All-optical UWB impulse generation based on cross-phase modulation and frequency discrimination

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All-optical ultra-wideband (UWB) impulse generation based on optical cross-phase modulation (XPM) and frequency discrimination is proposed and experimentally demonstrated. In the proposed configuration, an optical pulse train from a femtosecond pulse laser that is spectrum sliced to get the required pulse width is used as a pump, which is then injected into a nonlinear fibre together with a continuous-wave (CW) probe to create XPM. A fibre Bragg grating (FBG) is used as a frequency discriminator. By locating the cross-phase-modulated probe at the linear or the quadrature slopes of the FBG reflection spectrum, UWB monocycle or doublet pulses are generated.

Introduction: UWB-over-fibre is considered a technique with high potential to extend the coverage of UWB wireless communications by integrating the local UWB environment into a fixed wired network or a wireless wide-area infrastructure. To fully exploit the advantages provided by optics, it is also desirable that the UWB signals can be generated directly in the optical domain without the need of extra electrical to optical conversion. Several approaches have recently been proposed to generating UWB pulses using optical techniques [1–4]. The key limitations associated with these techniques include the need for a sophisticated circuit to process [1, 2] or generate [3, 4] the short pulses in the electrical domain and the use of an optical modulator to perform electrical to optical conversion, which make the systems complicated.

Recently, we proposed an approach to achieving optical phase modulation (PM) without using an optical phase modulator. In the approach, the PM is implemented all-optically based on cross-phase modulation (XPM) in a non-zero dispersion shifted fibre (NZ-DSF) [5]. UWB pulses were obtained by converting the phase-modulated probe to an intensity-modulated signal using an optical-filter-based frequency discriminator. In a proof-of-concept experiment, a CW light was intensity-modulated by an electrical pulse train to serve as the pump, which is then injected into the NZ-DSF fibre with a CW probe to create XPM. Since the optical pulse train was generated based on intensity modulation (IM) using an electrical pulse train from an electrical generator, the system is still not all optical, but hybrid. In addition, in the system a long NZ-DSF fibre (25 km) was used. The use of long NZ-DSF fibre could generate a significant walk off between the pump and the probe, leading to a strong dependence of the XPM index on the pump pulse frequency components [6]. When the wavelength separation ($\Delta\lambda$) between the pump and the probe is large, which is always the case since it would ease the suppression of the pump after the XPM, only a smaller fraction of the frequency components from the pump would contribute to the generation of the XPM, i.e. the lower frequency components contribute more than the higher frequency components. Consequently, the shape of the pump pulse cannot be transferred with fidelity to the probe through XPM, which leads to a distortion of the generated UWB pulses [5].

In this Letter, we propose and demonstrate a fully all-optical UWB impulse generator. Instead of using an electrical pulse generator and a high-speed optical modulator to generate the optical pulse train, the optical pulse train is generated by use of a femtosecond pulse laser (FSPL). To control the pulse width, a spectrum slicing filter is incorporated after the FSPL. The generated pulse train is then injected with a CW probe into a length of DSF that serves as the nonlinear medium, to achieve optical XPM. The phase-modulated probe is then converted to an intensity-modulated pulse at an FBG. Depending on the location of the probe at the FBG reflection spectrum, UWB monocycle or doublet pulses are generated. Since the optical pulse is generated using an FSPL, no electrical pulse generator is required. In addition, thanks to the use of the ultrafast optical pulse source and the DSF with a larger nonlinear coefficient, a much shorter fibre length ($\sim$400 m) is required, which reduces significantly the wavelength walk-off effect during the XPM, and the system stability is improved as well.

Experiment: The experiment setup is shown in Fig. 1. The pulse train generated by the FSPL has a pulse width of 475 fs with a repetition rate of 48.6 MHz, which has a 3 dB spectral bandwidth of 7.9 nm. Since the pulsewidth is too narrow for UWB generation, we use a tunable grating filter (TGF) to slice the spectrum of the FSPL. The TGF has a 3 dB bandwidth of 0.23 nm with a tunable range to cover the entire C-band. The spectra and the temporal waveforms representing a single optical pulse measured before and after the TGF are shown in Fig. 2. As can be seen after the spectrum slicing, the pulsewidth is extended to 20 ps.

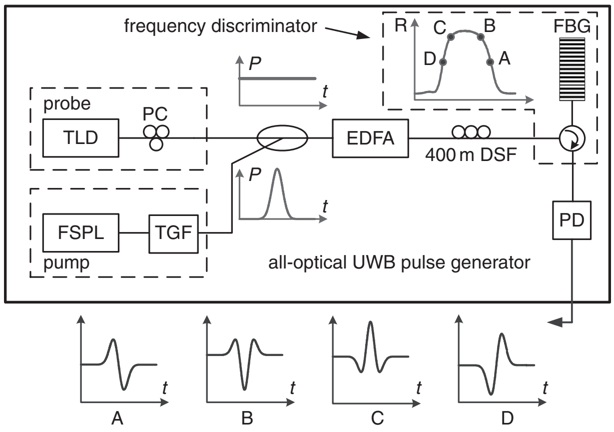

Fig. 1 *Experimental setup of proposed all-optical UWB pulse generator*

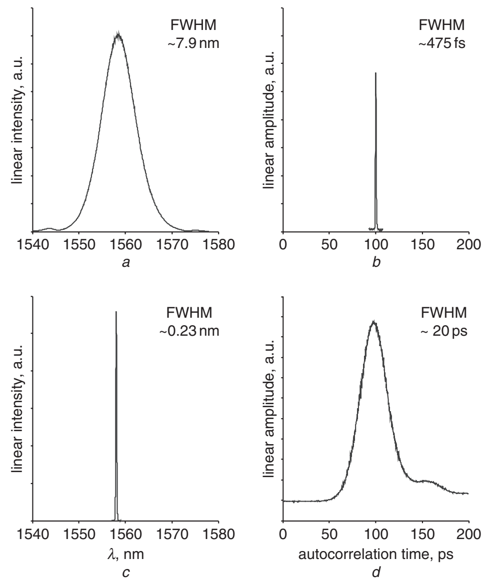

Fig. 2 *Spectrum and autocorrelation trace measured at output of FSPL; spectrum and temporal waveform measured at output of TGF*

a Spectrum at output of FSPL
b Autocorrelation at output of FSPL
c Spectrum at output of TGF
d Temporal waveform at output of TGF

The pump is then injected into a 400 m DSF with a CW probe. The CW probe is generated by a tunable laser diode (TLD), which is amplified by an erbium-doped fibre amplifier (EDFA) before being injected. The DSF has a chromatic dispersion coefficient of -3.4 ps/nm/km at 1558 nm, a nonlinear coefficient of 2.7 W^{-1} km^{-1}, and an effective mode-field area (MFA) of 51.5 m^2. Compared to the 25 km NZ-DSF used in [5], the length of the fibre to achieve a sufficient XPM depth is significantly reduced, owing mainly to the following two reasons: (i) the pump pulse obtained from the FSPL has shorter pulse duration with higher peak power and higher extinction ratio; and (ii) the deployed DSF has a smaller effective MFA, which leads to a larger nonlinear coefficient. In addition, since the EDFA has a broad amplification bandwidth, based on the structure in Fig. 1, the probe can also be amplified, which would increases the conversion efficiency.

The cross-phase-modulated probe is then sent to a frequency discriminator. The frequency discriminator consists of an FBG and an optical circulator. The PM to IM conversion is performed at the FBG by locating the probe at the linear or quadrature slopes of the reflection spectrum of the FBG. The FBG is fabricated in a hydrogen-loaded singlemode fibre by 244 nm UV illumination with a phase mask. It has a length of 10 mm, a peak amplitude reflectivity of 66%, a central wavelength of 1556.55 nm, and a 3 dB bandwidth of 0.35 nm. A proper Gaussian apodisation is applied during the FBG fabrication process to suppress the sidelobes.

The central wavelength of the TGF is tuned at 1561.5 nm, which is about 5 nm away from the mainlobe of the FBG reflection spectrum. The average optical power of the pump light measured before being injected into the DSF is +8 dBm, and that of the probe light is +4 dBm. For the wavelength separation $\Delta\lambda$ of 5 nm, the DSF gives a walk-off time of 6.8 ps, while this value is around 620 ps if the 25 km NZ-DSF [5] is used. Therefore, the system will not suffer from the walk-off problem. In addition, since the wavelength separation is large, the pump after the DSF can be easily filtered out by the FBG with a high suppression ratio. By tuning the wavelength of the probe, λ_{probe}, at four different locations of the FBG reflection spectrum, we obtain four different UWB pulses, as shown in Fig. 3. As can be seen, UWB monocycles are generated by locating the probe at the linear slopes of the FBG reflection spectrum and UWB doublets are generated by locating the probe at the quadrature slopes of the FBG reflection spectrum. In addition, the two monocycles or the two doublets are out of phase. These interesting results can be directly applied to implement different pulse modulation schemes, such as pulse shape modulation (PSM) and pulse polarity modulation (PPM). For the four UWB pulses, a slight asymmetry is observed, which is due mainly to the self phase modulation (SPM) of the pump pulse in the DSF, which leads to the pulse broadening and distortion.

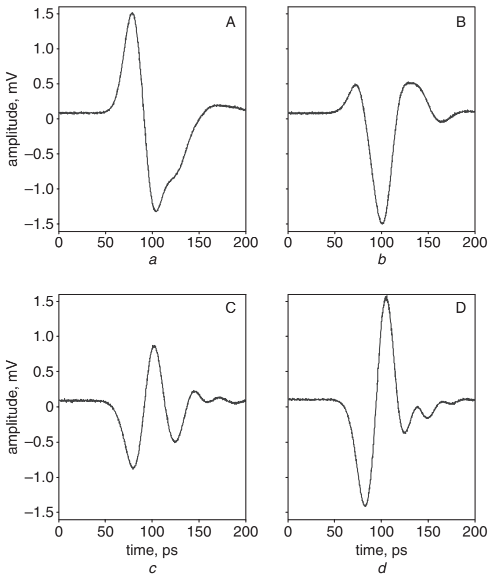

Fig. 3 *Temporal waveforms of output pulses, when probe wavelength is located at different locations of FBG reflection spectrum (A, B, C and D shown in Fig. 1)*

Conclusions: A fully all-optical UWB pulse generator that can generate UWB monocycle and doublet pulses with reversed polarities has been experimentally demonstrated. In the proposed setup, the optical pump pulse train with the required pulsewidth was obtained by spectrum slicing the pulse from the FSPL. By injecting the pump pulse into a length of DSF with a CW probe, we obtained the phase modulated probe, which was then applied to an FBG to perform PM to IM conversion. Depending on the location of the probe at the FBG reflection spectrum, UWB monocycle or doublet pulses with opposite polarity were obtained. This feature makes the implementation of PPM and PSM schemes possible in the optical domain, by simply switching the wavelength of the probe. More importantly, since the UWB pulses were generated in the optical domain, no electrical pulse generator and high-speed optical modulator are required, which reduce significantly the complexity and cost of the system.

8 November 2006
Electronics Letters online no: 20073432
doi: 10.1049/el:20073432

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