Frequency modulation CARS imaging with a fiber optical parametric oscillator

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We present coherent Raman imaging with a novel fiber optical parametric oscillator (FOPO). The FOPO combines a rapid and wide tunability to access Raman bands between 865 and 3050 cm^{-1} within only 5 ms with a frequency modulation (FM) at 20 MHz for fast switching between on- and off-resonance measurements.

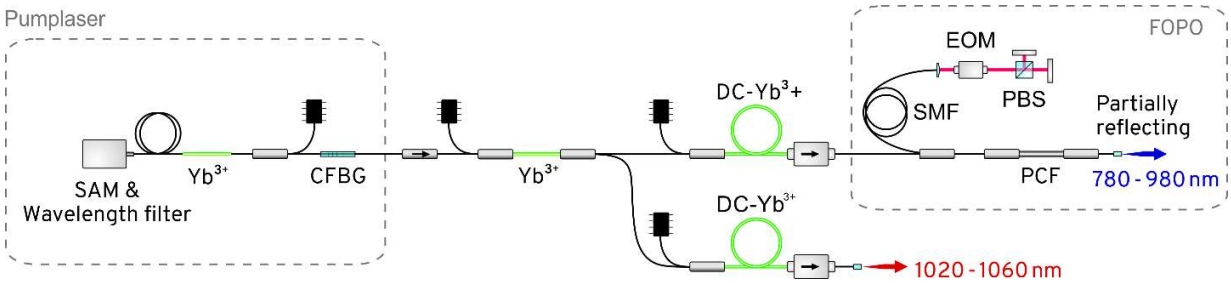

Fig. 1: Setup of the portable fiber optical parametric oscillator. SAM: saturable absorber mirror. Yb3+: Ytterbium-doped fiber; CFBG: chirped fiber Bragg grating. DC: double-clad fiber; SMF: single-mode fiber; EOM: electro-optic modulator; PBS: polarizing beam splitter; PCF: photonic crystal fiber

When measuring weak concentrations of Raman scatterers the maximum achievable sensitivity is usually limited by the non-resonant background in CARS microscopy [1] and by cross-phase modulation in SRS microscopy [2]. To overcome this limitation we implement a frequency modulation at 20 MHz by means of an unbalanced electro-optic delay in the feedback of the FOPO. The resulting two different round trip times in the FOPO together with chromatic dispersion and a fixed arrival time of the following pump pulses effectively result in two distinct wavelength filters, one on- and the other off-resonance. We present images and first concentration measurements of deuterated DMSO (dDMSO) achieving two orders of magnitude higher sensitivity compared to the performance without frequency modulation. The resolvable concentration of down to 0.5% is near to reported values within FM-CARS measurements using solid-state laser systems [1], however, now realized with a robust and portable fiber-based light source for improved applicability.

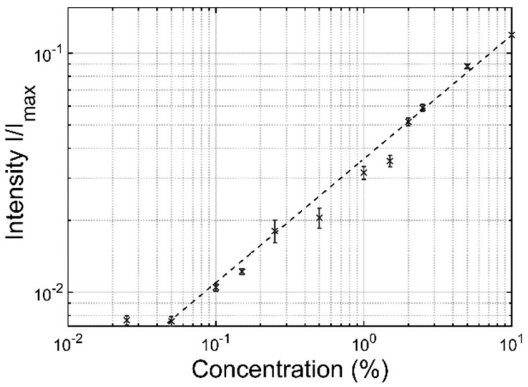

Fig. 2: Dilution measurements: I is the FM-CARS signal intensity from dDMSO dissolved in water, while I_{max} is the signal intensity from a pure dDMSO sample. The detector bandwidth was set to 1 Hz in all measurements.

References:

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