Simultaneous Implementation of Photonic OR and AND Logic Gates for CSRZ-OOK Signal Using Four-Wave Mixing (FWM) in a Highly Nonlinear Photonic Crystal Fiber (HNL-PCF)

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Abstract *A simultaneous implementation of photonic OR and AND logic gates for 10-Gb/s CSRZ-OOK signal is demonstrated using FWM in a 60-meter HNL-PCF. The logic integrity and system performance are experimentally evaluated by BER measurements.*

Introduction

Photonic logic gates are crucial elements in future optical networks to implement various optical signal processing functions. Until now, previous approaches using fibers, waveguides, and semiconductor optical amplifier (SOA) mainly emphasize a single logic function or separately implement a reconfigurable logic gate by varying the input power, the polarization or the operation wavelength [1-3]. The task becomes more complex when two or more logic gates need to be realized simultaneously. Moreover, most existing schemes are confined to conventional non-return-to-zero (NRZ) and return-to-zero (RZ) formats. Carrier-suppressed return-to-zero (CSRZ) on-off-keying (OOK) format is another widely used modulation format, as the CSRZ-OOK is a good candidate for the long-haul transmission due to its resilience to the fiber nonlinearity and group velocity dispersion [4]. However, because of the phase alternation between 0 and π at each bit transition, it is challenging to realize photonic logic gates for the CSRZ format. To the best of our knowledge, no scheme of all-optical logic gate for CSRZ format has ever been reported. In this paper, based on both degenerate four-wave mixing (D-FWM) and non-degenerate FWM (ND-FWM) arising in a 60-meter highly nonlinear photonic crystal fiber (HNL-PCF), we propose and demonstrate an all-optical logic scheme to simultaneously achieve OR and AND logic operations for the CSRZ-OOK signal. Compared with the SOA-based approaches, our scheme can be potentially operated at terabits per second thanks to the almost immediate response of fiber nonlinearity. Moreover, the use of HNL-PCF can effectively shorten the required fiber length and the operating wavelengths can be chosen flexibly as the dispersion of HNL-PCF can be optimized. Such a simultaneous multi-function logic unit is compact and cost-effective for future optical network nodes.

Operation Principle and Experimental Setup

Fig.1 shows the experimental setup of the proposed logic gates. Continuous-wave (CW) lights from two laser diodes LD1 and LD3 at λ_1=1556.56 nm and λ_3=1559 nm are combined by a coupler, and then externally modulated by two cascaded Mach-Zehnder modulators (MZMs) to generate CSRZ-OOK signals. MZM1 is used to generate NRZ signals driven by a 2^7-1 pseudorandom binary sequence (PRBS) electrical NRZ signal provided by a pulse pattern generator (PPG). MZM2 serves as a pulse carver to transform the NRZ format into its CSRZ format. Later, the dual-wavelength signals are separated by wavelength division multiplexer (WDM) in order to complete signal de-correlation by a 500-meter single-mode fiber (SMF). An optical delay line (ODL) is used to synchronize two data signals A and B at different wavelengths. A 10 Gb/s CSRZ-OOK clock at 1558.2 nm is generated by sinusoidally driving MZM3 at half the bit rate between its transmission maxima. The polarization controller 4 (PC4) and PC5 are used to adjust the relative polarizations of the three input lights. Finally, two input data signals together with a third CSRZ clock pulse train are multiplexed by an array waveguide grating (AWG1), and then amplified by an erbium-doped fiber amplifier (EDFA) with a saturation power of +25 dBm. Later, the amplified signals are launched to a 60-meter HNL-PCF (Crystal Fiber, NL-1550-POS-1), which has a nonlinear coefficient of 11 $W^{-1}km^{-1}$ and 5 dB insertion loss. It is worth noting that by optimizing the structure of PCF, the chromatic dispersion of the HNL-PCF has been flattened over the whole C-band. Inside the HNL-PCF, both D-FWM and ND-FWM occur and several new components are generated, as schematically shown in Fig. 1. Each of the generated components has a frequency of $f_{lmn}=f_l+f_m-f_n$ (where m≠n; and l, m and n select from 1, 2 and 3), and a phase of $\Phi_{lmn}=\Phi_l+\Phi_m-$

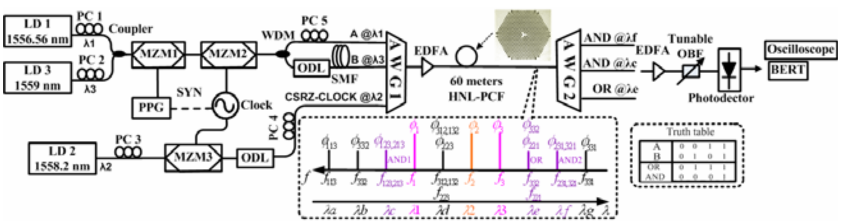

Fig. 1: Experimental setup of the photonic logic gates based on four-wave-mixing in HNL-PCF.

Φ_n. It is a D-FWM component when l=m, while it is a ND-FWM component when l≠m [5]. The generated components with wavelengths of λ_e=1559.8 nm, λ_c=1555.8 nm and λ_f=1560.6 nm are chosen as the output OR and two AND results, respectively. For logic AND gates, the selected components at λ_c and λ_f are ND-FWM components whose intensities depend on all three incident lights. Only when both A and B are binary '1' at a given bit transition (AB=11), the intensities of λ_c and λ_f components will exist, corresponding to the AND function. For logic OR gate, when either A or B, or both, are present (AB=10, 01, 11), D-FWM between the input data signals and the CSRZ clock will occur. As a result, the intensity of λ_e component will exist. However when both A and B are absent (AB=00), there is no intensity at λ_e. Therefore the OR logic function is realized successfully. For the CSRZ-OOK signal, special consideration has to be taken for the phase variation. According to simple calculations and the optical phase periodicity holds, all logic outputs have the same phase alternation as that of the input CSRZ signal. Therefore, the OR and AND logic gates can be achieved simultaneously for CSRZ-OOK signal in a single logic unit. Moreover, it is noted that the proposed logic schemes can be applied to the conventional NRZ- or RZ-OOK, if the CSRZ clock is replaced with a CW light from LD2. After AWG2 and individual amplification, the selected logic output is filtered out by a 0.8nm optical bandpass filter (OBF) to remove the amplified spontaneous emission (ASE) as well as the crosstalk.

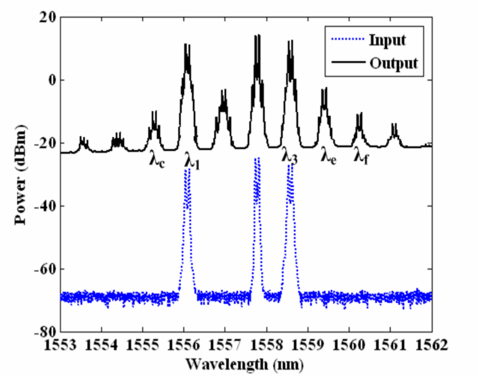

Fig. 2: Optical spectra before/after the HNL-PCF.

Experimental Results and Discussion

In order to verify the operation of the OR and AND logics for the CSRZ format, the optical spectra of all signals before and after the HNL-PCF was monitored by an optical spectrum analyzer (OSA) with 0.01 nm resolution, as shown in Fig. 2. It can be clearly observed that the selected components all exhibit two strong clock tones separated by 10 GHz, and the optical carriers are suppressed by about 10 dB, coinciding with the CSRZ format spectrum characteristics. Due to the components' constraint, we only experimentally extracted the OR result at λ_e and the AND2 result at λ_f. The temporal waveforms including the inputs A and B, the AND output, and the OR output were detected by a 43 GHz photodetector, as shown in Fig. 3. The correct AND and OR logic operations are simultaneously obtained successfully. Bit-error-rate (BER) measurements were preformed to evaluate the performance of the proposed logic unit. The measured BER of the two inputs, the AND and the OR outputs are plotted in Fig. 4. Compared with the input CSRZ-OOK signal, the power penalty of the OR output signal is 1 dB at the BER of 10^{-9}. The power penalty of the AND output signal is slightly increased to 1.2 dB. The power penalty might be attributed to the noises induced by the EDFA and the crosstalk from the neighboring signals.

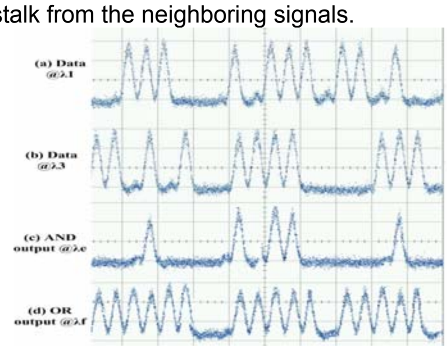

Fig. 3: Waveforms of two input data and corresponding logic outputs with CSRZ-OOK format. (a) Data A, (b) Data B, (c) AND result, (d) OR result.

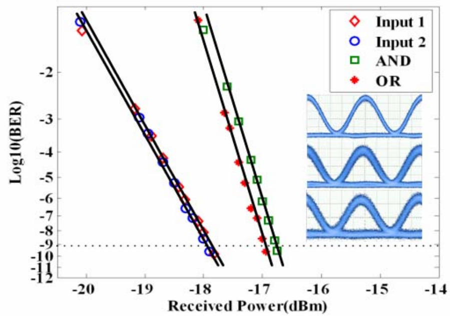

Fig. 4: The BER measurements of two input data, AND output and OR output with CSRZ-OOK format.

Conclusions

Using D-FWM and ND-FWM in a 60-meter HNL-PCF, we successfully demonstrated a simultaneous implementation of photonic OR and AND logic gates for CSRZ-OOK signal. The obtained waveforms and the BER results verified the logic integrity and system performance. Due to the femtosecond response time of the HNL-PCF nonlinearity, our scheme can support high date rate at 160 Gb/s or beyond without modification of the setup.

References

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