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NEW WAVELENGTH CONVERTER FOR PICOSECOND RZ PULSES

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Abstract: We propose an RZ-pulse wavelength converter which has a very simple device structure. Ultrafast wavelength conversion at an extremely low input power is demonstrated at 10-40 GHz repetition rates.

Introduction

Transmission systems that operate at 40 Gbps or more per WDM channel are expected to use an RZ-signal format due to its superior transmission properties. Wavelength converters will be used to cross-connect those signals among WDM channels. All-optical semiconductor switches /1-8/ can be used as RZ wavelength converters. Each time a signal pulse in a WDM channel (A) excites such a switch, it switches on and off a CW input light whose wavelength is chosen for another WDM channel (B). As a consequence, each channel-A pulse generates a channel-B pulse in the RZ format. In this paper, though, we report a new wavelength converter, whose structure is simpler than any all-optical switch, but that is capable of the same ultrafast performance.

Response time is the most important property of RZ wavelength converters. The ultrafast response of all-optical switches is based on a ‘push-pull interference’ mechanism, which overcomes the otherwise slow response time of 50 ps to 1 ns, as obtained from NRZ wavelength converters /9/. Thus, those ultrafast switches have interferometric structures in either symmetric Mach-Zehnder (SMZ /1-4/) or Sagnac (TOAD /5, 6/) configurations. The SMZ structure has an advantage in that its response is not limited by the pulse transit time through the semiconductor waveguide, while that of the TOAD is. The SMZ structure, which has a semiconductor waveguide in each interferometer arm, has been simplified into a polarization-discrimination SMZ (PD-SMZ /7, 8/) switch that has only one semiconductor waveguide. This simplification remarkably improved the stability of the interference condition.

We recently proposed a new wavelength converter, based on a further simplified SMZ structure /10/. This simplification was possible because it was designed specifically for wavelength conversion. This wavelength converter consists of only two essential components, an SOA and a split-delay interferometer. This structural simplicity should be beneficial for integration and long-term stability. Wavelength conversion of picosecond pulses from 1530 to 1560 nm has been demonstrated at a repetition rate of 82 MHz /10/. In this work, wavelength conversion at 10-40 GHz is reported.

Delayed-interference signal-wavelength converter (DISC)

Our wavelength converter (Fig. 1a), named DISC, is the simplest interferometric all-optical device ever reported. It is insensitive to the λ_1 input pulse polarization in principle, when using a polarization-insensitive SOA. The DISC function is shown in Fig. 2b, where the input pulse width is assumed to be much shorter than the delay time Δt to illustrate its mechanism clearly in the time domain. In the SOA, each λ_1 input pulse modulates both the phase and intensity of the co-propagating λ_2 light through the bandfilling effect and pulse gain saturation, respectively. The rise time is determined by the input pulse width, and the fall time is determined by the relatively long carrier recovery time at the SOA output. The λ_2 light is then split into fast (solid line in Fig. 1b) and slow (dashed line) components in the split delay. When they are recombined and interfere with each other, the two slow recovery components cancel each other at $t_0+\Delta t$ in both phase and intensity. So, the fall time as well as the rise time of the output pulse is determined by the input pulse width (Fig. 1c), without being restricted by the carrier recovery time. The output pulse width is determined by the delay time Δt. The initial phase bias is set to $+\pi$ using a phase shifter ψ_b in the split delay, to ensure destructive interference (for non-inverted conversion). The phase bias condition is independent of the SOA operating conditions in principle, because the SOA is placed outside the interferometer in the DISC.

Figure 1: Wavelength Converter (DISC)

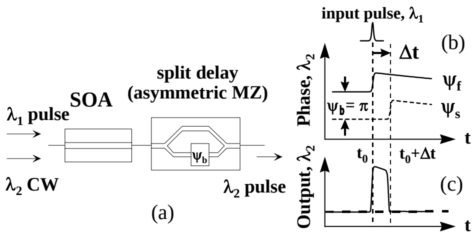
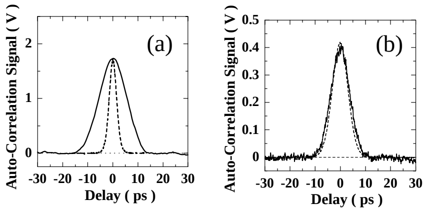


Figure 2: Output Pulse (auto-correlation traces)



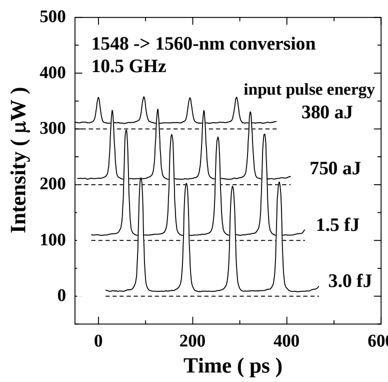
The output pulse width and shape depends on the delay time Δt with respect to the input pulse width. When Δt is much longer than the input pulse width (Fig. 1b), the DISC generates rectangular pulses (Fig. 1c). When Δt equals the input pulse width, on the other hand, the DISC should generate pulses whose width and shape are almost identical to those of the input pulse, according to our simulation. Furthermore, when Δt is shorter than the input pulse width, the DISC generates pulses even shorter than the input pulse. This pulse compression capability would be advantageous for wavelength converters used at network nodes.

Experiment

In this work, a birefringent calcite crystal was used as a split delay, where the signal light was split into two orthogonally polarized components, instead of two spatially separated components. The initial phase bias was controlled by rotating a waveplate and a polarizer. The output pulses were detected by both a streak camera (resolution= 8 ps) and an auto-correlator after being amplified by an EDFA. Input pulses at 1548 nm at repetition rates of 10.5 GHz and 42.0 GHz were generated by a mode-locked fiber ring laser (Pritel, Inc.), an optical multiplexer, and another EDFA. The CW single-mode input light (1560 nm) was generated by an external-cavity laser. The CW input power to the SOA was 5 uW.

First, we used a 14-mm-long calcite crystal whose Δt (14.3 ps) was much longer than the input pulse width (2.3 ps). The DISC should generate rectangular pulses which form a triangular autocorrelation trace. It is shown by the trace in Fig. 2a (solid curve: 12.1-ps 10.5-GHz output pulse, dashed curve: input pulse). This result suggests that the DISC can convert an RZ signal to an NRZ signal.

Figure 3: Wavelength Conversion at 10.5 GHz



Second, we used a 7.0-mm-long calcite crystal (Δt= 6.8 ps) together with 4.8-ps input pulses, to test wavelength conversion from 10.5 up to 40 GHz. Unfortunately, this Δt was slightly too long to generate pulses identical to the input pulse. The output pulse was estimated to have a 7-ps-wide rectangular-like shape, which should generate a 7-to-8-ps autocorrelation trace. A typical auto-correlation trace for the 1560-nm output pulses in Fig. 2b (solid curve, FWHM= 8.2 ps, dashed curve: 1548-nm input pulse, FWHM= 7.4 ps) matched the above estimation.

Figure 3 shows the input-pulse-energy dependence of the 7-ps 10.5-GHz output pulses measured with the streak camera. Although the SOA ASE remains as noise, we obtained a dynamic extinction ratio of 14 even with an input pulse energy of 750 aJ (= 750×10^{-18} J), which corresponds to an average power of 7.9 uW (-21 dBm). This demonstrates the excellent efficiency of the wavelength converter. This input pulse energy is two to three orders of magnitude smaller than those previously reported (100-500 fJ /3, 4, 6, 8, 10/). Taking into account the gain modulation contribution in addition to that of phase modulation, however, we believe that λ_1 input pulse energy on the order of the pulse gain saturation energy (typically, 0.5 to 1 pJ) divided by the unsaturated gain (typically, 100 to 500) is sufficient to transiently modulate gain for the λ_2 CW light in the SOA, and hence generate large λ_2 pulses at the DISC output. From this perspective, the above-mentioned input pulse energy of 750 aJ is reasonable.

Figure 4: Wavelength Conversion at 42 GHz

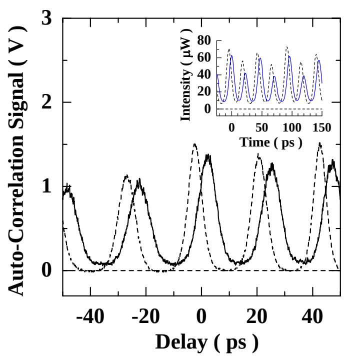


Figure 4 shows autocorrelation traces (and streak camera images in the inset) of 42-GHz output (solid line) and input (dashed line) pulses. The input pulse peak heights were not uniform because of an imbalance in the multiplexer. Clean output pulses were obtained. The dynamic extinction ratio of 12 was achieved at an input pulse energy of 6 fJ (average power= 250 uW= -6 dBm). This pulse energy was needed to compensate for the SOA carrier depletion at this higher repetition rate. The conversion efficiency at 42 GHz was still high. The conversion ratio from the input λ_2 CW power to output λ_2 pulse peak power was 16, and that from the input λ_1 pulse to the output λ_2 pulse was 0.076.

Summary

Using a new simple wavelength converter (DISC), we have demonstrated efficient ultrafast wavelength conversion of 10.5 to 42 GHz pulses from 1548 to 1560 nm.

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