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Optical Parametric Oscillator Based on Silicon Nitride Waveguides

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Fiber-based optical parametric oscillators (OPOs) have been used for decades as wavelength-tunable light sources, which are attractive for applications such as coherent Raman spectroscopy or imaging [1,2]. However, the higher nonlinearity of integrated waveguides opens the potential to pave the way towards a fully-integrated waveguide-based OPO (WOPO) light source on a single chip [3,4]. Here, we study the WOPO exploiting four-wave mixing (FWM) in silicon nitride (Si_3N_4) waveguides synchronously pumped by an ultra-fast fiber laser.

The experimental setup consists of a Si_3N_4 waveguide (800 nm high, 1050 nm wide, and 10 mm long) pumped by a mode-locked fiber laser around an emission wavelength of 1030 nm with 40 MHz repetition rate to generate signal and idler sidebands by degenerate spontaneous FWM, shown in Fig.1 (a). Additionally, a Fourier filter behind the pump laser was used to adjust the pump pulse duration between 370 fs and 1 ps (not shown). The signal sideband was coupled into a polarization-maintaining fiber (PMF) and fed back to temporally and spatially overlap with the next pump pulse to stimulate the FWM process. Dispersive tuning of the WOPO was achieved by adjusting the free-space delay (Δt).

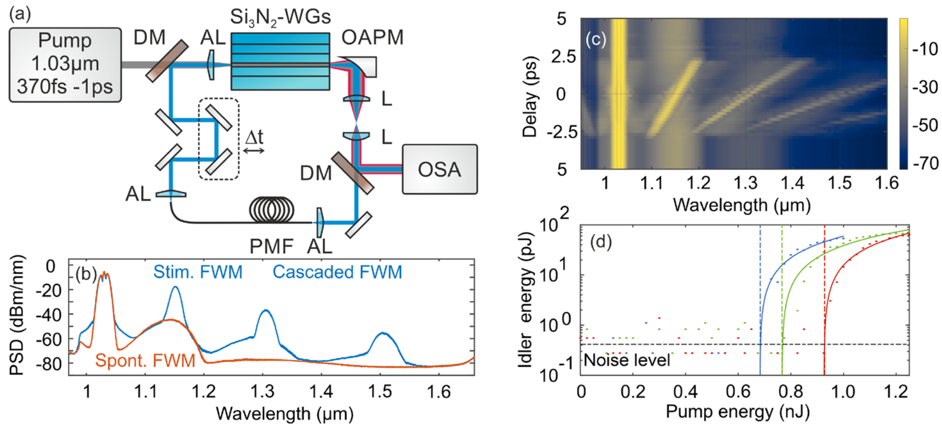

Fig.1 (a) Schematic of the experimental setup. (b) Spectra of spontaneous (red) and stimulated FWM (blue). (c) Color-coded output spectra of the WOPO as a function of the relative delay of the signal pulses at 1.25nJ pump energy. (d) External output energy of the WOPO as a function of external pump energy with different pump pulse durations (500, 700, and 900fs).

The presented WOPO showed 27 dB amplification in the idler sideband, followed by two stimulated cascaded FWM sidebands because of phase-matching between pump and idler waves. The tuning of the WOPO was accomplished by changing the free-space delay, thus, varying the temporal delay between stretched signal and pump pulses. As a result, the output idler wavelength was tuned from 1099 nm to 1194 nm, which corresponded to the bandwidth of the measured spontaneous FWM spectrum. The numerical calculations showed that, by engineering the waveguide dispersion, the accessible tuning range of the idler sideband could extend into 2 µm which is a compact pump source for various applications such as nonlinear microscopy. Moreover, to determine the oscillation threshold of the WOPO, the output idler energy versus pump energy was measured (Fig.1(d)), indicating an oscillation threshold at 0.68 nJ for 500 fs pump pulse duration, which increased with longer pump pulse duration. The maximum idler pulse energy of 63 pJ was extracted from the WOPO when pumped with 1.25 nJ at 900 fs.

In conclusion, compared to an earlier proof-of concept [4], this Si_3N_4-WOPO is even more advantageous for nonlinear microscopy and various other metrological applications by being operated at a 40 times higher repetition rate of 40 MHz, and is therefore representing an important step towards an all-integrated light source.

References

[1] M. Brinkmann, A. Fast, T. Hellwig, I. Pence, C. L. Evans, and C. Fallnich, “Portable all-fiber dual-output widely tunable light source for coherent Raman imaging,” Biomed. Opt. Express **10**, 4437 (2019).

[2] K. Yang, S. Zheng, Y. Wu, P. Ye, K. Huang, Q. Hao, and H. Zeng, “Low-repetition-rate all-fiber integrated optical parametric oscillator for coherent anti-Stokes Raman spectroscopy,” Opt. Express **26**, 17519 (2018).

[3] K.-Y. Wang, M. A. Foster, and A. C. Foster, “Wavelength-agile near-IR optical parametric oscillator using a deposited silicon waveguide,” Opt. Express **23**, 15431 (2015).

[4] N. M. Lüpken, D. Becker, T. Würthwein, K.-J. Boller, and C. Fallnich, “Toward integrated synchronously pumped optical parametric oscillators in silicon nitride,” Optics express **29**, 39895 (2021).