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H-8-1 (Invited)

All-optical signal processing based on ultrafast nonlinearities in semiconductor optical amplifiers

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(Invited paper)

1. Introduction

Digital optical processing techniques are expected to become increasingly important in futuristic ultrahigh capacity telecommunication networks. The highest bit-rate per channel that has been reached is greater than 1 Tbit/s [1]. In order to switch and route data at such high bit-rates ultrafast optical switches have to be realized. Semiconductor optical amplifiers (SOAs) are attractive as a nonlinear building blocks for such switches since they provide high gain, exhibit strong changes in the carrier-densities and allow photonic integration [2]. Ultrafast optical switching based on SOA nonlinearities can be realized by employing photon-generated changes in carrier density driven by two-photon absorption and free-carrier absorption [3, 4].

This paper highlights some of our research on all-optical logic based on ultrafast SOA nonlinearities. Theoretical and experimental results related to optical logic gates that are operated with sub-picosecond optical pulses can be found in [3, 4, 5]. Here we will discuss a passively mode-locked laser based on SOA nonlinearities and show how such a laser can act as a building block for an optical flip-flop memory.

2. Passively mode-locked ring laser

A schematic of our passive mode-locked laser is depicted in Fig. 1. First of all, the SOA acts as a laser gain medium. A second functionality of the SOA is to introduce nonlinear polarization rotation, similar as described in [6]. The isolator allows the light to propagate in one direction only and the filter selects the central wavelength. A small fraction of the lasing light is monitored by using a 90/10 output coupler.

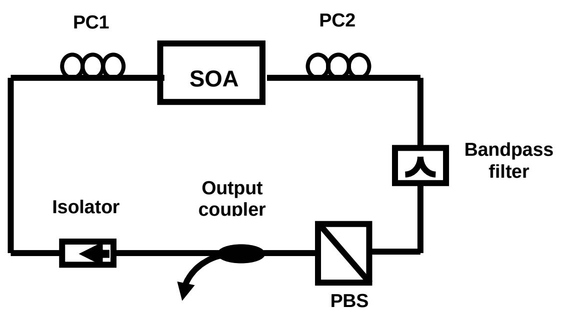

Fig. 1: Experimental setup of the SOA based ring-laser. SOA: semiconductor optical amplifier, PC1 and PC2: polarization controllers, PBS: polarizing beam-splitter.

Self-polarization rotation plays an essential role in this mode-locking concept [7]. Due to the fact that the peak of the pulse saturates the SOA, the gain experienced by the peak of the pulse differs from the gain experienced by the pulse wings. Since, the SOA gain saturation is polarization dependent, the refractive index saturation is also polarization dependent. The polarization controller PC1 adjusts the polarization of the SOA input light to be approximately 45^0 with respect to the orientation of the semiconductor layers. As the pulse propagates through the SOA, it experiences a change of polarization due to different gain and optical path length for the transverse electric (TE) and transverse magnetic (TM) components. Hence, by properly aligning the polarization controller PC2 with the orientation of the polarizing beam splitter (PBS), one can set the system such that only the leading and trailing edges of the pulse are blocked by the PBS. In this way, the nonlinear polarization switch acts not only as an amplifying element, but also as a pulse compressive element.

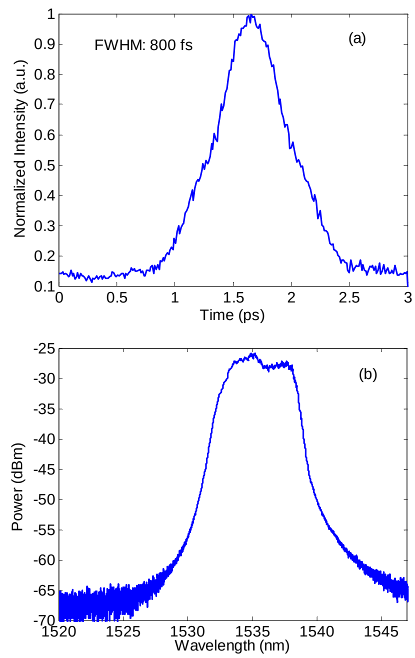

Fig. 2: Autocorrelation trace (a) and the spectrum (b) of the pulses. The pulse width is 800 fs (FWHM).

Fig. 2a shows the autocorrelation trace of the pulses that output from the ring when the injection current is 276 mA. We observe a pulse train with a repetition rate of 14.15 MHz. The pulses have a duration of 800 fs (full width at half maximum, FWHM), assuming a $sech^2$ pulse shape. Increasing the SOA injection current leads to a higher output power, but we observed mode-locking only when the SOA injection current was greater than 160 mA. For each injection current, the pulse width and the intensity of the output beam can be optimized by tuning the polarization controllers. Fig. 2b shows the measured optical spectrum of the output signal. The FWHM-bandwidth of the output signal is greater than 5 nm (0.62 THz). This indicates a time-bandwidth product of 0.48, which means that the pulse that outputs the laser is nearly transform limited. We observed an average power in the cavity of about 0.2 mW. It follows from Fig. 2b that the noise level was 35 dB lower than the signal level.

3. All-optical flip-flop memory

A mode-locked ring laser can act as a building block for an optical flip-flop memory. Fig. 3 shows the setup of an optical flip-flop based on two symmetrically coupled identical actively mode-locked ring lasers. Flip-flop operation is realized by symmetrically connecting the two cavities such that one laser acts as a master suppressing lasing action in the other laser, which consequently acts as a slave [8]. The role of master and slave can be interchanged due to system symmetry. The system has two states and each state is determined by the wavelength of the laser that is dominant. Thus the states of the flip-flop are determined by the central wavelengths λ_1 (1537 nm) and λ_2 (1547 nm) respectively. SOA1 was pumped with 170 mA of current and the injection current for SOA2 was 300 mA. To switch between the states, external light has to be injected into the master. The external light quenches the gain of the master so that lasing is stopped. The absence of light from the master laser allows the slave laser to start lasing and become the master. The flip-flop remains in the new state after the external light is removed.

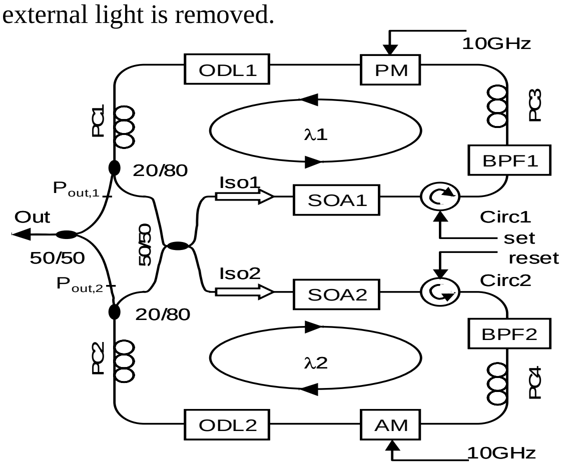

Fig. 3: Flip-flop based on two coupled actively mode-locked ring lasers with set and reset functions.

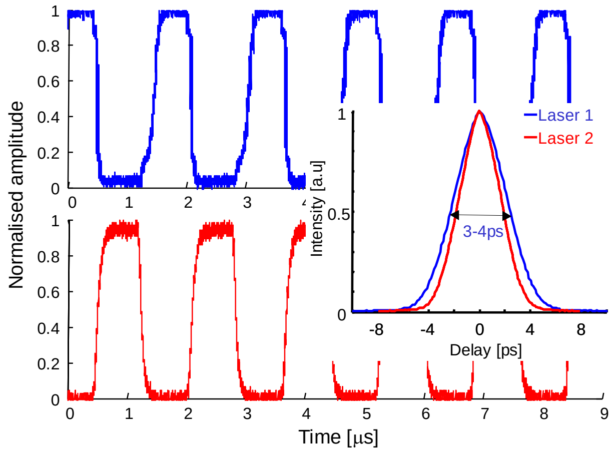

Fig. 4: Regular switching between two flip-flop states. The inset shows typical pulse-shapes.

The flip-flop switching speed is determined by the length of the cavities and the distance between the lasers. Since our experiments were performed on a proof of concept basis by using standard commercial pigtailed components, the lasers had cavity lengths of about 20 meters and the distance between the cavities was 3 meters.

The dynamic operation of the flip-flop is demonstrated by toggling its state by injecting a regular sequence of optical pulses into the laser that was currently the master. The injected pulses (1551 nm) had duration of a few nanoseconds, and the average power of the injected light was 1 mW. The pulses were injected into the flip-flop once every 0.96 μs through the set (or reset) port. The flip-flop output was detected by a slow photodetector and displayed on an oscilloscope. Due to the limitation of the detector response time, Fig. 4 only shows the envelope of the picosecond pulse train, however the regular switching between the states is clearly visible. It follows that the pulses can buildup after about 40 round-trips assuming the cavity length is 20 meters. The contrast ratio between the states was over 30 dB.

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References

[1] M. Nakazawa et al, Elec. Lett. **36** (2000) 2027
[2] D. Cotter, et al, Science **286** (1999) 1523
[3] X. Yang et al, Opt. Comm. **223** (2003) 169
[4] X. Yang et al, Opt. Comm. **236** (2004) 329
[5] H. Ju et al, CLEO 2004 Technical Digest (2004) CFJ1
[6] N. Calabretta et al, J. Lightw. Technol **22** (2004) 373
[7] X. Yang et al, Optics Express **12** (2004) 2448
[8] M.T. Hill et al, J. Quantum Elec. **37** (2001) 405