UWB monocycle pulse generation based on optical cross-polarization modulation

Shiguang Wang (王世光), Hongwei Chen (陈宏伟)*, Minghua Chen (陈明华), and Shizhong Xie (谢世钟)

State Key Laboratory on Integrated Optoelectronics, Tsinghua National Laboratory for Information, Science and Technology (TNList), Department of Electronic Engineering, Tsinghua University, Beijing 100084, China

E-mail: chenhw@tsinghua.edu.cn

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A novel all-optical method for ultra-wideband (UWB) monocycle pulses generation based on cross polarization modulation (CPM) effect in highly nonlinear photonic crystal fiber is proposed and demonstrated. Due to the CPM effect between the probe light and the pump pulse, a pair of polarity-reversed Gaussian pulses is produced. After proper differential delay, an UWB monocycle pulse with 84-ps width and the fractional bandwidth of 153% is generated after photodetection.

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Ultra-wideband (UWB) technologies for high-data-rate and short-range wireless communications have received extensive research interests and attention in recent years due to some distinct advantages, such as immunity to multi-path fading, large channel capacity, and low power spectral density[1−3]. Recently, UWB-over-fiber technologies are proposed to process and distribute UWB signals by optical methods, which can increase the bandwidth and transmission distance. One of the key technologies of UWB-over-fiber is optical generation for UWB signals, which is extensively investigated in the following approaches: using chromatic dispersion of the single mode fiber (SMF) or fiber grating as an optical frequency discriminator to implement phase modulation to intensity modulation (IM-PM)[4]; based on the nonlinear effects of cross gain modulation (XGM) and cross phase modulation (XPM) of the semiconductor optical amplifier (SOA) to generate a pair of polarity-reversed Gaussian pulses and followed by time delay devices[5−7]; by synchronous apodization modulation for Gaussian pulse sequence or photonic microwave filter to generate multi-band UWB (MB-UWB) pulses[8], etc. Since cross polarization modulation (CPM) effect in SOA or erbium-doped fiber (EDF) is widely investigated[9,10], it is also attractive to be used for UWB pulse generation.

In this letter, we propose a novel all-optical method to generate UWB monocycle pulses by CPM effect in highly nonlinear photonic crystal fiber (HNPCF), avoiding additional electrical-to-optical conversion and benefiting from the huge bandwidth of optical processing. We get two polarity-reversed Gaussian pulses in orthogonal polarization, which can be delayed by variable optical delay lines (VDLs) separately. Then an UWB monocycle pulse will be generated after photodetection. This scheme can be used for UWB-over-fiber communication, accurate positioning system, wireless sensor networks, and so on.

The basic principle of CPM is shown in Fig. 1. The polarization state of the input probe light is launched 45° to that of the pump pulse, which is along with the slow-axis of HNPCF. An optical wave vector can be divided into two components along the slow-axis and fast-axis of HNPCF. According to this, the probe light before HNPCF can be expressed as: $E_{\rm i} = (E_{\rm 0s}{\rm e}^{{\rm i}\phi_0}, E_{\rm 0f}{\rm e}^{{\rm i}\phi_0})$. After CPM, it turns to $E_0 = (E_{\rm 0s}{\rm e}^{{\rm i}(\phi_0+\phi_{\rm L}+\phi_{\rm NL})}, E_{\rm of}{\rm e}^{{\rm i}\phi_0})$, where ϕ_0, $E_{\rm 0s}$, and $E_{\rm 0f}$ stand for the initial phase, the amplitudes of the slow-axis and fast-axis components, respectively; $\phi_{\rm L}$ and $\phi_{\rm NL}$ are linear and nonlinear phase differences respectively between the slow-axis and fast-axis components of the output probe light. $\phi_{\rm L}$ is induced by the intrinsic birefringence in HNPCF, while $\phi_{\rm NL}$ is caused by the XPM effect between the probe light and the pump pulse. Consequently, the phase difference causing polarization rotation of the output probe light meets the following condition[11]: $\Delta\phi = \phi_{\rm L} + \phi_{\rm NL} = 2\pi L(\Delta n_{\rm L} + n_{2B} \mid E_{\rm p} \mid^2)/\lambda$, where L, λ, $E_{\rm p}$, n_{2B}, and $\Delta n_{\rm L}$ are the HNPCF length, probe light wavelength, pump power, Kerr coefficient, and linear refractive index difference between the two components. When $\Delta\phi$ equals π by adjusting the pump power properly, the polarization direction of the output probe light, after rotation, is perpendicular to that of the input probe light shown in Fig. 1, and a couple of polarity-reversed Gaussian pulses (g1 and g2) locating two orthogonal axes can be generated.

The experimental setup is shown in Fig. 2. Ultrashort pulses with the time duration of 2 ps and repetition rate of 10 GHz are emitted by a mode locked laser diode (MLLD), and modulated by a pulse

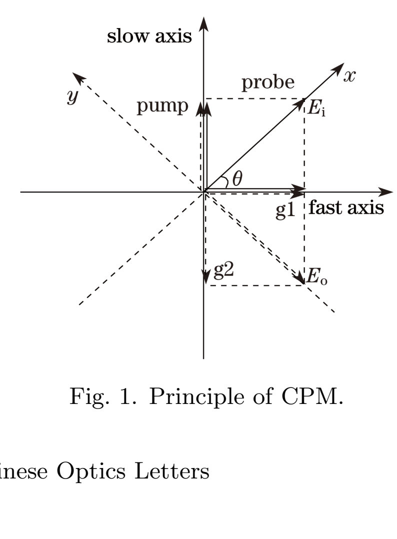

Fig. 1. Principle of CPM.

pattern generator (PPG) synchronously with fixed pattern '1000 0000 0000 0000' (one '1' every 16 bits). The modulation is completed by a Mach-Zehnder Modulator (MZM). So the signal repetition rate is 625 MHz. The modulated pump pulse is broadened from 2 ps to about 42 ps by passing through 1-km SMF. By using polarization controllers (PCs), the polarization direction of the pump pulse is maintained along the slow axis of HNPCF and that of the probe light 45° to the slow axis. The CPM effect between the pump light with the wavelength of 1554.3 nm and probe light with the wavelength of 1550 nm is completed through HNPCF after being amplified by an erbium-doped fiber amplifier (EDFA) with about 30-dBm output power. The HNPCF is lab-fabricated 50-m-long small-core photonic crystal fiber whose microscope image is shown in Fig. 2. It has a high nonlinear effect with the nonlinear coefficient of about 12 W^{-1}/km. As a result of CPM, the state of the probe light polarization is rotated 90° when the pump signal is "1", and is not changed when it is "0". The probe light passes through the optical bandpass filter (OBPF) freely by adjusting its central frequency to avoid disturbance from the pump pulse. The output of the OBPF is adjusted by a PC and split by a polarization beam splitter (PBS) yielding different time delay. Considering the optical path difference between two branches, the time delay between the two polarization components is about 42 ps by adjusting a VDL. After a polarization beam combiner (PBC) and an attenuator (ATT) for adjusting optical power, an UWB monocycle pulse is generated after a PIN detector. Further measurement can be achieved by optical spectrum analyzer (OSA), digital sampling oscillator (DSO), and electrical spectrum analyzer (ESA).

Figure 3(a) shows the broadened pump pulse with about 42-ps duration after 1-km SMF. The spectrum after the CPM effect in HNPCF is shown in Fig. 3(b), including the probe and pump light. The pump light is eliminated by an OBPF. The generated monocycle pulse with positive polarity is shown in Fig. 3(c), the pulse width of which is 84 ps, just twice of that of Fig. 3(a). It is very flexible to get a polarity-reversed monocycle pulse by tuning the PCs to change polarization states of the probe light before the PBS, as indicated in Fig. 3(d). The electrical spectrum of the UWB monocycle pulse is measured, as shown in Fig. 4. One can see that a–10-

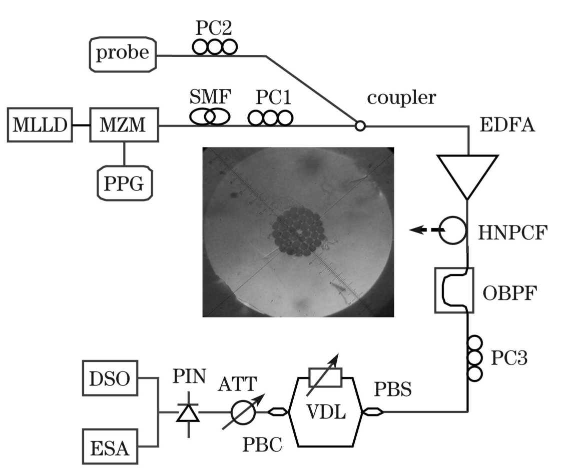

Fig. 2. UWB monocycle pulse generation configuration.

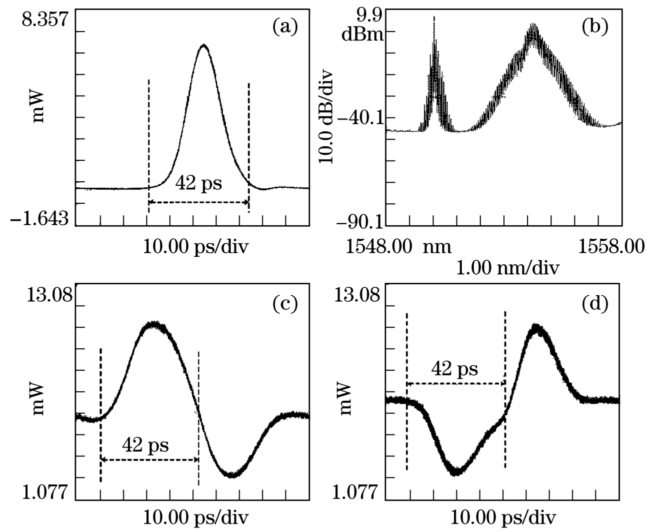

Fig. 3. (a) Input optical pulse; (b) optical spectrum after CPM; (c) generated UWB monocycle pulse with positive polarity and (d) with negative polarity.

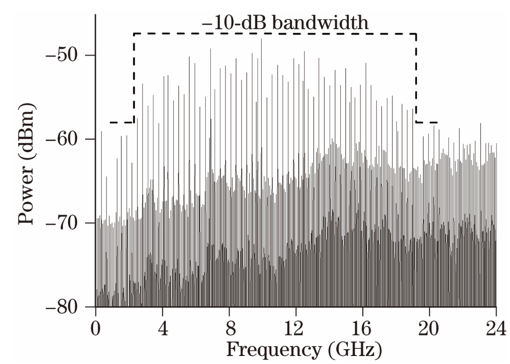

Fig. 4. Electrical spectrum of monocycle UWB pulses.

dB bandwidth occupies the frequency range from 2.5 to 18.9 GHz, which means a fractional bandwidth of 153%. It is a discrete frequency spectrum, the interval of which is just equal to the repetition rate of 625 MHz.

In conclusion, we propose and experimentally demonstrate a novel UWB monocycle pulse generation based on the CPM effect in HNPCF. An UWB monocycle pulse with the pulse width of 84 ps and the fractional bandwidth of 153% is generated, and a polarity-reversed monocycle pulse can also be flexibly obtained through tuning the PCs. This all-optical scheme avoids the bandwidth limitation of the electrical devices, and makes full use of large bandwidth, low loss, and high-frequency characteristics in optics. It is quite suitable for different kinds of UWB-over-fiber applications in the future.

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