40 GHz All-Optical XOR with UNI Gate

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Abstract: 40 GHz Boolean XOR is demonstrated using an Ultrafast Nonlinear Interferometer gate. The gate operates with low switching energy and signals from the same source. It may be used in networking applications without wavelength conversion.

Introduction

The appetite for lightwave networks of increasing capacity is continuing undiminished and it looks likely that from here on, the next jump in performance may be expected from increasing the channel data rates to 40 Gbps or beyond [1-2] as opposed to massively increasing the channel count at lower rates. As channel rates increase, full exploitation of the network performance will only be possible, if functions such as routing, protection and packet switching are carried out directly in the optical domain on the data stream. For this endeavor it is critical that high speed all-optical digital logic gates are available and so far a number of semiconductor-based, nonlinear interferometric devices have been demonstrated in several applications [3-6]. Recently a single-arm ultrafast nonlinear interferometer (UNI) gate has been demonstrated [7] and this has been shown to be capable of doing single rail AND logic up to 100 Gbps [8]. In order to perform feed-forward networking functions such as header recognition and feed-back functions such as encryption, dual rail logic and in particular Boolean XOR is also necessary and this was recently demonstrated at 20 Gbps [9]. In the present communication we demonstrate all-optical, Boolean XOR at 40 GHz using a UNI gate. This is to our knowledge the highest rate at which all-optical, Boolean XOR has been demonstrated so far with a semiconductor gate. The gate has been operated with three optical signals derived from the same source, so that it may be used directly without wavelength conversion.

Experiment

Figure 1 shows the experimental set up. The gate was powered with three optical signals, of which controls A and B were the logical inputs to the switch and the logical operation A XOR B appearing at the output of the gate, was

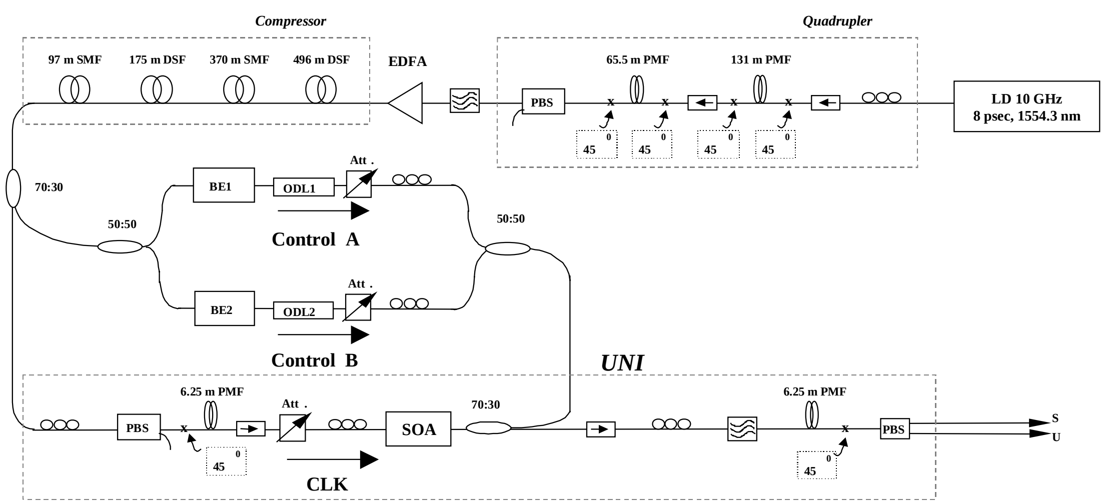

Figure 1: Experimental setup.

written on the incoming clock signal CLK. The three optical signals were produced from a packaged and pigtailed, gain switched DFB diode laser operating at 1554.3 nm. The diode was driven at 10 GHz from a synthesized signal generator and produced 8.1 ps pulses after compression in dispersion compensating fiber of total dispersion –46 ps/nm.

The 40 GHz pulse stream was obtained by bit interleaving the initial 10 GHz pulse train in a fiber quadrupler, consisting of two consecutive repetition rate doubling stages. The rate doubling was achieved using the birefringence of PM fiber with the input signal linearly polarized at 45^o to the birefringent axes of the fiber and the two relatively delayed components recombined in a fiber polarizer at the output of each stage. At the output of the fiber quadrupler a 40 GHz pulse train of 9 ps duration was obtained.

The 40 GHz stream was next power-amplified to 350 mW and compressed in a two-stage nonlinear fiber compressor. Each compression stage consisted of a length of dispersion shifted fiber (DSF), followed by standard single mode fiber (SMF). Each stage was designed using the software simulation tool PTDS from VPI, to give about π phase shift at the peak of the pulse so as to avoid the generation of satellite pulses. Figure 2 shows the autocorrelation trace of the 2.2 ps, 40 GHz pulse train after the compressor.

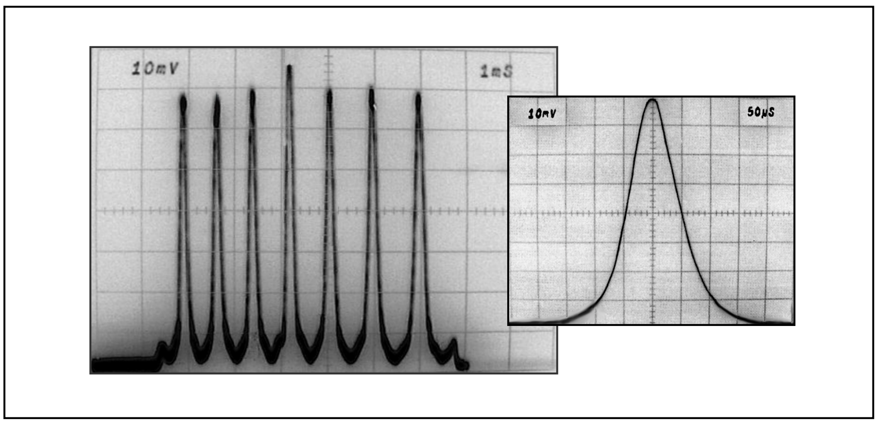

Figure 2: Autocorrelation of the 2.2 ps, 40 GHz pulse train after the fiber compressor.
50 µs on the timebase corresponds to 1.6 ps

The XOR logic gate was implemented using the UNI gate. The concept of operation of the UNI gate relies on polarization rotation of the incoming CLK signal in the presence of a control pulse in a SOA. The CLK pulse is split into two orthogonal polarization components, which are relatively delayed in a length of birefringent PM fiber before entry into the SOA. The length of the PM fiber is such as to insert a temporal displacement between the two polarization components equal to half the pulse repetition period and was 6.25 m.

For single rail logic operations, the control pulse is temporally synchronized with one of the two orthogonal polarizations of the clock. This causes a local, time-dependent refractive index change in the SOA, which in turn imparts a phase change only on the synchronized polarization component of the clock pulse. For dual rail logic such as XOR, the phase of each polarization state must be accessed and changed independently with the two control signals in the SOA. In our experiment this was achieved by temporally synchronizing and adjusting the polarization state of each control signal to be orthogonal to its respective CLK component, while the energy of each was adjusted to cause an equal phase change. Adjustment for these parameters was provided with variable delay lines, polarization controllers and variable attenuators. The SOA was a 1.5 mm long bulk InGaAsP-InP ridge waveguide device providing 30 dB small signal gain at 1558.9 nm at 680 mA. Isolators were used at the ports of the SOA to eliminate undesirable reflections. At the output of the SOA the orthogonal polarization components of the CLK signal were filtered, their relative delay was removed in 6.25 m of PM fiber and they were made to interfere in a fiber PBS with its axes spliced at 45^o with the PM fiber. With this arrangement and in the absence of any control pulses, the clock appears unswitched in one of the ports of the PBS, termed U. If either of the control pulses is present the clock appears switched in the other port, S.

Results and discussion

Successful accomplishment of Boolean XOR operation is guaranteed, when the switched port S of the gate records a logical ‘1’ if either A or B is ‘1’ and a logical ‘0’ if both A and B are ‘1’ or ‘0’. Figure 3 illustrates the logic output

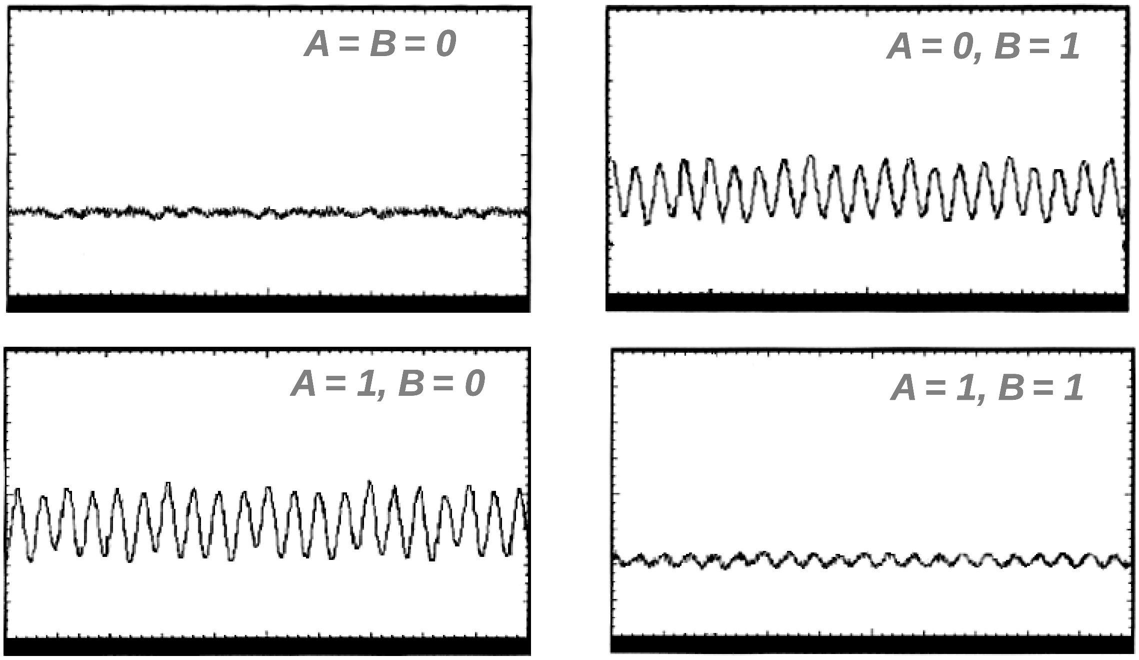

Figure3: Switched port outputs for the four logical combinations of clock A and B. The time-base is 50 ps.

of the switched port of the gate for the four combinations of control data A and B for full duty cycle signals. It was monitored by a 40 GHz photodiode and sampling oscilloscope and indeed shows the performance of Boolean XOR. The contrast ratio between the ON-OFF states of the gate was greater than to 5:1. Extinction was less for the A=1, B=1 state because of imperfect repetition rate quadrupling. The energies of the clock, control A and control B pulses were 3 fJ, 4.5 fJ and 4.5 fJ respectively and they are low enough that the gate may be used with optical signal provided directly from laser diodes without amplification, provided that the pulses are short enough.

Conclusion

In conclusion we demonstrate for the first time, to our knowledge, optical Boolean XOR at 40 GHz with a SOA-based, Ultrafast Nonlinear Interferometer gate. The gate was operated with clock and control signals from the same laser diode and it may be used without the need for wavelength conversion in applications requiring logical feed-back.

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