Filtering and High-Speed Switching Characteristics of a C-band Rapidly Tunable Wavelength-Selective MSM Detector

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Abstract We have developed an MSM based, electrically controlled, rapidly tunable photodetector in C-band with switching access time of 13.8 ns. We achieve 1 Gb/s error free transmission and show <±5 ps group delay ripple.

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Introduction

It has long been acknowledged that filters play a critical role in nearly all types of current optical systems, including simple channel-wavelength demultiplexing. Moreover, the wavelength-selective receivers in a wavelength-division-multiplexed (WDM) optical network would typically require a discrete filter or demultiplexer to be followed by a photodetector. Furthermore, future WDM optical networks might require the rapid reconfiguration of wavelength-selective receivers to enable more efficient routing and switching techniques (i.e., burst or packet switching). With the availability of tunable lasers with switching speeds of 5-20 ns [1] rapidly tunable de-multiplexers with this speed are highly desirable. Hence a laudable goal would be to have a receiver element that: (i) combines the detector and wavelength selectivity into a single structure, and (ii) can be wavelength tuned on the order 10's of nanoseconds. Currently existing combination of tunable filters and photo detectors, tuned by either thermal, mechanical or accoustic means, have wavelength tuning times ranging from a few milli-seconds to a few micro-seconds [2,3]. Our design combines the switching and filtering function into the detector and enables ~13.8ns wavelength switching speed.

We interfere a beam with a delayed version of itself to form an interference pattern on top of the fingers of a metal-semiconductor-metal (MSM) photodetector. The fingers can be individually biased to different voltages. Then we can choose an appropriate MSM biasing pattern such that only the net photocurrent collected is from the desired wavelength, with cancellation of the current from the undesired wavelengths. Since the biasing pattern is simply a set of voltages, the wavelength reconfiguration speed is essentially limited only by the electronic switching times for the bias pattern, hence we achieve a switching speed in the nano-second range.

In our previous work, we have theoretically modeled this detector and demonstrated it at 850nm [4] and performed the integration of this 850nm detector with its custom-designed CMOS electronics for high speed wavelength tuning [5].

In this paper, we demonstrate a wavelength-selective MSM detector, fabricated on an InAlAs/ InGaAs epitaxy layer, with a working range from ~1300nm upto ~1560nm, covering the whole telecommunication C-band and S-band. We demonstrate rapid switching of up to 1Gb/s of psuedo random bit sequences (PRBS). Additionally group delay ripple (GDR) measurements show <±5ps GDR in the filter passband.

Detector Based Filtering

The detector consists of three different regions, with each region having separate biases as shown in Fig. 1. The key to wavelength selectivity is to form a wavelength-dependent interference pattern that lines up with the MSM fingers in the center part of the device. We use a Michelson interferometer to generate two beams with an optical path length difference, and interfere them onto the detector. We also need to shine another controlled portion of the original signal beam (with no interference) on region III. With a change in the wavelength, the interference pattern will move on the surface of the detector. By biasing the two regions I and II with equal voltage but with opposite signs and biasing region III always positively, we will be able to get a sinusoidal filtering function from the detector (Figure (2a)). By toggling

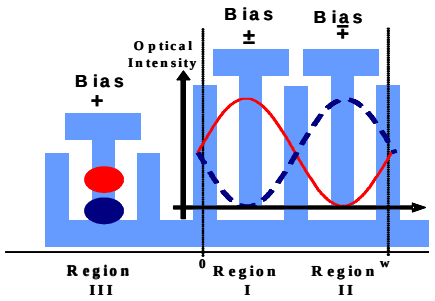

Fig. 1. Tunable MSM device, with the interference patterns of two wavelength channels $\lambda 0$ and $\lambda 0+\Delta\lambda$ shown as solid and dashed lines.

the voltages of the biases of regions I and II the filter function will have 180 degrees of phase change. This effect enables switching between the wavelengths at the maximum point of the sine filter shape and the minimum point of the filter as seen in figure 2a. The

filter shape in figure 2a was measured by modulation of a 100 MHz tone onto the tunable laser.

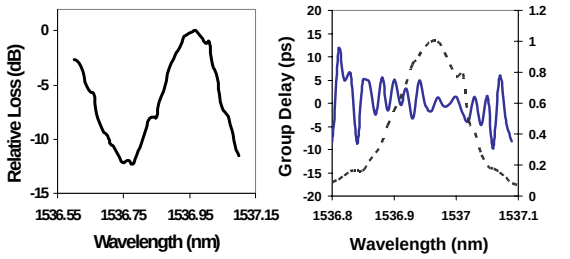

Fig. 2. (a) Amplitude response of the detector filter function (b) Group delay ripple across the pass band of the detector filter.

The free spectral range of the detector filter function depends on the delay in the Michelson interferometer. For our device the optical path length could be changed from ~5.3 mm to ~1.06 mm so the minimum channel spacing could change from ~30 GHz to ~6 GHz. This can allow very narrow filtering and small channel spacing. However when the channel spacing is small, the FWHM of filters and the bit rate transmittable will decrease. In our measurements we the free spectral range is ~0.54 nm and the switching channel spacing is ~0.27 nm with 1537 nm being one of the transmitted signals.

The filter shape of the detector will effect the bits passed through the detector. We have characterized the group delay ripple (GDR) across the passband as shown in Figure 2(b). The peak to peak ripple remains below ~5ps within the filter bandwidth and has a flat slope on average indicating that the filter effecitively induces no chromatic dispersion. The GDR was measured using modulation phase method with f_{mod} = 100 MHz and λ_{step}=0.01nm [6].

Digital Performance Results

Fig. 3 shows 200 Mbits/s data transmitted through the detector at 1537.0 nm and then at 1537.27 nm. The biases were constant during the measurement. The residual pattern seen in Fig 3(b) is due to the different frequency responses of positive and negative biasing of our MSM wafer . This will show up as crosstalk in the switching experiment.

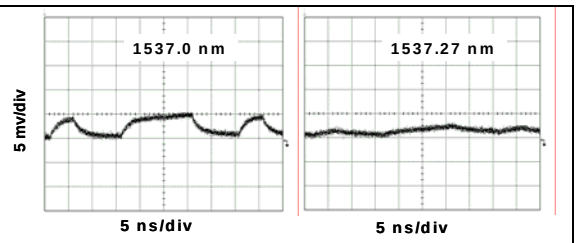

Fig. 3. 200 Mb/s data (a) received at 1537 nm and (b) discriminated at 1537.27 nm by the detector

In order to test the speed of the detector and the effect of the detector filter on bits, psuedo random bits were transmitted through the detector with constant voltages for the junction biases. Figure 4(a) shows the bit error rate curve for 1 Gbits/s modulated data at 1537 nm. The received PRBS bits can be seen in the inset. Figure 4(b) shows the power penalty curve due to the increase in the bit rate. It can be seen that 1Gb/s transmission has 1.6 dB power penalty vs. the 200 MHz transmission case. The non ideal shape of the filter and bounding wires connected to the chip were the main limitors to the detector speed.

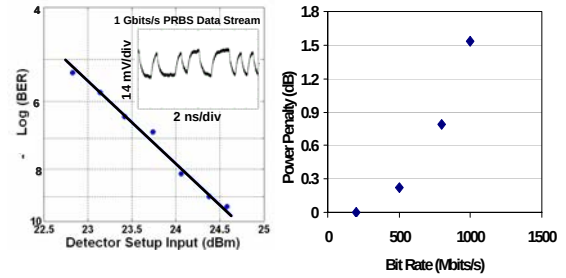

Fig. 4(a) BER curve of 1 Gb/s data through the detector. (b) Power penalty vs. data bit rate. 1.6dB penalty for 1 Gb/s data is measured.

Figure 5(a) shows the switching process. A 1537 nm signal modulated at 2 Gbits/s is transmitted through the detector. Two complimentary 12.5 MHZ clock signals are used for switching the two detector sections and a constant bias is used at the third

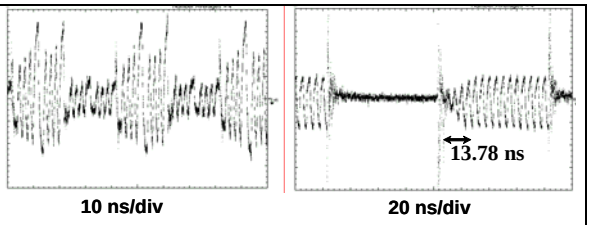

Fig. 5 (a) Switching of 2 Gbit/s data. (b) Switching time measurement of 13.78 ns.

section. Crosstalk of ~4 dB can be seen. In Figure 5(b) 800 Mbits/s of 101010 bits were sent through the detector and a 12.5 MHz square wave was used to turn the junctions on and off . The Switching speed of 13.78 ns is readily measured.

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