A Performance Optimization Method for SOA-MZI Devices[1]

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Abstract: We present a novel characterization method for semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI) switches which combines a pump-probe measurement with an interferometer bias scan. This enables optimal bias identification and better understanding of switching dynamics.

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1. Introduction

As bandwidth demands for telecommunication networks increase, optical signal processing techniques may be required to provide the necessary network capacity. The semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI) is an integrated all-optical switch which can operate at ultrafast speeds. Previous work with the SOA-MZI includes demonstrations of ultrafast switching speeds up to 336 Gbit/s [1], [2] as well as modeling of SOA-MZI devices [3], [4]. Conceptually, device operation is straightforward, as switching is achieved by inducing differential phase shifts in the SOAs located in each of the two arms of the interferometer. In practice, operating an SOA-MZI can be complex because signal and control pulse train intensities as well as bias currents for the switching and amplification SOAs must all be carefully balanced at a specific operating point for optimal extinction and switching speeds.

Here, we present a novel characterization technique for SOA-MZI all-optical switches that can be used to quickly identify optimal operational bias points and provide insight into key performance parameters such as SOA carrier recovery time and extinction ratio at multiple operational bias points. Furthermore, this characterization technique can offer insight into SOA-MZI device design improvements. We perform this measurement by combining a bias map of the constructive and destructive interference fringes of the interferometer with a pump-probe measurement. This technique enables ease of operation of single SOA-MZI gates and can also be used to simplify the design of multi-gate SOA-MZI-based logic for future optical signal processing applications.

2. Characterization Method and Results

We used a semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI) provided by Alphion Corporation (Figure 1). Wavelength conversion has been demonstrated with the device at 10 Gbit/s with extinction ratios of 8 dB in non-inverting operation and 10 dB in inverting operation. [5]. In this device, four switching SOAs are available though typically only two are used. Six amplifying SOAs are available for input or output amplification. The signal pulses arrive at the center input of the interferometer and are split into two identical copies, one in each arm of the interferometer. The initial bias of the interferometer is determined by the bias currents of the switching SOAs. When a control pulse is coupled into one arm of the interferometer, it causes a phase change in the signal pulse in that arm through cross-phase and cross-gain modulation. When the signal pulse copies are recombined at the output of the interferometer, constructive or destructive interference is achieved.

To characterize the operation of this device, we must determine the correct bias-current settings for the switching and amplification SOAs in the SOA-MZI, the optical power required to induce a π-phase shift, and the carrier recovery dynamics of the device. To do this efficiently, we have developed the pump-probe bias scan technique.

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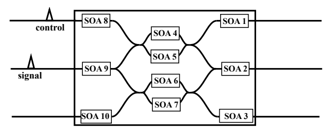
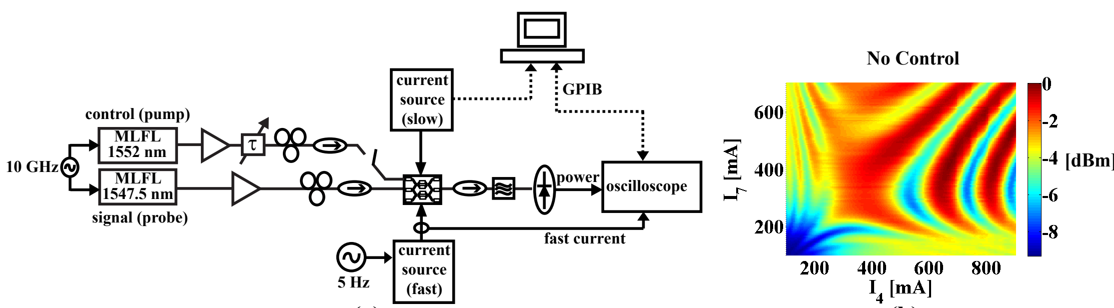


Fig. 1: Semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI). SOAs 4-7 switching SOAs; SOAs 1-3 and 8-10 are amplifying SOAs. In typical operation, only two switching SOAs are used (e.g., SOA 4 and SOA 7).

Figure 2(a) shows the experimental setup of the measurement technique. In this measurement, the control pulses act as the pump pulses and the signal pulses act as the probe pulses. We first demonstrate this characterization technique under static switching conditions (i.e., with no control pulse train). We map out the initial bias of the interferometer by varying the bias current to both switching SOAs and observing the output signal pulse power with a photodiode and oscilloscope. Control of the SOA current source through GPIB proved prohibitively slow, taking 9 hours. To improve the speed, we use a 1-Hz sawtooth wave to dither the current on one of the two switching SOAs ("fast current"), reducing the entire scan to only 7 minutes. This low-frequency dither was chosen to reduce the impact of thermal effects which can interfere with the accuracy of the measurement and to fall within the bandwidth of the current source. Thus, for each value of the "slow current", we quickly scan the "fast current" values. Figure 2(b) shows a measured static 2-D interferometer bias map, plotting the output signal power as a function of the bias currents on the switching SOAs (SOA 4 and SOA 7). These interference fringes show up clearly in the plot, indicating multiple potential operating points for inverting (bias at a peak) or non-inverting (bias at a null) operation.



(a) (b)

Fig. 2: (a) Experimental setup for the dynamic pump-probe bias scan. MLFL is a mode-locked fiber laser. At each pump-probe delay (τ), we obtain an interferometer bias scan through varying the current bias of the two switching SOAs and observing the signal (probe) power at the output. For the static pump-probe bias scan, the control (pump) input is turned off. (b) shows the output signal power of the SOA-MZI as a function of the current bias on the two switching SOAs (SOA 4 and 7). This is the result of a static bias scan. Areas of constructive and destructive interference show up clearly, indicating potential operating points for inverting and non-inverting operation.

We next demonstrate this characterization technique under dynamic switching conditions (i.e., with control pulse train input). For dynamic testing, we combine our bias scan approach with a pump-probe measurement to identify bias points with maximum extinction and investigate carrier recovery dynamics. As seen in Figure 2(a), control pulses are generated by a mode-locked fiber laser at 1552 nm with a repetition rate of 10 Gbit/s and are inserted into one arm of the interferometer. Signal pulses are generated with a second, synchronized mode-locked fiber laser at 1547.5 nm with a repetition rate of 10 Gbit/s. The average power of the control pulses is 0.4 dBm and the average power of the signal pulses is -8.1 dBm. At each pump-probe delay, we measure a bias scan using SOAs 4 and 7. This allows us to observe the effect of the control pulse on the signal pulse in the SOA-MZI as a function of the delay between them, thus revealing the extinction and carrier recovery dynamics at all operating points simultaneously. A series of plots taken at increasing signal pulse delays can be used to visually illustrate the SOA-MZI switching dynamics. Figure 3(a)-(c) shows bias scans taken at three fixed delays: when the control pulse precedes the signal pulse, when the control is overlapped with the signal, and when the control follows the signal.

From these pump-probe bias scans, we clearly see that the presence of the control pulse causes a phase shift in the SOA-MZI and thus switches the output signal pulse from constructive to destructive interference or vice versa. As the signal-pulse delay from the control pulse increases, we see the effect of the SOA carrier recovery. As Figures 3(a)-(c) shows, single-ended switching performance in the SOA-MZI is limited by the slow carrier recovery on the order of 50 ps in the control-pulse-excited SOA. We observe an operating point for inverting operation of

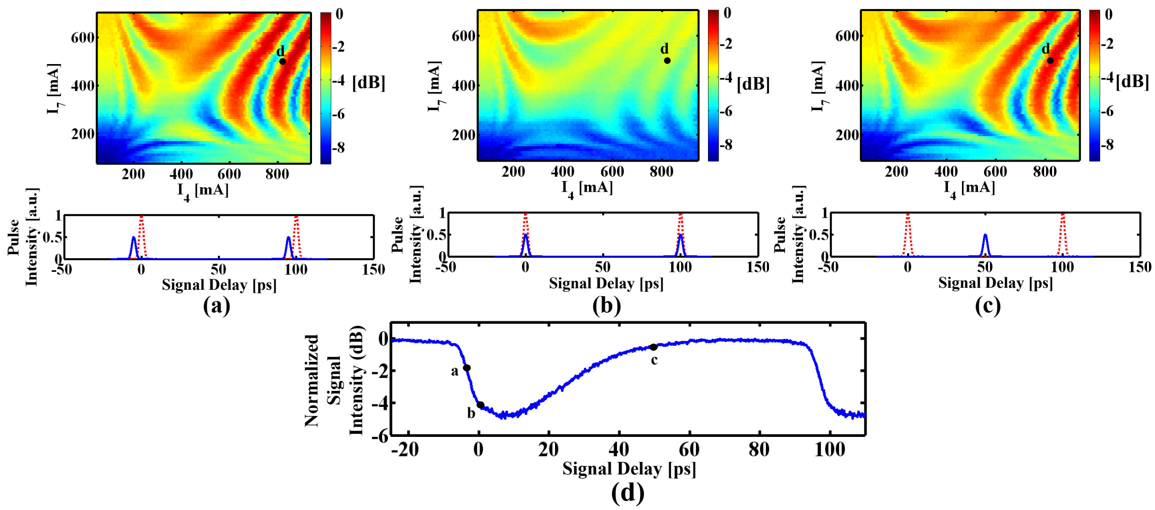


Fig. 3: (a)-(c) shows interferometer bias scans at signal pulse delays with respect to the control pulse of -5 ps, 0 ps, and 50 ps, respectively. "d" is an operating point found for the inverting operation of the switch. (d) shows a switching window measurement taken at operating point "d", with points "a", "b", and "c" indicating the delays illustrated in scans (a)-(c).

the switch at at I_4=820 mA, I_7=500 mA. From Figure 3(b), we can see that the arrival of the control pulse at 42.6 fJ contains enough energy to heavily saturate the switching SOA, thereby reducing the constructive or destructive interference in the interferometer and degrading the extinction ratio.

For optical signal processing applications, multiple cascaded SOA-MZIs capable of large extinction ratios and high-speed switching may be required. It is well-known that a differentially-driven SOA-MZI provides superior performance compared to single-ended operation [6]. By adding an additional control pulse to induce temporally-offset carrier dynamics in both switching SOAs, the parameter space for optimizing switch performance becomes more complex. Our pump-probe bias-scan technique can be adapted to characterize differentially-driven SOA-MZIs by simply varying the signal pulse delay with respect to both temporally-offset control pulses. Because of the short scan time required for our pump-probe bias-scan technique, we anticipate that this technique will prove invaluable for quickly finding optimal bias points for single- or multi-gate logic using differentially-driven SOA-MZIs.

In this presentation, we will use the pump-probe bias-scan technique to compare optimum performance achieved between single-ended and differentially-driven SOA-MZI switches. We will demonstrate that this technique can be used to efficiently find optimum operating points for high-speed high-extinction wavelength conversion in a monolithically-integrated SOA-MZI.

3. Conclusion

The semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI) offers ultrafast switching capabilities in a compact integrated package. However, finding the optimal bias of the SOA-MZI can be difficult given the complexity of the device. Here, we present a novel characterization method for SOA-MZI switches which combines a pump-probe measurement with a scan of the interferometer bias. As we have shown, this method enables the fast identification of optimum bias points and a better understanding of the switching dynamics in the device.

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