Efficient, High-Power, 16-GHz, Picosecond Optical Parametric Oscillator Pumped by an 81-MHz Fiber Laser

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Abstract: We report the generation of 16-GHz repetition-rate picosecond pulses in an optical parametric oscillator synchronously pumped by an 81-MHz Yb fiber laser, providing 650 mW of average power tunable over 1.45-1.75 μm.

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The development of ultrafast optical sources with very high repetition rates in the multi-GHz range is an active area of research due to the demand for such sources in a variety of applications including telecom systems with high bit rates, time-resolved spectroscopy, optical clocking, high-speed electrooptic sampling, optical switching, and analogue-to-digital conversion. Synchronously-pumped optical parametric oscillators (SPOPOs) are attractive candidates for the generation of high-repetition-rate ultrashort pulses with wide wavelength tunability from the UV to mid-IR. This feature can be of great importance in applications such as multi-channel telecom systems with each channel providing thousands of continuous-wave carriers or in spectroscopy, where several closely-separated wavelengths are required.

Apart from the established multi-GHz repetition-rate pulse sources such as edge-emitting semiconductor lasers and fiber lasers with low output power (few tens of milliwatts), there has been an effort to generate tunable multi-GHz picosecond pulses with SPOPOs [1]. However, the main drawback of this technique is the need for a custom-designed, high-power laser pump source with the same repetition-rate, which is a major challenge in itself. Here, we represent results of a technique for the generation of multi-GHz repetition-rate pulses in a picosecond SPOPO pumped by a mode-locked fiber laser at 81 MHz. This technique, which we have already demonstrated in femtosecond regime [2], has several advantages [3], making it possible to generate multi-GHz repetition-rate pulses using widely available, high-power mode-locked lasers with MHz repetition-rate. In addition, the upper limit to the attainable pulse repetition rate is set not by the minimum attainable physical length of the SPOPO cavity, but by the pump and circulating signal pulse durations.

The technique relies on the increase of cavity length by a fraction of pump laser cavity length [2,3]. In this method, to generate the Qth harmonic of the pump repetition-rate, we set the SPOPO cavity length to be (n/Q) times the pump laser cavity length (n is integer, $n>Q$ and with no common divisor). The $(n\text{-}Q).l_p/Q$ difference in SPOPO and pump cavity lengths compels every generated signal to travel Q round-trips inside the new elongated SPOPO cavity to build-up a distance equal to an integer number (n) of pump laser cavity lengths, before meeting the next pump pulse in the nonlinear crystal. This difference, independent of the value of n, causes a time difference of $(1/Q).l_p/c$ between generated signal pulses, which results in an output signal pulse train with a repetition-rate Q times that of the pump laser By deploying this technique, we demonstrate here the generation of signal pulses at nearly 200^{th} harmonic of a fiber pump laser repetition-rate.

The schematic of experimental setup is shown in Fig. 1. The picosecond SPOPO is based on a 50-mm-long

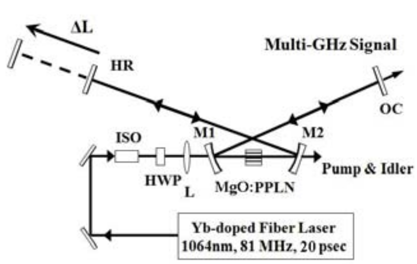

Fig. 1. Experimental setup of SPOPO. ISO: optical isolator, HWP: a half-wave plate, L: focusing lens.

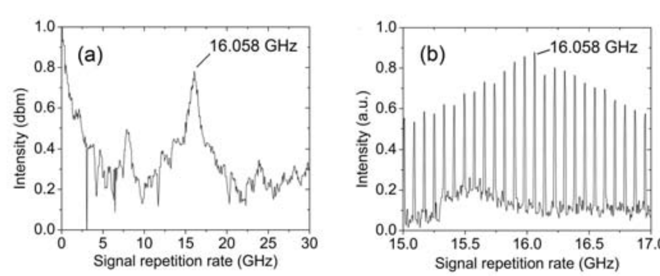

Fig. 2. (a) Frequency spectrum of output signal pulses in the picosecond SPOPO at the 198^{th} harmonic of pump repetition-rate (16.058 GHz), (b) a close-up view of the peak shown in part (a). Here the separation between peaks is 81 MHz which is the fundamental pumping repetition rate.

MgO:PPLN crystal containing seven gratings, equally spaced in period from 28.5 to 31.5 μm, and placed in an oven for temperature control. The crystal facets are antireflection (AR)-coated (R<1%) over 1.45-1.75 μm, and have high transmission (T>97%) for the pump at 1064 nm. The pump laser is a mode-locked Yb fiber laser (Fianium, FP1060-20), delivering pulses of 20 ps duration at 81-MHz repetition-rate. This repetition-rate corresponds to a standing-wave cavity length of 1851 mm. To demonstrate the concept and for the sake of simplicity, the SPOPO is configured in a four-mirror linear cavity with no intracavity dispersion compensation. The SPOPO cavity consists of two spherical mirrors, M1 and M2 (r=200 mm), one plane high-reflector (HR) and a plane output coupler (OC) with a transmission of ~5% over 1.33-1.56 μm. For every repetition-rate, Q, the linear cavity length of SPOPO is set to be 1851+(1851/Q) mm, where n=Q+1.

Because of potential interest for telecom applications, we have operated the SPOPO over the telecom band near 1550 nm. However, the SPOPO is easily tunable over 1.45-1.75 μm (limited only by the crystal coating) by changing the grating period or crystal temperature. By pumping the SPOPO at 5.22 W, the highest repetition-rate harmonic achieved was the 198th harmonic of the pump repetition rate, corresponding to 16.058 GHz. Figure 2 shows the frequency spectrum of the generated signals, representing a peak at 16.085 GHz. The data was obtained using an InGaAs photodetector (New Focus 1444, 20 GHz, 18.5 ps) and a spectrum analyzer (Anritsu MS2667c, frequency range of 9 kHz to 30 GHz).

For every harmonic, Q, there exists a train of n equally-spaced travelling signal pulses inside the cavity, where every pulse travels Q round-trips before experiencing gain with the next pump pulse. Therefore, by increasing the harmonic number, the amount of intracavity loss also increases in the absence of gain. This effect can be seen in Fig. 3. The SPOPO will continue to operate if the first signal pulse generated by a pump pulse does not vanish due to the intracavity losses, before reaching and meeting the next pump pulse. In our SPOPO, since the pump power is high, this phenomenon does not occur. Although the output signal power drops with the increase in harmonic number due to increased loss, as expected, beyond a certain harmonic number (198th), an increase in output power is observed, as shown in Fig. 3. This behavior is attributed to the increasing spatial overlap of the successive signal pulses in train, which results in partial gain of adjoining pulses to the main signal pulse reaching the next pump pulse and being amplified.

We studied the power performance of SPOPO at the highest repetition rate of 16.058 GHz, with the results shown in Fig. 4. At this repetition-rate, the SPOPO average pump power threshold was 3.17 W. The signal output power increases linearly with pump power, but beyond 4.5 W there is evidence of saturation in efficiency at around 12%. This may be due to thermal effects in the MgO:PPLN crystal and is currently under investigation. We also recorded the SPOPO signal spectrum and found it to be a clean single peak with a bandwidth of 0.45 nm.

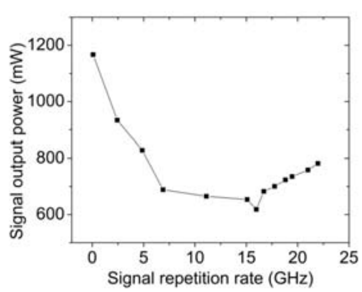

Fig. 3. SPOPO output power performance while increasing harmonic number, with a minimum at about 16 GHz.

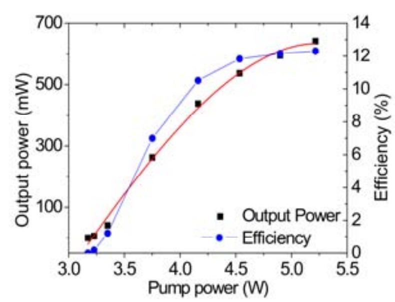

Fig. 4. SPOPO power performance in highest harmonic number at 16.058 GHz.

In conclusion, we have generated 650 mW of average power at 16.058 GHz repetition-rate tunable over 1.45-1.75 μm in a compact design based on a SPOPO pumped at 81 MHz by a picosecond Yb fiber laser at 1.064 μm.

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