High-energy, mid-IR, picosecond pulses generated by a compact, high-harmonic-cavity, optical parametric oscillator

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Abstract:

Synchronously pumped optical parametric oscillators (SPOPOs) are recognized as useful laser sources for the production of tunable pulses over a broad wavelength range, including the mid-IR. This could potentially enable mid-IR materials processing applications, such as resonant infrared pulsed laser deposition, if pulses of sufficient energy could be realised. However, it is challenging to construct SPOPOs pumped with low-repetition-rate (<10 MHz) high-pulse-energy laser sources as it would normally require extremely long cavity lengths (>30 m) to match the synchronous pumping requirement. Here we report the use of an OPO cavity that is just a small fraction of the length required to match the pump repetition rate, which allows the near-IR signal to resonate in the cavity at a high harmonic of the pump repetition rate while efficiently extracting high-pulse-energy mid-IR idler pulses.

The pump source was an Yb-fibre master-oscillator-power-amplifier system, providing linearly polarized, 150-ps pulses with a 1-MHz repetition frequency and 11-μJ energy at 1035 nm. The OPO consisted of a 4-mirror (two 250-mm radius-of-curvature mirrors and two plane mirrors) bow-tie ring cavity, with all mirrors coated with high reflection (HR) at signal wavelengths and high transmission at pump and idler wavelengths. A 40-mm-long MgO-doped periodically poled lithium niobate (PPLN) crystal, having five gratings with periods ranging from 29.5 to 31.5 μm in steps of 0.5 μm, was used as the non-linear gain medium. The pump beam was focused into the PPLN with a beam waist of 85 μm, to match the theoretically predicted signal beam waist of 90 μm. The OPO cavity length (1.554m) was set to 1/193 of the length required to match the 1MHz repetition frequency of the pump laser (300m). Without output coupling, the un-extracted signal pulses generated in the PPLN experienced 193 round-trips in the cavity before temporally overlapping with the next pump pulse. The idler pulses were extracted directly through one of the curved mirrors.

The repetition frequency of the signal leaking through the HR mirrors was measured to be the 193rd harmonic of the pump and the amplitude of the signal pulses was observed to gradually decay due to cavity losses until the next pump pulse arrived. The repetition frequency of the idler was the same as that of the pump as it was only generated in the presence of both pump and signal pulses. The OPO oscillated with a pump-pulse energy threshold of ~3 μJ and generated up to 1.7-μJ idler pulse energies at a wavelength of 3.2 μm. The idler output energy increased linearly with increasing pump energy at a slope efficiency of 21% and the maximum energy conversion efficiency was 15% from pump to idler. The idler had a spectral full-width at half-maximum bandwidth of 6 nm and the wavelength could be tuned from 2300 nm to 3500 nm by using different PPLN grating periods and temperatures. Without active stabilization or intentionally isolating the OPO from external interference, the OPO still exhibited a good stability with power fluctuation within ±6% in 30 minutes. The beam propagation factor (M^2) of the idler was measured to be ~2.2.