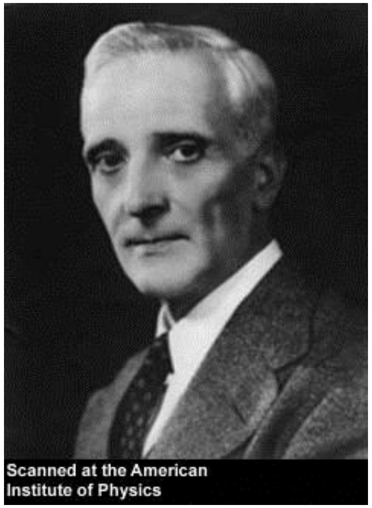
Nonlinear Optical Engineering

Stimulated Brillouin Scattering

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

Brillouin Scattering



Léon Nicolas Brillouin (1889 -1969)

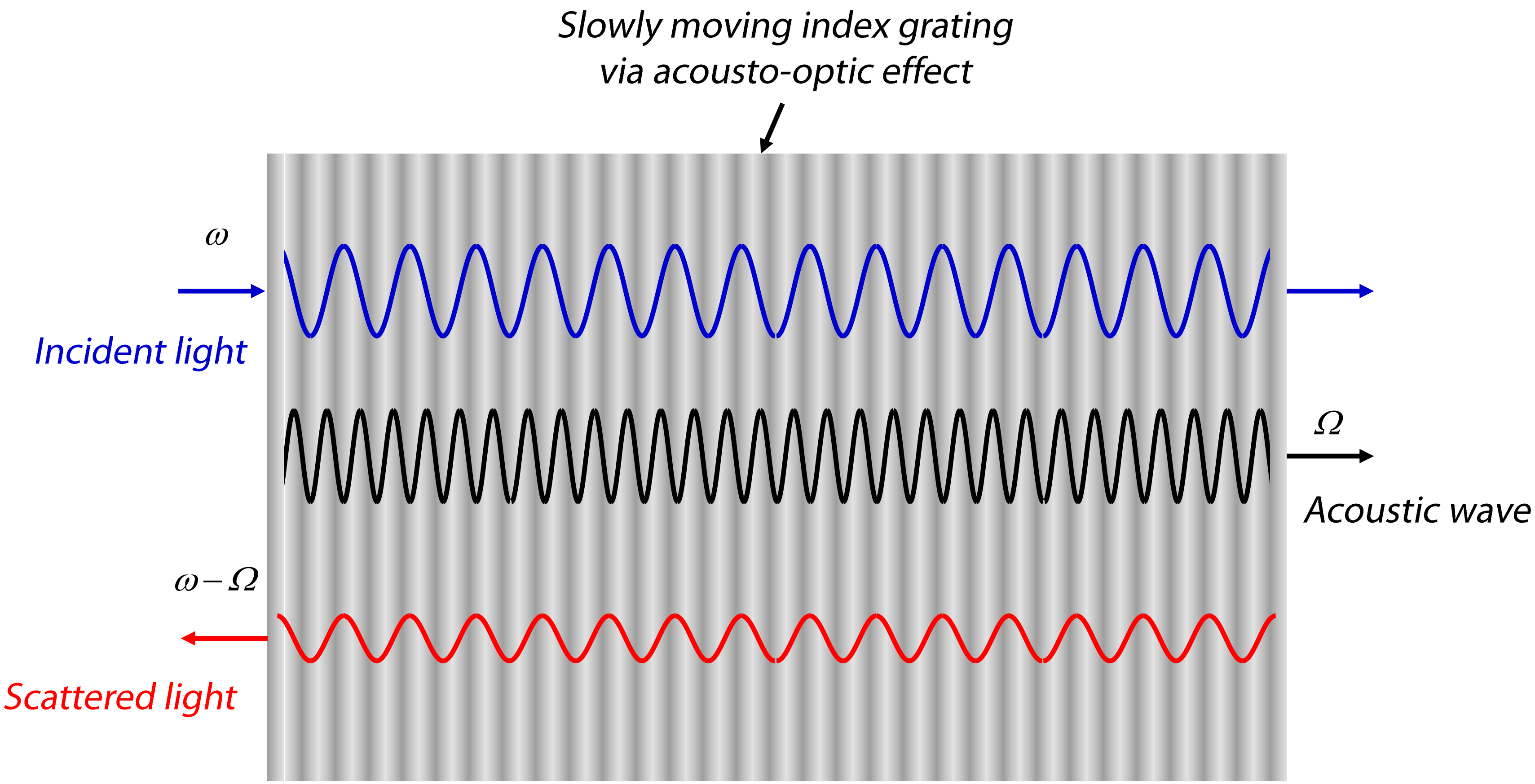
Predicted by Brillouin in 1922:

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

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

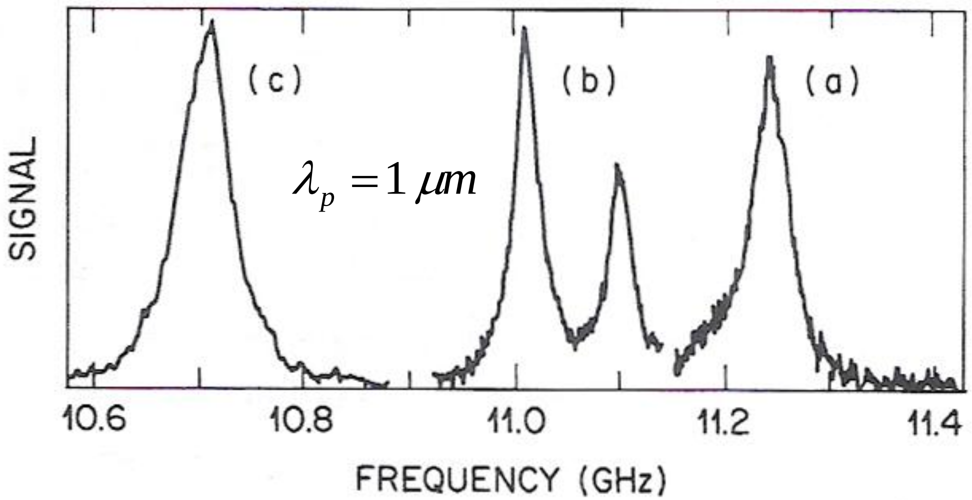
Nonlinear interaction between optical waves travelling in the opposite directions via acousto-optic effect

Stimulated Brillouin Scattering



Brillouin Gain

Brillouin-gain spectrum for fused silica:



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

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

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

$$\frac{d}{dz}\left(I_p - I_s\right) = 0 \text{ for lossless media}$$

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

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

$$g_B(\Omega) = g_p \frac{(\Gamma_B/2)^2}{(\Omega-\Omega_B)^2 + (\Gamma_B/2)^2}, \quad \leftarrow \exp(-\Gamma_B t)$$

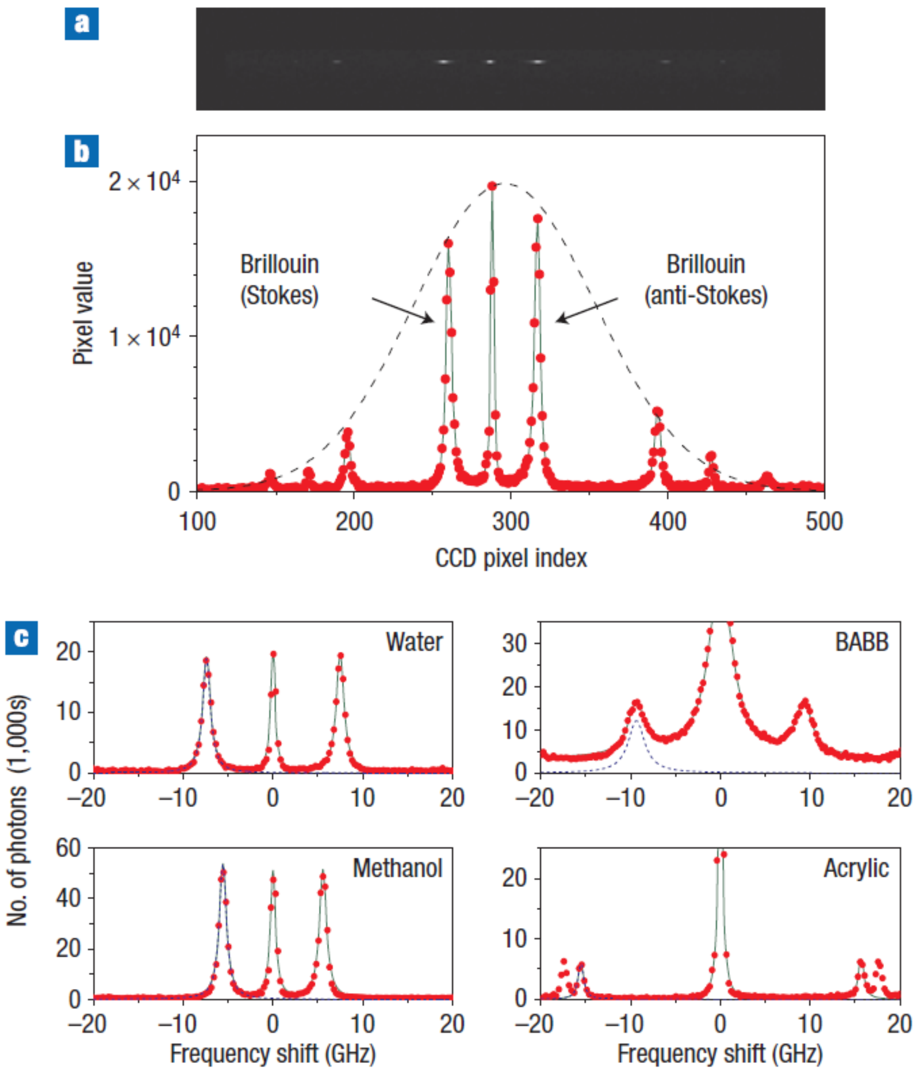
$$g_p = g_B(\Omega_B) = \frac{2\pi^2 n^7 p_{12}^2}{c\lambda_p^2 \rho_0 v_A \Gamma_B}.$$

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

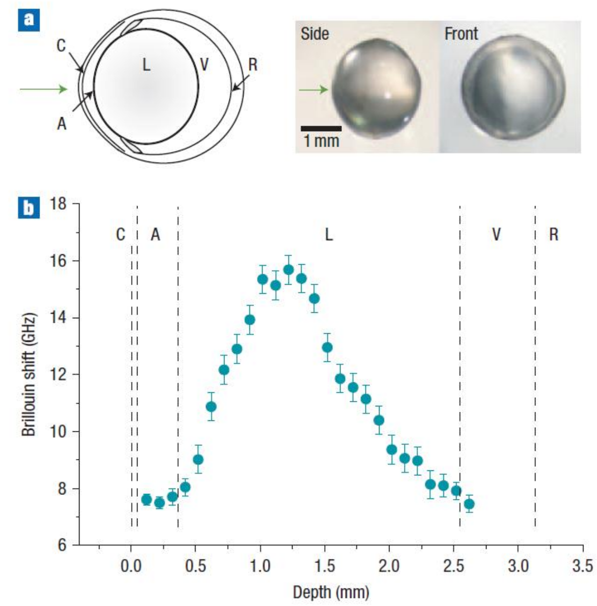
ν_B varies with the incident light frequency as well as material properties (density, strain & temperature)

Brillouin Spectroscopy

Intrapulse Raman scattering:

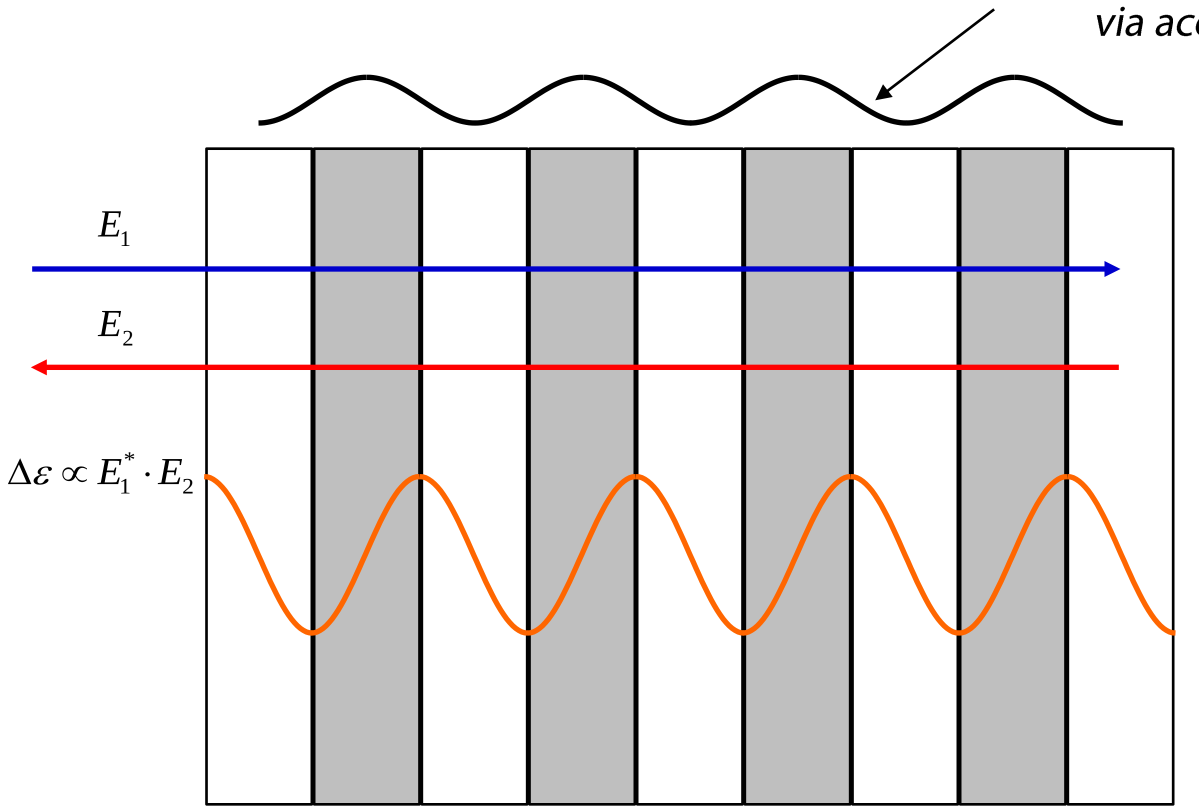


Nature Photonics, ***2***, *39 (2008)*



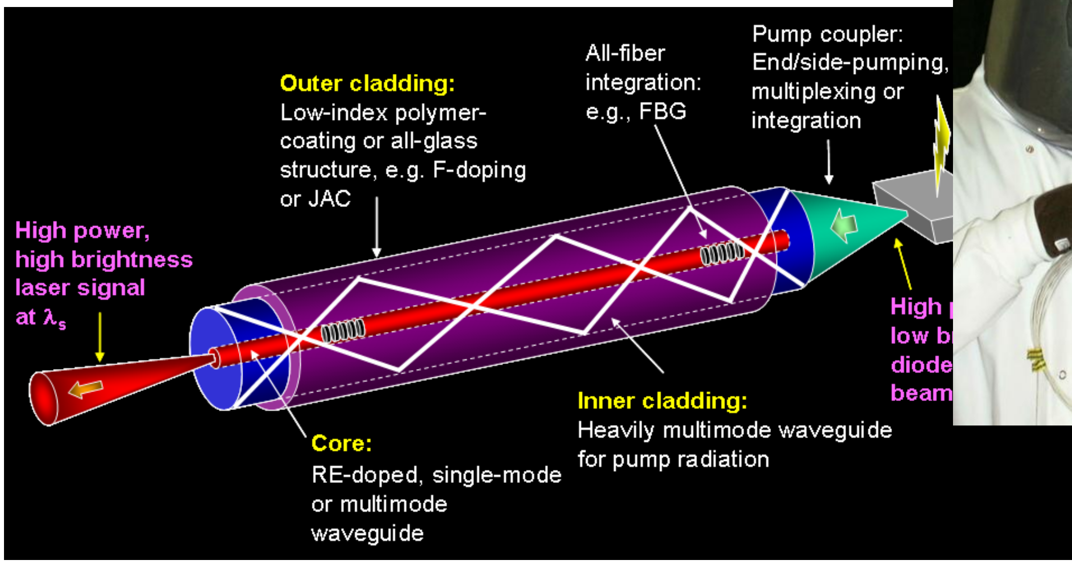
Phase Conjugation Mirror via SBS

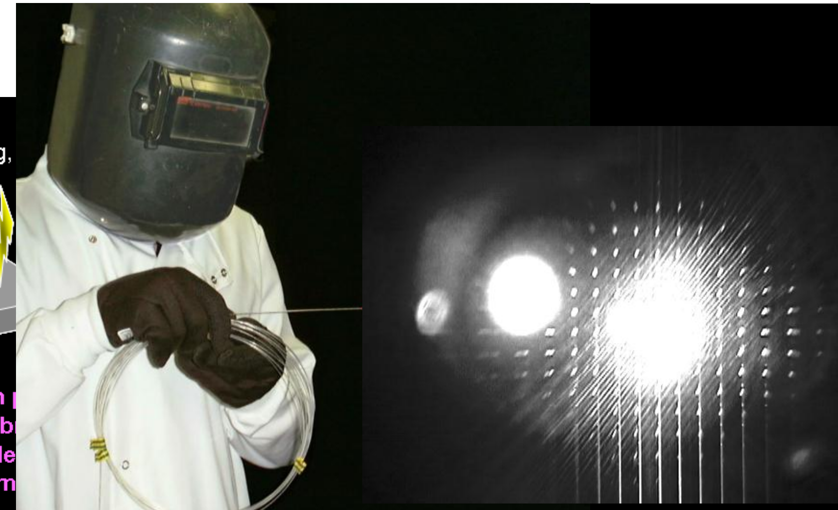
Slowly moving index grating via acousto-optic effect



Back reflection with phase-conjugation of the incident light!

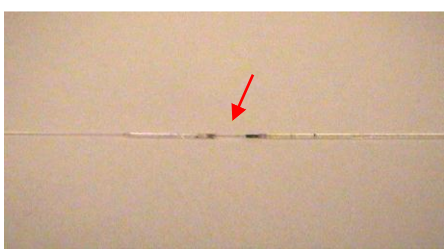
Thermal Characteristics of Fiber Lasers



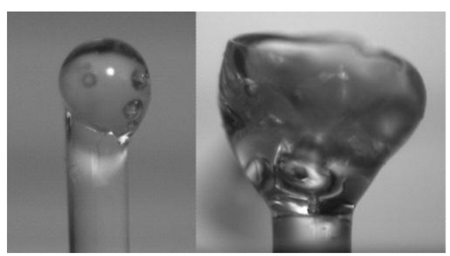


>1 kW available since Aug 2003:
Opt. Express **12**, *6088 (2004)*

- Easy thermal management, but still many thermal issues



Coating damage

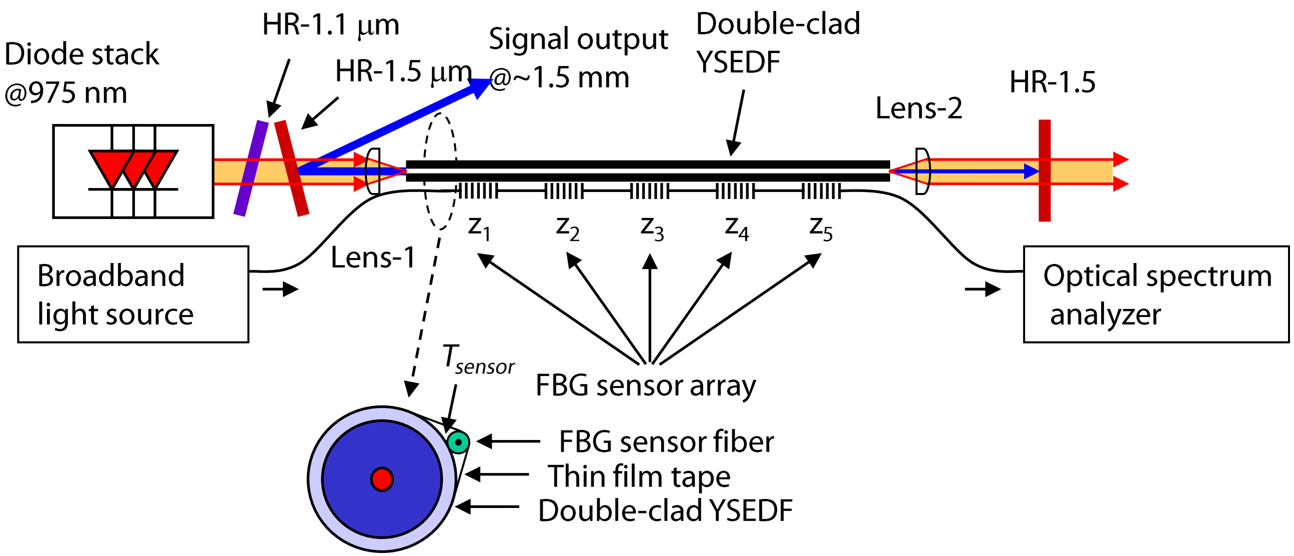


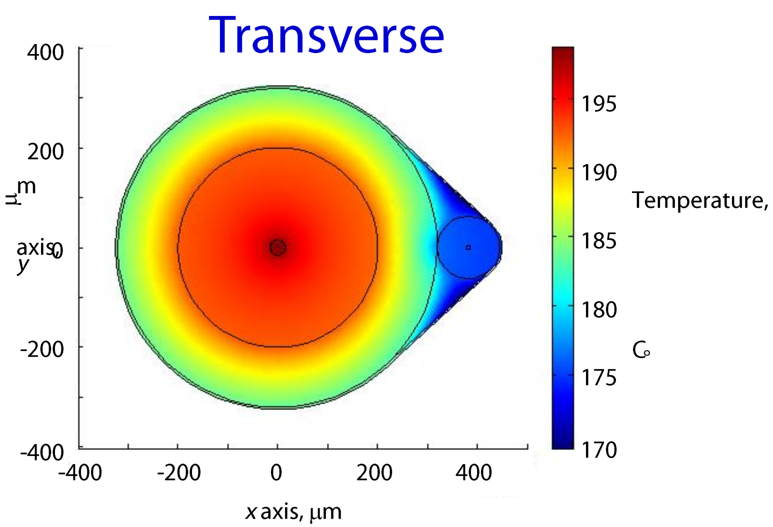
Glass damage

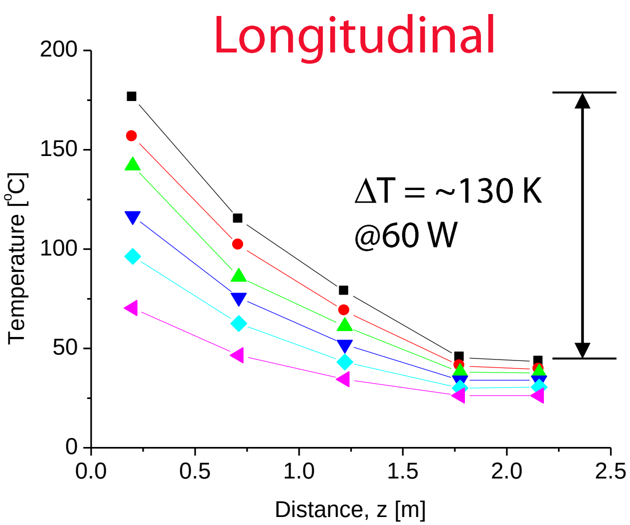
- Thermal characteristics linked to:
  material damage, efficiency,
  beam quality, spectroscopy,
  nonlinearity, photodarkening, etc.

Pump-Induced Temperature Gradient

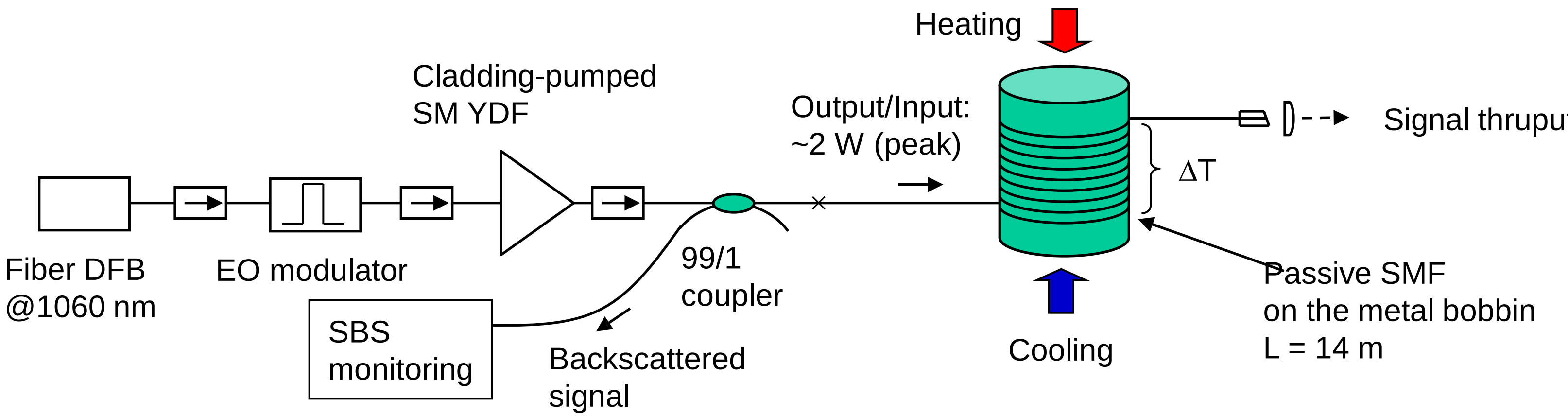
*Optics Express, **16**, 19865 (2008)*



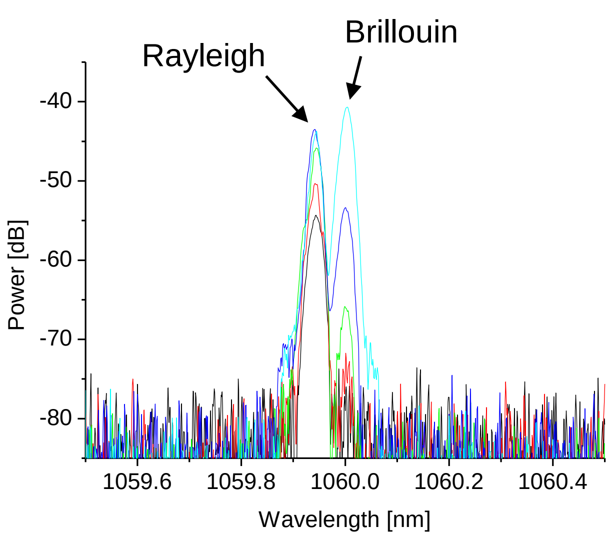




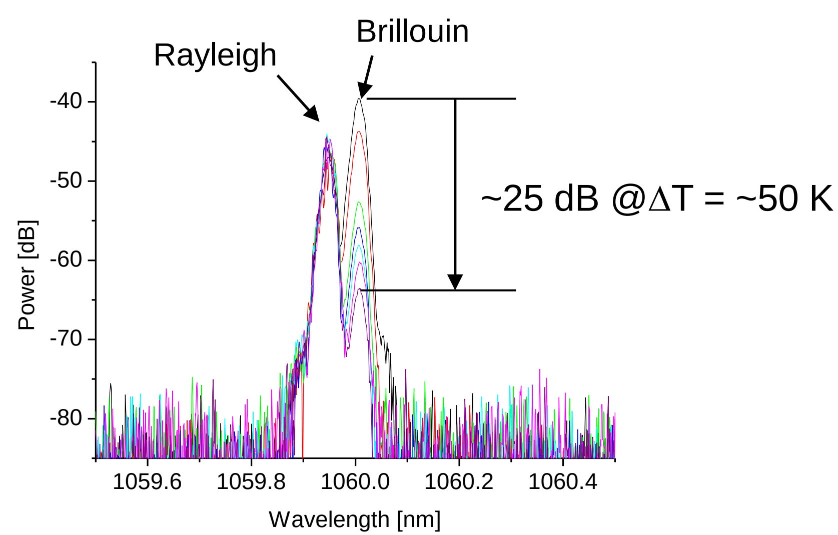
SBS Suppression via Temperature Gradient



Nonlinear increase of Brillouin Stokes



Brillouin Stokes decrease with ΔT



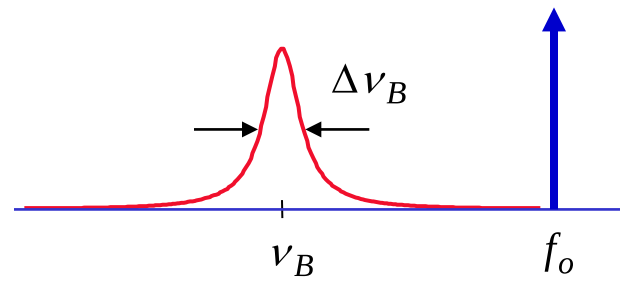
Brilloun Optical Time Domain Analysis (BOTDA)

Distributed Brillouin gain:

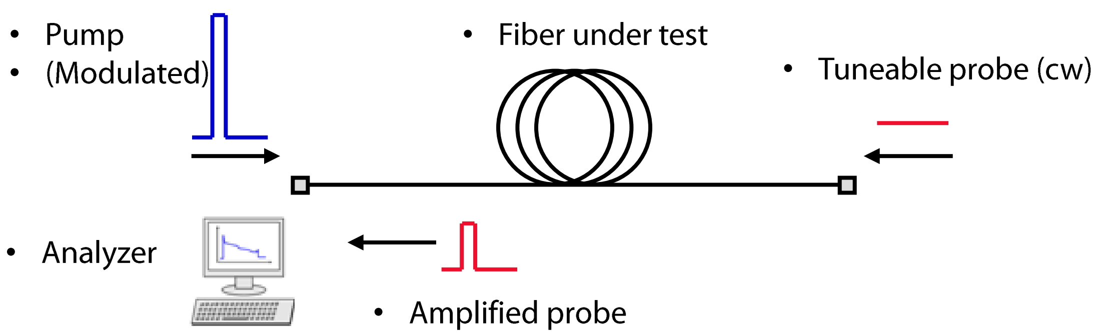
$$g_B(\nu, z) = \frac{(\Delta\nu_B(z)/2)^2}{(\nu - \nu_B(z))^2 + (\Delta\nu_B(z)/2)^2} \cdot g_{B0}$$

where

$$\nu_B(z) = C_{\nu\varepsilon}\delta\varepsilon(z) + C_{\nu T}\delta T(z)$$

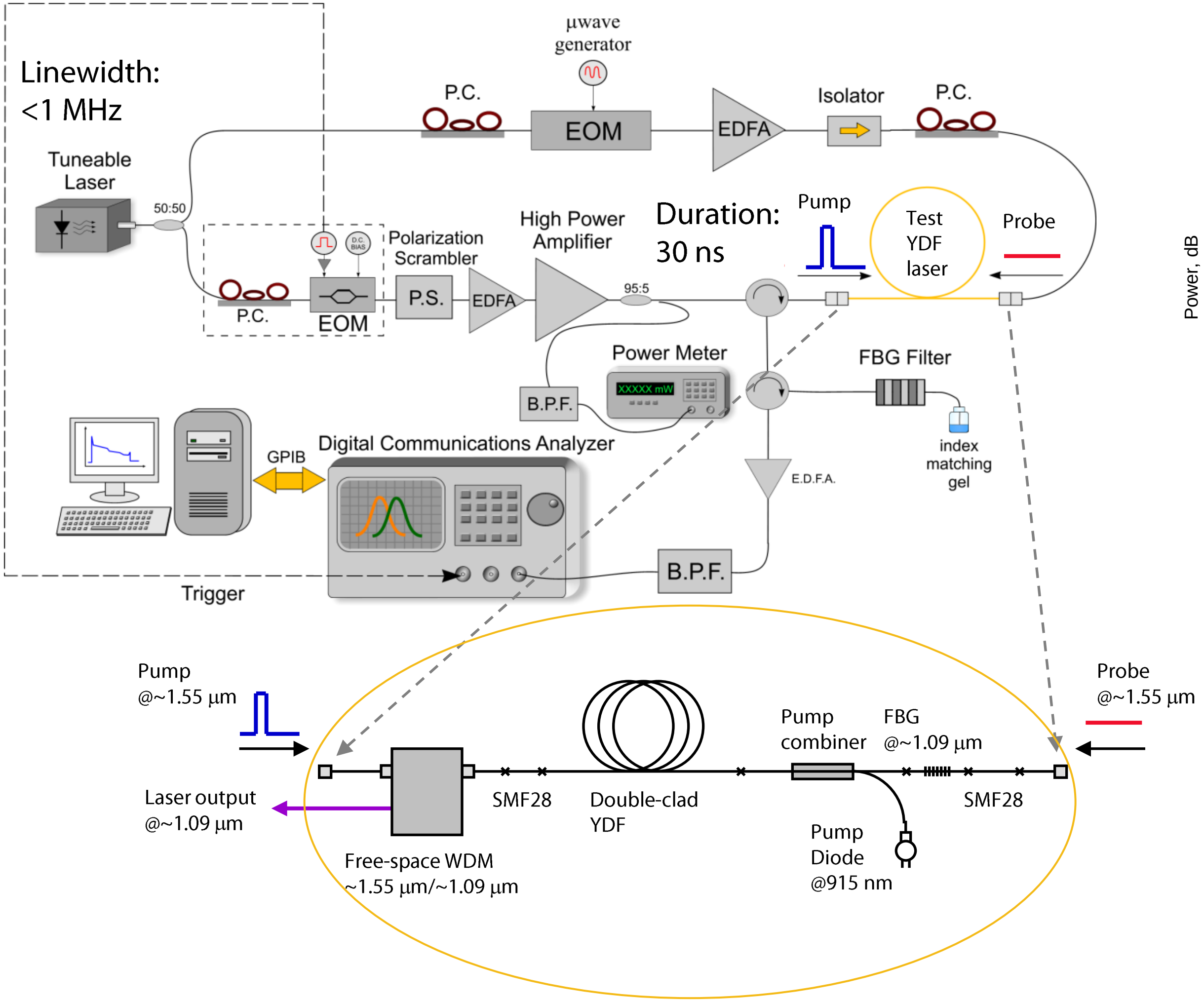


Triggering by spatially-resolved, stimulated processes:

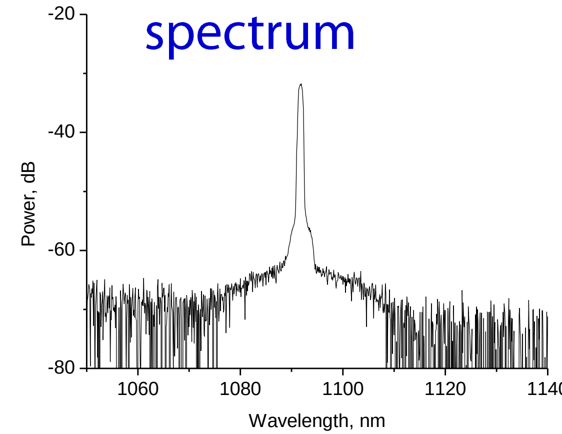


BOTDA Experimental Arrangement

Electron. Lett. 45, 153 (2009)



YDF laser spectrum



YDF laser characteristics

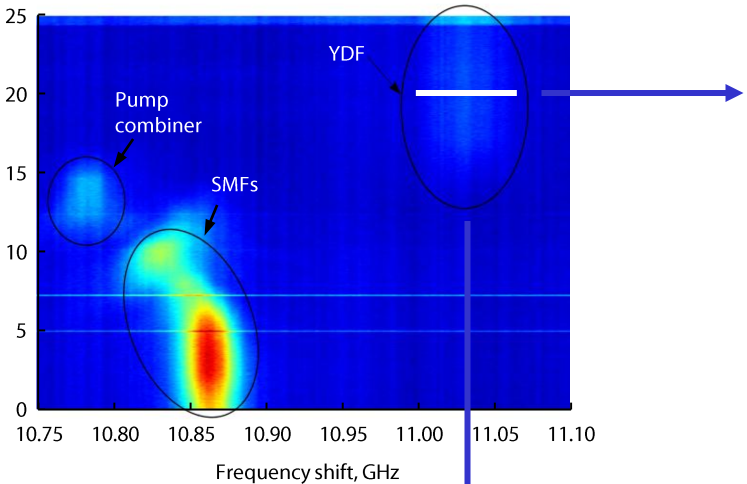
YDF: 6.1-µm core diameter, 0.13 NA (CorActive Las-Yb-06-02)

Lasing at ~1.09 µm

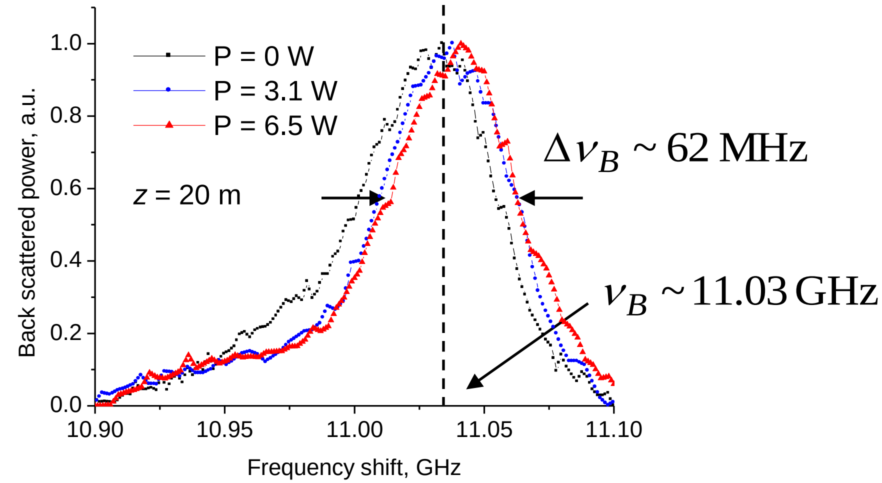
Max. power: 2.8 W at 6.5 W pump (Efficiency: ~46%)

BOTDA of an YDF Laser

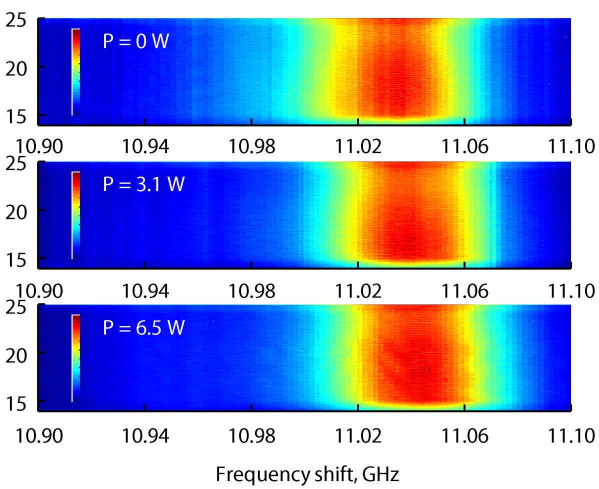
Overall BOTDA scan



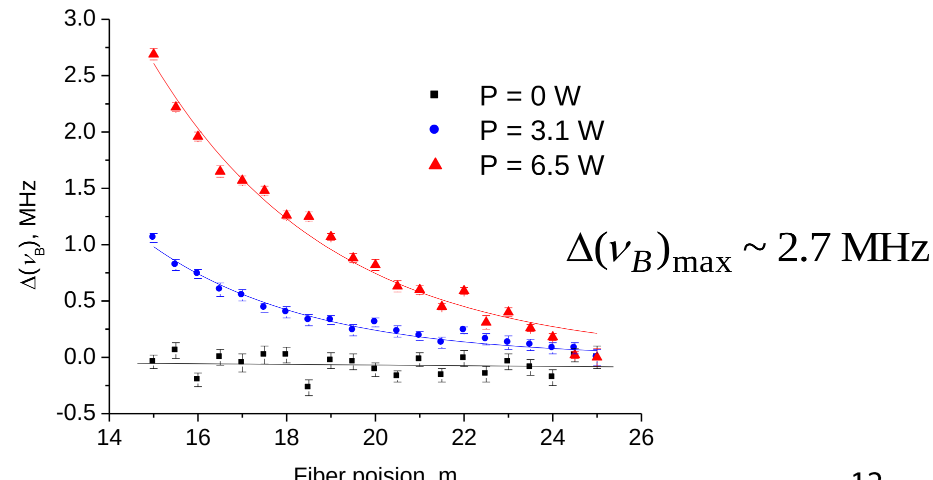
Brillouin scattered power



BOTDA scan of YDF section

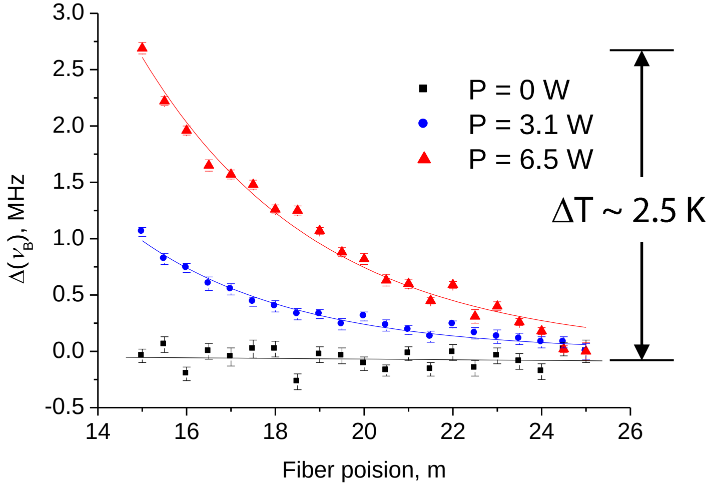


Brillouin shift frequency change



Temperature Dist. and Brillouin Gain Coefficient

Brillouin shift frequency change



Temperature distribution

Related with pump absorption

$\Delta(\nu_B)$ ~ 2.7 MHz → ΔT ~ 2.5 K

($C_{\nu T}$ ~ 1.1 MHz/K for 1.55 μm)

Extrapolation from 1.55 μm to 1.09 μm

$C_{\nu T}$ ~ 1.6 MHz/K for 1.09 μm

$\Delta\nu_B$ ~ 125 MHz for 1.09 μm

T. Kurashima et al., IEEE PTL **2**, 718 (1990)

Integrated gain coefficient for 1.09 μm

ΔT ~ 80 K → 20% reduction

(Brillouin gain broadening)

Brillouin gain broadening