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All-optical Flip-flop based on a single Distributed Feedback Laser Diode

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A novel concept for an all-optical flip-flop composed of a single distributed feedback (DFB) laser is proposed. A bistability in the laser power can be observed when light of a different wavelength is injected in the DFB laser. This can be explained by the drastical change of the carrier distribution in the laser due to spatial hole burning effects. It is possible to exploit this bistability for fast flip-flop operation by injecting pulses at both sides of the laser.

Introduction

The further development of our information technology has to fulfill the ever increasing need for faster network traffic. One of the main bottlenecks in future communication networks are the time-consuming electro-optical conversions. These can be avoided when packet or burst switched networks are implemented completely in the optical domain. All-optical flip-flops are one of the key components in realizing these all-optical networks. By acting as optical memory elements, they can store temporal decisions in photonic packet routers. [1]

Several designs for all-optical flip-flops have been proposed [2–4] that are based on a combination of a feedback loop and a nonlinear effect in the gain, e.g. coupled laser diodes, multimode interference bistable laser diodes and devices based on SOA-based Mach-Zehnder interferometers with a feedback loop. All these devices are however relatively complex.

We will demonstrate now 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. 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).

Bistability in a DFB laser

The injection of continuous wave light into a DFB laser will result in two different stable states for the same input power. This bistability arises from the strong influence of the carrier distribution on the threshold characteristics of a DFB laser. The injected light should have a wavelength that is not too close to the lasing wavelength (more than 1 nm)

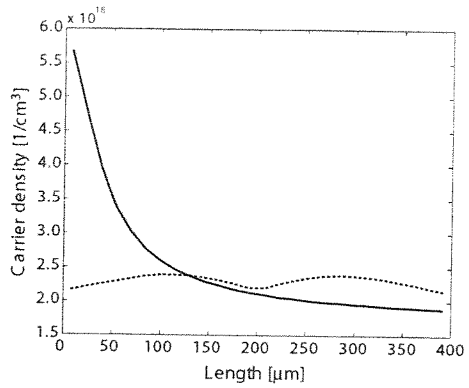


Figure 1: Longitudinal distribution of the carriers in the DFB-laser. Dashed: lasing state; Solid: non-lasing state.

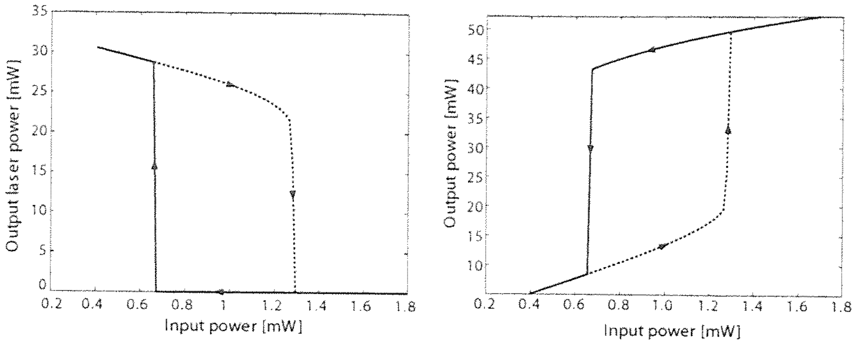
to avoid interaction with the DFB grating. In one of the states the laser is lasing and the externally injected light is weakly amplified due to gain clamping. The other state in contrary has a very high amplification of the external light, resulting in a strong non-uniform distribution of the carriers. This effect is known as spatial hole burning and it is well-known that it 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.

We use a commercial software package [5] based on a transmission line laser model (TLLM) to simulate the two different states in the laser. The longitudinal carrier distributions of the two states are depicted in Figure 1 for an anti-reflection coated DFB laser with a length of 400 μm and normalized coupling coefficient κL 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 hysteresis in the amplification of the injected light is depicted.

Flip-flop operation

The bistability in the DFB laser can be exploited for all-optical flip-flop operation by using positive pulses to switch between the two states. A bias CW light is injected in the DFB laser to make the device operative in the bistable regime. 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 leading to the state where the laser is switched off. 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.

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



(a)

(b)

Figure 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

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 3). 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.

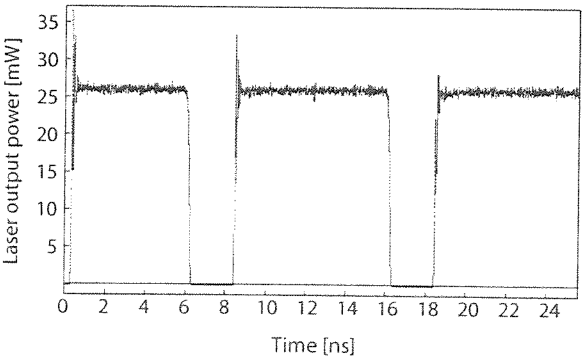


Figure 3: Simulation of the all-optical flip-flop behaviour in a single DFB-laser with the specifications of Figure 2.

Experimental results

We have observed the bistability experimentally in a $\lambda/4$-shifted laser with length 510 μm provided by Alcatel-Thales III-V labs. The hysteresis curve is shown in Figure 4. The current injection is 220 mA and a contrast ratio of 32dB is observed. In many of our devices we observed unstable behaviour which is possibly due to a low serial resistance in our laser diodes prohibiting the spatial hole burning effect.

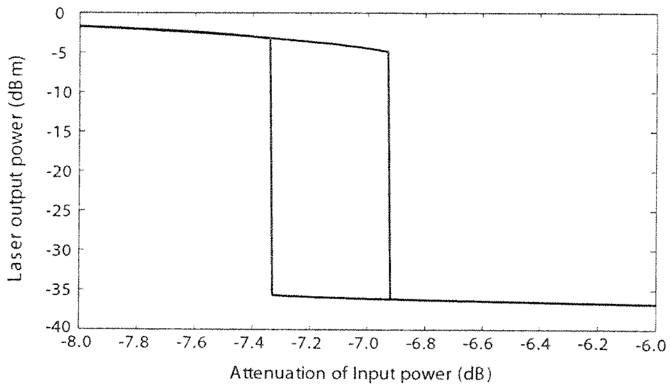


Figure 4: First experimental results on a $\lambda/4$-shifted laser with length 510 μm and I_{bias}= 220mA.

Conclusion

We numerically analyzed the use of a single distributed feedback laser as an all-optical flip-flop and experimentally demonstrated the bistability of the device.

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[5] VPItransmissionmaker.

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