A single Laser Diode for All-optical Flip-flop Operation

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Abstract— **We demonstrate the use of a single laser diode as an optical memory element. When continuous wave light is injected in a distributed feedback laser, we can observe a bistability in the lasing power. This bistability can be used for all-optical flip-flop operation.**

Keywords— **all-optical flip-flops, distributed feedback lasers, packet switching**

I. INTRODUCTION

TO optimalize the capacity of future optical communication networks, signal processing operations are more and more implemented in the optical domain to avoid time-consuming electro-optical conversions. This is for example the case in so called packet switched networks where packets of data are lead through the network based on the information that is contained in the packet header [1]. In such networks, there is a strong need for optical memory elements which can temporarily store the information of the packet header. Such memory elements are called all-optical flip-flops.

Several designs for all-optical flip-flops have been proposed [2–4]. Most of them are based on bistable effects. This means that two different output states are possible for the same input. The choice between the two different states depends on the history of the device. The bistability becomes useful for all-optical flip-flop operation when it is possible to switch between the two different output states by applying a short optical pulse.

We will demonstrate that we can use a single distributed feedback (DFB) laser as an all-optical flip-flop. Distributed feedback lasers are one of the main building blocks in optical communication networks. They have a gain medium which is structured with a diffraction grating, providing the optical feedback in the laser (see Figure 1). We will show that these lasers become bistable when continuous wave (CW) light with a wavelength different from the lasing wavelength is injected into the DFB. This bistability is observed in the lasing light as well as in the amplification of the external light and is due to non-linear effects having their origins in the carrier distribution (i.e. spatial hole burning).

II. BISTABILITY IN DFB LASER

When injecting continuous wave light into a DFB-laser, two stable states can be achieved for the same input power. This bistability arises from the strong influence of the carrier distribution on the threshold characteristics of a DFB laser. In one of the states the laser is lasing and the externally injected light is weakly amplified due to gain clamping. The other state in contrary has a very high amplification of the external light, resulting in a strong non-uniform distribution of the carriers. It is well-known that this sort of spatial hole burning effect can increase the threshold of a DFB laser diode, ultimately causing the laser to switch off. Therefore all the injected carriers in the device will be used to amplify the injected light.

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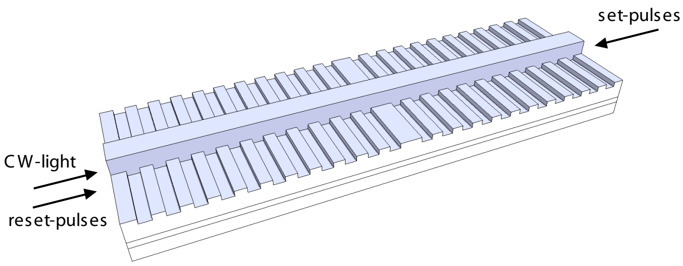
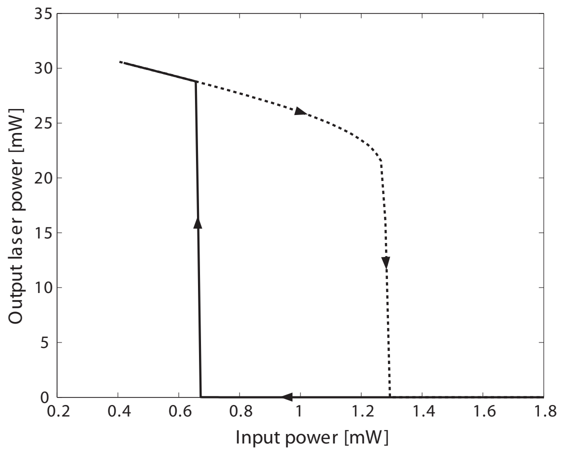


Fig. 1. Illustration of a DFB laser and its use for all-optical flip-flop operation

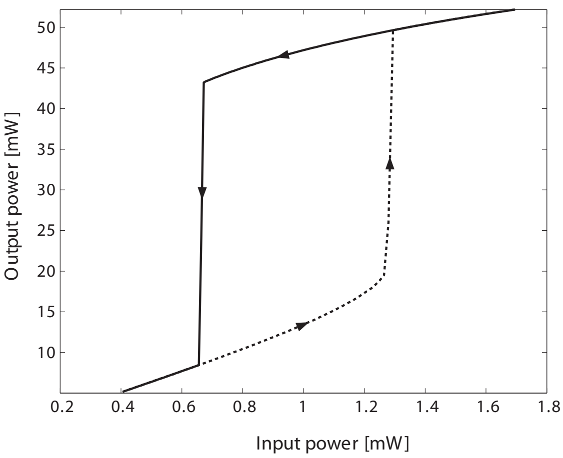
The two different states of the carrier density distribution are simulated with a commercial software package [5] and are depicted in Figure 3 for an anti-reflection coated DFB laser with a length of 400 μm. The normalized coupling coefficient κL gives an indication for the depth of the grating and has a value of 1.2. The laser is lasing at a wavelength of 1.57 μm and we inject CW light of 1.56 μm to simulate the hysteresis curve. In Figure 2a one can see the influence of the injected light on the lasing power, while in Figure 2b the bistability of the amplification of the injected light is depicted. There are no strict limitations for the wavelength of the injected light, except for the fact that it should not be too close to the lasing wavelength (more than 1 nm difference) to avoid interaction with the DFB grating.

The bistability curve depends on the parameters of the laser. The current injection power, losses inside the cavity, length and depth of the grating are the main parameters which influence the form of the bistability curve.

We can exploit this bistability for all-optical flip-flop operation (see Figure 1). To make the device operative in the bistable regime, a bias CW light is injected in the DFB laser. Switching from the lasing state to the non-lasing state can be done by injecting a short but strong pulse at the same side of the device as the CW light. This will cause a non-uniform carrier distribution and thus increase the lasing threshold. The uniform carrier distribution can then be restored by injecting a light pulse at the other side of the device. This will reduce the laser threshold and allow the laser field to switch on again.



(a)



(b)

Fig. 2. Simulation results of the bistable behavior of a $\lambda/4$-shifted and AR-coated multiquantum well DFB-laser with length 400 μm, κL 1.2 and active layer thickness 40 nm. The laser is electrically pumped with $I/I_{th} = 4$ and $I_{th} = 42.5$ mA. a) Laser output power as a function of the power of the injected light; b) Amplification of the injected light

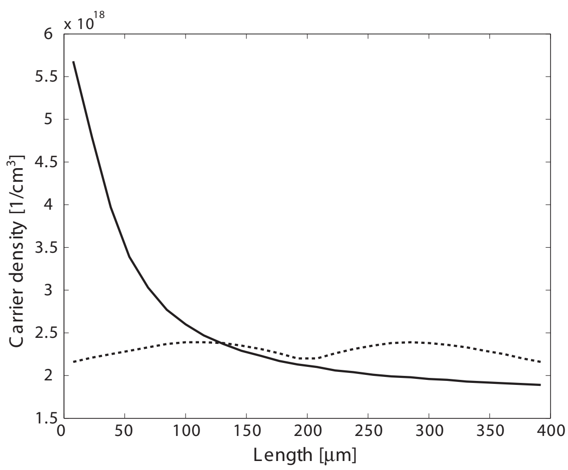


Fig. 3. Longitudinal distribution of the carriers in the DFB-laser. Dashed: lasing state; Solid: non-lasing state.

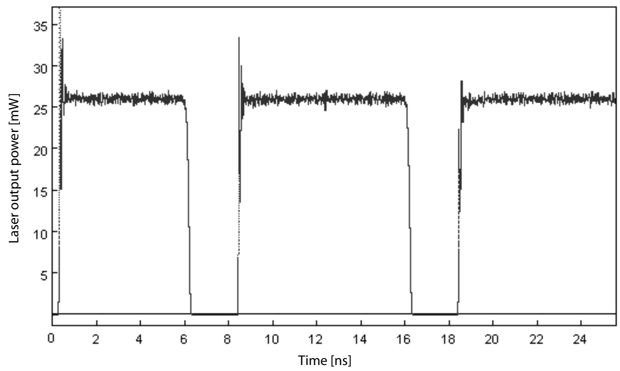


Fig. 4. Illustration of the all-optical flip-flop behaviour in a single DFB-laser with the specifications of Figure 2.

III. Dynamic behaviour

The dynamic behaviour of the DFB flip-flop with the specifications given in Figure 2 is simulated with a CW light injection of 1 mW at one side of the laser cavity. On the same side as the CW light we also inject the reset-pulses to move out of the hysteresis curve and switch off the laser. The set-pulses are injected on the other side of the device to restore the uniformity. The advantage of this approach is that we can use exclusively positive pulses. We simulate this for gaussian pulses of 200 ps with switch pulse energies of about 500 fJ (see Figure 4). The contrast ratio is 32 dB and we obtain switching times of about 250 ps. The laser will switch on faster by increasing the pulse energy, but the overshoot will be higher resulting in a longer stabilization time. Repetition rates up to 1.2 GHz can be achieved. There are no strict limitations on the wavelength of the pulses as discussed before.

IV. Conclusion

We demonstrated the use of a single distributed feedback laser diode as an all-optical flip-flop. The shape of the hysteresis curve depends on the parameters of the laser and on the bias current. Dynamic behaviour using positive pulses is simulated and predicts switching times of 250 ps.

Acknowledgments

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