Digital photonics for optical network nodes

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I. Introduction

The telecommunication industry has experienced a huge growth during the last decade and the need for bandwidth is expected to increase further as new internet-based services are being implemented. Optical fibers offer by far the best solution to transfer huge amounts of data traffic over large distances (up to 8 Tb/s over 510 km fiber [1]) and have been installed world wide. However, the electronic processing in the network nodes imposes a technological bottleneck at these high speeds. Besides the limited speed of electronic components, also the power consumption becomes an important issue: recent studies show that the total power consumption of the internet is comparable to the whole air traffic industry.

Photonics offers a solution for this problem by implementing all the necessary signal processing in the optical layer and thereby making the extremely power-consuming opto-electric (O/E) and electro-optic (E/O) conversions obsolete. In this article, an overview will be given of recent results obtained within my research on this topic. First, novel concepts for all-optical flip-flops will be demonstrated and a proof-of-principle of 40 Gb/s optical packet switching is shown. We conclude by discussing a novel technique for optical regeneration to reduce noise effects.

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II. All-optical flip-flops

One of the most important elements to be implemented in optical network nodes are all-optical flip-flops because of their ability to act as optical memory elements and store temporal decisions in all-optical packet routers. In general, they have a bistability in the amplitude or wavelength and one can switch between the two different states by injecting an optical pulse. Many different implementations of such devices have been proposed, but the main innovation in our research is the realization of extremely fast flip-flop operation (up to 40 - 50 ps switching speeds) in single laser diodes.

The first concept we realized is flip-flop operation in a single distributed feedback (DFB) laser [2]. DFB lasers are the standard elements in today's telecommunication industry and the name originates from the fact that the feedback (which is necessary for lasing operation) is not introduced by reflections at the facets of the cavity, but is distributed within the cavity by a corrugation (grating). By using a hysteresis effect in the distribution of the carriers, we can switch the laser on and off by injecting light pulses in the cavity (Fig. 1).

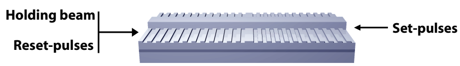

Figure 1. Schematic illustration of DFB flip-flop.

Another concept is based on a distributed Bragg laser where a grating is located outside the active laser section to reflect light at a specific frequency back into the cavity (wavelength-dependent mirror). By changing the current on the grating, we can tune the wavelength of the laser. However, due to mode competition within the laser cavity, a hysteresis can be observed in the wavelength tuning characteristic and therefore it is possible to switch between two wavelengths of the laser by sending optical pulses in the cavity (Fig. 2).

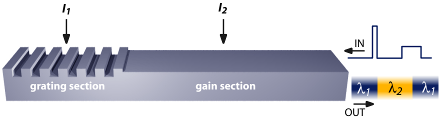

Figure 2. Schematic illustration of DBR flip-flop.

Microdisk or ring lasers can have laser operation in clockwise and counter-clockwise direction. Because of non-linear effects in the gain material of the laser, it is possible to suppress one of the two directions. When a pulse is injected in one direction, the laser will be locked in that state and switch only back to the other state when a pulse from the other side is injected (Fig. 3).

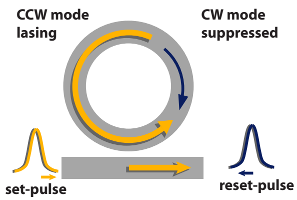

Figure 3. Schematic illustration of a ring laser flip-flop.

III. Packet switching

As a proof of principle, we demonstrate the use of the DFB flip-flop within an actual all-optical packet switching configuration. Based on the routing information (contained in the header of a data packet), a header processor switches the all-optical flip-flop on by sending an optical pulse. The optical flip-flop stores the temporal decision of the header processor while the payload is being transferred to the right output port. An illustration of the realization of all-optical packet switching using a DFB laser as all-optical flip-flop is demonstrated in Fig. 4 where the switched 40 Gb/s data packets are shown.

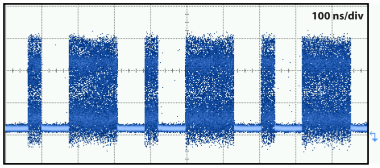

Figure 4. Switched 40 Gb/s optical packets.

IV. Regeneration

One of the major concerns for the implementation of all-optical networks, is the accumulation of noise which limits the cascadability of optical network nodes. Therefore, there is a clear need for devices which can reduce the noise on signals. We propose a novel regeneration scheme where a hysteresis in the decision characteristic increases the tolerance of noise and improves the bit-error rate of the signal. We demonstrated this novel method experimentally using the previously mentioned hysteresis in a distributed feedback laser.

V. Conclusions

We demonstrate novel concepts for all-optical flip-flops based on single laser diodes and their application in optical network nodes.

Acknowledgments

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References

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