Fast Phase Shifted asymmetrical DFB laser for all-optical flip-flop operation

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A DFB laser with an asymmetric coupling coefficient is proposed for flip-flop operation. It has been demonstrated in simulation that a high confinement factor of the active region and use of an asymmetric configuration result in very short rise and fall times. In our simulation, nearly 10ps fall time and 5ps rise time have been observed.

1. Introduction

All-optical signal-processing devices are playing an essential role in the future of optical-data networks [1]. In order to increase the network efficiency and raise the bandwidth, all optical switching networks are desirable, because they can reduce the switching energy as well as increase speed by avoiding optical-to-electrical or electrical-to-optical signal conversion. Bistable optical devices can be used as the basis of all-optical flip-flops, in which switching happens by set and reset optical short pulses [2-4].
Our approach for the all optical flip flop switching is based on a λ/4-shifted DFB laser, which becomes bistable by injecting a master laser light, with a wavelength is outside the DFB laser stop-band. 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. longitudinal spatial hole burning).

2. Flip flop operation

When a cw light is injected inside the DFB laser, it will result in the bistable condition for certain input power levels, (i.e. for the same input power, two different output states are recognizable). Both states are stable and the way to reach each of them can be explained by introducing the carrier density profile. When the DFB laser is on, because of the gain clamping effect, the injected signal will not amplify efficiently, so the carrier density is almost uniform, the threshold gain is low for lasing and the laser will remain in the on state.
On the contrary, the DFB laser is off for the second state, so the carrier inversion is large, the high amplification of the injected light makes the carrier density non-uniform as can be seen in Figure 1. While the system is off, the threshold gain is high and the DFB laser could not reach the lasing threshold, so the state is stable.

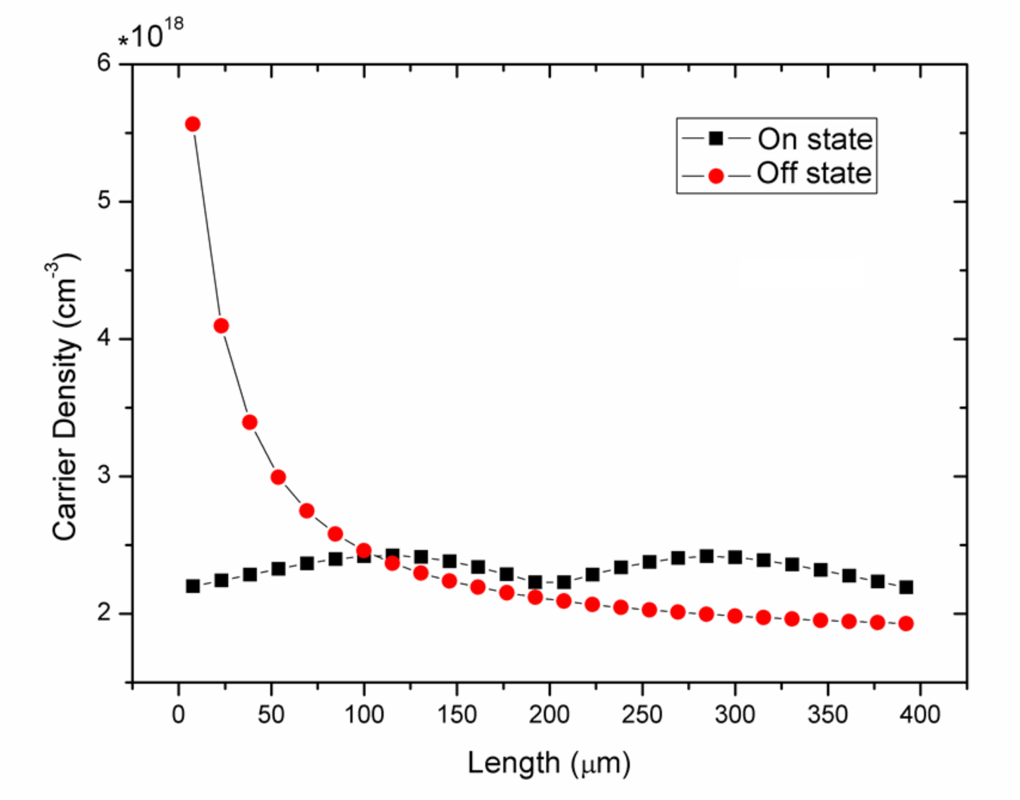

Figure 1: Longitudinal distribution profile of the carrier density in the DFB-laser.

Flip flop operation can be demonstrated by introducing the set and the reset pulses. The role of these pulses is to provide the temporary carrier density redistribution. If the reset pulse is injected from the same side as the cw light, it can pass through the laser cavity and make the longitudinal carrier density non-uniform, thus the laser is switched off. The set pulses can be injected from the other side to restore the uniformity and switch the laser on. The Optical spectra for the on and off states are shown in Figure 2. The laser is lasing at a wavelength of 1.57 µm and cw light is injected with a wavelength of 1.557 µm to simulate the hysteresis curve.

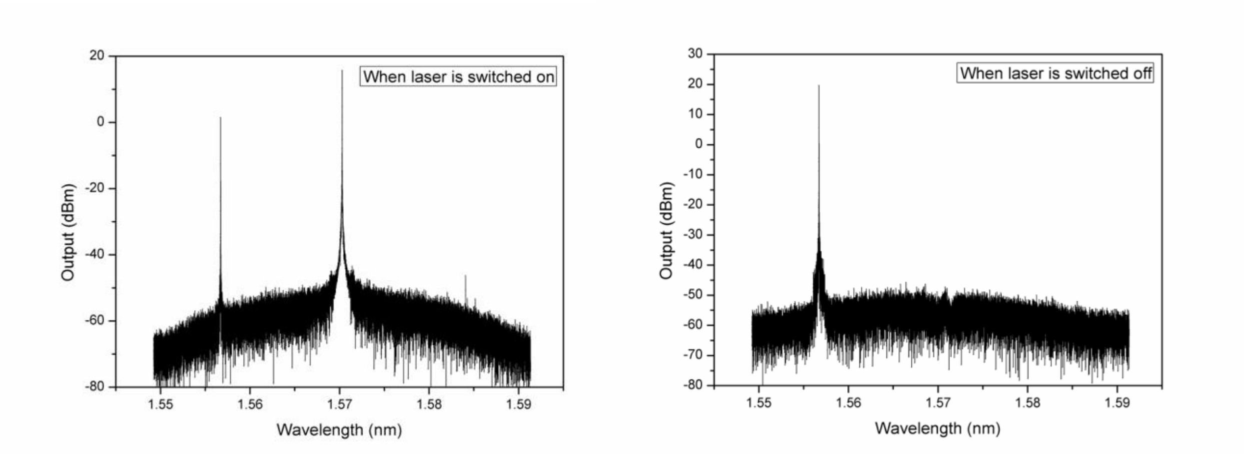

Figure 2: The output spectrum of the flip flop system (a) when the DFB laser is switched on and (b) when it is switched off.

3. Asymmetric design and Results

A fast performance for the processing application is desirable. Here we will discuss the influence of the grating structure and of the confinement factor of the active region on the flip flop operation speed.

We use a commercial software package, [5] based on a transmission line laser model (TLLM).

Our proposed structure has been depicted schematically in Figure 3. This is the two section DFB laser with two different coupling coefficients. For our simulation, the κ_1 is 3000 m^{-1} , κ_2 is 2550 m^{-1} and the length of the laser cavity is 400 µm. For the uniform laser κ=3000 m^{-1}.

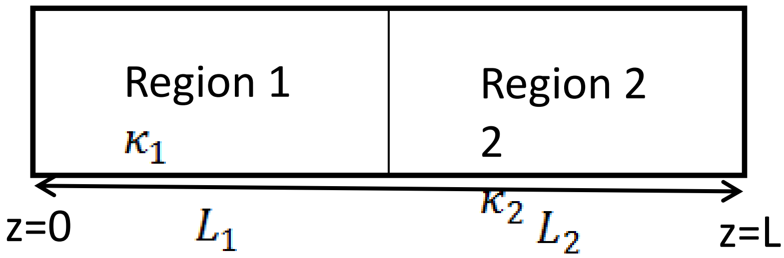

Figure 3: Schematic diagram of the phased-shifted DFB laser with two non-identical regions. $K_{1(2)}$, $L_{1(2)}$ are coupling coefficients and $L_{1(2)}$ is the cavity length for each region, respectively.

The influence of the asymmetric design and the confinement factor is shown in Figure 4, where it is clear that the asymmetric configuration is faster than the symmetric one. Another fact that can be extracted from results is that the high confinement factor will result in faster devices.

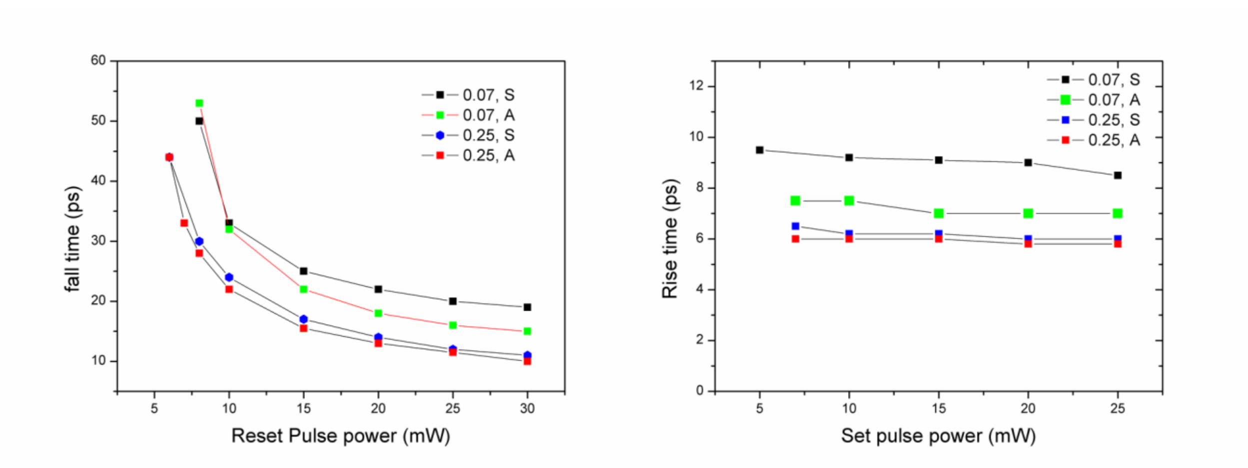

Figure 4: The simulated switching times for a DFB laser with length L=400µm and Γ_{low}=0.07 and Γ_{high}=0.25. Rectangular pulses have durations of 100 ps. (S: symmetric cavity, A: asymmetric cavity)

4. Conclusion

It was shown that under injection of a holding beam, we can obtain a hysteresis in the output of a distributed feedback (DFB) laser diode. The asymmetric structure can reduce the switching time dramatically. From the fabrication point of view, making a DFB laser with a high confinement factor is challenging, while the design and fabrication of a DFB laser with asymmetric coupling coefficients are rather easy. In this work, switching times as low as 10 ps have been achieved by set and reset pulses with the duration of 100 ps. The broadband operation and fast switching makes the DFB flip-flop an ideal candidate to apply in all-optical packet switched networks.

References

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