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Waveguide-based optical parametric amplification for coherent Raman imaging

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Silicon nitride (Si_3N_4) waveguides offer a versatile on-chip platform, on which nonlinear processes such as four-wave mixing (FWM) can be driven very efficiently due to the high nonlinearity [1]. Therefore, lower pump energies and shorter interaction lengths are necessary in comparison to fibers [2]. We experimentally exploit these advantages in a tunable waveguide-based optical parametric amplifier (WOPA) by stimulated FWM in Si_3N_4 waveguides for narrowband coherent anti-Stokes Raman scattering (CARS) imaging.

In the experiments, a fiber laser emitting 800 fs pulses centered at 1033 nm wavelength pumped a Si_3N_4 waveguide (950 nm high, 1300 nm wide, and 7 mm long) to generate sidebands by degenerate spontaneous FWM (Fig. 1(a), red line). In addition, a tunable cw radiation from a titanium:sapphire laser was coupled into the waveguide to stimulate the FWM process (Fig. 1(a), blue lines), resulting in an enhancement of the idler wave by 35 dB. The used pump energy (3 nJ) and waveguide length, respectively, resulted in an improvement by two orders of magnitude compared to fiber experiments [3].

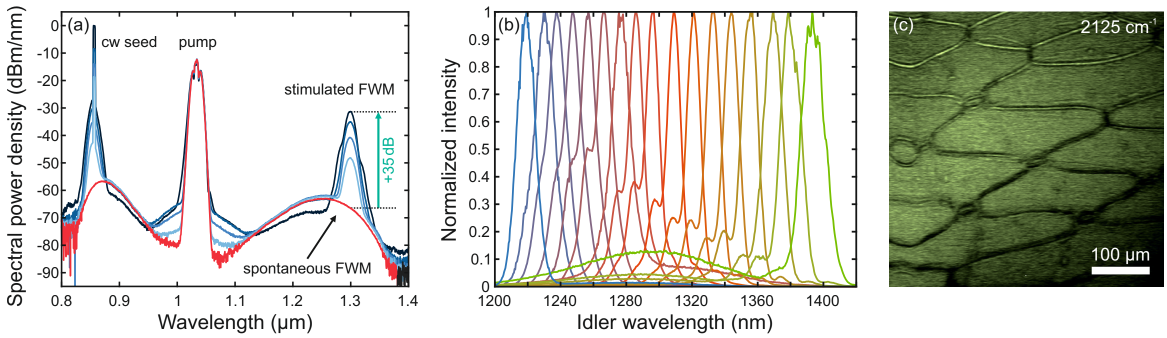

Fig. 1 (a) Spectra of spontaneous (red dashed curve) and stimulated FWM (blue curves) measured in a 1300 nm wide waveguide. (b) Stimulated FWM spectra tuned by changing the seed wavelength measured in a 1400 nm wide waveguide. (c) Recorded CARS image of a chlorophytum comosum leaf soaked with dDMSO.

The idler wavelength could be tuned from 1220 nm to 1400 nm (exemplary spectra shown in Fig. 1(b)) by changing the seed wavelength from 896 nm to 818 nm in a 1400 nm wide waveguide. Moreover, by choosing different waveguide widths wavelength conversion into different wavelength regions was enabled (compare Fig. 1(a) and (b)), ultimately covering the spectral range up to 1600 nm. These idler wavelengths enable label-free and chemically-selective CARS imaging from the fingerprint to the CH-stretch region. The applicability of the WOPA was demonstrated by acquiring CARS images (Fig. 1(c)) of a cross-sectional cut of a leaf of chlorophytum comosum, soaked in dimethyl sulfoxide-d_6 (dDMSO). The image acquisition was accomplished with lock-in detection with a pixel dwell time of 10 μs and image sizes of 1024×1024 pixels.

In the future, the WOPA light source has the potential to be set up as an all-integrated device. Furthermore, the setup could be miniaturized further by integrating the seed laser source on the chip [4] as well as the detection of the CARS signal [5].

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