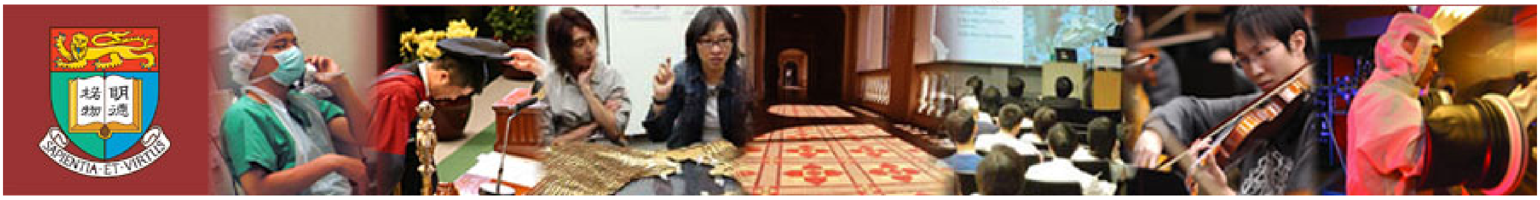

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Tunable Repetition Rate Multiplier Based on Fiber Optical Parametric Oscillator

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Abstract- **We demonstrate a tunable repetition rate multiplier based on fiber optical parametric oscillator. 2-6 times repetition rate multiplication of a 10-GHz pulse source is achieved with a tuning range of 20 nm in the L-band.**

I. INTRODUCTION

High-repetition-rate (10 GHz or above) picosecond pulses are in high demand in many applications such as ultrafast optical communications and ultrafast signal processing. By direct modulation using Mach-Zehnder modulators [1] or electroabsorption modulators [2], repetition rate up to 40 GHz can be achieved easily. The conventional direct generation of high quality short pulses with repetition rate over 40 GHz is difficult in practice since it requires ultra high-speed electronic components. An alternative way is to using all-optical repetition rate multiplication to achieve high-repetition-rate pulses [3-5]. Repetition rate multiplication through the temporal Talbot effect, which has been demonstrated using a dispersive fiber [3] or fiber Bragg gratings (FBGs) [4,5], is a simple and flexible approach. For example, tunable repetition rate multiplications of a 10 GHz pulse with multiplication factors of 2-3 [3] and 2-5 [4] have been demonstrated. In this paper, we propose an alternative solution to perform tunable repetition rate multiplication using a fiber optical parametric oscillator (FOPO). Since the time response of the parametric process in fiber is in the femtosecond range [6], repetition rate multiplication systems based on FOPO has potential to operate at data rates in the Tbit/s regime. In addition, along with repetition rate multiplication, a wide range of wavelength conversion can also be achieved since the FOPO can have a wide tunability [7]. In this paper, we demonstrate a FOPO which can achieve 2-6 times repetition rate multiplication of a 10 GHz pulse source, along with a wavelength conversion range of 20 nm in the L-band.

II. PRINCIPLE

When a pulsed pump is launched into a cavity with a gain medium [e.g., highly-nonlinear dispersion-shifted fiber (HNL-DSF)], the parametric fluorescence will be amplified and feed back to the fiber input as a seed. If we put an optical delay line (ODL) into the cavity, the cavity length can be adjusted accordingly. Thus, we can tune the ODL so that the round-trip time of the signal is an integral multiple of the separation between the pump pulses. The signal will be amplified every round trip and appear at the FOPO output. The repetition rate of the output signal is thus the same as that of the pump. To

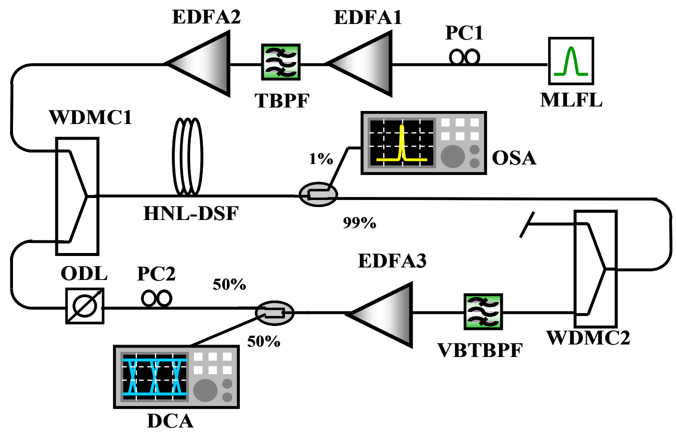

Fig. 1. Experimental setup of the FOPO. EDFA: erbium-doped fiber amplifier, TBPF: tunable band-pass filter, OSA: optical spectrum analyzer, PC: polarization controller, VBTBPF: variable bandwidth tunable-bandpass filter, MLFL: mode-locked fiber laser, WDMC: wavelength division-multiplexing coupler, DCA: digital communication analyzer.

achieve repetition rate multiplication, we can adjust the cavity length so that after the first round trip, the feedback signal has a time separation T with a succeeding pump pulse which is $1/N$ (N is an integer larger than 1) of the time separation between the pump pulses, thus at the second round trip, another signal pulse train will be generated with a time separation T with the original signal. Every signal pulse train interacts parametrically with the pump pulse only once each N round trip. The signal at the FOPO output will have a repetition rate that is N times that of the original pump pulse. Note that the single pass parametric gain should be able to compensate the multiple-pass loss of the cavity to allow the signal start to oscillating. By tuning the ODL, a continuously tunable repetition rate multiplier can be achieved accordingly.

III. EXPERIMENTAL SETUP

Fig.1 shows the experimental setup of the FOPO based repetition rate multiplier. The pulse source to pump the FOPO was generated by a picosecond MLFL with repetition rate of 10 GHz, pulsewidth of 10 ps and center wavelength of 1561 nm. The pump was amplified, filtered and coupled into the cavity through a WDMC1. The average power of the pump was measured to be 0.32 W after the WDMC1 at the fiber input, if we take duty ratio into consideration, the peak power of the pump was estimated to be 3.2 W. A 50-m long HNL-DSF was deployed as the gain medium, which had nonlinear coefficient of 14 $W^{-1}km^{-1}$, zero-dispersion wavelength (ZDW) of 1554.7 nm and dispersion slope of 0.035 $ps/nm^2/km$. The

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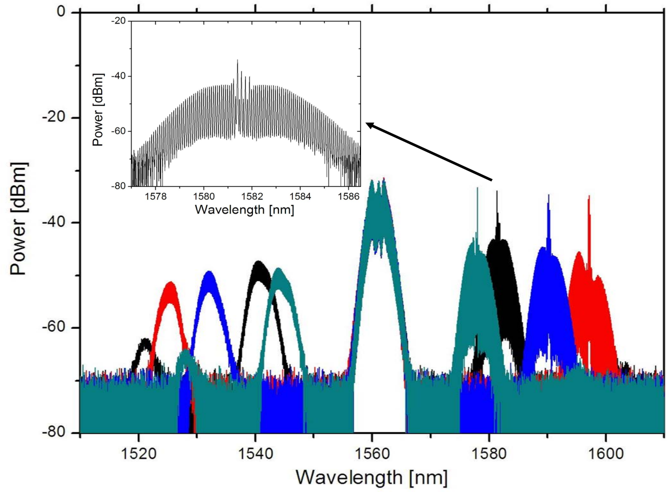

Fig. 2. Optical spectra measured at HNL-DSF output using OSA when the pump was at 1561 nm by tuning the intra-cavity VBTBPF as in Fig. 1. Inset is the enlarged version of the signal oscillating signal at 1582 nm.

output of the fiber was monitored by an OSA through a 1/99 coupler. WDMC2 was used to filter out the pump, and VBTBPF with a 0.7-nm 3-dB bandwidth was used to filter out the desired signal. As a result, the FOPO was only singly resonant with the signal. The EDFA3 in the cavity was an L-band EDFA, which used to compensate the cavity loss, amplifies the signal power to 20 mW. A 50/50 coupler in the cavity provided 50% feedback and 50% output. The PC2 in the cavity was used to align the SOP of the signal with that of the pump, while the ODL in the cavity was used to adjust the cavity length, thus to perform continuous tuning of the repetition rate, as discussed in the above section.

The waveform of the output signal was recorded using a DCA. The receiver module used was Agilent 86116A, which had an operating wavelength of 1000-1600 nm, an optical bandwidth of 53 GHz and an electrical bandwidth of 63 GHz.

IV. Results and discussions

Fig. 2 shows the optical spectra measured at the FOPO output port when the signal repetition rate is 20 GHz. The pump wavelength is fixed at 1561 nm. Tunability is achieved by tuning the VBTBPF center wavelength from 1578 nm to 1598 nm, which is as wide as 20 nm. Further tuning is limited by the FOPA gain region when the pump is fixed at 1561 nm. Inset is the enlarged version of the signal oscillating signal at 1582 nm. A frequency comb could be observed with longitudinal modes with separation of 0.16 nm, which corresponds to the 20 GHz repetition rate of the pulse train.

Fig. 3 shows the waveforms of pump and signal pulses measured using DCA. Fig. 3 (a) is the original pump pulse, which has a repetition rate of 10 GHz. Fig. 3 (b)-(f) are the output signal pulses at 20-60 GHz, respectively. The output signal here has a wavelength of 1582 nm. The pulsewidth of the output signal is measured to be 10 ps by the DCA, which is the same as the input pump pulse. At higher multiplication factor, the fluctuations of the intensity become larger, which

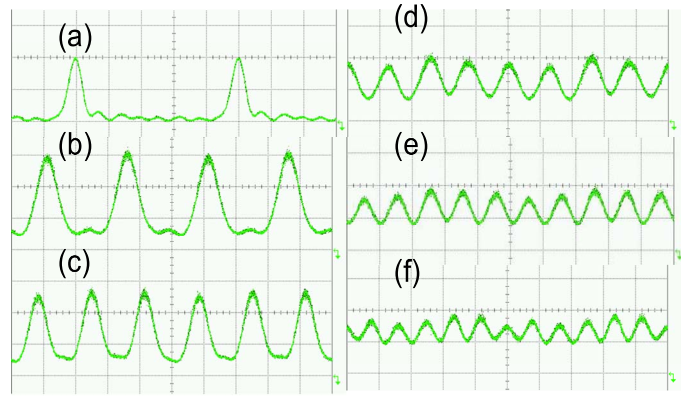

Fig. 3. Waveforms measured using DCA. (a) 10 GHz pump; (b)-(f) 20-60 GHz signal. The horizontal scale is 20 ps/div.

may due to the intrinsic constraint of this scheme. The multiplication factor is larger than that reported in [3,4]. In addition, the system has the potential to work in the Tbit/s range since the ultrafast response of the FOPA.

V. Conclusion

In conclusion, a tunable repetition rate multiplier based on a FOPO is demonstrated. 20-60 GHz repetition rate pulses could be obtained using a 10 GHz source by simply tuning the ODL. Along with repetition rate multiplication, wavelength conversion is also achieved with a tuning range of 20 nm in the L-band. This scheme has the potential to be an effective and flexible way of increasing the repetition rate of the pulses for future ultrafast optical communications.

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