Generation of an ultra-wideband triplet signal based on semiconductor optical amplifier*

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We propose a novel ultra-wideband (UWB) triplet signal source based on the cross-gain modulation (XGM) in semiconductor optical amplifier (SOA). In the proposed scheme, only an optical source and two SOAs are needed, so the all-optical structure is compact. A triplet optical pulse with center frequency of 6.25 GHz and fractional bandwidth of 83% is obtained by the scheme. The extinction ratio can be improved by the counter-propagating scheme. The triplet pulse signal with only one wavelength can be easily controlled, and can aviod the dispersion effect. The output triplet pulse signal is insensitive to the light wavelength shifts, its available wavelength range is wide, the dynamic range of the input power is more than 6 dBm, and the bias current of the SOAs is exhibited.

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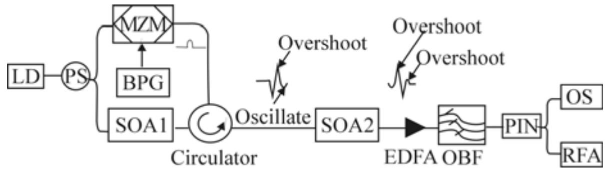
Ultra-wideband (UWB) wireless communication[1] needs no carrier and uses very short time interval (less than 1 ns) pulse signal. The UWB transmission in optical fiber (UWB-over-fiber) resolves the problem of the short transmission distance generated by the low power density[2]. At present, the hybrid approaches have been proposed to realize the all-optical UWB signal with phase modulator[3], all-optical band-pass filter (OBF)[4], fiber Bragg grating[5], pulse position modulation[6], nonlinear optical loop mirror[7], highly nonlinear photonic crystal fiber[8], short-terminated electro-absorption modulator[9] and periodically poled lithium niobate[10]. In addition, the semiconductor optical amplifier (SOA) is one of the most promising candidates for UWB generation due to high nonlinearity, optically-controlled manipulation and low power consumption, so the all-optical methods are reported with SOA[11-13].

In the paper, we propose a simple method to generate all-optical UWB triplet pulse by the cross-gain modulation (XGM) effect in the cascaded SOAs. The scheme has simple structure and stable performance, and the extinction ratio is improved by the counter-propagating scheme[14]. The output triplet pulse with only one wavelength can avoid the dispersion effect caused by two overlapping wavelengths, in which the dispersion compensation technique is dispensable.

The schematic diagram of generating triplet pulse based on the XGM in cascaded SOAs is illustrated in Fig.1. The bit pattern generator (BPG) is used to generate an electrical return-to-zero (RZ) signal, which is injected into the Mach-Zehnder modulator (MZM), so the light in the upper branch is modulated into a normalized Gaussian pulse train as pump light by MZM, and the light in the lower branch is used as the probe light. Probe and pump light is coupled into a broadband travelling-wave SOA simultaneously by counter-propagating scheme. Hence, the power of pump light is greater than that of probe light at the left of SOA1 due to XGM effect. The probe pulse has the similar shape changes with the polarity-reversed pump pulse at the left of SOA1, and then the probe pulse presents a monocycle shape immediately by the overshoot occurring at the rising slope of probe pulse. Due to the slow recovery of the carriers in SOA1, the negative pulse with the small amplitude is formed by the oscillation at the trailing edge of probe pulse. After the output probe light is input into SOA2, the probe light is over-amplified, and overshoot occurs at the first and second rising slopes of probe pulse in the propagation from the left to the right in SOA2, so the output probe light becomes triplet-like.



LD: laser diode; PS: power splitter; BPG: bit pattern generator; MZM: Mach-Zehnder modulator; EDFA: erbium doped fiber amplifier; OBF: optical band-pass filter; OS: oscilloscope; RFA: RF analyzer

Fig.1 Experimental setup for triplet pulse generation based on XGM in SOA

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The simulation parameters are the following values if no specified instructions: pulse width is 50 ps, the symbol rate is 20 Gbit/s with a fixed data pattern “1000 0000 0000 0000”, the repetition rate is 1.25 GHz, the optical peak power is 4 mW and wavelength is 1563.5 nm, the current of SOA1 is biased at 160 mA and the current is 90 mA in SOA2, the center wavelength of the filter is 1563.5 nm and its bandwidth is 0.25 nm. With parameters above, the output triplet pulses and RF spectra are shown in Fig.2. After the measurement, the 10 dB bandwidth is 6.25 GHz and the fractional bandwidth is 83%.

The results of Fig.3 display that with the increase of the input pulse width, the average optical power of the output triplet pulse is reduced slightly, and the waveform has better symmetry. The reason is that consumed carriers in SOA1 and SOA2 have effective gain recovery when the signal pulse width is larger, the phenomenon of overshoot in SOA1 is slightly advanced, and the effects generated by oscillation in SOA1 and the overshoot in SOA2 are more distinct. The 10 dB bandwidth is gradually narrower as evidently shown in Fig.3(d)-(f), and the corresponding spectrum is too wide to match the definition of UWB pulse when the input pulse width is 25 ps. When the input pulse width is 37.5 ps, the 10 dB bandwidth of the output RF signal is 8 GHz, which exceeds the definition of the FCC. When the input pulse width is 50 ps, 10 dB bandwidth of the output RF signal and the fractional bandwidth are 6.25 GHz and 83%, respectively. Therefore, the output triplet pulse can be obtained by setting appropriate input pulse width.

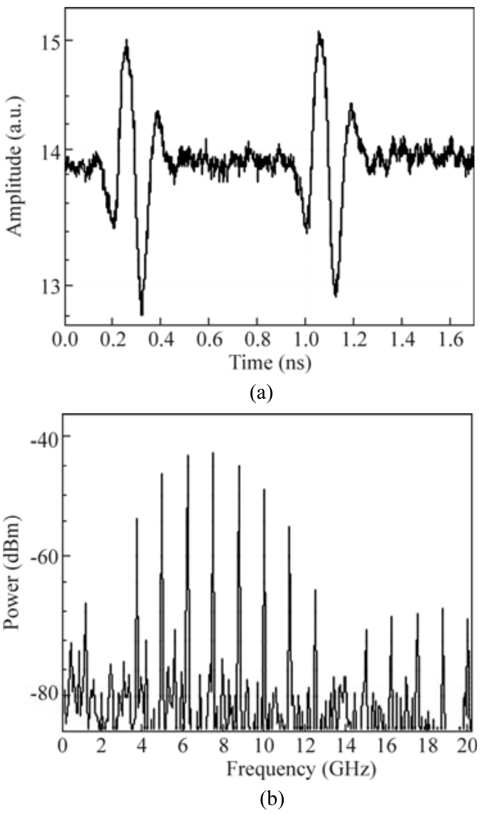


Fig.2 (a) Waveform for output triplet pulse; (b) RF spectrum for output triplet pulse

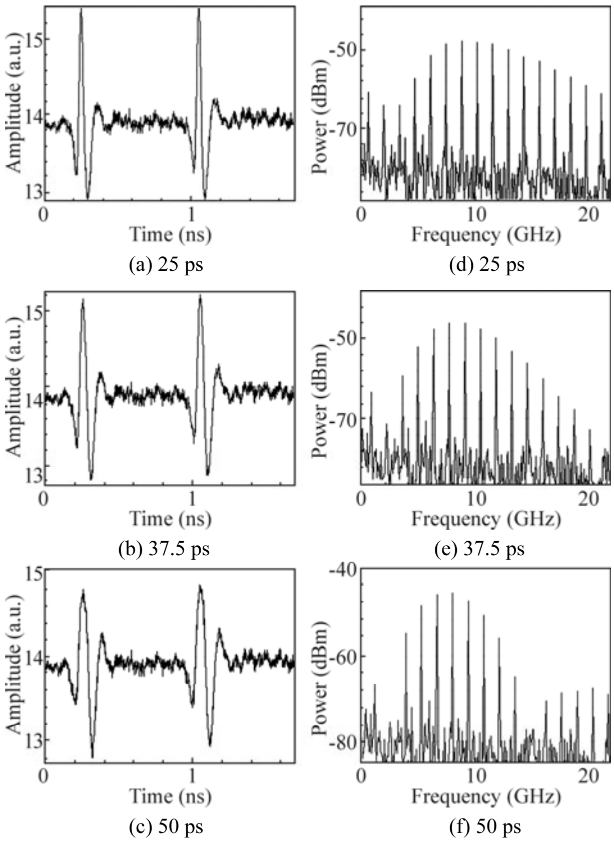


Fig.3 Waveforms and RF spectra for output triplet pulse with different input pump pulse widths

We only change optical source power to research the influence of the light power when the power of pump light is the same as the probe light power, and the results are listed in Fig.4. From Fig.4(a)-(d), the results show that the power of noise is higher when the optical source power is lower (-5 dBm). The input probe light and pump light consume more carriers when the optical source power is higher. Due to the fast depletion and slow recovery of the carriers in SOA, the effects generated by oscillation in SOA1 and overshoot in SOA2 are not obvious, and the amplitude of pulse generated by the overshoot is lowered, so the output triplet pulse is asymmetric, but the power of noise reduces. Therefore, as observed in Fig.4(e)-(h), when the source power varies from 3 dBm to 9 dBm, the output triplet pulse matches the definition of UWB pulse. On the contrary, the waveform of triplet pulse is compressed when the source power exceeds the above range, and the RF spectra of the triplet pulses can’t meet the definition of UWB pulse.

The influence of the light wavelength on the generated triplet pulse is also studied. We can see that the fractional bandwidth of the light at 1560 nm is 67% and the others are all 83% in Fig.5. The phenomenon demonstrates that the received triplet pulses are insensitive to the relative wavelength shifts. The waveforms and RF spectra of the output triplet pulse are displayed in Fig.6. The performance indicates that XGM effect has a good tolerance to the light wavelength shifts, and the light wavelength can be changed according to the demand.

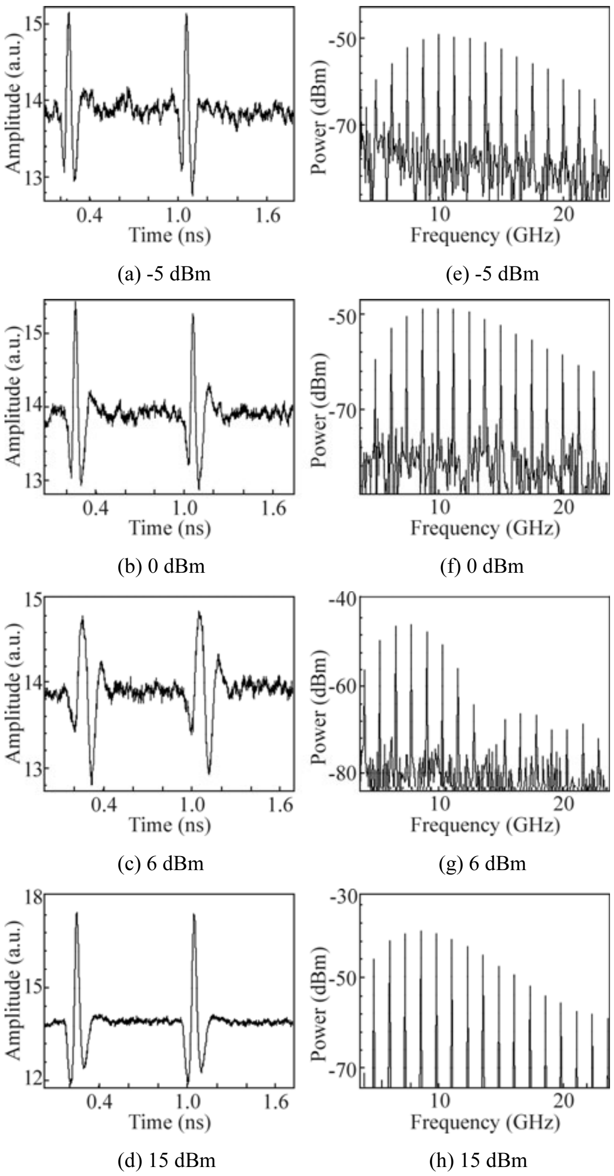


Fig.4 Waveforms and RF spectra for output triplet pulse when light source with different power values

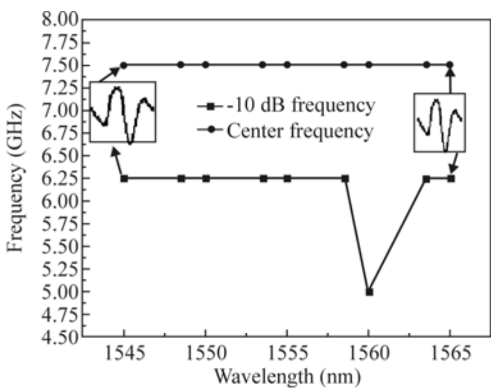


Fig.5 10 dB bandwidth and center frequency of output triplet pulse under different wavelengths

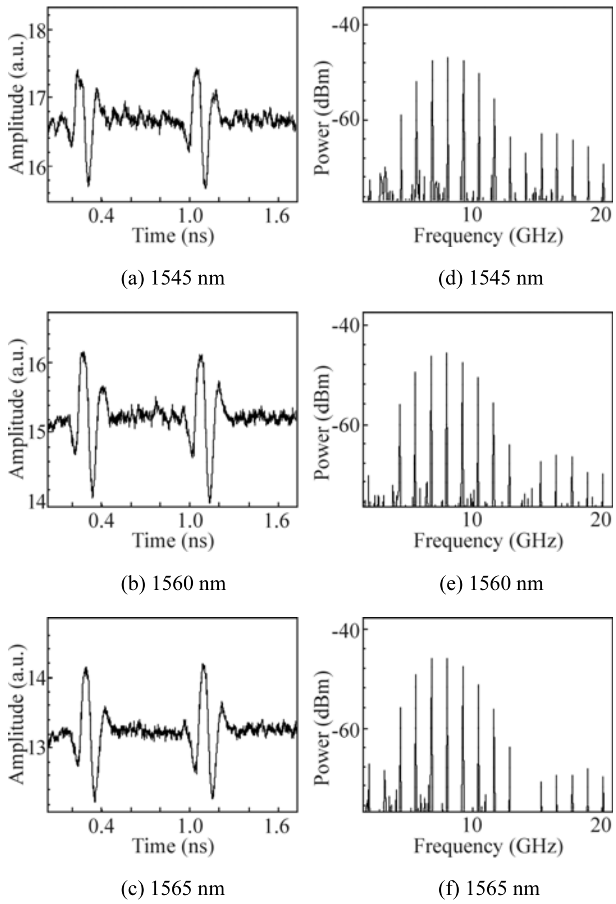


Fig.6 Waveforms and RF spectra for output triplet pulse with different wavelengths

The bias current of the SOA can affect the carrier density in SOA, and then affect the output pulse. When the bias current is relatively small, the carrier density in SOA1 reduces, the effect generated by oscillation is not obvious, so the output triplet pulse presents a doublet shape. The higher or lower bias current can result in the delay of the overshoot effect, waveform compression and asymmetry of the output pulse. Fig.7(d)-(f) indicate that the 10 dB bandwidth is widened when the injection current is larger or smaller. The symmetry of the output triplet pulse is improved when the bias current is around 160 mA.

To study the impact of the bias current in SOA2 on the output triplet pulse, we set the bias current in SOA2 at 70 mA, 90 mA and 110 mA, respectively, when the bias current in SOA1 remains at 160 mA. The simulation results are shown in Fig.8(a)-(c). The overshoot occurs when bias current in SOA2 arrives at the certain value. Due to the increased bias current, carrier density in SOA2 increases, and the average power of the output triplet pulse generated by overshoot is significantly higher, meanwhile the power of noise also increases. According to Fig.8(d)-(f), with the increase of bias current in SOA2, the center frequency is moved slightly towards the high frequency region. Therefore, the bias current in SOA1 and SOA2 is approximately 160 mA and around 90 mA, respectively, and the output triplet pulse is better.

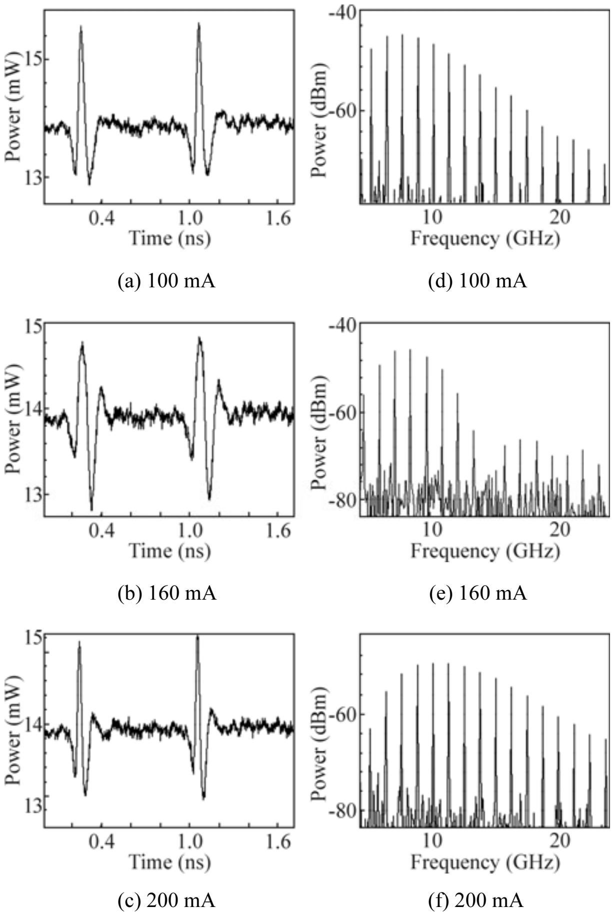
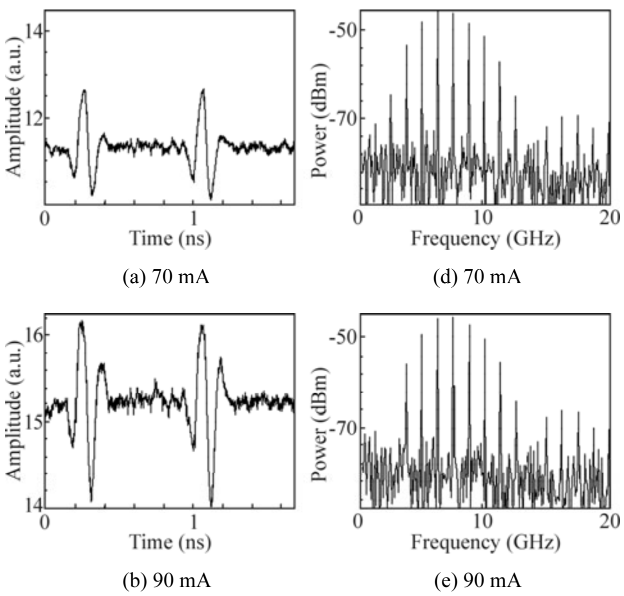


Fig.7 Waveforms and RF spectra for output triplet pulse when SOA1 with different injection current values



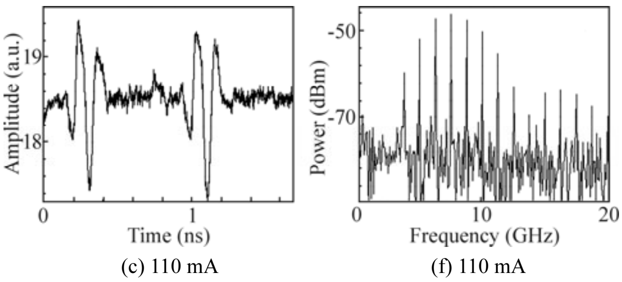


Fig.8 Waveforms and RF spectra for output triplet pulse when SOA2 with different injection current values

In summary, we present a UWB triplet pulse based on the XGM effect of the cascaded SOAs. The scheme has simple structure and stable performance, the output triplet pulse with only one wavelength can avoid the dispersion effect, and the extinction ratio is improved by the counter-propagating scheme. The effects of the input pulse width, the optical power, the light wavelength and the bias current in cascaded SOAs are studied and simulated by the software of Optisystem 7.0. The results show that the output triplet pulse is sensitive to the input pulse width and insensitive to relative light wavelength shifts, and the dynamic range of the input light power is more than 6 dBm. In the scheme, the system parameters and performance analysis supply the theoretic guidance to obtain the better UWB triplet signal.

References

[1] Yuan Yu, Jianji Dong, Xiang Li and Xinliang Zhang, IEEE Photonics Journal **4**, 327 (2012).

[2] Qing Wang and Jianping Yao, Optics Letters **33**, 1017 (2008).

[3] Hongwei Chen, Minghua Chen, Tianliang Wang, Mo Li and Shizhong Xie, Journal of Lightwave Technology **26**, 2492 (2008).

[4] Fei Zeng and Jianping Yao, IEEE Photon. Technol. Lett. **18**, 823 (2006).

[5] Yitang Dai and Jianping Yao, Journal of Lightwave Technology **26**, 2513 (2008).

[6] H. Mu and J. Yao, Electronics Letters **46**, 99 (2010).

[7] Tianye Huang, Jia Li, Junqiang Sun and Lawrence R. Chen, IEEE Photon. Technol. Lett. **23**, 1255 (2011).

[8] Fangzheng Zhang, Jian Wu, Songnian Fu, Kun Xu, Yan Li, Xiaobin Hong, Ping Shum and Jintong Lin, Optic Express **18**, 15870 (2010).

[9] Tsu-Hsiu Wu, Jui-pin Wu and Yi-Jen Chiu, Optic Express **18**, 3379 (2010).

[10] Jian Wang, Junqiang Sun, Xinliang Zhang and Dexiu Huang, IEEE Journal of Quantum Electronics **45**, 292 (2009).

[11] Jianji Dong, Xinliang Zhang and Dexiu Huang, Frontiers of Optoelectronics in China **2**, 40 (2009).

[12] Weiwei Zhang, Junqiang Sun, Jian Wang, Cheng Cheng and Xingliang Zhang, IEEE Photon. Technol. Lett. **21**, 271 (2009).

[13] Fei Wang, Jianji Dong, Enming Xu and Xinling Zhang, Optical Express **18**, 24588 (2010).

[14] Wang Faqiang, Zhao Yu and Zhu Zhuqing, Chinese Journal of Lasers **31**, 1495 (2004). (in Chinese)