Simulation of the switching of an All-Optical Flip-Flop based on a SOA/DFB-Laser Diode Optical Feedback Scheme

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Abstract: All-Optical flip-flop operation using a SOA and DFB laser diode in an optical feedback scheme is presented. The device is based on the gain difference in the SOA and DFB laser diode for the different stable states. Flip-flop operation is shown for set and reset pulse widths of 10 and 150ps of 5W and 3.5mW respectively.

Keywords: Flip-flop, SOA, DFB laser diode.

1. Introduction

All-optical packet or burst switched networks are promising solutions for the ever growing data traffic in telecommunication networks because they don't require opto-electronic conversions in intermediate nodes of the network. For such networks, and especially for the processing of optical labels or optical headers, there is a need for all-optical flip-flops [1], in which a certain output state (e.g. determining the routing) can be set from a short input pulse (e.g. derived from a header) and in which this output state is maintained until a reset pulse is applied. In essence flip-flops are based on bistable devices, which for certain operation conditions can operate in one of two stable states

Over the years several examples of bistable optical components, such as coupled laser diodes or a single SOA-based Mach-Zehnder interferometer with a feedback loop, usable as all-optical flip-flops have been proposed [2,3].

Here we present first simulation results on the use of a DFB-laser diode and a SOA in an optical feedback scheme as an all-optical flip-flop. Using this device bistable operation has been obtained previously over a broad wavelength range and easy tunability of the domain of bistable responses has been shown [4]. The bistability was observed in both the output power of the SOA and (inverted) in the output power of the laser diode. We also point out that the bistability reported here is not the narrowband dispersive bistability observed in a DFB amplifier. The DFB is biased above threshold in our scheme and the input wavelength is far from the lasing wavelength.

2. Device description and operation principle

As shown schematically in Figure 1 the device consists of a travelling wave SOA which is bi-directionally connected through a coupler with a DFB-laser diode. This means that part of the output power of the laser diode gets coupled into the SOA and at the same time an equal fraction of the output power of the SOA gets coupled into the laser diode.

When the injected input signal power is low, the power that is injected into the laser diode is also relatively low, so the laser operates well above threshold and injects power into the SOA. The SOA is in this case saturated by the injected laser power and the amplification inside the SOA for the input signal is low. When however the injected input signal power is increased above a certain threshold value, the output power of the SOA will be sufficiently high to cause a small decrease in the output power of the laser diode. In this case less total power is injected into the SOA (due to the decrease in injected laser power) and the gain in the SOA rises providing a higher output power and consequently a bigger influence on the laser power can be found for the same input power due to the optical feedback between laser diode and SOA. A sudden flip from low to high SOA gain occurs, accompanied with the switching off of the laser diode.

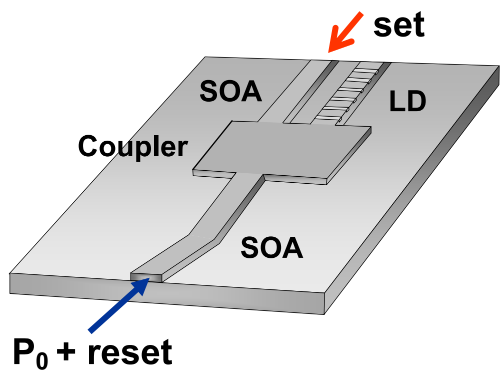

Figure 1 : Structure of an all-optical packet router

The bistability in this feedback scheme originates from the difference in gain in the SOA (and in fact also in the laser diode) between the two states, one being the state where the laser is ON and the SOA is saturated by the injected laser power, the other being the state where the laser is OFF and the SOA is only influenced by the input power. This can of course be exploited for use as an all-optical flip-flop by injecting the device with additional optical pulses that can change the state of the device for a fixed input power (the holding power).

Looking again at Figure 1 one can notice that when the laser is in the ON-state it can be switched off by injecting an extra reset pulse together with the holding power required to keep the device within the bistable domain. By applying a reset pulse using the extra SOA after the coupler as input waveguide when the laser is in the OFF-state the gain of the SOA can temporarily be suppressed, thus reducing the output power of the SOA which allows the laser to again build up its laser field.

The results presented here have been obtained with a commercial available software package [5]. The device used in the presented simulations consists of a 500μm long SOA and a 350μm long QW-shifted DFB laser diode. Both the laser diode and the SOA have anti-reflection coated facets. The lasing wavelength is 1552nm while the wavelengths of holding power and (re-)set pulse are respectively 1543 and 1537nm. The coupling ratio between laser diode and SOA is 0.5 and the drive currents of laser diode and SOA are respectively 60 and 85mA. The set and reset pulses are first order Gaussian pulses. Here only the behaviour of the laser signal (at the backside of the laser diode) is shown.

3. Simulation results

The bistable domain that is obtained by the device described above can be seen in Figure 2. As long as the input power is sufficiently low, the output power of the laser diode only decreases slowly but at a certain input power (here around 0.14mW) the laser diode switches off. When decreasing the input power again the laser diode switches on for a lower input power than the input power where the switch off occurred. This is caused by the fact that the higher gain in the SOA due to the switched off laser provides sufficient amplification for lower input powers to keep the laser in the OFF-state.

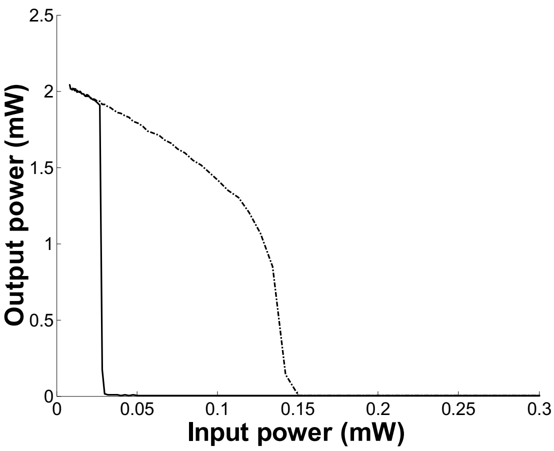

Figure 2 : Static response of the SOA/DFB laser diode feedback scheme.

When choosing a holding power inside the stable domain shown in Figure 2 the output state of the laser diode is determined by the history of the device. For the further simulations this holding power is chosen at about 0.13mW. Now the switching between the ON and OFF state of the laser diode can be accomplished by injecting set and reset pulses at respectively the frontside and backside of the device.

In Figure 3 it can be seen that by using first order Gaussian optical pulses with a FWHM of 150ps and a peak power of 3.5mW as set and reset pulses the state of the laser can be switched between the ON and OFF state. The switching energy is then 29.4nJ. It can be noticed that while the laser seems to switch off almost instantaneously there seems to be a delay on the switching on of the laser diode.

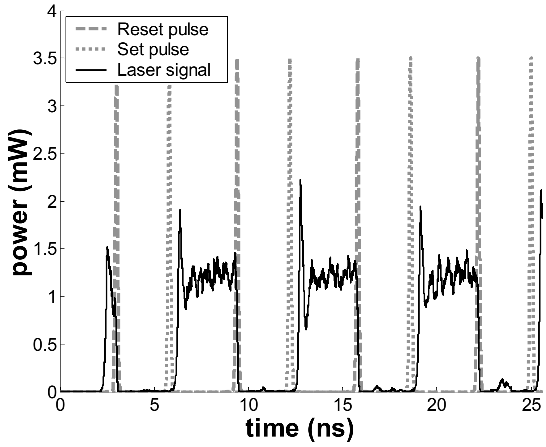

Figure 3 :Flip-flop operation for a pulse FWHM of 150ps and peak pulse power of 3.5mW.

Figure 4 shows that also shorter pulses can be used to set and reset the optical flip-flop. By using Gaussian optical pulses with a FWHM of 10ps and a peak optical power of 5W (corresponding with a switching energy of 11μJ) we can again switch the laser between the ON and OFF state. Again we note that a turn-on delay can be seen between the set pulse and the actual switching of the laser diode.

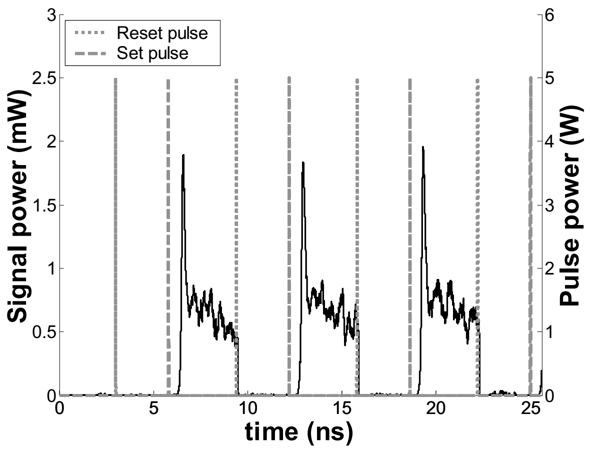

Figure 4 :Flip-flop operation for a pulse FWHM of 10ps and peak pulse power of 5W.

Following the results of Figure 3 and 4 we can conclude that shorter pulses require more energy to change the state of the optical flip-flop. The set pulse needs to cause a sufficiently long decrease in gain in the SOA for the laser diode to switch back on. For longer pulses this decrease in gain is accomplished by the presence of the pulse power in the SOA which saturates the SOA, but for shorter pulses the pulse power needs to put the SOA in deep saturation, causing a longer recovery time for the gain in the SOA. A similar effect can be seen in the reset case.

Looking at Figure 5 where the response of the device around the reset pulse is shown for the case of Figure 4 (FWHM of 10ps and peak power of 5W for the optical pulses), we notice that a delay of about 100ps is introduced between the time of the pulse and the time of the response of both the laser diode and SOA. This delay can be explained by the roundtrip time in the feedback loop (typically around 10-20ps) combined with extra delays added by the simulation tool in the connections.

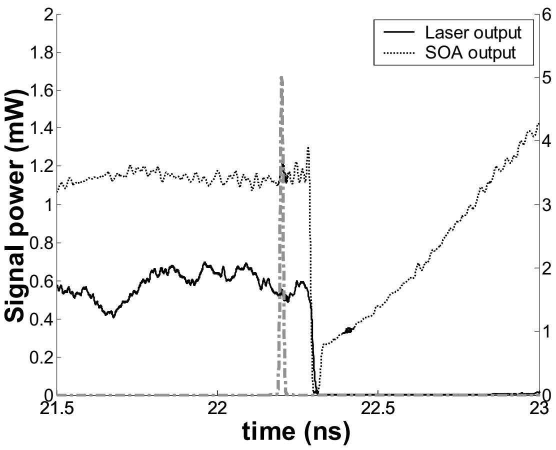

Figure 5 :Response of the laser diode and SOA around the reset pulse for a pulse FWHM of 10ps and peak pulse power of 5W.

For the set pulse, shown in Figure 6, we can again see the same delay for the response of the SOA. The response of the laser diode, i.e. the switch ON of the laser diode experiences an additional delay of about 300ps, which corresponds to the turn-on delay of the stand alone laser diode. When considering the intial delay of about 100ps between both the set and reset pulse and the signal as fixed, the actual switching time can be assumed of the order of a couple of hundred ps.

In both cases the response of the output signal of the SOA shows a very fast initial response followed by a much slower transition to the steady state value for the respective state. This is in this case caused by the fact that both set and reset pulse pass trough the SOA causing depletion of the carriers along the way.

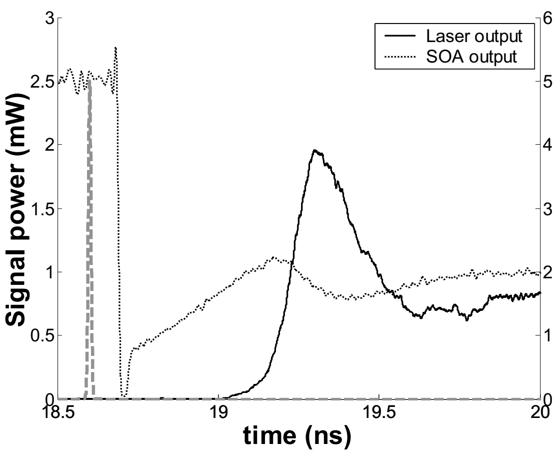

Figure 6 :Response of the laser diode and SOA around the set pulse for a pulse FWHM of 10ps and peak pulse power of 5W.

The reason for the relative high holding power in these simulations as compared to the position of the bistable domain lies in the fact that both the set and reset pulse pass through (and deplete carriers in) the SOA. After the passage of a pulse the gain will be temporarily lowered and in the case of the reset pulse, this lower gain may cause the output power of the SOA right after the pulse to be to low to keep the laser switched off and the OFF-state can not be maintained. By using a different input waveguide for the reset pulse this problem can be overcome and lower holding powers can be used.

4. Conclusion

For the first time flip-flop operation has been shown (numerically) using a SOA/DFB laser diode feedback scheme. Excellent flip flop operation for both 150ps and 10ps pulses has been obtained, corresponding with switching powers of respectively 3.5mW and 5W.

5. Aknowledgment

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7. Glossary

SOA: Semiconductor Optical Amplifier

DFB: Distributed Feedback

QW: Quarter Wave

FWHM: Full Width Half Maximum