Sub-pJ and simultaneous multiple wavelength switching of an all-optical flip-flop based on a DFB-LD with integrated SOA

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Abstract *Sub-pJ switching of a SOA and DFB laser diode based all-optical flip-flop is presented. Simultaneous switching of multiple wavelengths is demonstrated with switch times as low as 100ps and an ER over 15dB.*

Introduction

All-optical packet switched networks have been proposed as the future telecommunication networks able to cope with the massive bandwidth requirements resulting from the huge growth of the internet and its services. One of the key components in these packet switched all-optical networks is an all-optical flip-flop, which can be switched between different (channel) wavelengths using optical pulses derived from the packet header, and of which the output can be used as pump signal for an all-optical wavelength converter [1-2].

Previously we reported on the use of a mutually optically coupled semiconductor optical amplifier (SOA) and distributed feedback (DFB) laser diode as an all-optical flip-flop (AOFF) [3]. Here we present new results on this device with very low required pulse energies (150-400fJ), fast switching times (50-100ps) and high output extinction ratio (>15dB). We also demonstrate that the device can exhibit simultaneous all-optical flip-flop operation on different output wavelength channels for a single set-reset control sequence. This may be of interest when multicasting is required.

Principle of operation

The device is essentially based on the optical feedback between a SOA and (1 or more) DFB laser diode(s). A schematic representation of the device is shown in Figure 1. When a constant input power is injected into the SOA this power is amplified inside the SOA and part of this amplified power is injected into the laser diode. At the same time an equal fraction of the laser output power is injected into the SOA. Two operating conditions can be observed, in the first one the amplified (high power) input signal is strong enough to quench the DFB laser diode, resulting in a high signal output power and a low laser output power. The second state is defined by the fact that the amplified (low power) input signal does not quench the laser resulting in saturation of the SOA by the laser output power leading to a low signal output power and a high laser output power.

It has been shown before [4] that depending on the coupling ratio between the SOA and the DFB laser diode and the drive currents to both the SOA and the DFB laser diode the device can exhibit bistability where the two states can occur for the same input power. The selection of the desired output state can be done by injecting appropriate set and reset pulses into the device. A set pulse (injected into one of the DFB laser diodes) temporarily lowers the gain of the SOA giving the DFB laser diode(s) the time to rebuild their laser field. A reset pulse (injected at the SOA side) helps to quench the laser diode(s). The output states can be obtained at the SOA side (by using a circulator) or at the back side of the DFB laser diode(s). By using optical band pass filters the different output signals (laser output signal(s) and input signal) can be separated.

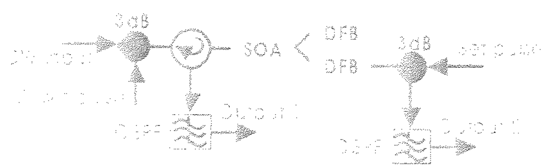

Figure 1: Schematic representation of the proposed all-optical flip-flop.

Experimental results

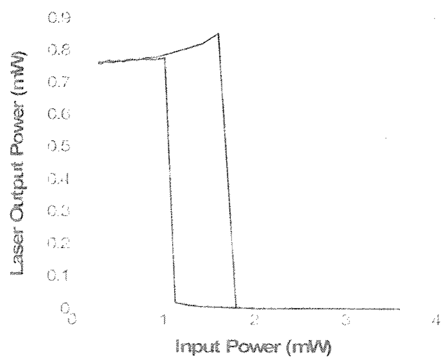

Figure 2: Static transfer function of the laser output power as a function of the CW input power to the SOA.

Two laser diodes, with respective currents of 56mA and 46mA and wavelengths of 1541nm and 1543nm are simultaneously driven. The drive current for the SOA is 120mA. The wavelength of the injected signal power was 1547nm, but the device has shown good operation characteristic for a wavelength range over 10nm. Figure 2 shows the static response of one of

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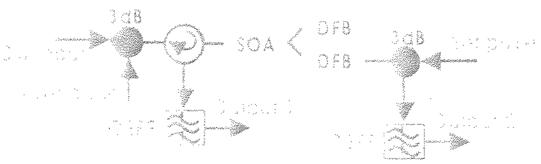

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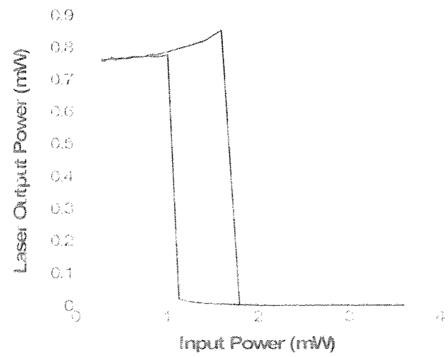
Experimental results



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In the dynamic experiments the device is operated as shown in Figure 1. A CW input signal with power chosen such that the device operates inside the bistability region is injected into the SOA. The output state of the device can be selected by injecting appropriate (set and reset) pulses. The set pulses cause the laser power to rise and the signal power to drop while the reset pulses cause the signal power to rise and the laser power to drop.

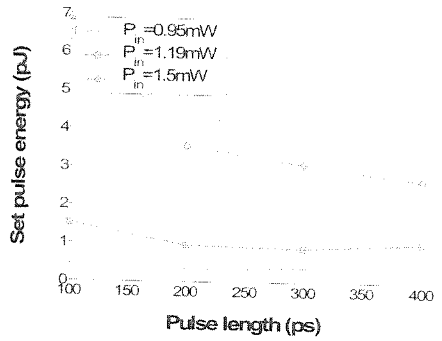

Figure 3: Evolution of the required set pulse energy for AOFF-operation as a function of used pulse length for different CW input power.

Figure 3 and 4 show the evolution of the required set and reset pulse energy to obtain AOFF-operation as a function of the used pulse length for different CW input powers. A set pulse energy as low as 340fJ, combined with a reset pulse energy as low as 240pJ, can be observed for a CW input power of 0.95mW and a pulse length of 100ps.

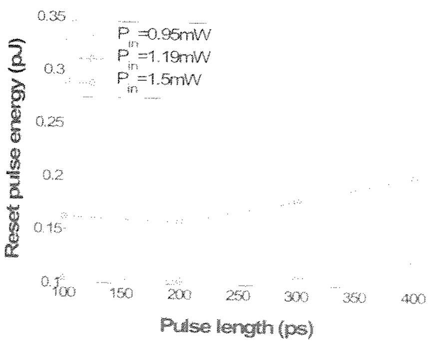

Figure 4: Evolution of the required reset pulse energy for AOFF-operation as a function of used pulse length for different CW input power.

An example of the laser output waveforms for a CW input power of 0.95mW and a pulse length of 100ps is given in Figure 5. An extinction ratio of 16dB and rise and fall times of around 100ps has been measured in both cases. The output waveform of the injected signal is an inverted version of the laser output waveforms.

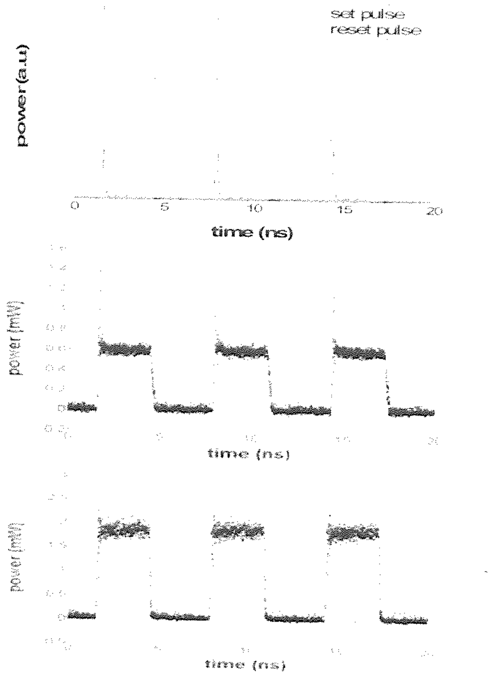

Figure 5: Laser output waveform for a CW input power of 0.95mW and a pulse length of 100ps. Top: set and reset pulse train; Middle: laser 1 at 1541nm, Bottom: laser 2 at 1543nm.

Conclusions

All-optical flip-flop operation with a SOA and DFB.laser diode combination has been shown with pulse energies below 1pJ together with fast switching times in the range of 100ps and an ER of over 15dB. The device can simultaneously exhibit multiple (identical or inverted) output states at different wavelengths making the device a possible candidate for future multicast applications.

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September 16 – 20, 2007
Berlin, Germany

33rd European Conference and Exhibition on Optical Communication

Volume 2
Proceedings
Tuesday,
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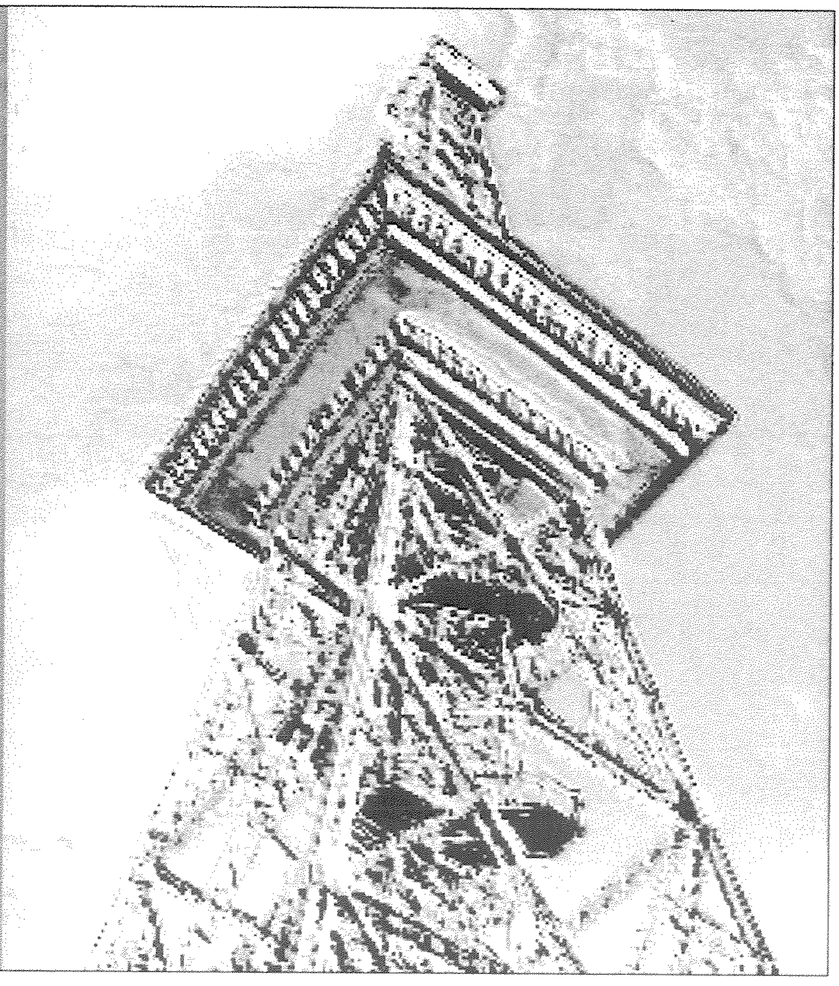
2007



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Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.

ISBN 978-3-8007-3042-1
(5 Bände incl. CD-ROM)

Druck & Bindung: druckmuck@digital e.K., Berlin 2007-09