TuP7
2:00 PM – 3:30 PM

Efficient Performance Optimization for Ultrafast All-Optical Switching in SOA-MZI Devices[1]

Jade P. Wang[1], Bryan S. Robinson[1], Shelby J. Savage[1], Scott A. Hamilton[1], Erich P. Ippen[2], Ruomei Mu[3], Hongsheng Wang[3], Jiten Sarathy[3], Boris B. Stefanov[3]

1: Optical Communications Technology Group, MIT Lincoln Laboratory, Lexington, MA 02140
2: Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139
3: Alphion Corporation, Princeton Junction, NJ, 08550

Abstract: We present a simple method for optimization of ultrafast switching performance in semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI) devices. By simultaneously measuring switching dynamics over all possible interferometer bias points, we acquire an extinction map which accurately identifies operating conditions for high extinction and optimal switching.

Keywords: Integrated optical devices, all-optical switching.

1. Introduction

Ultrafast all-optical signal processing techniques can potentially alleviate increasing congestion in current telecommunication networks by increasing network capacity, reducing complexity and decreasing latency. Realizing such advantages will require integrating high-performance all-optical devices for ease of manufacturing, installation and operation. One such device is the semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI), an integrated all-optical logic gate that has been demonstrated to operate at speeds of up to 336 Gb/s for demultiplexing [1], 80 Gb/s in bit-wise switching [2] and 40 Gb/s for optical regeneration [3].

Conceptually, device operation is straightforward, relying on an optically-induced phase shift between the two arms of the interferometer, each of which contains at least one SOA. In practice, however, determining the optimal bias point for fast switching speeds and high extinction can be time-consuming. It involves optimization over many parameters including signal and control pulse energies, their relative delays, and the bias currents for the switching and amplifying SOAs.

To address this issue, we have developed a novel characterization technique for quickly and effectively locating the optimal operating point for ultrafast switching in a SOA-MZI device [4]. We combine a pump-probe measurement with a bias map of the constructive and destructive interference fringes of the interferometer. This allows us to create an extinction map identifying operating points for high switch extinction. This same information also allows us to construct a dynamic bias map, which displays the switching dynamics of the device over all possible bias points, and to obtain a better understanding of switching device dynamics. This measurement technique significantly simplifies the operation of single SOA-MZI devices and is even more critical for multi-gate SOA-MZI-based logic designs in future optical signal-processing applications. We have previously used this method to demonstrate error-free optical regeneration at 10 Gb/s over 10,000 km [5].

2. Optimization Method and Results

We used an SOA-MZI device provided by Alphion Corporation (Figure 1). In typical operation, two switching SOAs (SOAs 4 and 5 in Figure 1) and 4 amplifying SOAs (SOAs 1-3 and 6) are used. Device operation is as follows: signal pulses arrive at the center input port and are split into identical copies in each arm of the interferometer, recombining destructively or constructively at the output. A control pulse is coupled into one arm of the interferometer, inducing a gain and phase change in the signal pulse of that arm through cross-gain and cross-phase modulation in the switching SOA. In non-inverting operation, this control pulse alters the interferometer bias from destructive to constructive interference. In inverting operation, the interferometer bias moves from constructive to destructive operation. When operated in differential mode, a second copy of the control pulse is coupled into the second arm of the interferometer and arrives after the signal pulse to rebalance the interferometer. This reduces the effect of the long carrier recovery time on switch operation and enables faster switching.

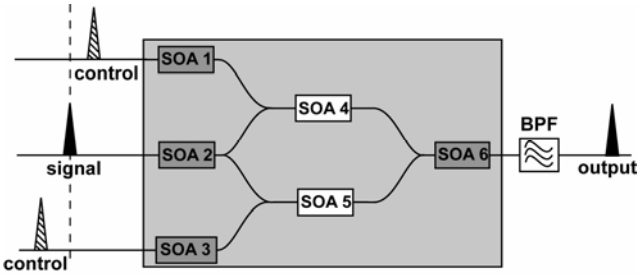

Figure 1 : Schematic of SOA-MZI. Amplifying SOAs shown in dark grey; switching SOAs in white. Control pulses shown striped; signal pulses are black. BPF = bandpass filter.

The optimal operating point of the SOA-MZI depends mainly upon the current bias of the switching SOAs, the optical pulse energy of the control pulses and the relative delay between the signal and control pulse. To efficiently and accurately pinpoint the optimal operating point, we developed a pump-probe bias-scan technique. This combines a pump-probe measurement with a

---

[1] This work was supported by the Air Force Research Laboratory (AFRL), under Air Force contract #FA8721-05-C-0002. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government.

1-4244-1122-X/07/$25.00©2007 IEEE

measurement of the interferometer bias map. An interferometer bias map is obtained by measuring the average signal power at the interferometer output as a function of the two switching SOA currents. Figure 2 shows the setup of the measurement technique. To speed up measurement, we sweep the upper SOA current across all possible current values using a 1-Hz sawtooth wave. We use GPIB control to slowly step through all possible current values in the lower SOA. This maps out the initial bias of the interferometer in the absence of optical switching. To combine this with a pump-probe measurement, we add the control pulses at a delay τ with respect to the signal pulse. At each value of τ, we measure a new interferometer bias map. If we refer to the signal pulse as the "probe" and the control pulse as the "pump", we are simultaneously performing a pump-probe measurement at each possible set of SOA current values.

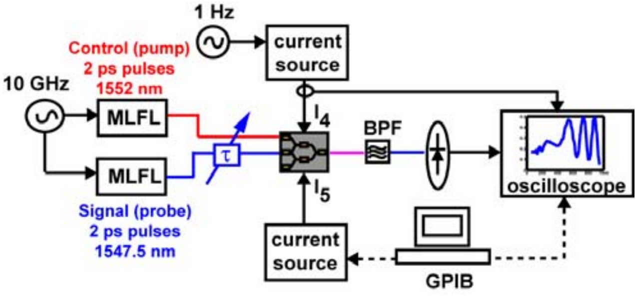

Figure 2: Block diagram of pump-probe bias scan method. BPF = bandpass filter; MLFL = modelocked fiber laser.

The result is a set of interferometer bias maps indexed by signal-control delay. This can either be displayed as a dynamic bias map [4] to reveal details about the switching dynamics at different interferometer biases or as an extinction map (Figure 3a) to pinpoint regions of high extinction suitable for ultrafast switching. In Figure 3a, we see regions of high extinction and regions of low extinction. High extinction regions occur for both non-inverting and inverting operation, separated by regions of low extinction. Optimal extinction for non-inverting operation was found to be 8.8 dB at I_4 = 893.5 mA and I_5 = 470.0 mA and is marked with a black square in Figure 3a. Even higher extinction (10.4 dB) can be found for inverting operation at I_4 = 801.6 mA and I_5 = 317.6 mA (marked with a black star).

To illustrate the accuracy of this method, we demonstrate wavelength conversion at both the optimal operating point and at an operating point slightly de-tuned from optimal (marked by the black triangle in Figure 3a). We operate the device in non-inverting mode to avoid an unnecessary inversion of the wavelength-converted data. Figure 3b shows the bit-error-rate curves for wavelength conversion at the two operating points. It is clear from this plot that even a slight change in the SOA current biases can cause a significant penalty (1 dB at 10^{-9}) to the BER.

3. Conclusion

We have demonstrated an efficient and accurate performance optimization method for ultrafast all-optical switching in semiconductor optical amplifier Mach-Zehnder interferometer switches. By combining a pump-probe measurement with a fast interferometer bias scan, we are able to quickly obtain information about switching dynamics over all possible bias points as well as to locate operating points for optimal extinction at a glance.

4. References

[1] S. Nakamura, Y. Ueno, and K. Tajima: "*Error-free all-optical demultiplexing at 336 Gb/s with a hybrid-integrated Symmetric-Mach-Zehnder switch*", Optical Fiber Communications Conference (OFC '02), Postdeadline Papers, FD3 (2000).

[2] H. Dong, H. Sun, Q. Wang, N.K. Dutta, and J. Jaques, "*80 Gb/s All-optical logic AND operation using Mach-Zehnder interferometer with differential scheme*", Optics Communications, 265 (1), 79–83 (2006).

[3] B. Lavigne, P. Guerber, P. Brindel, E. Balmefrezol, and B. Dagens, "*Cascade of 100 optical 3R regenerators at 40 Gbit/s based on all-active Mach-Zehnder interferometers*", 27th European Conference on Optical Communication (ECOC 2001), 3, 290-291 (2001).

[4] J. P. Wang, B. S. Robinson, S. J. Savage, S. A. Hamilton, E. P. Ippen, R. Mu, H. Wang, L. Spiekman, B. Stefanov, "*A Performance Optimization Method for SOA-MZI Devices*", Optical Fiber Communications Conference (OFC 2007), OthT4(2007).

[5] J. P. Wang, S. J. Savage, B. S. Robinson, S. A. Hamilton, E. P. Ippen, R. Mu, H. Wang, L. Spiekman, B. Stefanov, "*Regeneration using an SOA-MZI in a 100-pass 10,000-km Recirculating Fiber Loop*", Conference on Lasers and Electro-optics (CLEO 2007), CMZ1 (2007).

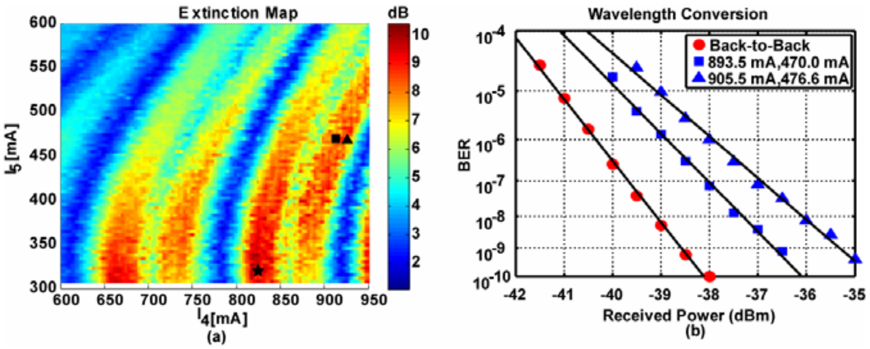

Figure 3: (a) Extinction map measurement from pump-probe bias-scan. A square shows the optimal non-inverting operating point found. The triangle shows a non-optimized operating point. (b) Bit-error-rate measurements of wavelength conversion performed at optimal (square) operating point and non-optimal (triangle) operating point.