Nonlinear Optical Engineering

Stimulated Raman Scattering

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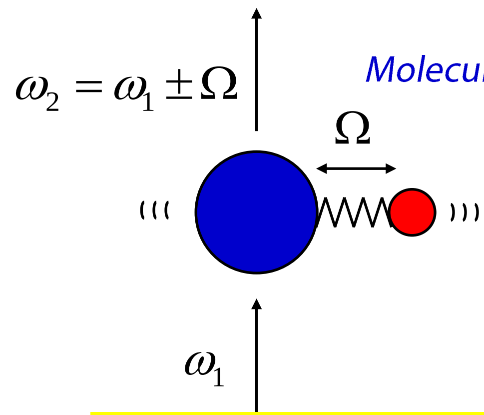
Raman Scattering

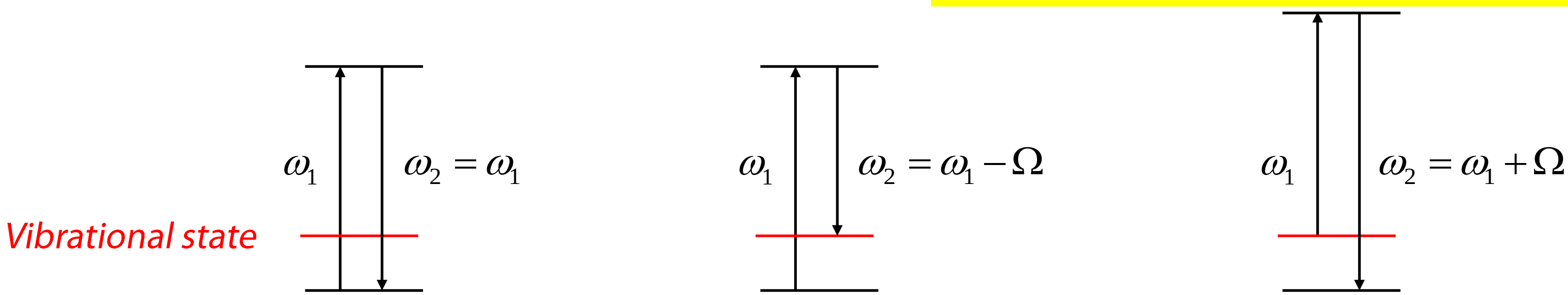
C. V. Raman
(Chandrasekara Venkataraman, 1888 -1970)

The Raman effect was discovered in 1928 by C. V. Raman.

Inelastic scattering ← molecular vibrations



Does every kind of molecule vibrate?



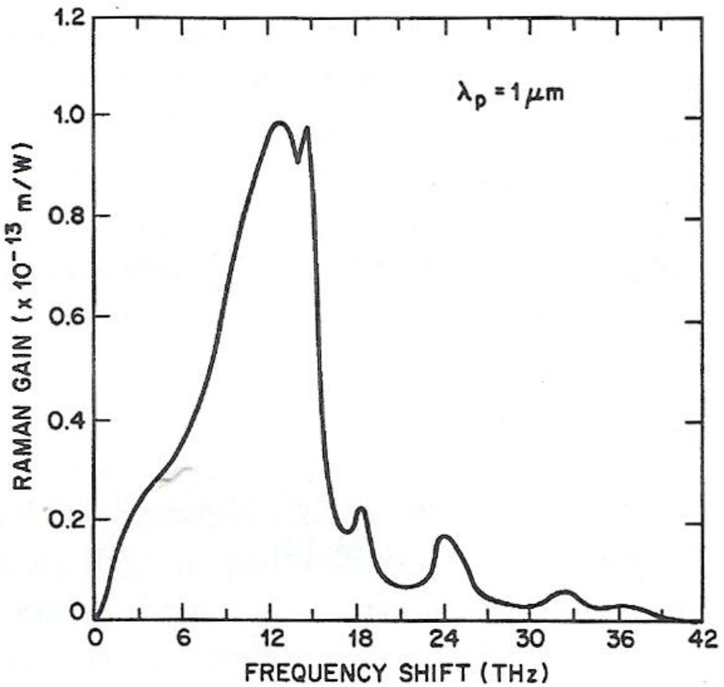
Elastic scattering: Rayleigh scattering

Inelastic scattering: Stokes scattering

Inelastic scattering: Anti-Stokes scattering

Raman Gain

Raman-gain spectrum for fused silica at a pump wavelength:



Source: Nonlinear Fiber Optics, G. P. Agrawal

$$\frac{dI_s}{dz} = g_R I_p I_s - \alpha_s I_s,$$

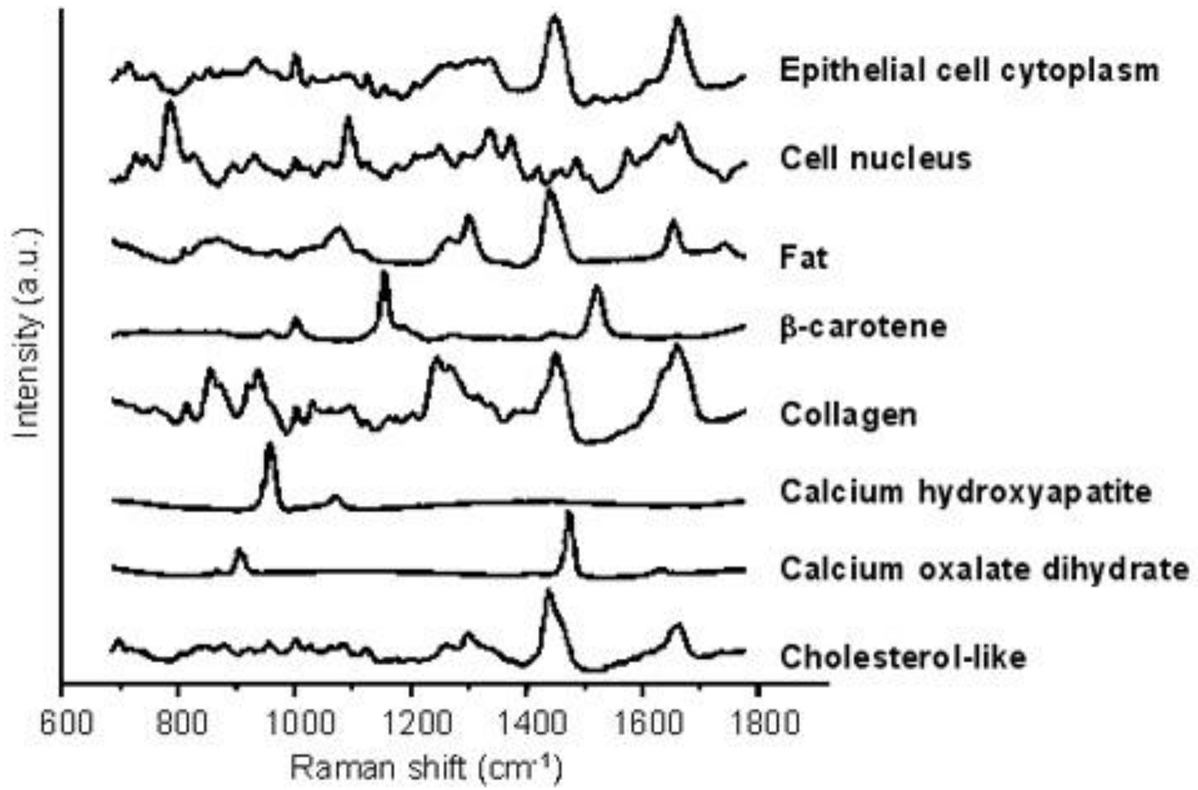
$$\frac{dI_p}{dz} = -\frac{\omega_p}{\omega_s} g_R I_p I_s - \alpha_p I_p.$$

$$g_R \sim 10^{-13}\ \text{m/W},\ \Omega_R \sim 13.2\ \text{THz}$$

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

Raman Spectroscopy

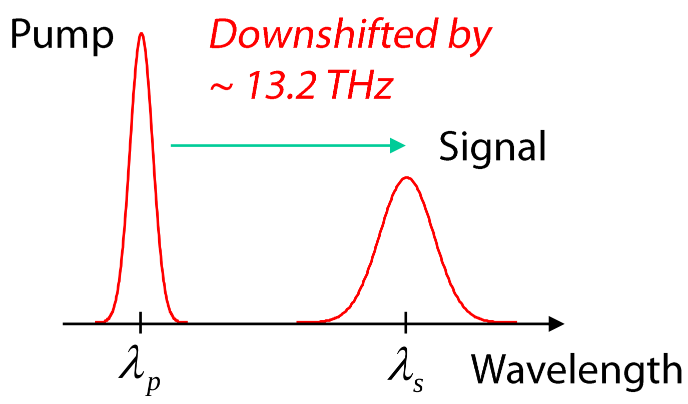
Raman spectra vary with materials:

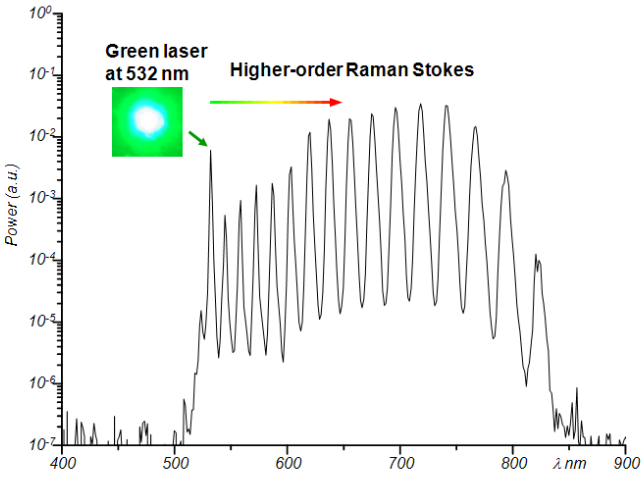


Source: http://web.mit.edu/spectroscopy/research/biomedresearch/Raman_breast.html

Stimulated Raman Scattering

Pump and Signal (Raman Stokes):





Raman Soliton: Dispersion and SPM balanced

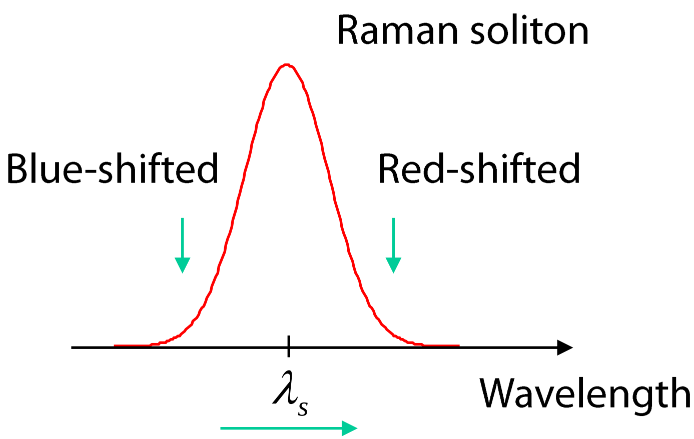
$$\frac{\partial A_p}{\partial z} + \frac{i\beta_{2p}}{2}\frac{\partial^2 A_p}{\partial T^2} = i\gamma_p[|A_p|^2 + (2 - f_R)|A_s|^2]A_p - \frac{g_p}{2}|A_s|^2 A_p,$$

$$\frac{\partial A_s}{\partial z} - d\frac{\partial A_s}{\partial T} + \frac{i\beta_{2s}}{2}\frac{\partial^2 A_s}{\partial T^2} = i\gamma_s[|A_s|^2 + (2 - f_R)|A_p|^2]A_s + \frac{g_s}{2}|A_p|^2 A_s$$

where $T = t - z / v_{gp}, \quad d = v_{gp}^{-1} - v_{gs}^{-1}$

Soliton Self-Frequency Shift (1)

Intrapulse Raman scattering:



Continuous energy transfer via Raman scattering from blue-shifted components to red-shifted components

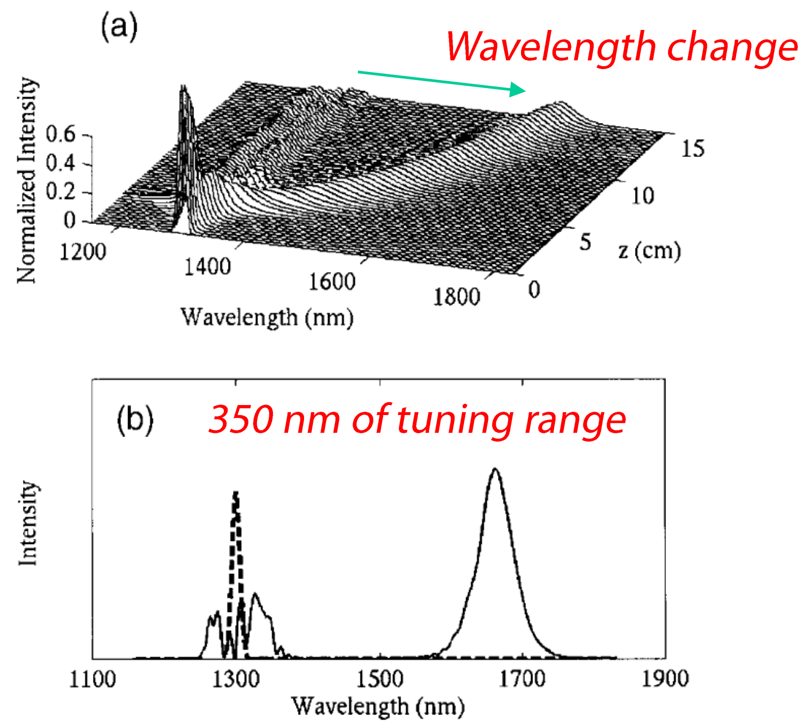


Fig. 3. (a) Simulated pulse-spectrum propagation in a 15-cm TASMF. (b) Input (dashed curve) and output (solid curve) spectra. Simulation parameters: $L_{NL} = 0.6$ cm, $L_D = 20$ cm, $L_D' = 25$ m, and $T_R = 3$ fs.

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Amount of frequency shift:

$$\Delta\omega_R(z) = -8|\beta_2|T_R z/(15T_0^4)$$

The peak power of the pulse can determine the wavelength for a fixed fiber length!

Soliton Self-Frequency Shift (2)

Photonic bandgap fiber with anomalous dispersion:

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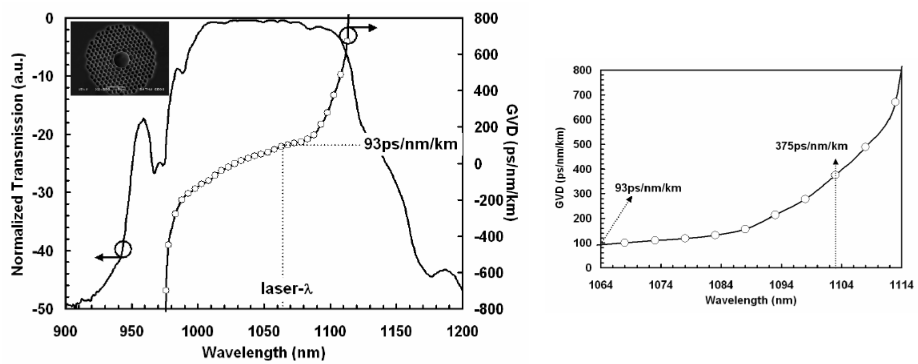
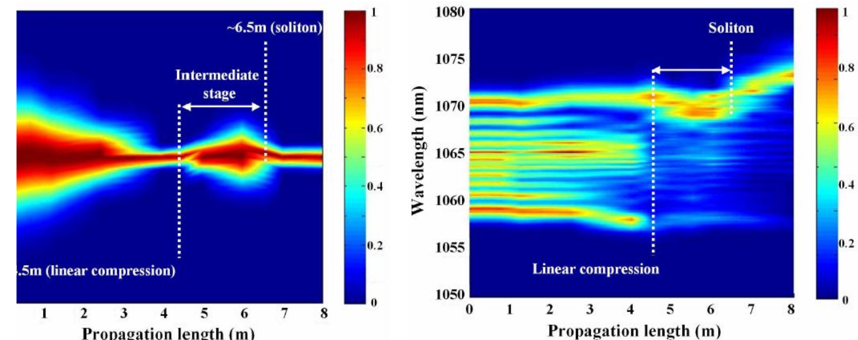


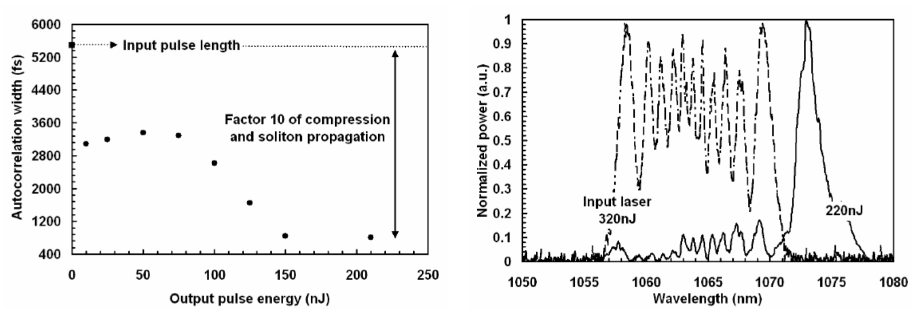
(a) (b)

Fig. 1. (a). Normalized transmission (solid curve) and GVD (circle points) versus the wavelength. Fiber cross-section used in the following experiments is shown in the inset.; (b) GVD zoom between 1064nm and 1114nm.



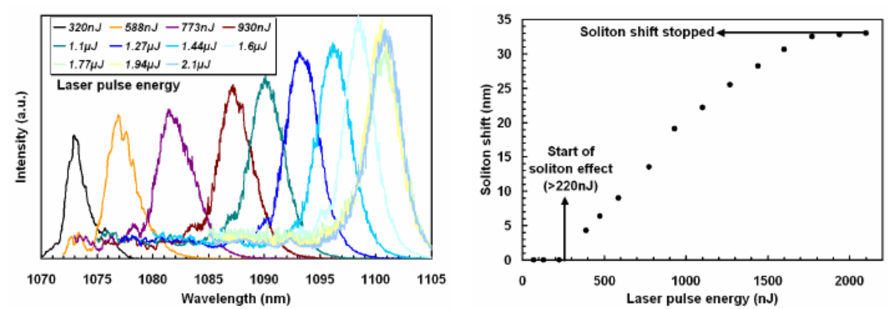
(a) (b)

Fig. 3. (a). Normalized experimental output pulse width and (b) spectrum as a function of the fiber propagation for 320nJ laser pulse energy. (Linear interpolation is used for the plot)



(a) (b)

Fig. 2. (a). Output pulse autocorrelation width (without deconvolution factor) as a function of output pulse energy; (b). Spectra before (dashed curve) and after (solid curve) propagation in 8m length of HC-PBGF for 320nJ laser pulse energy (220nJ×77%=170nJ-soliton).

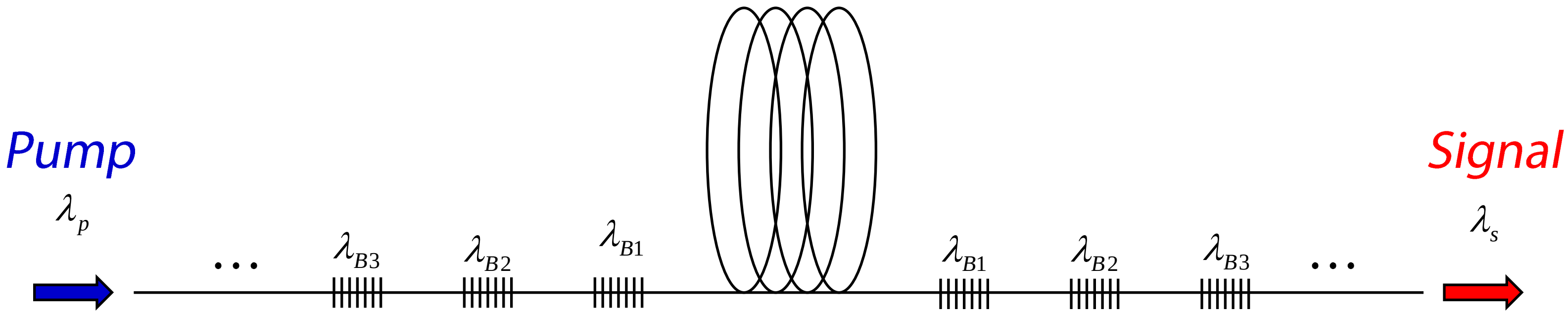


(a) (b)

Fig. 4. (a). Spectra recorded at the output of 8m length of HC-PBGF : zoom on the soliton part (residual pump at 1064nm not shown). (b) Soliton shift versus the laser pulse energy. The laser pulse energy threshold (>220nJ) relating to the soliton effect is also indicated.

Cascaded Raman Fiber Lasers

Cascaded stimulation of Raman scattering:



Wide-range wavelength access!

Double-Clad Raman Fiber Lasers

Inter-modal stimulated Raman scattering :

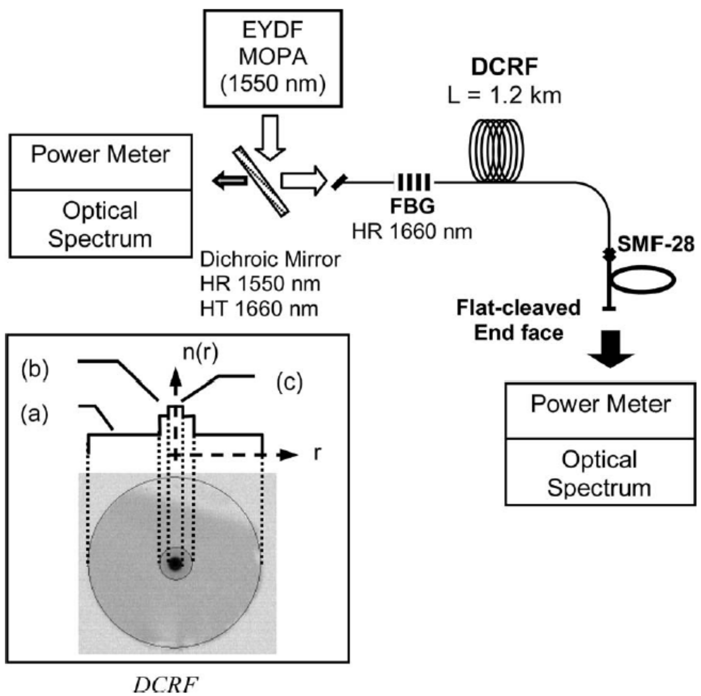


Fig. 1. Experimental setup of the high-power cladding-pumped Raman fiber laser. Inset, double-clad Raman fiber idealized refractive index profile and cross section: (a) outer silica cladding; (b) germanium-doped inner cladding; (c) core.

Opt. Lett. ***31***, *2290 (2006)*