH} P_{dc} = (3\alpha_{SH} / 4)\epsilon_0 \chi^{(3)} |E_p|^2 |E_{SH}| \cos(\Delta k_p + \phi_p)$$



Second-Harmonic Generation (2)

Simple theory:

Coupled amplitude equation:

$$\rightarrow \frac{dA_1}{dz} = i\gamma_1(|A_1|^2 + 2|A_2|^2)A_1 + \frac{i}{2}\gamma_{SH}^* A_2 A_1^* \exp(-i\kappa z)$$

$$\rightarrow \frac{dA_2}{dz} = i\gamma_2(|A_2|^2 + 2|A_1|^2)A_2 + \frac{i}{2}\gamma_{SH} A_1^2 \exp(i\kappa z)$$

$$\leftarrow \gamma_{SH} = (3\omega_1 / 4n_1 c) \epsilon_0^2 \alpha_{SH} f_{112} \chi^{(3)} |E_p|^2 |E_{SH}|^2$$

$$\leftarrow \kappa = \Delta k_p - \Delta k$$

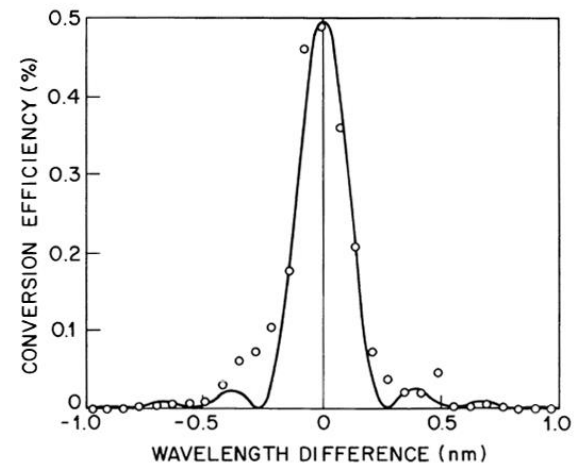
Undepleted pump approximation:

$$\rightarrow A_1(z) = \sqrt{P_1} \exp(i\gamma_1 P_1 z) \quad \rightarrow A_2 = B_2 \exp(2i\gamma_1 P_1 z)$$

$$\rightarrow \frac{dB_2}{dz} = i\gamma_{SH} P_1 \exp(i\kappa z) + 2i(\gamma_2 - \gamma_1) P_1 B_2$$

$$\rightarrow P_2(L) = |B_2(L)|^2 = |\gamma_{SH} P_1 L|^2 \frac{\sin^2(\kappa' L / 2)}{(\kappa' L / 2)^2}$$

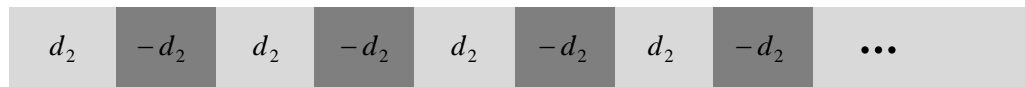
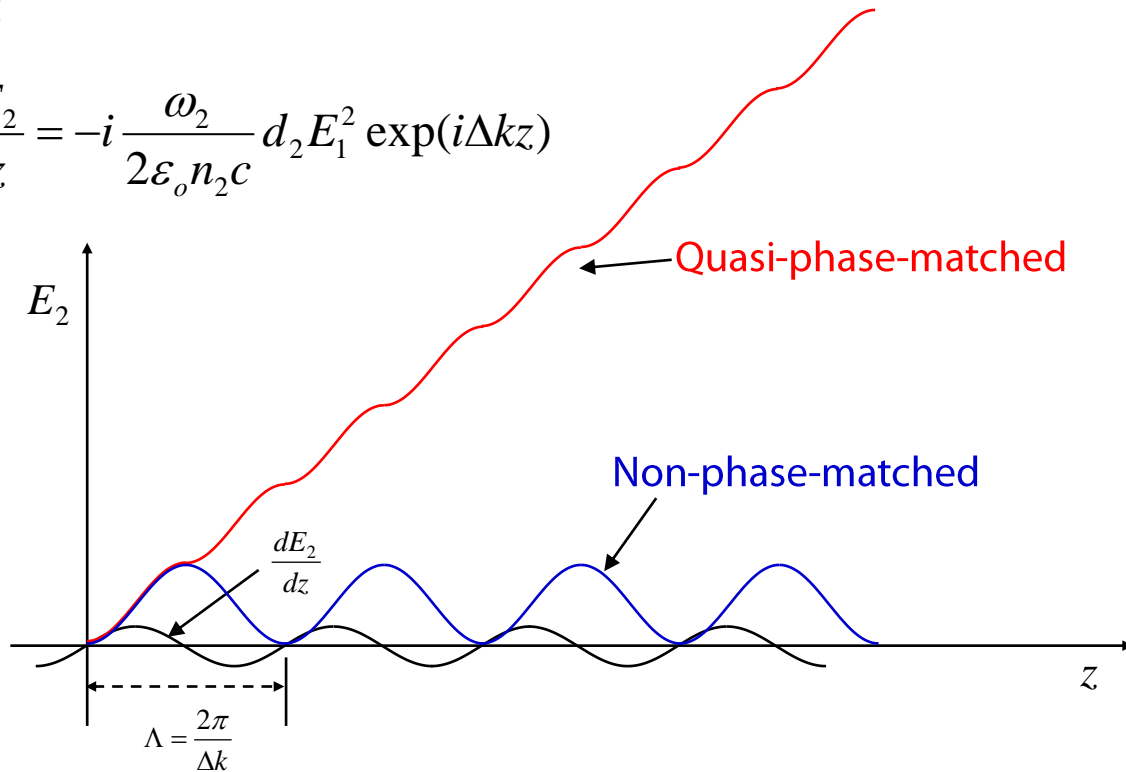
$$\leftarrow \kappa' = \kappa - 2(\gamma_2 - \gamma_1) P_1$$



Quasi-Phase Matching

SH field:

$$\frac{dE_2}{dz} = -i \frac{\omega_2}{2\varepsilon_0 n_2 c} d_2 E_1^2 \exp(i\Delta k z)$$



Quasi-phase-matched



Non-phase-matched

→ Periodic spatial modulation of the nonlinear coefficient:
e.g. PPLN (periodically-poled lithium niobate), PP glass, etc.