FULL-OPTICAL LOGICAL GATES FOR OPTICAL SIGNAL PROCESSING

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Summary This paper is dedicated to full-optical logical NOT, AND and NAND gates. In the first section are described logical functions based on Mach-Zehnder interferometric structure. The second part deals with full-optical logical gate AND, that utilizes TOAD structure. The last one is focused on the exploitation of logical gate AND for optical head separation from payload data. Simulations and final design were realized in simulation environment Virtual Photonic close up to 150 Gb.s^{-1} bit rate.

1. INTRODUCTION

In recent years rising requirements for transfer rates of networks can be observed. The amount of transmitted data capacity grows rapidly and the question is how we can increase capacities in present transmission lines. The only one possibility is a construction of optical networks, that are able work with transmissions rates up to hundreds Gb.s^{-1}. These bit rates are not possible unless optical node will not work in full-optical mode, i.e. switching and controlling must be full-optical. Full-optical logical gates utilize nonlinear effects in Semiconductor Optical Amplifier (SOA) or in High Non-Linearity Fiber (HNLF). Full-optical logical gates are able to operate with the following nonlinear effects. The first is Four Wave Mixing (FWM). This nonlinear effect generates new spectral components. Additional effects are Cross Phase Modulation (XPM) and Cross Gain Modulation (XGM). XPM changes the phase or amplitude between the two input optical signals with non-linear refractive index modification. XGM changes the phase or amplitude of optical signal with modification of nonlinear gains. We are able to construct logical gates through the interferometric structures as Mach – Zehnder Interferometer (MZI) or Terahertz Optical Asymmetric Demultiplexer (TOAD).

2. INTERFEROMETRIC STRUCTURES

Mach – Zehnder interferometer

MZI (Fig. 1) contains two nonlinear elements (SOA). Optical data signal is divided at the input of optical splitter into the two in power equal signals. Both signals are led into the two different arms and interfere in the optical output coupler [1].

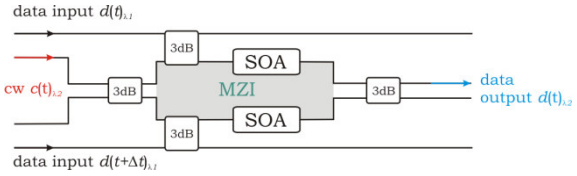

Fig. 1. Ultra-fast Nonlinear Interferometer [1]

Terahertz Optical Asymmetric Demultiplexer

TOAD (Fig. 2) is based on Sagnac interferometer. SOA shifted from a fiber loop center is used as a nonlinear element. Input signal is divided by 3dB optical splitter onto two signals (parts) that are dilated and counter propagating through fiber loop. Because SOA is soft offset, opposing signals reach SOA in different time. When signals come through a loop, both interfere in 3dB coupler. If control signal is absent, both signals are passing through loop unchanged (but carrier wave one from signals is in anti-phase) and in the coupler at the straight port we observe destructive interference. If the control signal is present, the nonlinear changes in SOA are significant. The phase change between two counter propagating signals occur and consequently we observe constructive interference on the output port and the same signal as at input. We can utilize TOAD for various logical functions as, e.g. AND, NOT and XOR. Complicated logical functions we can make by combination of several TOAD-s [1].

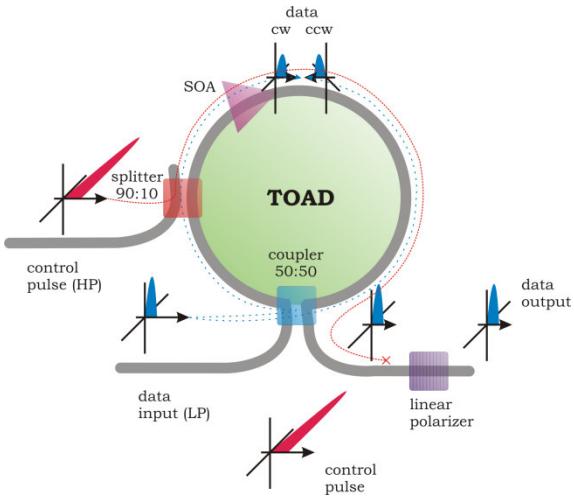

Fig. 2. This TOAD works with orthogonally polarized signals (input and control) [1]

3. STRUCTURES SIMULATION

Full-optical gate NOT simulation

Two signals (Fig. 4) enter the optical logical gate (nonlinear element is SOA). First signal is control signal with power 0.05 mW at the wavelength 1553.6 nm and second is a data signal with power 0.5 mW on the wavelength 1552 nm. As a main effect is utilized XGM and control signal changes data signal by gain influence. At the output port we get inverted data signal (Fig. 5). Simulations are performed close up to 150 Gb.s^{-1} bit rate [2].

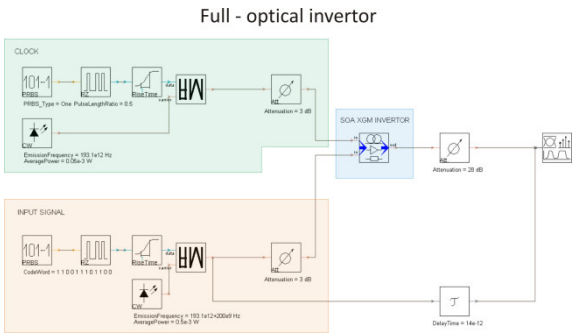

Fig. 3. Scheme of full-optical inverter

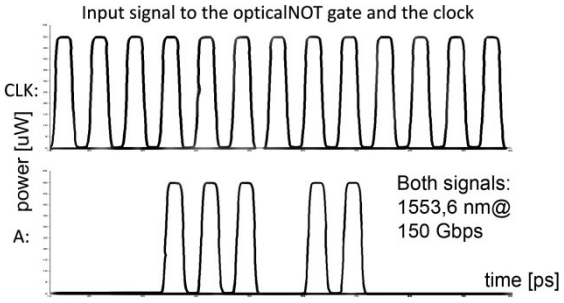

Fig. 4. Signals at input

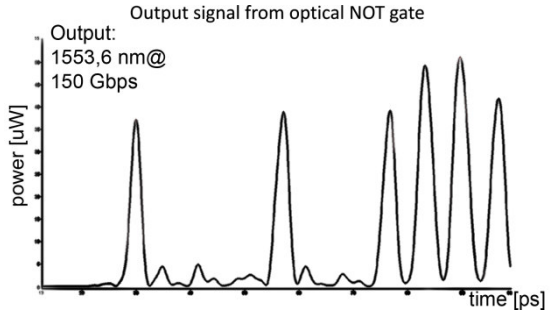

Fig. 5. Output signal

Full-optical AND gate simulation

MZI is chosen to achieve full-optical logical gate AND. Logical function is created by the two input optical signals (Fig. 7). Input signal A is led into the upper arm of MZI, where XPM effect in SOA, affects a phase of signal B which is subsequently changed. Input signal B is through the 3 dB splitter divided into the both arms of MZI.

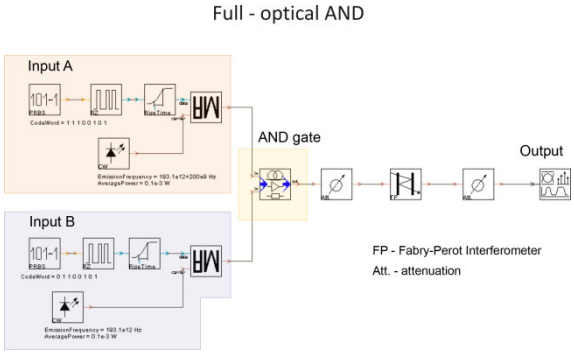

Fig. 6. Scheme full-optical AND gate

Constructive or destructive interference can occur in the output coupler. If both input signals are log 1, we can observe the constructive interference on the output port of coupler, i.e. output signal will be log 1. If one from input signals has power level log 0, we can observe the destructive interference onto output port, i.e. output signal will be log 0 (Fig. 8). Simulations are performed close up to 150 Gb.s^{-1} bit rate [2].

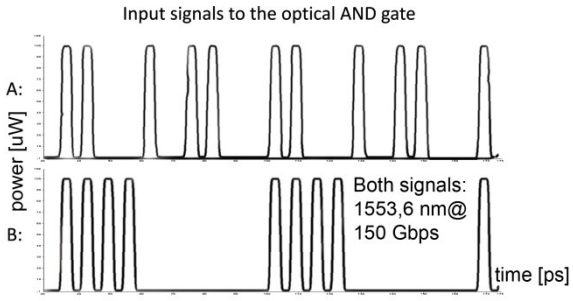

Fig. 7. Input signals in to the optical AND gate

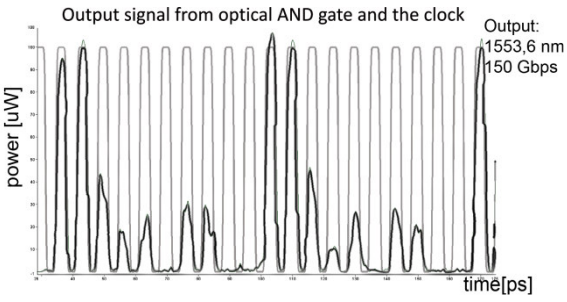

Fig. 8. Output signal from AND gate

Full-optical NAND gate simulation

Full-optical logical gate NAND was created from optical gate AND and optical gate NOT. In the first stage, two input optical signals (Fig. 10) enter pass through logical function AND. In the second stage, the output signal from gate AND with control optical signal go into the input ports of NOT gate. Output signal (Fig. 11) from NOT gate is NAND function. Operation principles are identical with both optical gates mentioned before [2].

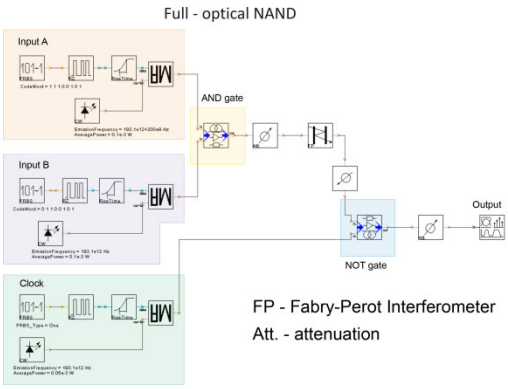

Fig. 9. Scheme full-optical NAND gate

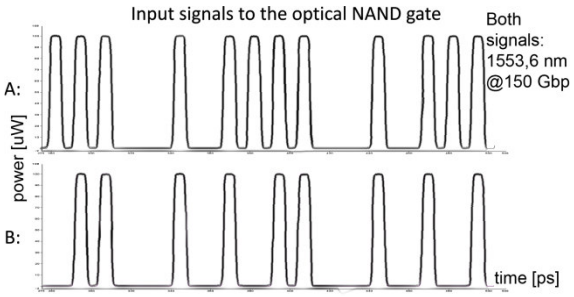

Fig. 10. Input signals to the gate

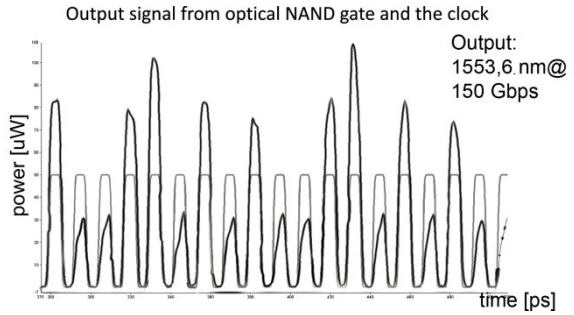

Fig. 11. Output signal from NAND gate

Full-optical AND (TOAD) gate

Logical function is created by the two input optical signals (Fig. 12). It is necessary to have one control signal and one data signal for correct work of TOAD. In our case, signal A is a data signal and signal B is a control signal. If both signals are ones, the constructive interference or log 1 will appear on the output of coupler. In the other case the destructive interference or log 0 takes a place (Fig. 13). It is necessary that both input signals' widths are within the range of several ps (in our simulation we set to 5 ps) for acceptable TOAD operation [2].

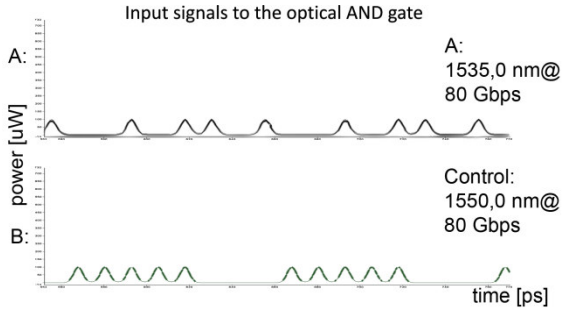

Fig. 12. Input signals to the AND gate

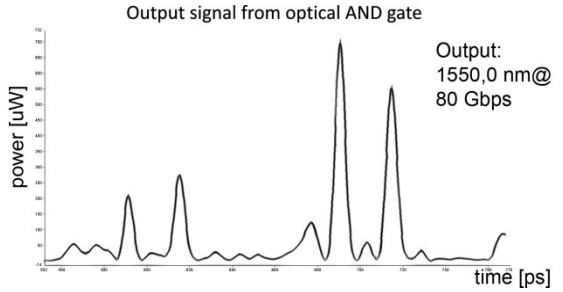

Fig. 13. Output signal from TOAD AND gate

Simulation of TOAD structure for head recognition and payload selection from data stream

Input data stream (Fig. 14a – bit sequence 01 000 10011011) includes control part (head), protective bits and useful data. For head separation from input data stream is used control signal bit sequence 11 000 00000000 (Fig. 14b – the first two bits are control - head) and to select useful data from input data stream is used control signal bit sequence 00 000 11111111. Between head and useful data are included three protective bits, due to suppression of ISI (inter symbol interference) [3, 4, 5].

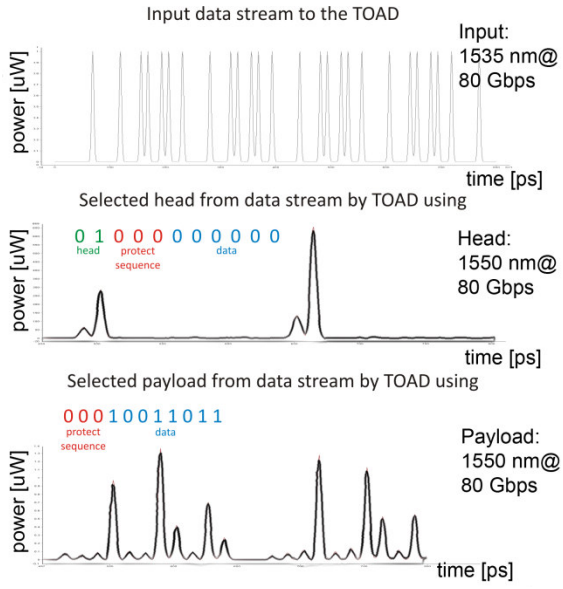

Fig. 14. Recognition the heads bits and selecting payload using TOAD

4. CONCLUSION

Full-optical logical gates will play very important role in future high-speed optical network. Advantages of described structures are their easy integration and using at high bit rates, which are not possible in the network with electro-optical and opto-electrical converters. In the first part we have demonstrated full-optical logical gates with MZI structure with bit rate close up to 150 $Gb.s^{-1}$. In the second part we have demonstrated full-optical separation head from useful data by the TOAD at bit rate 80 $Gb.s^{-1}$. It is expected that TOAD will be used in full-optical node. In the case of a cascade of full-optical logical gates, there will be a requirement to resolve a power level of log. 0, which is not zero in the output port of optical gates. If the power level of log 0 is not sufficiently low, the optical logical gates won't work properly.

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