Numerical and experimental study of the switching times and energies of DFB-laser based All-optical flip-flops

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Abstract: We report on the switching times and energies of a DFB all-optical flip-flop and their dependence on device and operating parameters. Numerical as well as experimental results are discussed.

Keywords: all-optical flip-flop, switching times, DFB

Introduction

All-optical flip-flops (AOFFs) could have an important role in future all-optical packet switches [1]. Previously [2,3], we have shown that a robust AOFF can be obtained from a AR-coated, λ/4-shifted DFB laser in which a CW beam is injected. The bistability for a certain power range of the CW beam is then due to the spatial hole burning, induced by the CW beam and affecting the mirror losses. It has been shown before that both the CW beam and the switching pulses can be of relatively arbitrary wavelength (but not too close to the lasing wavelength) and that switching in about 75 ps is possible with pulse energies of 200 fJ [2].

In this paper we report on the thorough analysis of the switching times and energies that can be achieved with such an AOFF. Using numerical simulations, we have investigated how the switching times depend on the laser structure and on the operating conditions. The dependence on the operation parameters has been investigated experimentally on a single DFB laser.

The all-optical flip-flop configuration that has been investigated numerically and experimentally is shown in Figure 1. The reset pulses (to switch off the laser) are injected at the same side as the CW beam to induce a carrier density non-uniformity, whereas the set pulses (to switch on) are injected at the opposite side and serve to restore the carrier density uniformity.

Figure 1 : Configuration of the DFB-based all-optical flip-flop

2. Simulations and results

2.1 Brief description of the simulations

The simulations were done using the commercial software package VPI Transmissionmaker (©, [4]). The following device parameters have been varied: differential gain, normalized coupling coefficient, device length, the non-linear gain coefficient and the linear recombination coefficient. Furthermore, bias current, CW injected power and switching pulse power and duration have been investigated.

We first simulated the bistability in the laser output power vs. the injected CW power and then studied the switching. A typical switching behaviour is as shown in Figure 2. The switching shows the typical ringing behaviour found when switching on the bias current of laser diodes. Due to the fact that the average gain in the off-state is higher than the threshold gain, the ringing is however significantly more pronounced. Using a higher non-linear gain to dampen this ringing didn't change much either. We define the switch-on time as the time over which the laser power increases from 10 to 90% of the steady state ON value. Reset pulse lengths were 200 ps and set pulse lengths 125 ps.

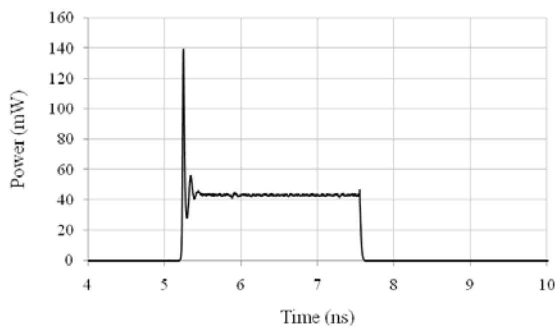

Figure 2 : Typical switching behaviour of DFB AOFF

2.2 Main results

Rise times and fall times (switch-on and switch-off times resp.) are given vs. the pulse power in Figure 3. The laser has κL=1.2, L=400μm and a bias current of 200mA. The switch-on times are decreasing significantly when increasing the differential gain while the fall times are independent of it. We investigated also the influence of the kL-value, the bias current, the length and the recombination parameters. Switch off times decrease mainly with decreasing κL, whereas switch-on times decrease with increasing bias current and differential gain. Furthermore, the required switching energy decreases sharply with decreasing κL.

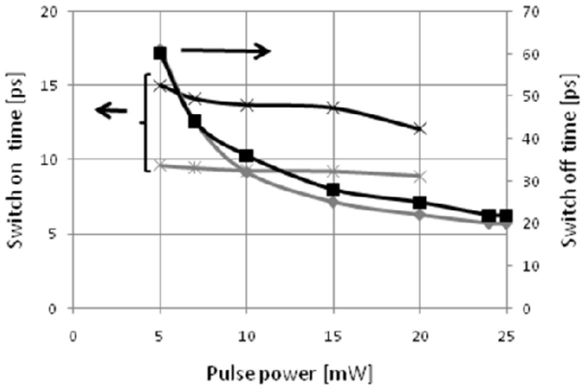

Figure 3 : Simulated switch-on and switch-off times vs. the pulse power (dark lines are for dg/dN=3 e-20 m^2 and grey lines for dg/dN=5 e-20 m^2).

3. Experimental results

The measurements were all done on a DFB laser diode from Alcatel-Thales III-V Labs with a length of 400 μm and a normalized coupling coefficient κL of 1.6. The laser has a threshold of approximately 30 mA and emits light at 1553 nm. CW light with a wavelength of 1543 nm was injected. For a bias current of 150 mA, the CW light injection resulted in a bistable region for input powers between 6.5 and 7.3 dBm. Figure 4 shows how the switch-on and swich-off times decrease with the energy of the injected pulse. The injected pulses were 150 ps long. With sufficiently energetic switch pulses, switching times of 40 ps can be reached. Part of these switching times may be caused by rise and fall times of the injected pulses though.

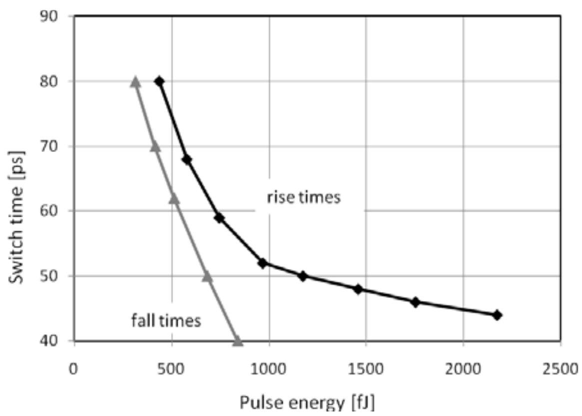

Figure 4 : Experimental switch-on and switch-off times (rise and fall times) vs. the switching energy.

Figure 5 shows how the switching time changes as the CW injected power is varied. As can be seen, there was no significant influence of the CW power in the experiments, as opposed to the numerical results.

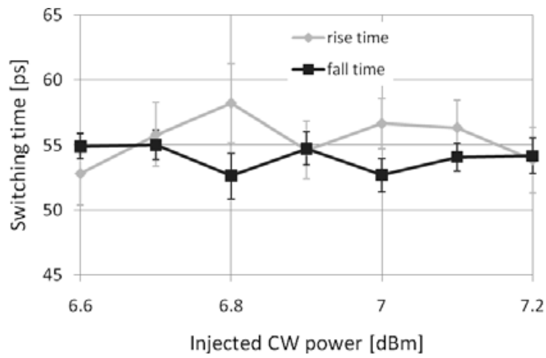

Figure 5 : Experimental switch-on and switch-off times (rise and fall times) vs. the CW injected power.

5. Conclusion

We have discussed the switching times of a DFB-based AOFF and its dependence on various structural and operational parameters. Both experimental and numerical results have been shown.

One of the main conclusions is that theoretically switch-on times of 10 ps and switch-off times of less than 20 ps are possible. Switch off times and required switching energies decrease with a smaller laser length and lower κL-value. Switch-on times mainly decrease with increasing bias current and increasing differential gain. Parameters like the non-linear gain coefficient and the recombination rates have very little influence. Required pulse energies decrease with decreasing κL.

6. Acknowledgment

The authors gratefully acknowledge Alcatel-Thales III/V-labs for providing the DFB laser diodes. This work is supported by the Fund for Scientific Research (FWO), the IAP-project “Photonics@be” and the Erasmus Mundus program. The work of K. Huybrechts is supported by the Institute for the Promotion of Innovation through Science and Technology (IWT).

7. References

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