All-Optical Flip-Flop Based on Dynamic Brillouin Gratings

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One of the most essential building blocks in modern electronics is the flip-flop. A flip-flop operates bi-stably between two states, remaining at a given output level (high or low level) until a specific input control signal changes. For many years, photonics has attempted to build all-optical flip-flops [1-3]; however, the success of these approaches has usually been limited by the dependence of the bi-stable operation on bit-rate and optical power [1,2]. Furthermore, in most of the reported demonstrations, the storage time is inherently short. Typically, the figure-of-merit of these devices is measured by the time-bandwidth product, which is defined as the storage time of the device times the available bandwidth. State-of-the-art values are in the order of 10-100.

This work proposes a method to generate all-optical flip-flops based on dynamic Brillouin gratings (DBGs) in polarisation maintaining fibres (PMF) [4]. Contrarily to existing approaches, this method can allow extremely long storage times and arbitrarily high bandwidth response. The technique relies on generating a very long, weak DBG along a PMF. The experimental setup here used as a proof-of-concept is shown in Fig. 1(a) (see ref. 4 for details). The DBG is generated by launching two continuous-wave pumps (Pump1 and Pump2) through the opposite sides of a 1 m-long Panda PMF. Both pumps are amplified by Erbium-doped fibre amplifiers (EDFAs) up to 25 dBm and aligned to the fast axis of the PMF. An electro-optic modulator is used to shift the optical frequency of one of the pumps, so that the frequencies fulfil the condition: $f_{\mathrm{Pump1}} = f_{\mathrm{Pump2}} - \nu_{\mathrm{B}}$, where ν_{B} (=10.8 GHz) is the Brillouin frequency along the fast axis of the PMF. The created DBG acts as the all-optical equivalent of an integrator [4]. To read the DBG, 300 ps pulses with controlled phase are generated (see lower branch in Fig. 1(a)) and launched along the slow axis of the PMF at the probe frequency $f_{\mathrm{Probe}} = (n_{\mathrm{fast}}/n_{\mathrm{slow}}) f_{\mathrm{Pump1}}$, where n_{fast} and n_{slow} are the fibre refractive indexes along fast and slow axes. The output state of the flip-flop is changed (i.e. set and reset) using pulses with opposite phases. This flip-flop response is then observed at frequency $f_{\mathrm{R}} = f_{\mathrm{Probe}} - \nu_{\mathrm{B}}$.

The correct operation of the flip-flop is experimentally demonstrated using two out-of-phase pulses separated by 3.5 ns and 6.5 ns, as shown Fig. 1(b) and 1(c). The first section of the measured time-domain signals represents the reflection of the first pulse (the output is set to a high level at the arrival of the pulse). The length of the response is limited by the length L of the PMF (storage time < $2n_{\mathrm{slow}}L/c$, being c the speed of light). The second pulse (π-phase shifted) resets the device before the storage time limit. Results indicate that when the phase modulation is turned off, the two reflections sum up in phase (grey curves), leading to a constructive interference that results in an amplitude proportional to the integral of the two pulses (i.e. 4x the response of a single pulse). However, when the phase of the second pulse is shifted by π, the two reflections arrive to the photo-detection with opposite phases, thus cancelling out each other and resetting the flip-flop (red curves). The time-bandwidth product is calculated to be ~30, being in this experiment mainly limited by the relatively low bandwidth of the used pulses and short PMF.

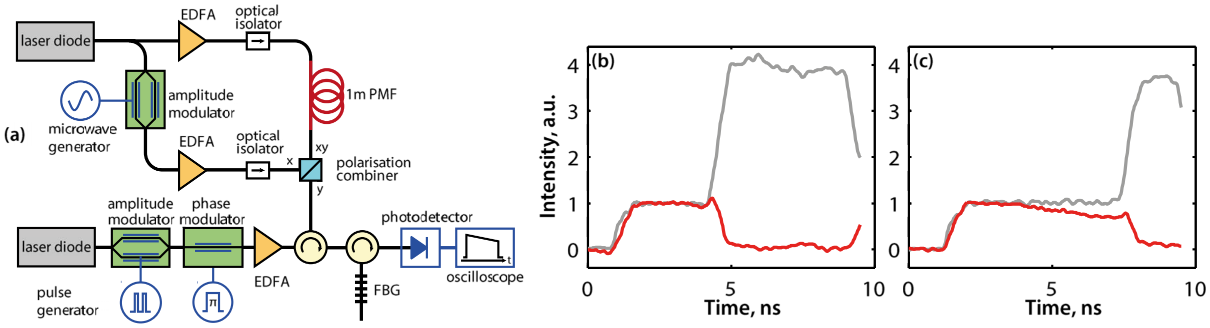

Fig. 1 Experimental demonstration of an all-optical DBG-based flip-flop. (a) Experimental setup. Results for flip-flop (red curves) and integrator (grey curves) resulting from two 300 ps pulses separated by (b) 3.5 ns and (c) 6.5 ns.

In summary, the proposed flip-flop configuration could provide, ideally, extremely long storage times when compared to reported passive schemes, being fundamentally limited only by the length of the PMF and its birefringence uniformity. Typical birefringence non-uniformities of today's PMFs limit the storage time up to about 10 ns (1 m of fibre), as here demonstrated. To achieve microsecond storage times (100 m of PMF), an improvement of roughly 2 orders of magnitude in the uniformity of the PMF birefringence would be required.

References

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