FPPO Applications

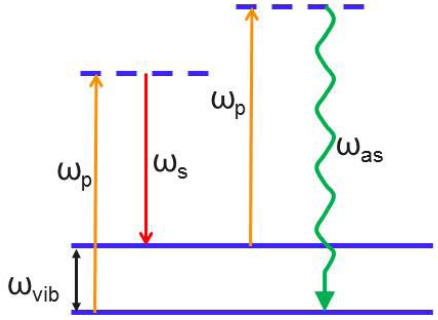
Ultrafast OPO System

MICROTECH® instruments, inc.

Application Notes:

Coherent anti-Stokes Raman Scattering (CARS) is a four-wave mixing process that is used to probe molecular vibrations. When used as an imaging technique CARS presents several attractive properties:

- Blue shifted emission easily separated from background fluorescence
- High intensities required for nonlinear interaction allow confocal imaging
- Using inherent vibrational contrast removes need for fluorescence labeling
- Enables chemically selective imaging



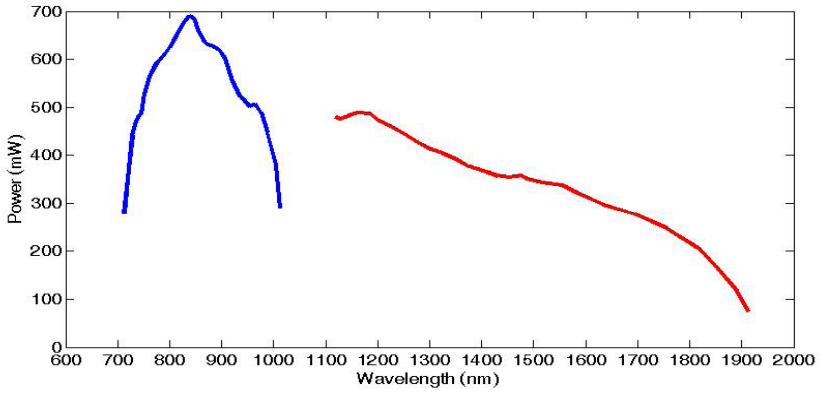
$$\omega_p\text{-}\omega_s = \omega_{vib}$$

$$\omega_{as} = 2\omega_p\text{-}\omega_s$$

Figure 1. Energy level diagram for CARS process. The pump and Stokes difference frequency is tuned to a molecular vibration, creating a vibrational coherence. A second interaction with the pump excites the molecule to a virtual state, where it emits a blue shifted anti-stokes photon to return to the ground state.

By tuning the frequency of the pump beam it is possible to selectively image different chemical species. Since most Raman transitions have line widths of less than 10 cm^{-1}, the use of picosecond pulses allows for a sufficiently narrow spectrum and high peak power to drive the nonlinear process while maintaining spectral selectivity.

Figure 2. Spectral Coverage of FPPO-ps. The signal power (blue) is 250-500 mW from 720-1000 nm, while the idler (red) is 100-400 mW from 1150-1800 nm.



The FPPO is the first commercially available fiber laser pumped OPO system specifically designed for CARS imaging. Output pulses have durations of 6 ps or less, linewidths less than 10 cm^{-1} (typical 6 cm^{-1} or 0.4 nm for 800 nm), and all pulses are synchronized in time at rep rate of 109 MHz. The FPPO output consists of three separate beams: the signal beam (tunable from 720-1000 nm), the idler beam (tunable from 1150-1800 nm) , and a beam from the pump laser fixed at 1064 nm. Tuning is accomplished through a combination of crystal temperature, cavity length, and the adjustment of an intracavity filter. Using the 1064 nm light as the stokes beam and the signal beam of the OPO as the pump beam, Raman modes from 600 cm^{-1} to 4200 cm^{-1} can be probed. Typical output powers are 250-700 mW for the signal and 100-400 mW for the idler, but if higher powers are required a higher power fiber laser can be used for pumping.

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A typical experimental set-up is shown in figure 3, using the FPPO-ps as a light source. After overlapping the pulses in time, the beams are combined with a dichroic mirror and then focused onto a sample with a microscope objective. A scanning mirror (or a scanning stage) is used to illuminate different part of the sample. The anti-Stokes light is separated from the excitation light with a short-pass filter, and then focused onto a detector.

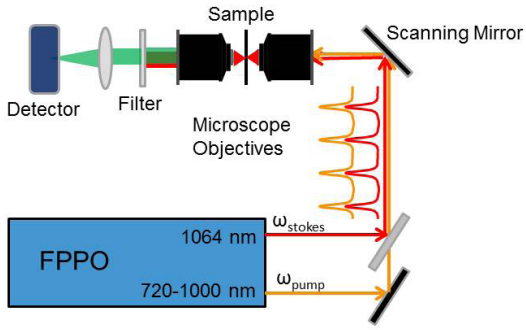
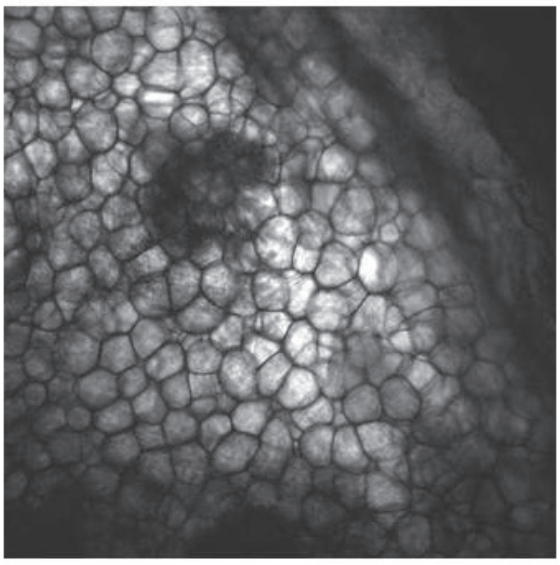
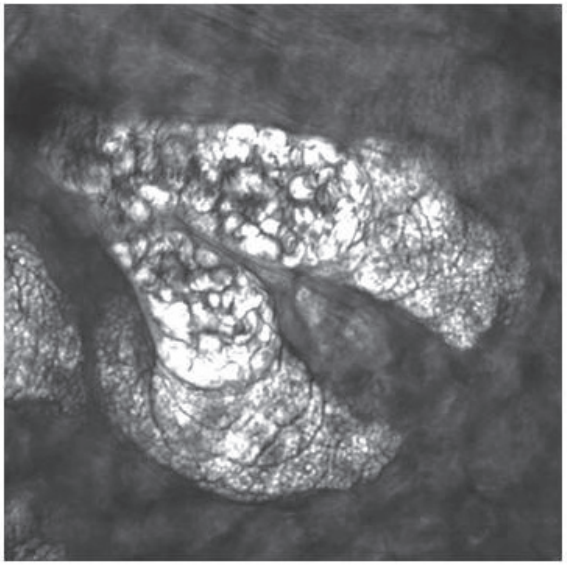


Figure 3. Experimental set-up for CARS microscopy. The FPPO-1000 provides the pump beam from the OPO signal and the Stokes beam from the fiber laser pump.

To demonstrate the application of the FPPO for CARS microscopy, images of a mouse ear were taken at by the Xie group at Harvard University. Using the OPO signal beam tuned to 816.8 nm and the fundamental at 1064 nm, the lipid band at 2845 cm^{-1} was excited. The emitted anti-Stokes light at 662.8 nm was then separated from the excitation light with a filter and detected with a photomultiplier tube.



318 µm x 318 µm



127 µm x 127 µm

Figure 4. CARS images of a mouse ear. The pump and stokes beam were tuned to excite the lipid vibration at 2845 cm^{-1}. Two images at different locations of the sample are shown. The image on the left has an area of 318 µm x 318 µm and the image on the right image has an area of 127µm x 127 µm

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