All-optical multibit address recognition at 20 Gb/s based on TOAD

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All-optical multibit address recognition at 20 Gb/s is demonstrated based on a special AND logic of terahertz optical asymmetric demultiplexer (TOAD). The semiconductor optical amplifier (SOA) used in the TOAD is biased at transparency status to accelerate the gain recovery. This is the highest bit rate that multibit address recognition is demonstrated with SOA-based interferometer. The experimental results show low pattern dependency. With this method, address recognition can be performed without separating address and payload beforehand.

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In very high-speed optical time division multiplexing system, ultrafast all-optical signal processing methods are needed for packet header address recognition. Among packet header address recognition, multibit address recognition methods is more practical and there have been many demonstrations about it[1−4]. Nowadays, semiconductor optical amplifier (SOA) based interferometer gets more and more applications. The feasibility of device integration and high-speed operation make it be a promising candidate for all-optical signal processing. But so far the highest bit rate of multibit address recognition with SOA-based interferometer is only at 12.5 Gb/s by ultrafast nonlinear interferometer (UNI)[4]. Based on terahertz optical asymmetric demultiplexer (TOAD), address recognition was realized according to one bit of the multibit address[5]. The essential multibit address recognition based on TOAD has not been reported.

As is well known, the processing rate of SOA-based interferometer is restricted by the gain recovery time of the SOA. There are primarily several solutions: 1) using clamped gain SOA (CG-SOA)[6], 2) using gain-transparent SOA (its maximum gain wavelength is different from that of the signal data)[7], 3) injecting assist light near transparency wavelength[8], and 4) using SOA biased at transparency status[9], and so on. Among them, using SOA biased at transparency status needs neither assist light injection nor a special SOA. The only demand is a conventional SOA biased properly. Although the gain decreases, a conventional erbium-doped fiber amplifier (EDFA) is enough to compensate it. Thereby, this method is convenient and economical.

In this paper, based on the algorithm for binary word recognition proposed in Ref. [10], we demonstrate all-optical multibit address recognition at 20 Gb/s by only one AND gate of TOAD[11,12]. A SOA biased at transparency status was used in the TOAD to increase the address recognition rate and depress pattern dependency. To demonstrate the validity of this method, address recognition of two series of packet bit patterns was performed.

The principle for binary word recognition with only one logical AND operation is as follows[10].

n-bit word $W = w_1 w_2 \cdots w_n$ and $T = t_1 t_2 \cdots t_n$ satisfy the logic:

$$Q = \sum_{i=1}^{i=n} (w_i \cdot \overline{t_i}) = \begin{cases} 0, & if \quad W = T \\ 1, & if \quad W \neq T \end{cases} \qquad (1)$$

where $\overline{t_i}$ is the logical complement of t_i. Suppose W is the packet header address, T is the local address, then we can carry out address recognition according to Eq. (1). The recognition result is n-bit "0" for completely same W and T, and at least one bit "1" for different W and T.

The penalty is the restricted range of n-bit words that can be used[10]. For 4-bit address, the valid coding is 1100, 1010, 0101, 0011, 0110, and 1001. For 3-bit address, the valid coding is 100, 010, 001, or 110, 011, 101.

The experimental setup is shown in Fig. 1. Gain-switched distributed feedback semiconductor laser (GS-DFB laser) 1 and GS-DFB laser 2 are modulated at 2.5 GHz by the same synchronous digital hierarchy (SDH) analyzer. GS-DFB laser 1 produces 15-ps pulses after compression in dispersion compensating fiber (DCF). This signal is used to generate packet composed of 4-bit packet header address, generated and coded arbitrarily by a fiber-multiplexer with a polarization controller (PC) in each arm and a polarizer, and an empty payload. Another function of the polarizer is to insure the pulses in the packet header address being at the same polarization status before entering the TOAD. GS-DFB laser 2 produces 2-ps pulses after compression in DCF and comb-like dispersion profiled fiber (CDPF). This signal is used to generate the logic complement of the local address, $\overline{\text{local address}}$, by a passive multiplexer consisting of two couplers and a variable optical delay line (ODL1). With this multiplexer and ODL2 in front of the TOAD, which is primarily used to temporally synchronize the packet header address and the $\overline{\text{local address}}$, all of the valid coding of the 4-bit address can be generated, as shown in Fig. 2. The bit rates of the packet and the local address are both 20 Gb/s. Two attenuators (Atts) are used to adjust the power of the packet stream and the $\overline{\text{local address}}$ stream. All of the experimental results in this paper were gotten by a 50-GHz sampling oscilloscope.

All-optical address recognition is achieved in TOAD

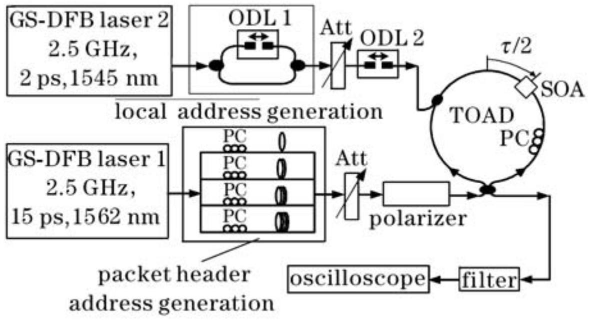

Fig. 1. Experimental setup for 4-bit address recognition.

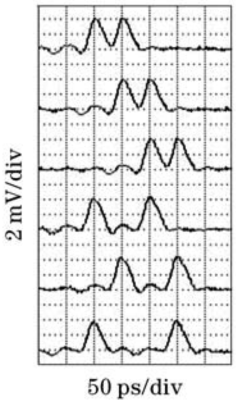

Fig. 2. Six kinds of valid coding of local address. From top to bottom: 1100, 0110, 0011, 1010, 0101, 1001.

by an AND operation of the packet header address and the local address according to Eq. (1). Here is the mechanism of it. Address bit "1" in the local address serves as control pulse for TOAD to open a switching window. If the corresponding address bit in the packet header address is also "1", TOAD outputs "1". Otherwise, TOAD outputs "0". However, address bit "0" in the local address can not drive TOAD to open a switching window and corresponding to this address bit, TOAD always outputs "0". That is to say, only as the corresponding bits in the packet header address and the local address are both "1", TOAD outputs "1", and for any other circumstance, TOAD outputs "0". Therefore, for the valid coding of equation (1), if the packet header address is completely same to the local address or complementary to the local address, TOAD outputs full "0", otherwise, outputs at least one "1". Figure 3 shows the address recognition results for packet header address 0110, 1010, 1001 with six kinds of local address mentioned above.

It can be seen from Fig. 3 that the experimental results fit well with the theory and successful address recognition is achieved. At the input of the TOAD, the average optical power of the packet stream and the local address stream were −14 and 4.5 dBm, respectively. The SOA was biased at transparency status with the working current of 130 mA. In this circumstance, optical signal propagating through it experiences no net gain or absorption. The gain recovery time is decided by in-band effect such as carrier heating and two photon absorption, and has

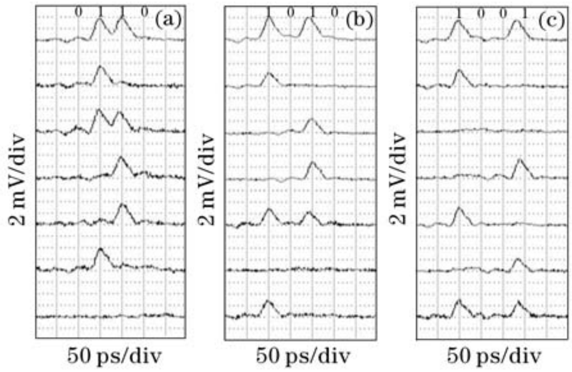

Fig. 3. Address recognition results for packet header address (a) 0110; (b) 1010; (c) 1001. The seven traces from top to bottom in each graph are packet header address and its address recognition results with local address 1100, 0110, 0011, 1010, 0101, 1001.

the values of a few picoseconds. This increases the address recognition rate greatly and avoids the serious pattern dependency caused by the long gain recovery time.

In order to demonstrate the feasibility of this address recognition method, address recognition of packet at 20 Gb/s including 3-bit header address and 4-bit payload and a guard time of 25 ps between them was also performed. The experimental setup is shown in Fig. 4. The packet header address 110 (101) is still generated by the fiber-multiplexer with a PC in each arm and a polarizer. Afterwards, it is multiplexed in the following passive multiplexer and produces the whole packet 110 1100 (101 1010). The generation of the local address 100, 010, 001 and the synchronization of the two addresses are realized by ODL2. The three kinds of local address are shown in Fig. 5 and the address recognition results are shown in Fig. 6.

The experimental results also show high consistency with the theory. It can also be seen from Fig. 6 that whatever the payload is, it does not affect the recognition

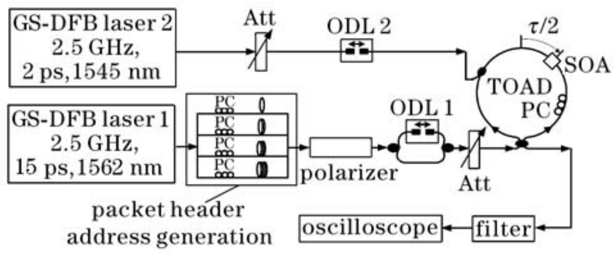

Fig. 4. Experimental setup for address recognition of 7-bit packet including 3-bit header address and 4-bit payload.

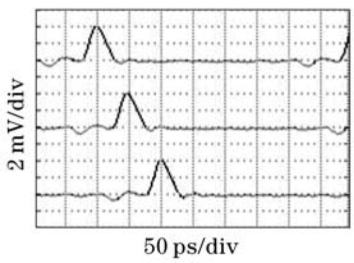

Fig. 5. Local address. From top to bottom: 100, 010, 001.

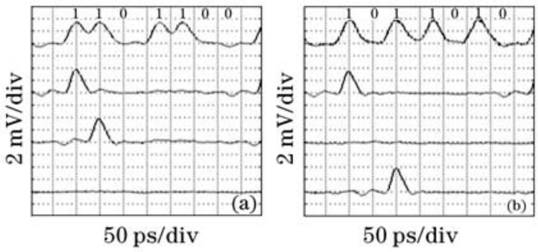

Fig. 6. Address recognition results for packet (a) 110 1100; (b) 101 1010. The four traces from top to bottom in each graph are 7-bit packet and its address recognition results with local address 100, 010, and 001.

result. That is to say, there is no need to separate address and payload before address recognition. This simplifies the system design and is also its advantage over address recognition with XOR logic. Furthermore, since the payload does not affect the recognition result, we believe that the bit rate of the payload that this method can process is farther above 20 Gb/s that is demonstrated in this letter.

In this letter, we have demonstrated the highest bit rate all-optical multibit address recognition with SOA-based interferometer. It is performed by only one logical AND operation of TOAD with a SOA biased at transparency status. This method simplifies the system design because the separation of address and payload is not required. The recognition result can be used to perform all-optical packet routing.

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References

1. D. Cotter, J. K. Lucek, M. Shabeer, K. Smith, D. C. Rogers, D. Nesset, and P. Gunning, Electron. Lett. **31,** 2201 (1995).
2. T. Nakahara, R. Takahashi, and H. Suzuki, in *Proceedings of Optical Fiber Communications Conference* WM5 (2002).
3. T. J. Xia, Y. Liang, K. H. Ahn, J. W. Lou, O. Boyraz, Y.-H. Kao, X. D. Cao, S. Chaikamnerd, J. K. Andersen, and M. N. Islam, IEEE Photon. Technol. Lett. **10,** 153 (1998).
4. S. A. Hamilton, B. S. Robinson, T. E. Murphy, S. J. Savage, and E. P. Ippen, J. Lightwave Technol. **20,** 2086 (2002).
5. I. Glesk, J. P. Solokoff, and P. R. Prucnal, Electron. Lett. **30,** 1322 (1994).
6. J. C. Simon, P. Doussière, P. Lamouler, I. Valiente, and F. Riou, Electron. Lett. **30,** 49 (1994).
7. S. Diez, R. Ludwig, and H. G. Weber, IEEE Photon. Technol. Lett. **11,** 60 (1999).
8. J. L. Pleumeekers, M. Kauer, K. Dreyer, C. Burrus, A. G. Dentai, S. Shunk, J. Leuthold, and C. H. Joyner, IEEE Photon. Technol. Lett. **14,** 12 (2002).
9. Y.-H. Kao, I. V. Goltser, M. N. Islam, and G. Raybon, in *Proceedings of CLEO 1997* CTuJ4 (1997).
10. D. Cotter and S. C. Cotter, Electron. Lett. **29,** 945 (1993).
11. J. P. Sokoloff, P. R. Prucnal, I. Glesk, and M. Kane, IEEE Photon. Technol. Lett. **5,** 787 (1993).
12. H. Pang, Z. Zhang, S. Yan, X. Sun, and M. Zhang, Chin. J. Lasers (in Chinese) **28,** 641 (2001).