An Integrated 4-f-Imaging-Based Reconfigurable Optical Add-drop Multiplexer Employing an Opto-VLSI Processor

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***Abstract*— A novel integrated reconfigurable optical add-drop multiplexer (RODAM) structure is proposed and demonstrated experimentally. The ROADM employs an interface substrate that enables the integration of a fiber collimator array and an Opto-VLSI processor to realise a 4-f imaging system through optical beam steering. Experimental results demonstrate the principle of add/drop multiplexing with crosstalk of less than -27dB and insertion loss of less than 8dB over the C-band.**

***Keywords* — Microphotonics, wavelength division multiplexing, liquid crystal on silicon.**

I. Introduction

Reconfigurable optical add-drop multiplexers (ROADMs) are key devices in dynamic wavelength-division multiplexing (WDM) optical communication networks. A ROADM enables individual or multiple wavelengths carrying data channels to be added and/or dropped from a transport fiber without the need to convert the WDM channels to electronic signals and again back to optical signals. The main advantages of using ROADMs in optical networks are the ability to dynamically allocate the available network bandwidth to individual users without affecting the traffic, and to equalize the power levels of the different wavelength channels processed through every ROADM [1] [2]. ROADM structures based on micro-electro-mechanical systems (MEMS) have been reported [3], where small mirrors are deformed or reoriented using electrostatic forces to steer optical beams and couple them into different output fiber ports. Planar lightwave circuits (PLCs) have also been used for ROADM structures [4]. Opto-VLSI processors based on liquid crystal on silicon technology have recently been used for add/drop multiplexing of a large number of wavelength channels [5] [6].

In this paper, a new integrated ROADM structure based on 4-f imaging system implemented with the use of an Opto-VLSI processor and a fiber-lens collimator array, is proposed and demonstrated. By partitioning the Opto-VLSI processor into pixel blocks and driving each pixel block with a “drop” or a “thru (i.e. through)” steering phase hologram, arbitrary WDM channel add/drop multiplexing can be achieved.

II. Integrated ROADM Structures

The proposed ROADM structure is shown in Fig. 1 (a). It comprises two Arrayed Waveguide Gratings (AWGs) for wavelength multiplexing and demultiplexing, a silicon substrate that integrates an array of fibers and an array of microlenses formed onto the top glass layer of an Opto-VLSI processor. As illustrated in Fig. 1(b). The silicon substrate is perforated at the top and bottom sides for accommodating optical fibers and microlenses, respectively. The fibers are partitioned into fiber pairs, each pair is positioned at the appropriate distance from the corresponding microlens to form a 4-f imaging system. Each lens has its optical axis offset in relation to the symmetry of the paired fibers so that through beam steering the signal from a fiber is switched to either of the fiber pairs, by means of multi-phase beam steering holograms (or blazed gratings) dynamically uploaded into the Opto-VLSI processor [7].

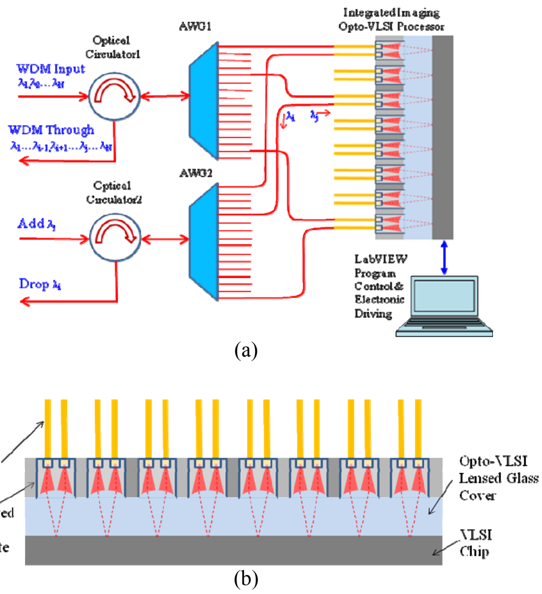

Fig. 1. (a). Opto-VLSI based ROADM structure with using two AWGs, arrayed fiber pairs and a lens array realizing any reconfigurable add-drop and through operations of wavelength signals; (b). The integrated imaging structure showing an array of fiber interfaces and an array of microlenses on top of a VLSI chip.

The input WDM signals in Fig. 1(a) are routed, through a circulator, to AWG1 for channel demultiplexing. Each wavelength channel is assigned to a fiber pair which forms a 4-f imaging system with its corresponding microlens. The upper fibers of the fiber pairs are connected to AWG1, while the lower fibers are connected to AWG2. Each lens is used to collimate the divergent beam from its associated upper optical fiber. The spacing between the upper fiber and the optical axis of the corresponding lens is around a quarter of the fiber array spacing. The collimated beams (wavelength channels) from the different upper fiber ports are projected onto the active window of the Opto-VLSI processor, which is placed at a distance equal to the focal length of the microleses.

III. EXPERIMENT AND RESULTS

The experimental setup for demonstrating the principle of the ROADM structure is shown in Fig. 2. A 1-dimentional 256-phase 4,096-pixel Opto-VLSI processor was used, having a pixel size of 6mm×1µm with a dead space between adjacent pixels of 0.8µm. An off-the-shelf 16-port fiber array of spacing 250µm was used and aligned to a 4-element lens array of focal length 2.42mm and spacing 1mm. The Opto-VLSI processor was also aligned to and placed at 2.42mm from the lens array in order to form 4-f imaging. To investigate the drop and thru operations of the ROAMD structure, four optimized phase holograms were synthesised to steer two input wavelength channels at λ_1=1547.5nm and λ_2=1530.3nm launched into port 2 and port 14 of the fiber array, respectively. The optical beam of port 2 was steered by phase holograms either to fiber port 2 for thru operation or to fiber port 3 for drop operation. Similarly, the other wavelength channel λ_2=1530.3nm that was simultaneously launched into fiber port 14, was steered to fiber port 14 for thru operation or to fiber port 15 for drop operation.

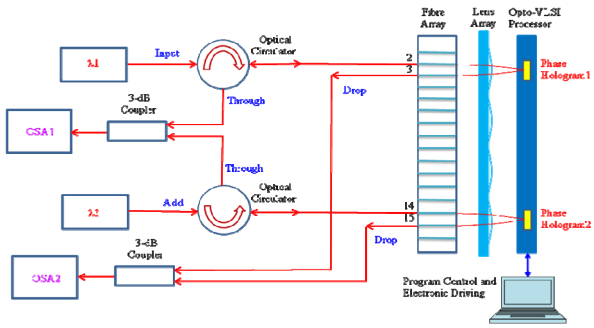

Fig. 2. Experimental setup demonstrating the add/drop and thru operations of the Opto-VLSI-based ROADM structure.

The measured optical power levels at the four output ports of the ROADM system for drop and thru scenarios are shown in Fig. 3 (a)-(d). Figs 3 (a) and (b) show the optical spectra of the signals received at the drop and thru ports when λ_1 is passed thru while λ_2 is dropped. For this scenario, the crosstalk, defined as the ratio of the thru or dropped power at λ to the power at λ received at the drop or thru port, was -34.7dB measured at λ_1 in fiber port 3 and -27.5dB measured at λ_2 in fiber port 14. Fig. 3(c) and (d) show the optical spectra of the signals received at the drop and thru ports when λ_1 was dropped while λ_2 was passed thru. For this scenario, the crosstalk was -28.6dB measured at λ_1 in fiber 2 and -31.8dB measured at λ_2 in fiber 15. These experimental results demonstrated the concept of the proposed ROADM structure.

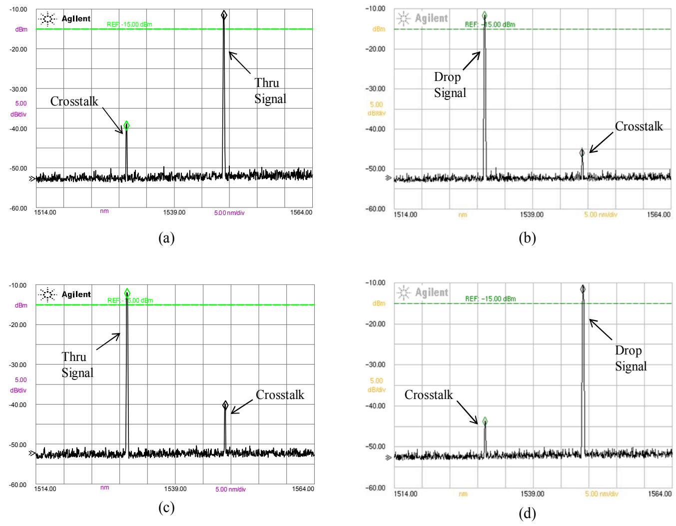

Fig. 3. Experimental results showing the drop and thru operations for λ_1 and λ_2 channels.

The input optical power levels for both signals λ_1 and λ_2 were +1dBm, the 3-dB coupler at the thru and the drop ports introduced around 3.3dB loss, and the circulator loss was 1.6dB. Therefore, with a measured output signal power of around -11.9dB the total insertion loss of the ROADM structure was therefore around 8dB. This loss was mainly contributed by the fiber-to-fiber beam coupling loss, the Opto-VLSI loss and polarization dependent loss.

IV. CONCLUSION

A novel integrated Opto-VLSI-based reconfigurable optical add-drop multiplexer structure utilizing a 4-f imaging system has been proposed and demonstrated experimentally. Experimental results have demonstrated the principle of add/drop multiplexing with crosstalk of less than -27dB and insertion loss around 8dB over the C-band of optical telecommunications.

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