All-optical modulation and time-division-multiplexing of 100 Gbit/s signal using quasi-phasematched mixing in LiNbO₃ waveguides


All-optical modulation and time-division-multiplexing is experimentally demonstrated using quasi-phasematched mixing in an LiNbO₃ waveguide. A 100 GHz, 1.545 µm clock is modulated by two channels of 10 Gbit/s signals to generate 1.595 µm subchannels in a 100 Gbit/s signal.

Introduction: Ultrahigh-speed modulation of optical pulses is one of the important technologies for optical time-division-multiplexed (OTDM) transmission over 100 Gbit/s [1]. We have proposed all-optical modulation using four-wave mixing (FWM) in a semiconductor optical amplifier (SOA) and confirmed error-free operation at 100 Gbit/s [2]. In this experiment, the signal-to-noise ratio (SNR) of the output FWM pulse was limited by the low conversion efficiency of the FWM process in an SOA and the accumulation of the amplified spontaneous emission (ASE) noise. Quasi-phasematched mixing in periodically poled LiNbO₃ (PPLN) waveguides are attracting interest because they have high conversion efficiency [3] with negligible additive noise. This Letter presents successful experimental results for all-optical modulation using a PPLN device. A 100 Gbit/s optical clock was all-optically modulated by two 10 Gbit/s signals to produce a TDM signal with a 10 ps time interval as a wavelength-converted component.

Experimental: Fig. 1 shows the experimental setup. A 4.2 ps, 100 GHz (1.545 µm wavelength) optical pulse train was generated by a modelocked fibre ring laser (ML-FRL) followed by a planar-lightwave circuit (PLC)-TDM multiplexer. The two 10 Gbit/s signal pulses (all-mark) were generated by a 3.3 ps, 1.551 µm wavelength ML-FRL and an optical coupler. Time delay was added to each signal and the two signals were recombined by another optical coupler. The 100 GHz clock and the two signals were then coupled and introduced into the PPLN device. The schematic structure of the PPLN device is also shown in Fig. 1. The PPLN device used in this experiment was a 40 mm long waveguide with domain inversion period of 14.7 µm. In this device, cascaded nonlinear process generated the 1.595 µm modulated component. First, the second harmonic of the 1.515 µm pulse was generated, then the 0.750 GHz pulse and the 1.543 µm, 100 Gbit/s pulse was produced. The 1.559 µm frequency difference component between the 10 GHz signal and 100 GHz clock, through frequency generation, was only 14.7 µm. In the experiment, the temperature of the device was set to 98 °C to avoid photorefractive effects. Fig. 2 shows the input and output optical spectra of the PPLN device. The average output power of the 100 GHz clock, the 10 GHz input signal and the modulated output signal were 5.1, 6.7 and -16.1 dBm, respectively. The fibre-to-fibre insertion loss of this pigtailed device was low (3.2 dB), thus high conversion efficiency was expected. The conversion efficiency from the 1.543 µm component (100 GHz clock) to the 1.595 µm component for one channel was -12.1 dB, where...
we considered that one of the ten pulses of the 100GHz clock overlapped the 10GHz signal. Fig. 3 shows the measured optical waveforms with a < 1 ps resolution optical sampling oscilloscope (Anritsu-SA014B): (a) input 10GHz signal, (b) input 100GHz clock, and (c) output signal. In Fig. 3, waveforms of the two 10GHz subchannels with relative time delays of 10, 20 and 40ps are shown. As seen in the Figure, no pulse distortion was observed in the optical parametric process and all-optical modulation and time domain multiplexing was realised with high SNR.

Discussion: In the experiment, we used one PPLN device to confirm its basic operation. In all-optical time-domain multiplexing for all subchannels, it is necessary to cascade this process with several devices to avoid signal interference at the input of the device; this device has advantages in cascading because of its low insertion loss (3dB) and excess-noise-free nature. The wide wavelength tuning range of the device (~66nm) is another advantage because we can tune the output wavelength. The conversion efficiency, which depends quadratically on the input signal power, would approach 0dB with an increase of 6dB in the input power. A further increase is possible with improved waveguide designs. This configuration has the potential to realise a compact all-optical time-division multiplexer over 100Gb/s.

Conclusion: An all-optical signal modulator and a time-division multiplexer have been constructed using quasi-phasematching in a PPLN device. A 100GHz clock was modulated and multiplexed in the time domain by two channels of a 10GHz signal to form subchannels of a 100Gb/s signal.

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Fig. 2 Optical spectra of PPLN device

(a) Input: 
\[ \lambda_1 = 1.543100 \text{nm}, \lambda_2 = 1.55100 \text{nm} \]

(b) Output: 
\[ \lambda_1 = 1.543100 \text{nm}, \lambda_2 = 1.55100 \text{nm} \]

Resolution: 0.1 nm

Fig. 3 Measured waveforms

(a) 10GHz signal (pulsewidth: 3.3ps)
(b) 100GHz clock (pulsewidth: 4.2ps)
(c) Output signal (pulsewidth: 4.0ps)
(i) \( \Delta t = 10 \text{ps} \)
(ii) \( \Delta t = 20 \text{ps} \)
(iii) \( \Delta t = 40 \text{ps} \)