# Wavelength-Tunable Nearly-Transform-Limited Pulse Generation Based on Fiber Optical Parametric Oscillator

Yue Zhou, Kim K. Y. Cheung, Sigang Yang, P. C. Chui, and Kenneth K. Y. Wong*

Photonic Systems Research Laboratory, Department of Electrical and Electronic Engineering,
The University of Hong Kong, Pokfulam Road, Hong Kong. *kywong@eee.hku.hk

**Abstract** *We demonstrate an all-fiber widely-tunable sub-picosecond fiber optical parametric oscillator based on highly-nonlinear dispersion-shifted fiber. Nearly-transform-limited sub-picosecond pulses are generated over a 60-nm tuning range around 1550 nm.*

## Introduction

Transform-limited pulse generation is crucial to the success of long-distance and high-bit-rate transmissions. While nearly-transform-limited pulse generators based on erbium-doped fiber lasers[1] and semiconductor optical amplifiers[2] have been investigated comprehensively. On the other hand, fiber optical parametric amplifier (FOPA) offers high gain and wide-gain bandwidth[3], which allows nearly-transform-limited pulse generation in potential regions where practical lasers currently are not available by using fiber optical parametric oscillator (FOPO) configuration.

Using FOPO configuration, nearly-transform-limited pulse generators have been demonstrated with wide wavelength tuning range in the near-infrared regime[4]. However, most telecommunication applications require sources in the spectral region near 1550 nm. Some picosecond FOPOs were designed to operated in this regime[5,6], but usually with limited tuning range (~40 nm). In our previous work, a picosecond FOPO was demonstrated with a tunability of 250 nm around 1550 nm[7]. However, the pulses were far from transform-limited. Thus, building a widely-tunable FOPO with nearly-transform-limited pulse around 1550 nm is highly desirable.

In this paper, we demonstrate a widely-tunable picosecond FOPO based on a spool of highly-nonlinear dispersion-shifted fiber (HNL-DSF). The ring cavity is synchronously pumped with a picosecond mode-locked fiber laser (MLFL). Nearly-transform-limited sub-picosecond pulses are generated over a 60-nm tuning range around 1550 nm. This scheme may be useful for generating nearly-transform-limited pulse in non-conventional wavelength bands.

## Experimental Setup

The experimental setup of widely-tunable sub-picosecond pulse generator is shown in Fig. 1. The pump is generated by a MLFL which generated short pulse with repetition rate of 10-GHz, pulsewidth of 2-ps. The output from pulsed laser is intensity-modulated by a 156.2-MHz electrical pulse with duty ratio of 1/64 to increase the peak power of the pump. The pump is then amplified by EDFA1 and EDFA2, and filtered by TBPF1 with a 1-nm bandwidth to produce a high-power, low-noise pump. The pump

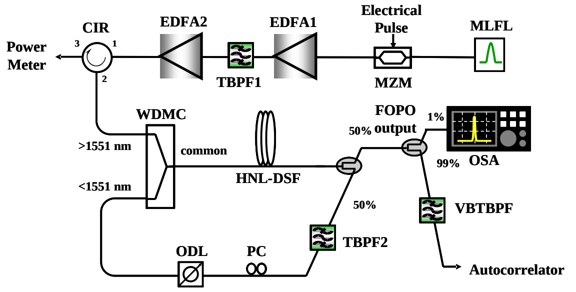


**Fig. 1:** Experimental setup of FOPO-based pulse generator. ODL: optical delay line, PC: polarization controller. EDFA: erbium-doped fiber amplifier, TBPF: tunable band-pass filter, OSA: optical spectrum analyzer, VBTBPF: variable bandwidth tunable band-pass filter, MZM: Mach-Zehnder modulator, CIR: circulator.

is broadened to 3.5 ps by the TBPF1, and is then passed through a circulator; while the reflected power by stimulated Brillouin scattering (SBS) is monitored using a power meter. Since the linewidth of the pump pulse is larger than the bandwidth of the SBS, the SBS is low and therefore the phase modulator is not required to suppress SBS. The average power of the pump is measured to be 60 mW after the circulator. Since the amplified spontaneous emission (ASE) noise in the pump is also amplified by the EDFAs, the peak power of the pump is measured to be only 5 W using a digital communication analyzer (DCA). It is then coupled into the cavity for parametric amplification through the wavelength-division multiplexing coupler (WDMC), which has a cutoff wavelength of 1551 nm.

A spool of HNL-DSF with nonlinear coefficient of 14 $W^{-1}km^{-1}$, zero-dispersion wavelength (ZDW) of 1554.7 nm and dispersion slope of 0.035 $ps/nm^2/km$, is deployed as the gain medium inside the cavity. A 50/50 coupler in the cavity provides 50% feedback and 50% output. The feedback branch is filtered by the TBPF2 with a bandwidth of 1 nm, so that only the idler (anti-Stokes wave) returned to the HNL-DSF through WDMC. Tuning is achieved by adjusting the center wavelength of TBPF2, from 1500 nm to 1550 nm. As a result, the FOPO is only singly resonant with the idler. The PC inside the cavity is used to align the state of polarization (SOP) of the idler with that of the pump, while the ODL in the cavity is used to adjust the cavity length thus the round trip time of the idler matches the pump repetition rate, so as to synchronize the idler with the pump.

The FOPO output spectrum is monitored by an OSA through a 1/99 coupler. A VBTBPF with a 4-nm bandwidth is used to filter out the desired signal or idler. The pulsewidth of the signal (idler) is measured using an autocorrelator.

**Results and Discussion**

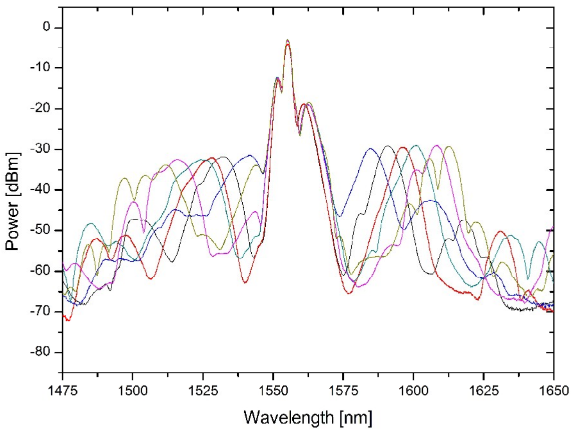


**Fig. 2:** Optical spectra measured at FOPO output when pump was at 1555 nm by tuning the intra-cavity TBPF2 as in Fig. 1.

Fig. 2 shows the optical spectra measured at the FOPO output port. The pump wavelength is fixed at 1555 nm and its spectrum broadening is due to self-phase modulation (SPM). The asymmetric structure may be due to the relatively small dispersion of the fiber at the pump wavelength[8]. Wavelength tuning can be achieved by tuning the center wavelength of the TBPF2 inside the cavity. The pump power is slightly adjusted to maintain almost the same peak for all spectra. The achievable output tuning range is from 1511.5 nm to 1541.7 nm and from 1583.1 nm to 1613.2 nm, which is as wide as 60 nm. The smaller peaks are higher order four-wave mixing (FWM) components.

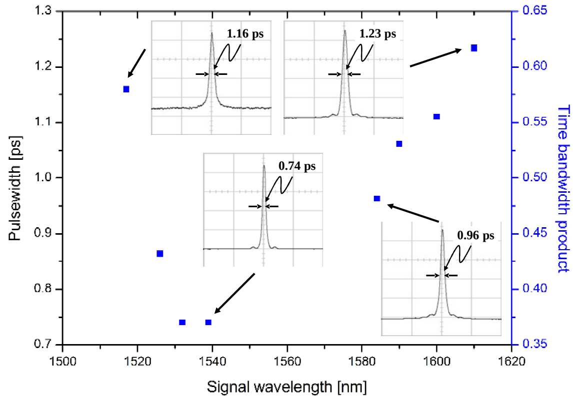


**Fig. 3:** Pulsewidth and time bandwidth product versus signal wavelength. Insets are autocorrelation traces measured by autocorrelator.

Fig. 3 shows the pulsewidth and the time-bandwidth product (TBP) as a function of signal wavelength. It can be observed that the pulsewidths of the signal are narrower than that of the pump (3.5 ps) because of the pulse compression effect[9]. The compression ratio matches well with the theoretical value of 4 to 5 when the signal is close to the pump[9] thus the walk-off between the signal and the pump is small. However, when the signal is moved away from the pump, the walk-off becomes larger, thus makes the signal pulse broader and the compression ratio smaller (2.5 to 4). The TBP is calculated to be around 0.37 to 0.61, which is slightly larger than that of the transform-limited soliton pulse, 0.315. This indicates that nearly-transform-limited pulse is generated across a 60-nm tuning range. This tuning range of nearly-transform-limited pulse around 1550 nm, is larger than those picosecond FOPOs reported[5,6].

The main limiting factor of extending the tuning range of the sub-picosecond pulse generator is the walk-off between the pump and the signal. The larger the frequency detune, the larger the walk-off between the pump and signal, thus leading to a shorter interaction length of the signal and pump and a lower parametric gain.

**Conclusions**

In this paper, a widely-tunable picosecond FOPO based on HNL-DSF was demonstrated. The output was continuously tunable from 1511 nm to 1541 nm and from 1583 nm to 1613 nm. Nearly-transform-limited sub-picosecond pulses were generated with compression factor of 2.5 to 5. This technique would be useful for generating nearly-transform-limited pulse in non-conventional wavelength bands.

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**References**


1 S. Pan et al., IEEE PTL. **18**, 604 (2006).
2 L. Duan et al., J. Lightwave Technol. **21**, 930 (2003).
3 M. E. Marhic et al., IEEE J. Select. Topics. Quant. Electron. **10**, 1133 (2004).
4 Y. Deng et al., Opt. Lett. **30**, 1234 (2005).
5 J. Lasri et al., IEEE Photon. Technol. Lett. **15**, 1058 (2003).
6 D. K. Serkland et al., Opt. Lett. **24**, 92 (1999).
7 Y. Zhou et al., Opt. Lett. **34**, 989 (2009).
8 N. Tzoar etal., Phys. Rev. A. **23**, 1266 (1981).
9 T. Torounidis et al., J. Lightwave Technol. **23**, 4067 (2005).