Welcome to Ray Chen’s Research Summary Page

My research topic at the final stage of my Ph. D education is “Performing Dynamic Optical Filtering and De-Multiplexing in CMOS Electronics”. This is the extension of the DARPA sponsored (under Chip-Scale WDM project) Ph. D research project, “CMOS-Controlled Tunable Photodetectors”, my advisor, Professor David A. B. Miller, created for me a few years ago based on my interdisciplinary background and interests between photonics and high speed analog/mixed signal IC design.

Motivation and Background Introduction

Why is it interesting and novel to perform dynamic optical filtering and de-multiplexing in CMOS? And what is the point of doing this? Since all of the currently available optical tunable filters such as AOTFs (Acousto-Optical Tunable Filter) and de-multiplexers such as AWG devices (Arrayed Waveguide Grating multiplexer/demultiplexer) are doing signal processing in optics domain, which doesn’t have much degrees of freedom to control, and there isn’t any integrated component module available for dynamic optical de-multiplexing, the CMOS chip I am working on can sort out the WDM signal to their colors and can dynamically re-allocate all of the output channels simultaneously within a nanosecond.

In Fig. 1 below is the standard implementation of a simplified dynamic wavelength allocation WDM network in downstream case. The central office end (transmitter end) uses an AWG device to couple all of the colors to a single mode fiber and sends the WDM signal to the end users end (receiver end). At the receiver end, there should be a “1XN power splitter” to split the WDM signal into N (channel) parts and each split WDM signal passes a discrete-component tunable filter (usually AOTF with microsecond tuning time) followed by a standard photodetector (usually a PIN photodetector). When the network is doing channel re-allocation, the tunable filters can be tuned to select a different color. The CMOS chip I am working on is to use electronics to implement the novel tunable photodetector algorithm we developed to integrate the multiple components (“1XN power splitter”, tunable filter array and standard photodetector array) at the receiving end into one CMOS chip (the detector part will be flip-chip bonded on).

Fig. 2 below shows the role of the novel “CMOS 1XN Optical Tunable Demux” in a simplified dynamic wavelength allocation WDM network. This novel component takes the WDM optical signal in, and sorts it to the color at the electrical outputs. In addition, the electrical outputs can be re-configured from extracting data in one wavelength to the other within a nanosecond.

The CMOS-Controlled Tunable Photodetectors

In order to briefly explain the how this CMOS tunable optical demux works, it is necessary to briefly explain the working principle of the “CMOS-Controlled Tunable Photodetector” [1-4].
All filtering functions performed in either an optical or a microwave system relies on some kind of electromagnetic wave interference (resonance is kind of interference), it is just some of the interference is achieved inside the device/circuits and some of the interference is achieved outside of the device. In this “CMOS-Controlled Tunable Photodetector”, at this research stage, the interference generated by an interferometer is illuminated on the Metal-Semiconductor-Metal (MSM) photodetector as shown in Fig. 3. In Fig. 3, at the left, there are two interference patterns (with different interference path length difference) aligned in phase with each other (for demonstration purpose) and a DC beam shone on the two wavelength discrimination detector; at the middle, it is the SEM picture of the device. In Fig. 3, at the right, there are detectors flip-chip bonded onto its customized driver and receiver and we have demonstrated that the wavelength swapping access time of this chip is ~nanosecond. The interference pattern is formed by a beam interfered with a delayed version of it, and the path length difference between the two interfered beams determines how sensitive to wavelength the device is. The detailed explanation and mathematical model can be referred in [4]. Since the position of the interference pattern is wavelength sensitive, the device under the illumination of it is a wavelength sensitive device.

The “CMOS-Controlled Tunable Photodetector” is physically consisted of a few Metal-Semiconductor-Metal (MSM) detectors laid side by side. MSM photodetector is a physically symmetrical device with two back-to-back Schottky junctions. Therefore, as we expected, the $I_{ph}$ versus $V_{bias}$ characteristics is symmetrical to zero bias, which means that as we bias the biasing node to the common node positively (negatively), we will get positive (negative) photocurrent flowing from the biasing node to the common node. For an array of MSM pixels under the illumination of the wavelength sensitive interference patterns, we can control the biasing patterns applied onto MSM to construct the spectral response we are interested in for filtering [2]. Since the control is by electrical means other than mechanical or thermal means, the state reconfiguration time is as fast as the electronics switching time [3].

What happens if a wavelength sensitive interference pattern is shone on a MSM device with separate finger control and how the fingers should be controlled? The algorithmic detail can be referred to [1].

**CMOS 1XN Optical Tunable Demux**

A specific biasing pattern applied onto the biasing fingers of the detector can select one wavelength while canceling out the rest. And another wavelength can be selected if another biasing pattern is applied. For the tunable detector operated in this scheme, the detector can take only one wavelength at a time although the optical interference pattern information can be re-used to select the others. Hence, by taking all of the optical information into the CMOS chip and re-distributing them, simultaneous multiple wavelength detection can be achieved. Since the channel re-allocation is done through changing the electronic biasing pattern, this can also be achieved in a CMOS chip. This is what I am working on now. It is currently in the layout stage and should be taped out very soon.
Fig. 1: A simple WDM network—the current implementation. At the receiver end, each user requires a tunable filter followed by a standard photodetector to extract the data bit streams.

Fig. 2: A simple WDM network—the next generation fully-integrated solution. At the receiver end, a tunable filter followed by a standard photodetector “array” scheme can be replaced by a single 1XN dynamic optical tunable demux CMOS chip with simultaneous nanosecond reconfiguration time for all of the channels.

Fig. 3: The device on the left picture is under the illumination of two interference patterns and a DC beam. The device in the middle picture is taken under SEM. The device is flip-chip bonded onto its customized CMOS driver/receiver chip and we have demonstrated that the wavelength swapping access time is ~nanosecond.
References


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