Nonlinear Optical Engineering

Stimulated Brillouin Scattering (1)
(NFO 5th ed: 9.1 ~ 9.3)

Yoonchan Jeong

School of Electrical Engineering, Seoul National University

Tel: +82 (0)2 880 1623, Fax: +82 (0)2 873 9953

Email: yoonchan@snu.ac.kr

Basic Concepts (1)

Predicted by Brillouin in 1922:

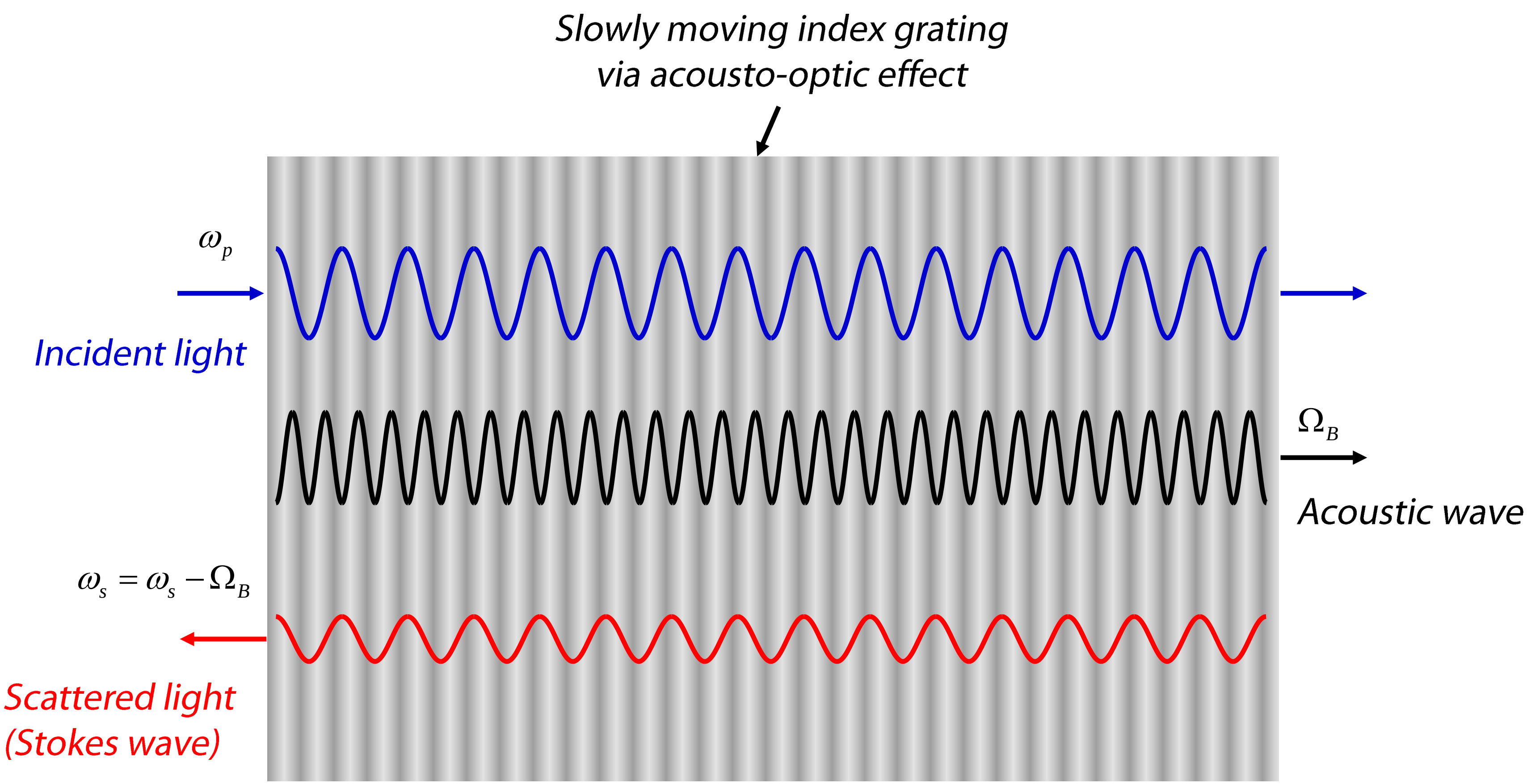
The process of stimulated Brillouin scattering (SBS) was first observed by Chiao *et al.* in 1964.

Also related with inelastic scattering: frequency shift in the order of 1 ~ 10 GHz

Nonlinear interaction between optical waves travelling in the opposite directions via acousto-optic effect

Basic Concepts (2)

Physical process:



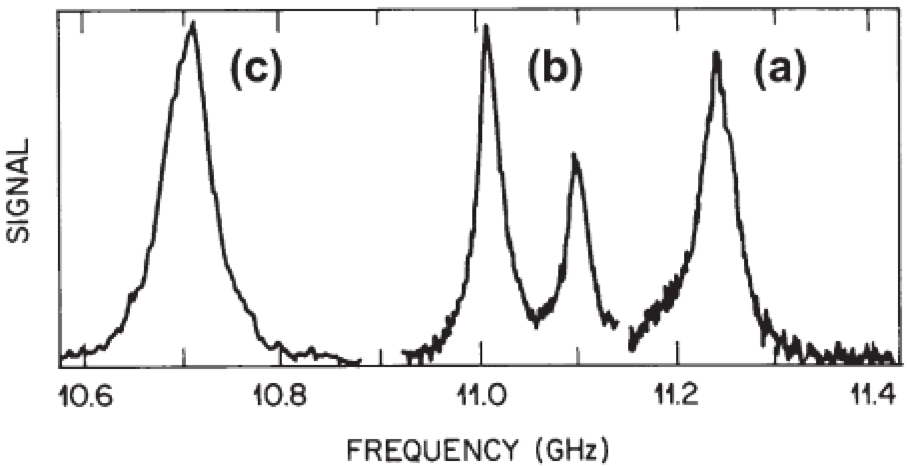
$$\rightarrow \Omega_B = \omega_p - \omega_s, \quad \mathbf{k}_A = \mathbf{k}_p - \mathbf{k}_s$$

$$\rightarrow \Omega_B = v_A |\mathbf{k}_A| \approx 2 v_A |\mathbf{k}_p| \sin(\theta / 2)$$

$$\rightarrow \nu_B = \Omega_B / 2\pi = 2 n_p v_A / \lambda_p \approx 11.1\,\mathrm{GHz} \; @ \; \lambda_p = 1.55\ \mu m$$

Basic Concepts (3)

Brillouin-gain spectrum:



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

$$\leftarrow \exp(-\Gamma_B t)$$

$$\rightarrow g_B(\Omega) = g_p \frac{(\Gamma_B/2)^2}{(\Omega-\Omega_B)^2+(\Gamma_B/2)^2}$$

$$\leftarrow g_p \equiv g_B(\Omega_B) = \frac{4\pi^2\gamma_e^2 f_A}{n_p c\lambda_p^2 \rho_0 v_A \Gamma_B}$$

$$g_B \sim 5\times10^{-11}\ \text{m/W for silica glass}$$

$$\nu_B \sim 11.25\,\text{GHz},\ \Delta\nu_B \sim 17\ \text{MHz}$$

For a broadband CW pump:

$$\rightarrow g_c(\omega_s) = \int_{-\infty}^{\infty} \frac{g_p\Gamma_B/2}{\Gamma_B/2 + i(\omega-\omega_s-\Omega_B)} S_p(\omega-\omega_p)\,d\omega \qquad \leftarrow \int_{-\infty}^{\infty} S_p(\omega-\omega_p)\,d\omega = 1$$

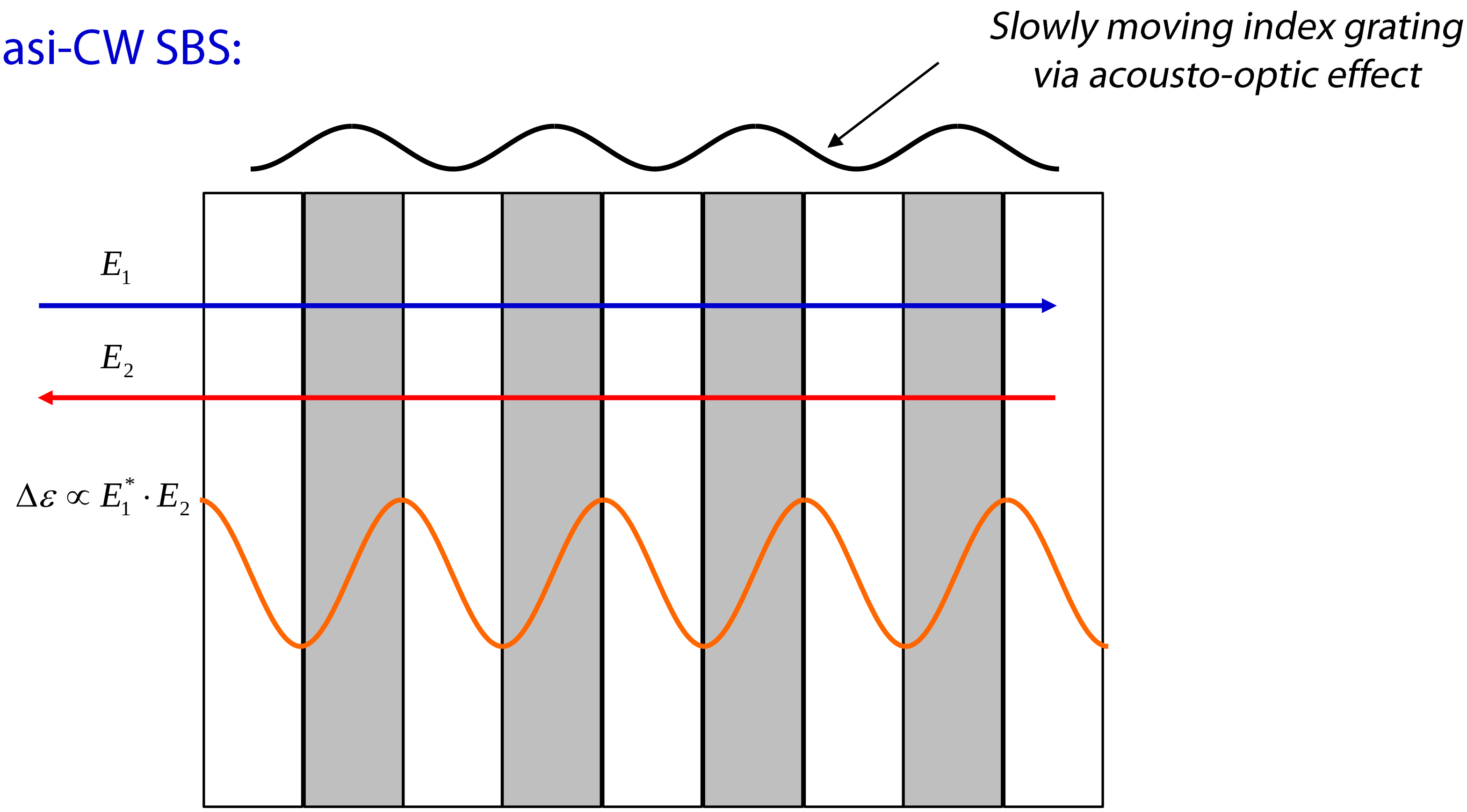
$$\rightarrow g_B^{eff}(\omega_s) = \mathrm{Re}[g_c(\omega_s)]$$

Lorentzian spectrum: phonon lifetime, i.e. ~10 ns for silica glass

ν_B varies with the incident light frequency as well as material properties (density, strain & temperature)

Basic Concepts (4)

Quasi-CW SBS:



Coupled equations for pump and Stokes waves:

$$\rightarrow \frac{dI_p}{dz} = -g_B I_p I_s - \alpha I_p$$

$$\rightarrow -\frac{dI_s}{dz} = +g_B I_p I_s - \alpha I_s$$

$$\rightarrow \frac{d}{dz}\left(I_p - I_s\right) = 0$$ ← For a lossless medium

Basic Concepts (5)

Quasi-CW SBS:

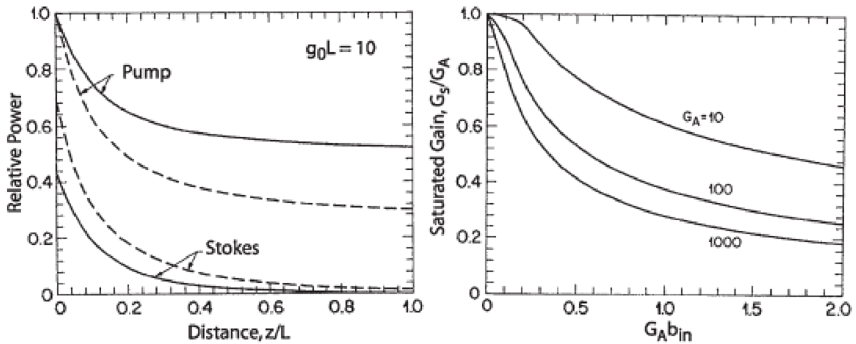
With a non-depleted pump approximation:

$$\rightarrow I_p(z) = I_p(0)e^{-\alpha z}$$

$$\rightarrow I_s(0) = I_s(L)\exp(g_B P_0 L_{eff} / A_{eff} - \alpha L)$$

Critical pump power:

$$\rightarrow g_B(\Omega_B)P_{cr}L_{eff} / A_{eff} \approx 21$$



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

Gain saturation:

$$\leftarrow \alpha = 0$$

$$\rightarrow \frac{d}{dz}\left(I_p - I_s\right) = 0 \quad \rightarrow I_p - I_s = C$$

$$\rightarrow \frac{I_s(z)}{I_s(0)} = \left(\frac{C + I_s(z)}{C + I_s(0)}\right)\exp(g_B C z) \quad \leftarrow C = I_p(0) - I_s(0)$$

$$\rightarrow I_s(z) = \frac{b_0(1-b_0)}{G(z) - b_0} I_p(0) \quad \leftarrow G(z) = \exp[(1-b_0)g_0 z]$$

$$\leftarrow b_0 = I_s(0) / I_p(0), \quad g_0 = g_B I_p(0)$$

$\rightarrow G_s = I_s(0) / I_s(L) = b_0 / b_{in}$ ← Saturated gain $\leftarrow b_{in} = I_s(L) / I_p(0)$

$\rightarrow G_A = \exp(g_0 L)$ ← Unsaturated gain