All-optical ultra-wideband doublet signal source based on the cross-gain modulation in a semiconductor optical amplifier*

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We propose a novel scheme to generate the ultra-wideband (UWB) doublet signal pulse based on the cross-gain modulation (XGM) in a semiconductor optical amplifier (SOA). In the scheme, only an optical source and an SOA are needed. As there is only one wavelength included in the output doublet signal pulse, no time difference between the upper and down pulses is introduced during the transmission process. By using the software of Optisystem 7.0, the impacts of the optical power, the SOA current, the wavelength and the input signal pulse width on the generated doublet pulse are simulated and tudied numerically. The results show that when the pulse width of the input signal pulse is larger, the output signal pulse is better, and is insensitive to the change of wavelength. In addition, the ultra-wideband positive and negative monocycles can be generated by choosing suitable optical source power and SOA current.

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The ultra-wideband (UWB) radio signal should have a 10 dB bandwidth greater than 500 MHz or a fractional bandwidth, i.e., the signal bandwidth/signal center frequency, greater than 25%[1]. Recently, the UWB radio technology brings many advantages, such as high transfer rate, low power and good anti-jamming capability. However, the UWB signals can only propagate for a short distance of a few meters due to its low power density and greater transmission loss. In order to overcome the shortcoming, the UWB-over-fiber technology is developed, and people begin to study the generation of the UWB signal in optical domain. Recently, many schemes to generate the UWB signals have been proposed[2-12].

In this paper, we propose a scheme for all-optical UWB doublet pulse generation based on the cross-gain modulation (XGM) of the semiconductor optical amplifier (SOA), in which both the signal light and probe light are coupled into the SOA in opposite directions, and only an optical source and an SOA are needed, so the scheme is simple and low cost.There is only one wavelength included in the output doublet signal pulse, which can avoid the time difference between the upper and down pulses during the transmission process.

The schematic diagram of experimental setup is shown in Fig.1, which generates doublet pulse based on the XGM in SOA. The light from optical source (laser diode:LD) with constant power is equally splitted into two parts through a power splitter (PS). The upper branch is modulated to signal light through Mach-Zehnder modulator (MZM) by a bit pattern generator (BPG), while the down one is used as the probe light. The probe light and signal light are coupled into a wideband travelling-wave SOA through opposite directions. The probe light is amplified gradually during the propagation process from left to right, and achieves the maximum at the right side of SOA, while the signal light is amplified gradually during the propagation process from right to left, and achieves the maximum at the left side of SOA. The signal light is strong while the probe light is weak at the left side of

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SOA, so the probe light obtains a polarity-reversed Gaussian shape at the left side of SOA due to XGM. The monocycle pulse is formed because of the overshoot at the pulse leading edge of probe light during the propagation process. Because the gain of the Gaussian pulse at the leading edge is larger than that at the trailing edge, the pulse peak is moved to the leading edge, which can not lead to fully cancellation of signal light and polarity-reversed probe light when the attenuation signal light and the probe light are superimposed directly. As a result, the ultra-wideband doublet pulse is generated. The output probe light passing through a Gaussian optical band-pass filter (OBF), which is used to get rid of the noise, is transformed to electrical signal by an avalanche diode (APD). The output doublet pulse and its radio frequency (RF) signal can be observed from the oscilloscope (OS) and the RF spectrum analyzer.

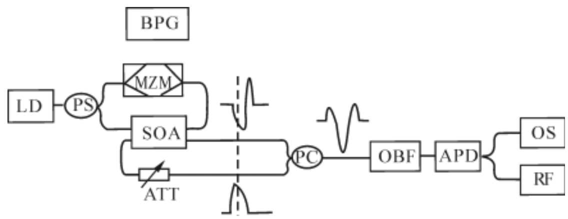

Fig.1 Experimental setup for doublet pulse generation based on SOA-XGM

By using the software of Optisystem7.0, the proposed scheme to generate ultra-wideband doublet pulse based on XGM in a SOA is implemented. During the simulation, the symbol rate is 20 Gbit/s with fixed data pattern "1000 0000 0000 0000", the optical power is -5 dBm, and its wavelength is 1563.5 nm. The active region length of SOA is 600 μm, and its current is 80 mA. The center frequency of the filter is 1563.5 nm, and its bandwidth is 0.35 nm. The signal pulse width is 1 bit. The attenuator is set to 23 dB. If no specified instructions, the system parameters always use the above values.

To research the impact of optical source power on the generated doublet pulse, we change the source power with the other parameters remained. The output probe light and its RF spectrum with different optical source powers are shown in Fig.2. When the optical source power is too low (-15 dBm), as shown in Fig.2(a), the output signal is reduced by noise. With the optical source power increasing, the average power of output signal increases. The negative monocycle pulse can be formed, due to the left positive pulse of doublet pulse is offset when the optical power is increased to a certain extent, as shown in Fig.2(d). It is because the amplification of signal light decreases when the power of probe light increases, while the external attenuation is not decreased correspondingly, leading to the fully offset of signal light. However, the right positive pulse of doublet pulse disappears when the source power continues to increase, as shown in Fig.2(e). It is because the large optical source power consuming large amount of carriers leads to the disappearance of overshoot. The RF signals corresponding to the different source powers are shown in Fig.2 (f)-(j). It can be seen that the RF signal is almost drowned by noise when the source power is too low. However, the RF signal does not meet the US federal communications commission (FCC) UWB definition when the optical source power is too high. In the paper, the output UWB signals match the FCC UWB definition well when the source power is between -7.5 dBm and 7.5 dBm. The output doublet pulse can be generated when the source power is relatively low, while the negative monocycle signal can be generated when the source power is relatively high. Therefore, the output monocycle and doublet pulses can be obtained by setting appropriate optical source power.

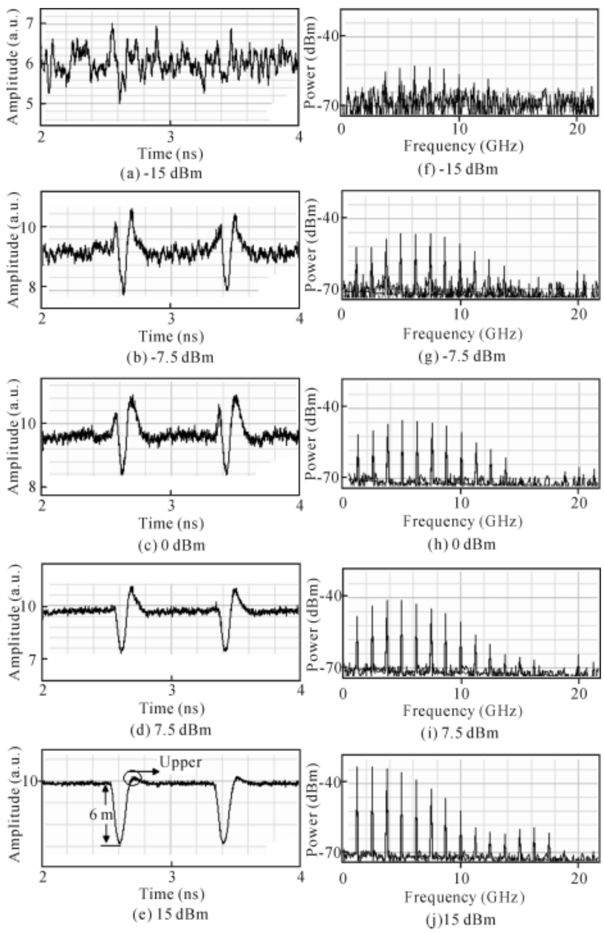

Fig.2 Waveforms and RF spectra for output pulse in cases of optical source with different powers

Keep other parameters unchanged except for the SOA current. The simulation results are shown in Fig.3. We can obtain the positive monocycle pulse when the SOA current is relatively small (50 mA), which is shown as Fig.3(a). The overshoot of the probe light is not obvious, due to the incident carrier density is too low. As the SOA current increases, the average power and the overshoot amplitude of the output signal are also increased, which can form the doublet pulse. When the SOA current is too large, the lower pulse of the doublet is fully offset, which is shown as Fig.3(c). It is because the amplification of signal light increases when the SOA current increases, while the external attenuation is not increased correspondingly. Seen from Fig.3(d) - (f), the RF spectra of output signals would exceed the FCC UWB definition when the SOA current is too large. The output UWB signals match the FCC UWB definition well when the SOA current is between 0.5 mA and 0.8 mA.The output doublet pulse can be obtained when the SOA current is relatively large, while the positive monocycle pulse can be obtained when the SOA current is relatively small.

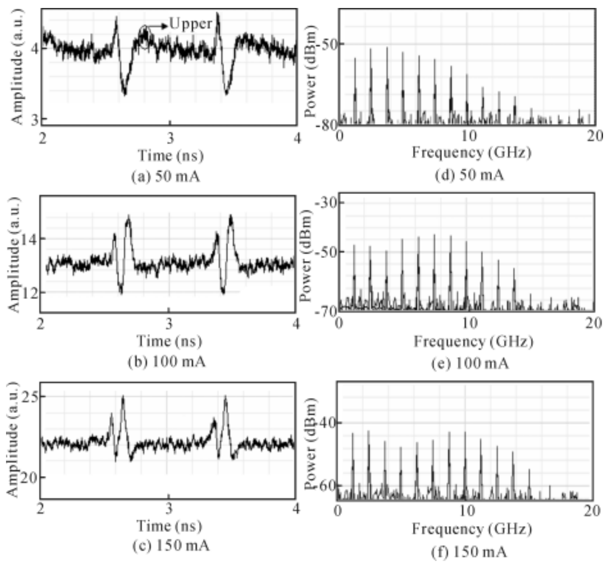

Fig.3 Waveforms and RF spectra for output pulse in cases of SOA with different incident currents

We change the wavelength of the optical source while other parameters are remained. The result is shown in Fig.4. From Fig.4 we can see the output doublet pulse almost has no change in the time domain when the optical source with different wavelengths. The fractional bandwidths of the generated doublet pulses increase generally when the wavelength increases, and then remains unchanged within a certain range. They are all greater than 116.7%, and all satisfy the FFC UWB definition. So the output ultra-wideband doublet pulses of our scheme are insensitive to the wavelength change.

When the input signal pulse widths are 0.5 bit, 0.75 bit and 1 bit, respectively, the obtained doublet pulse and its RF spectra are shown in Fig.5. From Fig.5, we can see that with the increasing of input pulse width, the output pulse width of

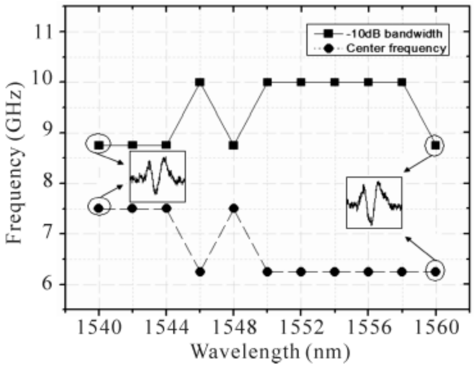

Fig.4 Curves for the -10 dB bandwidth and center frequency of output doublet pulses in the cases of different wavelengths

the doublet is also increased, while the amplitudes of both the left upper pulse and lower pulse are decreased. It is because with the increase of the input pulse width, the gain saturation at its trailing edge is recovered partly[13], and the power cancellation of amplified pump light and polarity-reversed Gauss shape of probe light is increased. From Fig.5 (d)-(f), when the input signal pulse width is 0.5 bit, the corresponding spectrum is so wide that the FCC UWB definition is not satisfied. While the input signal pulse width is 0.75 bit and 1 bit, the widths of the output doublet pulse spectra are in the range of the definition, and the fractional bandwidth is 160% and 146.67% , respectively. So the output doublet pulse can match the FCC UWB definition better when the input signal width is larger.

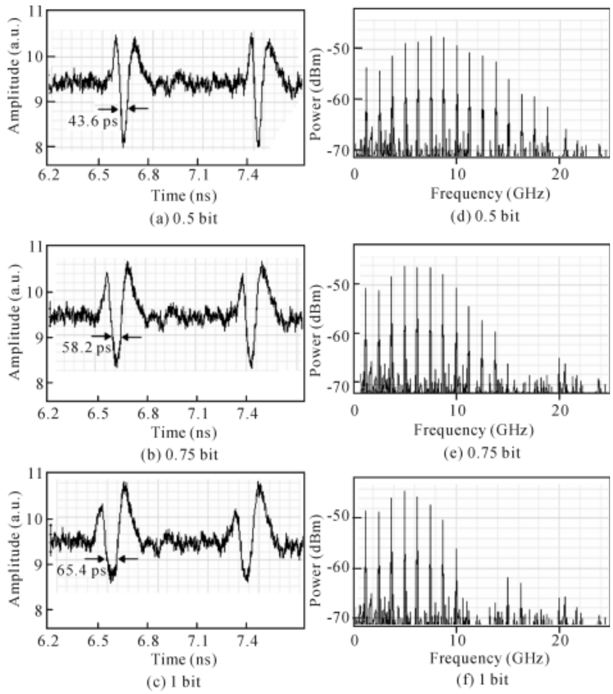

Fig.5 Waveforms and RF spectra for output doublet pulse in cases of different input signal pulse widths

We propose a novel scheme to generate ultra-wideband doublet signal pulse based on the XGM in an SOA. In the scheme, the opposite working way is used, and only one optical source and an SOA are needed. By using the software of Optisystem 7.0, the impacts of the system parameters on the output pulses are simulated and studied numerically. The results show that the scheme has better output signal pulse when the pulse width of the input signal is larger, and it is insensitive to the change of optical source wavelength. In addition, the ultra-wideband positive and negative monocycle pulses can be generated by choosing suitable SOA current and optical source power. By analyzing the impacts of the system parameters on the output signal, we can obtian theoretical guidance on how to generate good ultra-wideband signals.

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