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Towards Transparent All-Optical Label-Swapped Networks: 40 Gbit/s Ultra-Fast Dynamic Wavelength Routing Using Integrated Devices

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Abstract *All-optical routing of 40 Gbit/s 1.6 ns packets is demonstrated employing integrated devices based on SOA-MZIs. The scheme allows wavelength transparent operation and sub-nanosecond dynamic wavelength selection for future packet/label switched networks.*

Introduction

In order to increase data processing speed, all-optical label swapping (AOLS) technology has been recently proposed to, directly in the optical domain, contend with multiprotocol label swapping (MPLS) requirements [1,2]. However, AOLS can only be fully exploited if data routing is performed on a packet-by-packet basis. In this paper, an integrated optical flip-flop prototype based on SOA-MZI structures is employed to achieve dynamic 40 Gbit/s wavelength routing with potential for sub-nanosecond operation.

All-optical flip-flop memory and routing

Fig. 1(a) shows the block diagram of the wavelength router, while Fig. 1(b) depicts the schematic layout of the SOA-MZI flip-flop prototype. The device behaves as a bistable switch between two continuous wave lasers (CW), λ_1 and λ_2, based on the interaction of two coupled SOA-MZIs [3]. The principle of operation can be briefly explained as follows. The phase shifter Φ_1 is tuned such that maximum power transfer of λ_1 is redirected to *MZI_2* through the lower arm of the balanced coupler in *MZI_1*. This light modifies the gain and phase shift that λ_2 experiences in *SOA_2*. If Φ_2 is chosen properly, the amplified λ_2 at *SOA_2* output can be redirected to the upper arm of the *MZI_2*, thereby leaving *SOA_1* unperturbed. The flip-flop will maintain this λ_1 state indefinitely as *MZI_1* suppresses *MZI_2*. Since the device is symmetrical, the state λ_2 can be dominant in an identical manner.

The states can be toggled by injecting a suitable light pulse into the dominant MZI via *Reset_1* or *Set_2*. The injection of this pulse perturbs the gain and phase of the SOA of the dominant MZI such that the suppression of the second MZI is inhibited. Toggling between states is achieved by injecting a light pulse and its delayed version into the set and reset ports respectively. The temporal delay between pulses determines the flip-flop set time, which is closely related to the packet length in an AOLS scenario.

This specific implementation yields several advantages. Firstly, the switch speed of the device is determined by its physical size, which can be minimised due to its fully integrated nature, leading to switching speeds less than 200 ps. Additionally, the requirements imposed on the set and reset pulses are greatly relaxed, as the pulse width required to toggle states is similar to the switching speed of the device. Experimentally, states were successfully changed employing 75 ps pulses, and switching with 50 ps pulses is expected after further prototype optimisation. This feature will substantially alleviate interconnection issues in AOLS networks as described in [4]. This speed comes at the expense of a reduced contrast ratio between stages, whose optimised static value was ~13 dB. Most importantly, this scheme is fully transparent in the wavelength operation band of the SOA without the need for customised designs, which enhances its versatility and sets this device as a strong candidate for future all-optical applications where fast switching is essential. Finally, all-optical routing is achieved connecting the output of the flip-flop to a SOA-MZI wavelength converter. The 40 Gbit/s data are applied in a differential scheme

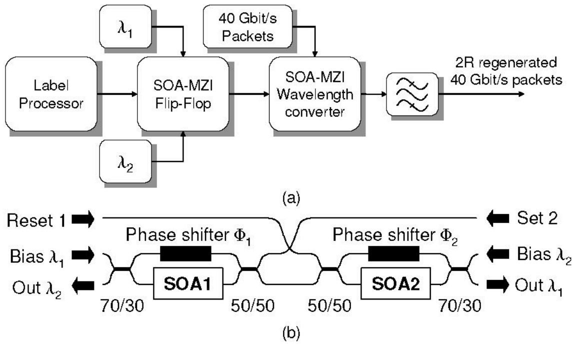

Fig. 1 Block diagram (a) and SOA-MZI flip-flop prototype layout (b). Φ: phase shifter.

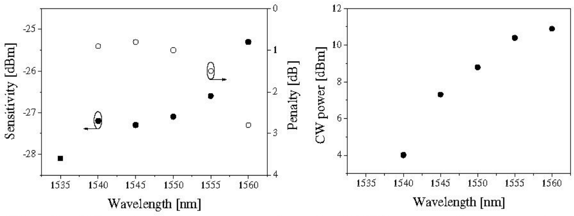

Fig. 2: Wavelength conversion to 1535 nm using constant current in SOA-MZI. Right: CW power for best performance.

configuration to improve the response of the SOAs. Wavelength conversion over the entire C band was achieved using constant driving current for the SOAs by adjusting the CW power, thereby assuring wavelength transparency is preserved (Fig. 2).

Experimental set-up and results

The two bistable wavelengths powering the optical flip-flop (λ_1 & λ_2) were chosen at 1559 and 1562 nm. The 40 Gbit/s data signal was encoded on a pulse train generated by a short pulse laser emitting at 1545 nm. Power and polarisation control were accessible at different points of the system.

Initially, the performance of the system was characterised statically. The state of the flip-flop was set manually, either to 1559 or 1562 nm, to assess the quality of CW light generated by the flip-flop. A PRBS of length 2^{31}-1 was used. BER measurements were obtained and can be compared with results from an external tuneable laser source in Fig. 3. The power penalty is less than 1.5 dB, and can be ascribed to a reduced signal-to-noise ratio at the flip-flop output.

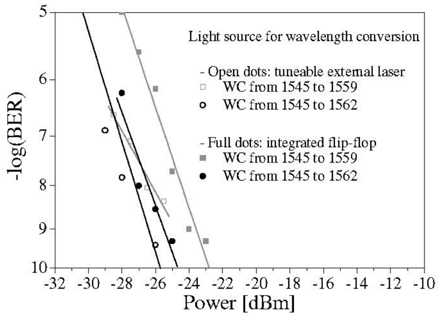

Fig. 3: BER measurements for static flip-flop operation

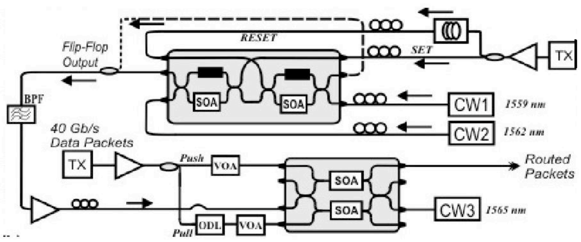

Fig. 4: Experimental set-up of the optically controlled wavelength converter

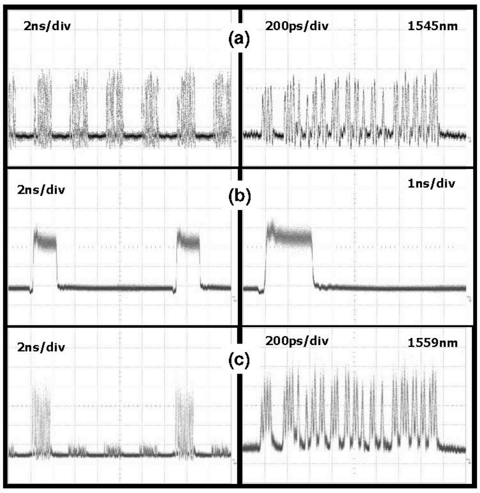

Fig. 5: All-optical routing demonstration: (a) generated packets, (b) flip-flop CW triggered output, (c) routed packets

Fig. 4 shows the experimental set-up implemented to demonstrate dynamic all-optical routing. In this case, toggling between flip-flop states is automatically triggered by an external pulsed signal, which is generated by modulating a CW at 1565 nm with a user defined pattern. The pulse width and period of the control signal are 400 ps and 13 ns respectively. As suggested in the text and shown in the figure, the *RESET* pulse is a delayed version of the *SET* pulse, in this case 2 ns, thereby setting the maximum packet length for the experiment. A 40 Gbit/s pattern generator is programmed to generate 1.6 ns data packets with a periodicity of 2.7 ns. A counter-propagating holding beam is used to minimise transients within the SOAs and reshape the regenerated signal at the targeted flip-flop wavelength. Fig. 5 depicts typical oscilloscope traces demonstrating all-optical routing functionality. Fig. 5(a) shows the generated packet structure (left) and a close up of the targeted packet (right). Fig. 5(b) illustrates the flip-flop generated CW block when triggered by the *SET* and *RESET* pulses. Finally, Fig. 5(c) shows the corresponding wavelength converted packets, which can be all-optically routed with an additional wavelength-selective element. The SOAs are driven with 120 mA and 340 mA in the flip-flop and wavelength converter respectively.

Conclusions

As all-optical processing concepts are being developed to circumvent the limitations currently imposed by electronics and substantially increase the throughput of optical communication systems, the need for devices able to cope with these new speed requirements is accentuated. Dynamic ultra-fast all-optical wavelength conversion based on a novel integrated flip-flop prototype has been presented. The design ensures wavelength transparency is achieved over the entire SOA gain band. All-optical 40 Gbit/s wavelength routing of 1.6 ns packets is shown, with an ultimate switching speed under 200 ps. This allows optimised bandwidth exploitation due to reduced guard-bands requirements in packet switched networks. Considering the latest SOA-based wavelength conversion [5], the flip-flop design can be used for specific wavelength routing at rates beyond 160 Gbit/s.

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