Self-oscillation and coherent control of flexural vibrations in dual-nanoweb fiber

Johannes R. Koehler, David Novoa, and Philip St.J. Russell

Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058 Erlangen, Germany

Optical phonons in molecular media have a flat dispersion band with a cut-off frequency in the THz range and cause stimulated Raman scattering (SRS). Transverse acoustic vibrations in the guiding cores of microstructured optical fibers share very similar dispersion, though at much lower cut-off frequencies $\Omega_R$. As a result, Stokes and anti-Stokes scattering of core-guided light is automatically phase-matched, giving rise to stimulated Raman-like scattering (SRLS) (Fig. 1 (a)).

An example of a system with giant SRLS gain is dual-nanoweb fiber, which consists of two closely-spaced silica nano-membranes suspended inside a capillary fibre (Fig. 1(b)). Light launched into the even fundamental mode (FOM) of the coupled nanoweb pair causes an attractive gradient pressure between the nanowebs, giving rise to a large optomechanical nonlinearity and permitting optical driving of flexural nanoweb vibrations. When more than a few mW of single-frequency (CW) laser light is launched into an evacuated fiber, the fundamental flexural mode is found to self-oscillate, generating many Stokes/anti-Stokes sidebands (Fig. 1(c)) [1]. Since, unlike in SRS, group-velocity dispersion is insignificant over the small spectral range (a few tens of MHz) considered, phase-matched intra-modal scattering between many adjacent sidebands is possible using identical phonons. Under these circumstances, however, self-oscillation by CW pumping is not expected, since phonon-creation and annihilation rates should be exactly balanced, an effect known as gain suppression. By tracking the spatio-spectral evolution of nanoweb vibrations [2], i.e., driving them selectively with dual-frequency light and sweeping the beat-frequency $\Omega_B$ while probing the vibrational amplitude interferometrically from the side of the fiber, we find (Fig. 1(d)) that stimulated inter-modal scattering (SIMS) to a higher-order optical mode (HOM) frustrates SRLS gain suppression. This occurs when the frequencies of SRLS ($\Omega_R$) and SIMS ($\Omega_M$) accidentally match at one location – the result of structural non-uniformities.

The optical beat-note driving SRLS is unaffected by optomechanical back-action. This enables simultaneous coherent control of nanoweb vibrations along the whole length of the fiber, by imprinting steps in relative phase between the components of dual-frequency driving light [3]. Sequentially repeated at time intervals shorter than the acoustic lifetime, the vibrational amplitude becomes constant and is tunable via the depth and switching rate of the phase steps. Transverse and axial probing (Fig. 1(e)) confirm this concept, which will work in any system supporting SRLS.

References: