Experimental research of a 300-Gb/s-class, semiconductor-based all-optical gate which contains an optical-spectrum's amplitude-and-phase synthesizer

Takehiro Nishida[1], Ryoichi Nakamoto[1, a)], Jun Sakaguchi[1, b)], Satoshi Shinada[2], Naoya Wada[2] and Yoshiyasu Ueno[1]

1. Univ. of Electro-Communications (UEC), Dept. of Electronic Engineering,
1-5-1, Chofugaoka, Chofu-shi, Tokyo 182-8585 Japan,
Tel: +81-42-443-5207, Fax: +81-42-443-5207, e-mail: nishida@ultrafast.ee.uec.ac.jp
2. National Institute of Information and Communications Technology (NICT),
4-2-1, Nukuikita, Koganei-shi, Tokyo 184-8795, Japan

a) present affiliation: Sumitomo Electric Industries, Ltd.
b) present affiliation: Nara Institute of Science and Technology (NAIST).

Abstract

When using ultrahigh-speed optical data pulses whose repetition rate is larger than 200 GHz, approximately, the signal waveforms after our all-optical gate in the conventional delayed-interference (DI) scheme is supposed to be strongly distorted, due to the previously reported fast gain-recovery component from the semiconductor optical amplifier (SOA) inside our all-optical gate. We had numerically demonstrated that a particular optical-spectrum-synthesizer (OSS) design could remove the waveform distortion. In this talk, we report the progress of experimental demonstration that the all-optical gate with OSS removes the waveform distortion. We characterized the spectral resolution and the extinction ratio of the OSS through time-multiplexing experiment and demonstrated numerically wavelength conversion considered the characteristics. As a result, it is hopeful to demonstrate experimentally wavelength conversion with the spectrum-synthesizer.

1. Introduction

All-optical wavelength converters based on semiconductor optical amplifiers (SOAs) are promising devices for future high-capacity wavelength-division-multiplexing (WDM) networks, due to their ultrahigh response, low power consumption, and integration potential[1]. 320-Gb/s wavelength conversion with the delayed-interference (DI) scheme has recently been demonstrated[2]. For ultrahigh-speed signal processing above 320 GHz, pulse width shorter than 1 ps is required. It has been reported that under ultra-short control pulses the gated output waveforms with the DI scheme is distorted since the SOA gain recovery has fast and slow components (Fig. 1) due to carrier temperature relaxation and electron-hole recombination respectively[3]. Ueno *et al.* had numerically demonstrated a particular OSS design with the expanded DI scheme, by which the gated waveform distortion has successfully been removed[4].

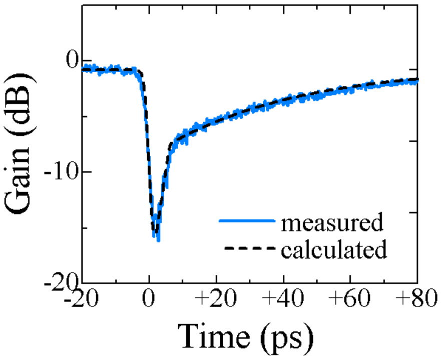


Fig. 1. Measured (solid) and calculated (dashed) SOA gain recovery. Input pulses are 2.0-ps 10-fJ at repetition frequencies of 1.25-GHz. The fast and slow recovery time constants were 6.0 ps and 50 ps, respectively.

In this talk, we report the progress of experimental demonstration that all-optical gate with OSS removes the gated output waveform distortion.

2. All-optical gate with optical-spectrum-synthesizer

Figure 2 shows a schematic view of all-optical wavelength conversion gate with the OSS. Input data pulses (λ_1) injected into SOA deplete the carrier density through stimulated emission, which leads to a change in the gain and refractive index. This change causes a continuous wave (cw) light (λ_2) to be cross-gain

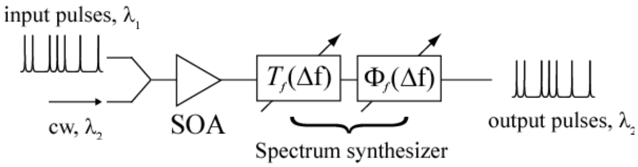


Fig. 2. The new scheme of our all-optical gate which contains an optical-spectrum's amplitude-and-phase synthesizer.

modulated (XGM) and cross-phase modulated (XPM). The cw light through XGM and XPM is input to the OSS that independently controls the intensity and the phase of spectrum in special manners[4]. Finally, the time domain re-shaped waveform is generated.

3. Time-multiplexing with VBS

In advance to experimentally studying the gate scheme in Fig. 2, we characterized the spectral resolution, the extinction ratio, and the other specifications of one of our proto-type OSS (it is called variable bandwidth spectrum shaper[5] (VBS, Optoquest Co., Ltd.) due to the control function), using an experimental setup which is schematically shown in Fig. 3. A 10-GHz 2.0-ps clock pulses was generated by a mode-locked laser diode (MLLD). The 10 GHz pulse train was input to VBS. VBS can control spectral resolution with 10 GHz for the whole C-band. VBS output spectrum components spacing was adjusted to 20 or 30 GHz with the extinction ratio control monitoring optical spectrum analyzer (OSA). The time-resolved waveform of the multiplexed output was measured by optical sampling oscilloscope (OSO).

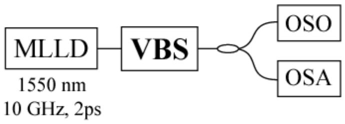
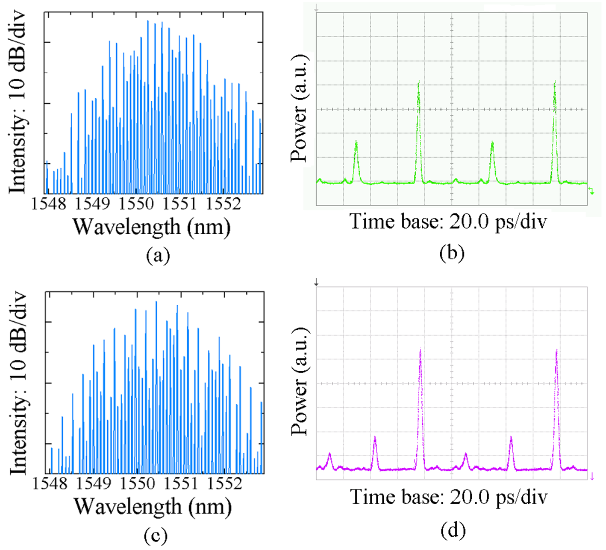


Fig. 3. Our experimental setup for characterizing our proto-type variable bandwidth spectrum shaper (VBS), with which we tried to multiplex our mode-locked pulse train in the time domain.



(a) (b) (c) (d)

Fig. 4. Optical spectra and waveforms measured at the output of the VBS.

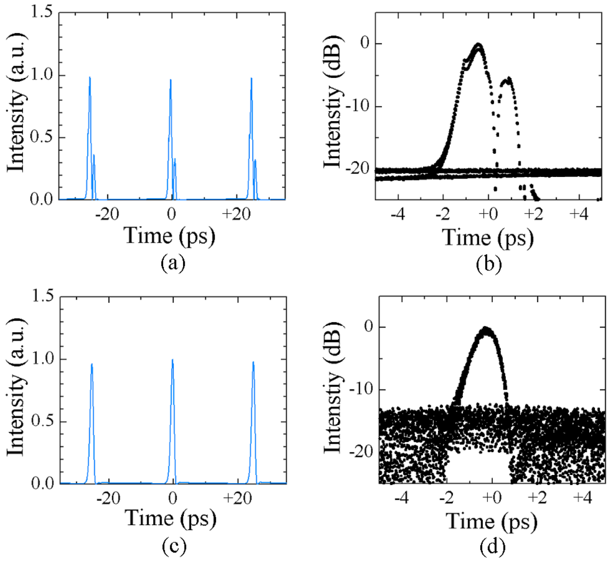
(a), (b): multiplexing from 10 GHz to 20 GHz.
(c), (d): multiplexing from 10 GHz to 30 GHz.

Figure 4 represents output spectra and waveforms with transmissivity control of spectrum-synthesizer. In multiplexing from 10 GHz to 20 GHz, the ratio of the first-blue (red) spectrum component to the central spectrum component was 13 dB (Fig. 4(a)). The synthesizer output spectrum components were not 20 GHz spacing. It was because that the spectral resolution was larger than 10 GHz. The interval of pulses was 54.5 ps (18.3 GHz) and 45.5 ps (22.0 GHz) (Fig. 4(b)). In multiplexing from 10 GHz to 30 GHz, the interval of pulses was 30.0 GHz (Fig. 4(d)).

4. Numerical simulation taking the measured characteristics of VBS into account

According to the results in section 3, we demonstrated numerically wavelength conversion with the OSS set to extinction ratio 13 dB for the pulse width 1.0 ps, bit-rate 40 Gb/s input pulses. For comparison, we also demonstrated wavelength conversion with the DI scheme.

Figures 5 (a) and (b) show the gated waveforms by the clock pulses and eye-diagrams of the gated waveform by the data pulses in the DI scheme. We observed the gated



(a) (b) (c) (d)

Fig. 5. Waveforms and eye-diagrams at the output of our all optical gates.

(a), (b): with the delayed-interference scheme.
(c), (d): with the spectrum-synthesizer scheme in Fig. 2.

waveforms with strong distortion. Figures 5 (c) and (d) respectively show the output waveforms by the clock and eye-diagrams by the data in the OSS scheme. In this case, we observed the output waveforms with little distortion, which indicated that the waveform distortion was successfully removed even by the spectrum-synthesizer set to the maximum extinction ratio 13 dB.

5. Conclusion

We characterized the spectral resolution and the extinction ratio of VBS through time-division-multiplexing experiment. The spectral resolution and the extinction ratio were from 9.7 GHz to 11.6 GHz and 13 dB, respectively. According to these results, we have demonstrated numerically that wavelength conversion with OSS for the 1.0-ps 40-Gb/s input pulses results in the removal of the gated waveform distortion. Thus, it is hopeful to experimentally demonstrate wavelength conversion with VBS.

In the presentation, we will present some experimental results with using VBS. We will demonstrate wavelength conversion with the DI and OSS schemes using VBS for the 1.0-ps 40-GHz input clock pulses.

References

1. Y. Ueno, S. Nakamura, and K. Tajima, "Nonlinear phase shifts induced by semiconductor optical amplifiers with control pulses at repetition frequencies in the 40–160-GHz range for use in ultrahigh-speed all-optical signal processing," J. Opt. Soc. Am. B **19**, 2573 (2002).
2. Y. Liu, E. Tangdiongga, Z. Li, H. de Waardt, A. M. J. Koonen, G. D. Khoe, X. Shu, I. Bennion, and H. J. S. Dorren, "Error-Free 320-Gb/s AllI-Optical Wavelength Conversion Using a Single Semiconductor Optical Amplifier," IEEE J. Lightwave Techhnol. **25**, 103 (2007).
3. J. Mørk, T. W. Berg, M. L. Nielsen, and A. V. Uskov, "The Role of Fast Carrier Dynamics in SOA Based Devices," IEICE TRANS. ELECTRON. **E87-C**, 1126 (2004).
4. Y. Ueno, R. Nakamoto, J. Sakaguchi, and R. Suzuki, "Optical-spectrum-synthesizer design within an all-optical semiconductor gate to reduce waveform distortion induced by carrier-cooling relaxation at sub-Teraherz frequencies," Optics Express. **14**, 12655 (2006).
5. S. Anzai, M. Mieno, Y. Komai, N. Wada, T. Yoda, T. Miyazaki, and K. Kodate, "Amplitude, Phase, and Bandwidth Tunable High-resolution Optical Spectrum Shaper and its Application for Optical Communication Systems," OFC/NFOEC 2008, JthA25, San Diego, 2008.