OPTOELECTRONICS LETTERS Vol.8 No.1, 1 January 2012

Optical transient waveform monitoring based on cross-gain modulation in semiconductor optical amplifier*

YANG Yi(杨义)[1,2**], **XIAO Zhong-yin**(肖中银)[1], **LIU Jian-sheng**(刘建胜)[3], **and WANG Guan-jun**(王冠军)[3]
1. Key Laboratory of Specialty Fiber Optics and Optical Access Networks, Shanghai University, Shanghai 200072, China
2. College of Information Science and Technology, Donghua University, Shanghai 201620, China
3. School of Electronic and Information Engineering, Beihang University, Beijing 100191, China

(Received 8 October 2011)

An all-optical transient waveform equivalent time sampling system based on cross-gain modulation (XGM) in semiconductor optical amplifier (SOA) is presented. A noisy SOA dynamic model and PIN equivalent circuit function are employed for system evaluating. The results show this SOA-XGM sampler with subtracting postprocessing can achieve picosecond sampling window. The shape of sampling window can be adjusted by SOA bias current and amplitude of control pulse. Compared with amplified spontaneous emission (ASE) noise of SOA and thermal noise in PIN, the jitter of sampling control pulse causes most sampling error. Simulations show that this SOA-XGM sampler can be a capable candidate for transient waveform sampling.
Document code: A **Article ID:** 1673-1905(2012)01-0040-3
DOI 10.1007/s11801-012-1141-0

The measurement of optical transient waveform, which has long duplicate cycle and low stability, is difficult by using the common commercial equivalent-time sampling oscilloscope[1]. If the autocorrelation method is employed, the waveform should be estimated in advance for the autocorrelation data fitting. Because of their low gains and conversion efficiencies, the correlation methods are inefficient for the direct measurement of low power waveforms[2]. Frequency-resolved optical gating (FROG) and spectral phase interferometry for direct electric-field reconstruction (SPIDER) suffer from their complexity, while it is difficult to be integrated with other components[3,4]. Recently, equivalent time sampling technologies using nonlinear materials have been presented[5-9]. Compared with the equivalent time sampling based on fiber, grating and nonlinear crystal, the sampling through semiconductor optical amplifier (SOA) can achieve simple structure, stable performance, easy control, low cost and high integration[10]. The sampling gain of SOA is suitable for measuring weak waveform, too. Some SOA-based samplers, such as Terahertz optical asymmetric demultiplexer (TOAD) and symmetric Mach-Zehnder interferometer (SMZI) optical switch, have been demonstrated[11,12]. In the paper, a simple and low-cost SOA-based sampler with picosecond temporal resolution at least for measuring transient short optical pulse is presented. The optical sampler is realized through cross-gain modulation (XGM) in SOA, and insensitive to the polarization of measured pulse.

The configuration of the SOA-XGM sampler is shown in Fig.1. The input transient pulse is replicated to a pulse train with equivalent interval through a passive pulse replicator formed by 90:10 coupler, variable optical delay line (VODL) and polarization maintaining (PM) fiber. The amplitude scale

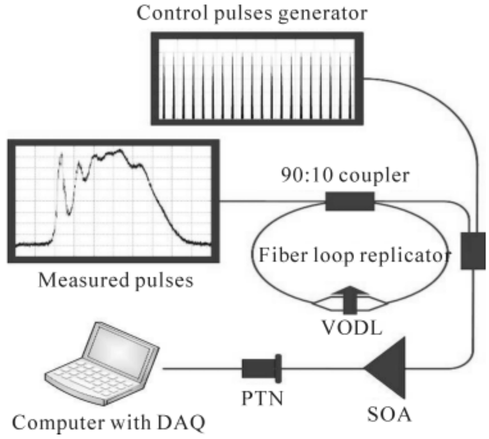

Fig.1 Configuration of SOA-XGM sampler

* This work has been supported by the National Natural Science Foundation of China (No.61077068), and the Science and Technology Commission of Shanghai Municipality (STCSM) (No.08DZ2231100).
** E-mail: YiYang@dhu.edu.cn

of each pulse is defined by splitting ratio of coupler. The interval between replicated pulses depends on the length of PM fiber, and can be adjusted by the VODL. The pulse train injects to SOA with XGM control pulses. The rising edge of XGM control pulse is important, and pulse compression technique with high nonlinear fiber could be employed. The sampled waveform and the control pulse are separated by optical band-pass filter (OPBF). PIN diode broadens the sampled waveform for data acquisition (DAQ).

The working principle of SOA-XGM sampler is shown in Fig.2. If the time-base of replicated pulses train has a defined shift with that of control pulse train, the waveform amplitude of this position can be achieved by subtracting the sampled data. It should be noted that the sampling results in subtracting need an amplitude balance. By introducing interpolation, the original transient waveform can be reconstructed. In our simulation, we use the SOA sub-section model based on the theory presented by Tang and Shore[13]. The amplified spontaneous emission (ASE) noise is added at the interfaces between adjacent sub-sections. PIN block is designed under George's dynamic response function[14]. Two equivalent noise sources are introduced to simulate the jitter in control pulse and the thermal noise of PIN.

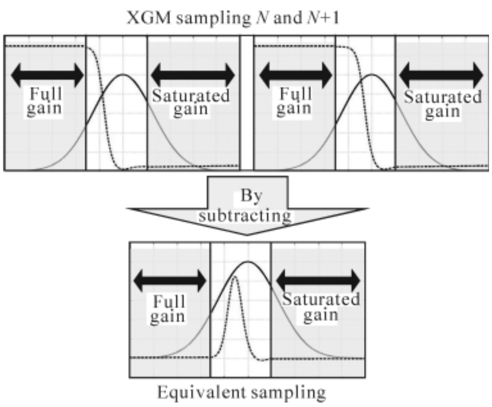

Fig.2 Working principle of SOA-XGM sampler

The sampling efficiency can be optimized by controlling the bias current of SOA and the amplitude of sampling control pulse. In simulation, a control sech pulse train with full width at half maximum (FWHM) of 1 ps is used. The change of gain due to bias current of SOA and amplitude of control pulse are presented in Fig.3. As can be seen from Fig.3, the gains are compressed below 1 ps, so that sampling windows with rising edge at picosecond level can be obtained. With adjusting the time-base between replicated pulse train and control pulses, the picosecond temporal resolution subtracted sampling windows is achieved. As shown in Fig.3, higher bias current brings bigger unsaturated gain. But there are only small differences between saturated gains under different bias currents. Control pulse with higher energy brings better sampling window shape, because it causes gain compressing and suppresses remnant energy oscillation in each sampling result more effectively.

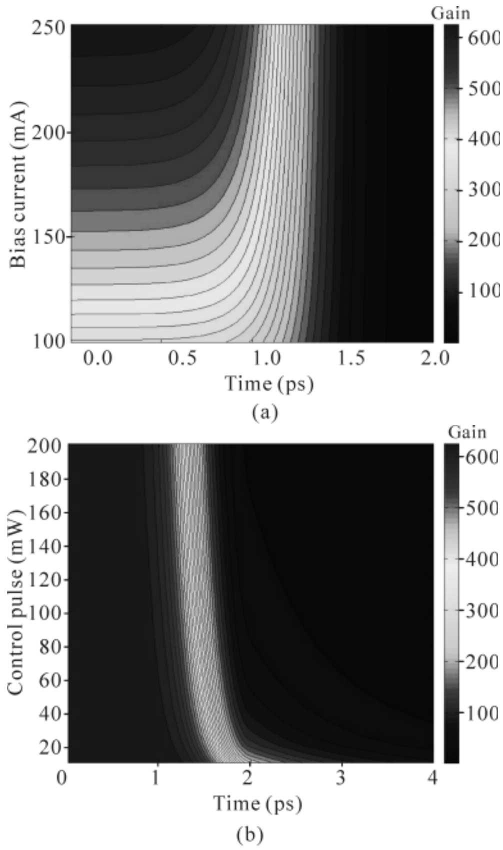

Fig.3 Changes of gain due to (a) bias current of SOA and (b) amplitude of control pulse

The Monte Carlo method (MCM) is introduced for analyzing system error. The results show that ASE noise of SOA is reduced in sampling results because of the broadening effect in PIN, in which the bandwidth is between several hundred MHz and several GHz. The thermal noise of PIN is averaged by DAQ, too[15]. But the sampling error caused by

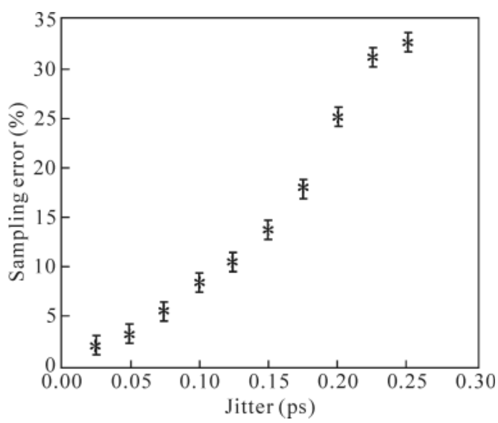

Fig.4 Mean sampling error and related deviation due to jitter of control pulse

control pulse jitter can't be suppressed, and it contributes to the most of the system error. The MCM results in Fig.4 show that the sampling error is greater than 20% when standard deviation of control pulse jitter exceeds 0.2 ps for the measured pulse with FWHM of 2.5 ps. To suppress this jitter error, the control pulse source should be chosen carefully, and fiber-based passively mode-locked lasers may be a qualified low-cost candidate for this occasion.

In conclusion, a SOA-XGM sampler is presented in this paper. Its sampling processing can be adjusted by bias current and control pulse. The control pulse jitter causes main sampling error, and can be reduced by introducing high steady time-base laser. Simulation results show this SOA-XGM sampler can sample transient waveform with high efficiency.

References

[1] J. Chou, J. A. Conway, G. A. Sefler, G. C. Valley and B. Jalali, IEEE Journal of Lightwave Technology **27**, 5073 (2009).

[2] J. Chung and A. M. Weiner, IEEE Journal of Selected Topics in Quantum Electronics **7**, 656 (2001).

[3] P. Bowlan and R. Trebino, Optics Express **19**, 1367 (2011).

[4] T. Witting, D. Austin and I. A. Walmsley, Optics Express **17**, 18983 (2009).

[5] M. Westlund, P. Andrekson, H. Sunnerud, J. Hansryd and J. Li, IEEE Journal of Lightwave Technology **23**, 2012 (2005).

[6] D. Tang, J. Zhang, Y. Liu and W. Zhao, Chinese Optics Letters **8**, 630 (2010).

[7] N. Yamada, H. Ohta and S. Nogiwa, IEEE Photonic Technology Letter **16**, 215 (2004).

[8] C. Ning, A. Yang, J. Cui, S. Shen, X. Wu and Y. Sun, Optics Communications **284**, 1412 (2011).

[9] J. Erps, F. Luan, M. Pelusi, T. Iredale, S. Madden, D. Choi, D. Bulla, B. Luther-Davies, H. Thienpont and B. Eggleton, IEEE Journal of Lightwave Technology **28**, 209 (2010).

[10] L. A. Jiang, E. P. Ippen, U. Feiste, S. Diez, E. Hilliger, C. Schmidt and H. G. Weber, IEEE Journal of Quantum Electronics **37**, 118 (2000).

[11] Y. Yang, Z. Zheng and Z. Li, Simple Optical Waveform Monitoring Based on SOA and Low-bandwidth PIN, Photonics Asia **6839**, 15 (2007).

[12] A. Bogoni, F. Ponzini, M. Scaffardi, P. Ghelfi and L. Poti, IEEE Journal of Selected Topics in Quantum Electronics **10**, 186 (2004).

[13] J. M. Tang and K. A. Shore, IEEE Journal of Quantum Electronics **35**, 1704 (1999).

[14] G. George and J. P. Krusius, IEEE Journal of Lightwave Technology **12**, 1387 (1994).

[15] D. F. Williams and K. A. Remley, IEEE Transactions on Microwave Theory and Techniques **49**, 1013 (2001).