Efficient and Broadband Generation of Mid-Infrared Pulses by Optical Parametric Amplification in Dispersion-Engineered Thin Film Lithium Niobate

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Introduction. Optical parametric amplification (OPA) is an enabling technology for molecular spectroscopy and quantum photonics. Pumped by mature near-infrared lasers, OPA sources can generate broadband light in the mid-infrared (MIR) [1]. In many cases, low power requirements and compact footprints are crucial. However, in order to achieve sufficient parametric gain in standard nonlinear crystals, MIR OPA sources require driving lasers with high pulse energies and peak powers. These are typically provided by bulky and expensive ultrafast laser amplifiers. Here, we demonstrate a simple and efficient broadband MIR source based on OPA in thin-film lithium niobate (TFLN) on sapphire waveguides. These devices are directly driven by a commercially available mode-locked Yb-fiber laser and seeded by a CW telecom source to generate broadband pulses of MIR light. Confining light into nanophotonic TFLN waveguides allows for strong normalized efficiencies and the ability to engineer the waveguide dispersion by tuning its cross-sectional geometry. Here we dispersion-engineer symmetric temporal walk-off between the telecom signal and MIR idler near 3200 nm, with respect to the 1045-nm pump. Under these conditions, the large parametric gain centered around the peak of the pump pulse traps the signal and idler, thereby enabling OPA over distances much longer than the pulse-splitting length [2]. As a result, when pumped with picojoules of pulse energy, these devices efficiently generate short pulses of signal and idler. We observe ~60% of conversion efficiency for on-chip pump pulse energies of 7 pJ and measure up to 140 nm of idler bandwidth, which supports pulses as short as 75 fs. These devices represent one of the most compact sources of MIR light reported to date.

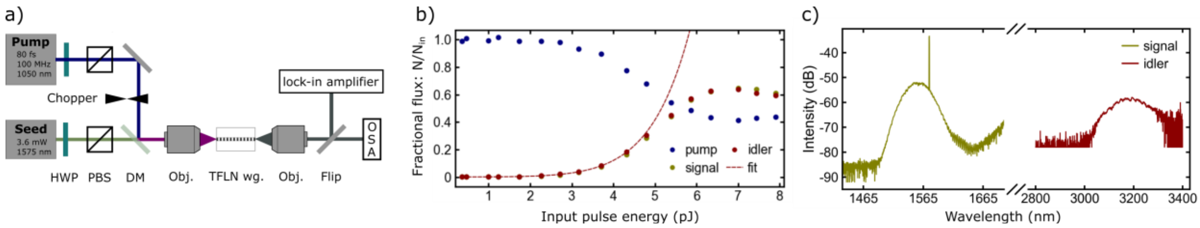

Fig. 1 a) Experimental setup. HWP, half-wave plate; PBS, polarizing beam-splitter; DM, dichroic mirror; Obj., reflective objective; TFLN wg., thin film lithium niobate waveguide; Flip, flip mirror; OSA, fiber-coupled optical spectrum analyzer. b) Generated signal and idler conversion efficiency (green and red dots, respectively). Dashed red: fit of the optical parametric growth. Fractional pump photon flux in blue. c) Generated signal and idler power spectral density in log scale for an input pulse energy of ~4 pJ. Both curves are offset for a better readability.

Experimental results. We use a 5-mm-long periodically poled TFLN nanowaveguide with a top width of 2885 nm, a film thickness of 1035 nm and an etch depth of 650 nm leading to a pump-signal and pump-idler group-velocity mismatch of +/- 20 fs/mm, respectively. The characterization setup is shown Fig. 1(a). The waveguide is pumped using a mode-locked laser delivering 80-fs pulses with a repetition rate of 100 MHz at a central wavelength of 1045 nm and seeded with 10 µW of on-chip average power from a CW laser emitting at 1575 nm. We chop the pump beam before the dichroic mirror [Fig. 1(a)] and use lock-in detection to obtain CW-background-free measurements of the average signal and idler output power generated by OPA. Under ~4.5 pJ of on-chip input pulse energy, the measured signal and idler output power are in a good agreement with the predicted exponential growth (Fig. 1(b), dashed red curve), reaching unsaturated gains as large as 37 dB. Above 4.5 pJ of pulse energy, the gain enters a saturated regime. In this regime, the depleted pump no longer traps the generated signal and idler and the three pulses walk off from each other [2]. As a result, using a maximum of 7.9 pJ of input pulse energy, the on-chip signal and idler average power reach up to 320 µW and 160 µW, respectively, corresponding to a conversion efficiency of 60% with respect to the on-chip pump photons. The measured signal and idler spectra [Fig. 1(c)] display a full-width at half maximum of approximately 37 nm and 140 nm, respectively, corresponding to sub-80-fs pulse durations assuming transform limited pulses.

Conclusion. We have demonstrated an efficient and broadband MIR source using OPA in dispersion-engineered TFLN nanophotonic waveguides. Using a commercially available pump and seed, we generated up to 160 µW of MIR average power and measured a 140-nm-broad idler spectrum centered at ~3200 nm. We believe this technology will open a new path for compact, efficient and broadband OPA.

References

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