Fast Operation of a Broadband All-Optical Flip-Flop Based on a Single DFB-laser Diode

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Abstract

We demonstrate an all-optical flip-flop based on a single DFB-laser diode with repetition rates up to 2 GHz, set/reset-pulses of 7 ps and 200 fJ, a switch-on time of 75 ps and a switch-off time below 20 ps.

Introduction

Since new internet-based services (such as VoIP, VoD, …) are creating a need for faster network traffic, all-optical signal processing techniques draw more and more attention to implement future all-optical packet switched networks [1]. All-optical flip-flops offer one of the main functionalities: they can act as memory elements and temporarily store the routing information contained in the header of the data-packet, so the payload can be transferred to the correct output port. Several designs for all-optical flip-flops have been demonstrated, however they are often relatively slow or rather complex [2-3]. In [4] we proposed numerically a fast flip-flop based on a single Distributed FeedBack (DFB) laser diode, one of the standard elements in today's optical communication.

In this paper we give experimental results on the flip-flop operation in a Distributed Feedback laser. We do this by using ultra-short pulses of 7 ps long with energies below 200 fJ.

Concept

All-optical flip-flops are in general based on a bistability whereby it is possible to switch between the two different states by using optical pulses. We observed that a bistability in the lasing power of a DFB-laser can be obtained by injecting continuous wave (CW) light with a wavelength outside the stopband of the DFB-grating. There can be two distinct states:

1. *The DFB-laser is lasing*
   Since the injected light has a different wavelength, it is not susceptible to Bragg diffraction on the grating. Therefore the laser acts as a gain-clamped amplifier and only a small amplification is obtained.
2. *The DFB laser is switched off*
   The injected light will experience a strong amplification througout the laser cavity. This will cause a non-uniform longitudinal distribution of the carriers (spatial hole burning). This spatial hole burning will affect the the Bragg grating and therefore significantly increase the losses for lasing, causing the laser to remain switched off.

To use the laser as an all-optical flip-flop, CW-light is injected to operate in the bistable regime. By injecting an optical pulse on the left side of the laser, we move out of the hysteresis curve, causing the laser to be switched off. Injecting a pulse from the other side, the uniformity of the carriers in the cavity can be restored and the laser will switch on again.

Figure 1: Concept of flip-flop behaviour

Bistability

We observed a bistability in a $\lambda/4$-shifted DFB-laser of 400 μm and with an AR-coating on the facets. The laser emission wavelength is 1553.7 nm and the injected light has a wavelength of 1543 nm. In Figure 2 the hysteresis-curve is depicted for a laser with a current injection of 120 mA. The extinction ratio is 32 dB.

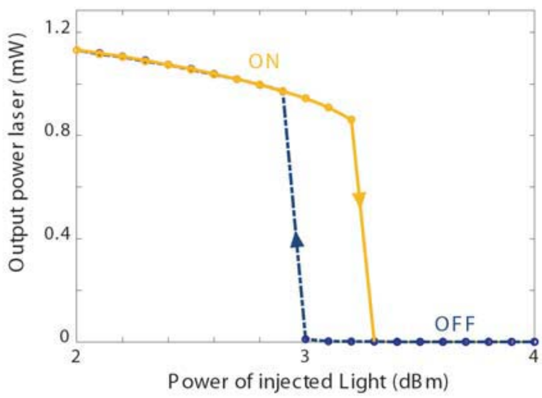

Figure 2: Bistability in a $\lambda/4$-shifted DFB-laser of 400 μm with a current injection of 120 mA. The injected light has a wavelength of 1543 nm.

Experimental set-up

To perform the experiments, we make use of a picosecond pulse source generating optical pulses with a duration of 7 ps at a rate of 10 GHz. To decrease the repetition rate, we feed the light through an optical modulator which is driven by a bitpattern generator. The pulses are amplified through an erbium-doped fiber-amplifier (EDFA) and split by a directional coupler. On the left side of the device, the pulses are combined with CW-light by another directional coupler. We control the amplitude of the pulses by using attenuators. A lensed fiber is used to inject the light into the DFB-laser.

Using a circulator combined with a filter that is set at the lasing wavelength, we can visualize the flip-flop operation. The optical scope operates at a sampling frequency of 30 GHz. Therefore, we can not properly visualize the width of the ultra-short pulses.

Results

Experiments were done at different repetition rates and different wavelengths. In Figure 3 flip-flop operation is depicted with light injected at a wavelength of 1543 nm and at a repetition rate of 1.25 GHz. We observe a switch-off time of 20 ps which corresponds to the resolution of our optical scope. The switch-on of the laser takes about 75 ps. The energies of the pulses are 75 fJ for the set-pulses and 190 fJ for the reset-pulses. The injected CW-light was measured to be 2.5 mW. The mentioned values are those measured before the coupling with the lensed fiber.

In Figure 4, a similar result is shown, but now at a repetition rate of 2 GHz.

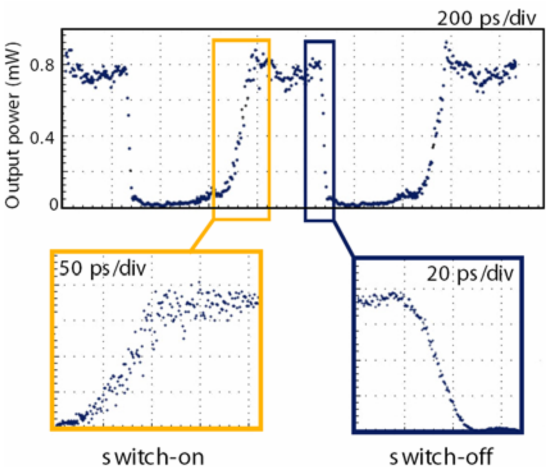

Figure 3: Flip-flop operation with injected light at a wavelength of 1543 nm with a repetition rate of 1.25 GHz.

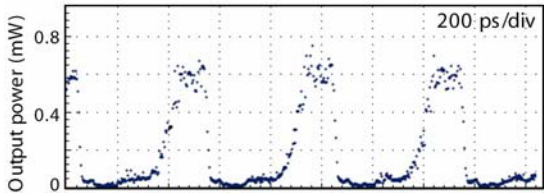

Figure 4: Flip-flop operation with injected light at 1543 nm at a repetition rate of 2 GHz

We also did experiments at a longer wavelength by injecting light at 1560 nm. The wavelength can be chosen any value as long as there is enough amplification by the gain medium (except in a range of 4 nm around the lasing wavelength). In Figure 5, flip-flop operation with injected light at 1560 nm is depicted. The repetition rate is again 1.25 GHz. The reset-pulses are 50 fJ and the set-pulses 125 fJ.

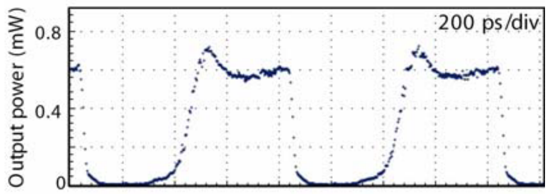

Figure 5: Flip-flop operation with injected light at a wavelength of 1560 nm and repetition rate 1.25 GHz.

Conclusions

All-optical flip-flop operation in a single DFB-laser diode was demonstrated for repetition rates of 2 GHz, with a switch-on time of 75 ps and an almost immediate switch-off. Pulses with a duration of 7 ps and energies below 200 fJ were used to obtain this result. The flip-flop can operate over a broad wavelength range for the injected signals.

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