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Zhenglin Wang
Edith Cowan University

Kamal Alameh
Edith Cowan University

Rong Zheng
Edith Cowan University

Chung Poh
Edith Cowan University

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Zhenglin Wang, Kamal Alameh, Rong Zheng and KiakChung Poh
Centre for Micro-Photonics, Electron Science Research Institute
Edith Cowan University, 100 Joodalup Drive, WA, 6027, Australia.
Email: z.wang@ecu.edu.au

ABSTRACT

Reconfigurable multi-channel optical filters are presented in this paper. The operation principle of the reconfigurable filter is based on the dynamic beam steering capacity of Opto-VLSI processor in conjunction with a high dispersion free space grating. The dispersion grating separates the input signal spectrum while the Opto-VLSI processor is driven by optimised phase holograms to dynamically select the wavelengths to be coupled into the output port. Experimental results show that up to 8 bands can be synthesised, with a wavelength tuning span of 10 nm and a 3dB bandwidth less than 0.5nm.

KEYWORDS

Opto-VLSI processors, optical filters, reconfigurable architectures, wavelength division multiplexing.

1. INTRODUCTION

Recently, reconfigurable optical filters have attracted research interests for their applications as wavelength selection or transmission control elements in wavelength division multiplexed (WDM) systems. A varity of fiber-optic filter structures have been demonstrated based on different approaches, such as Sagnac grating interferometers [1], long-period fiber gratings [2], Mach–Zehnder interferometers [3], side-polished fiber filters [4] and variable channel spacing dual segmented Sagnac–Lyot filters [5]. These reported optical filters normally have fixed channel output specifications and few, if any, of them have reconfigurability in terms of channel centre wavelength, spacing and channel attenuation response.

With the development of erbium-doped fiber amplifiers (EDFA), reconfigurable filters have become key elements for multiwavelength erbium-doped fiber lasers (EDFL) [6], [7]. In this paper, we report a tuneable optical filter structure employing an Opto-VLSI processor that can realise WDM equalisation through beam steering, multicasting or reshaping [8]. A reconfigurable optical filter can be realised by using a dispersion grating in conjunction with an Opto-VLSI processor operating in the beam steering mode. We experimentally demonstrate an 8-channel dynamic optical filter of 3 dB bandwidth as small as 0.5nm. The filter has wavelengths tunable range from 1525nm to 1535nm, wherein, arbitrary passbands can be synthesised, each band can dynamically be attenuated by optimising the phase hologram of the Opto-VLSI processor.

2. OPTO-VLSI PROCESSOR

An Opto-VSLI processor is an array of liquid crystal (LC) cells whose crystallographic orientations are independently addressed by a Very-Large-Scale-Integrated (VLSI) circuit to create a reconfigurable, reflective, holographic diffraction grating plate. Application of voltage between the electrodes of the VLSI circuit induces a phase hologram in the LC layer, resulting in optical beam steering and/or beam shaping. Fabricated Opto-VLSI devices are electronically controlled, software-configured, polarisation independent, cost effective because of the high-volume manufacturing capability of VLSI as well as the capability of controlling multiple fibre ports in one compact Opto-VLSI module, and very reliable since beam steering is achieved with no mechanically moving part. These features open the way for numerous reconfigurable optical components. Fig. 1(a) shows a typical layout of an Opto-VLSI processor. Also shown is typical LC cell design. Usually Indium-Tin Oxide (ITO) is used as the transparent electrode, and evaporated aluminium is used as reflective electrode. The ITO layer is generally grounded and a voltage is applied at the reflective electrode by the

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VLSI circuit below the LC layer. Opto-VLSI processors can generate stepped blazed grating for optical beam steering, as well as multicasting grating for arbitrary beam splitting, where the diffraction orders are deliberately enhanced to generate an arbitrary beam splitting profile. Recent advances in nematic LC materials and Layer thickness control have allowed the incorporation of a thin quarter-wave-plate (QWP) layer between the LC and the aluminum mirror to accomplish polarization-insensitive multi-phase-level Opto-VLSI processors. These attractive capabilities of Opto-VLSI processors make them ideal platforms for reconfigurable optical components. Fig. 1(b) illustrates the steering and multicasting capability of Opto-VLSI processors. For a small incidence angle, the maximum steering angle of the Opto-VLSI processor is given by [9]

$$\theta_{\max} = \frac{\lambda}{M \cdot d} * \frac{180}{\pi} \qquad (1)$$

where M is the number of phase levels, d is the pixel size, and λ is the wavelength. The maximum diffraction efficiency of an Opto-VLSI processor depends on the number of discrete phase levels that the VLSI can accommodate.

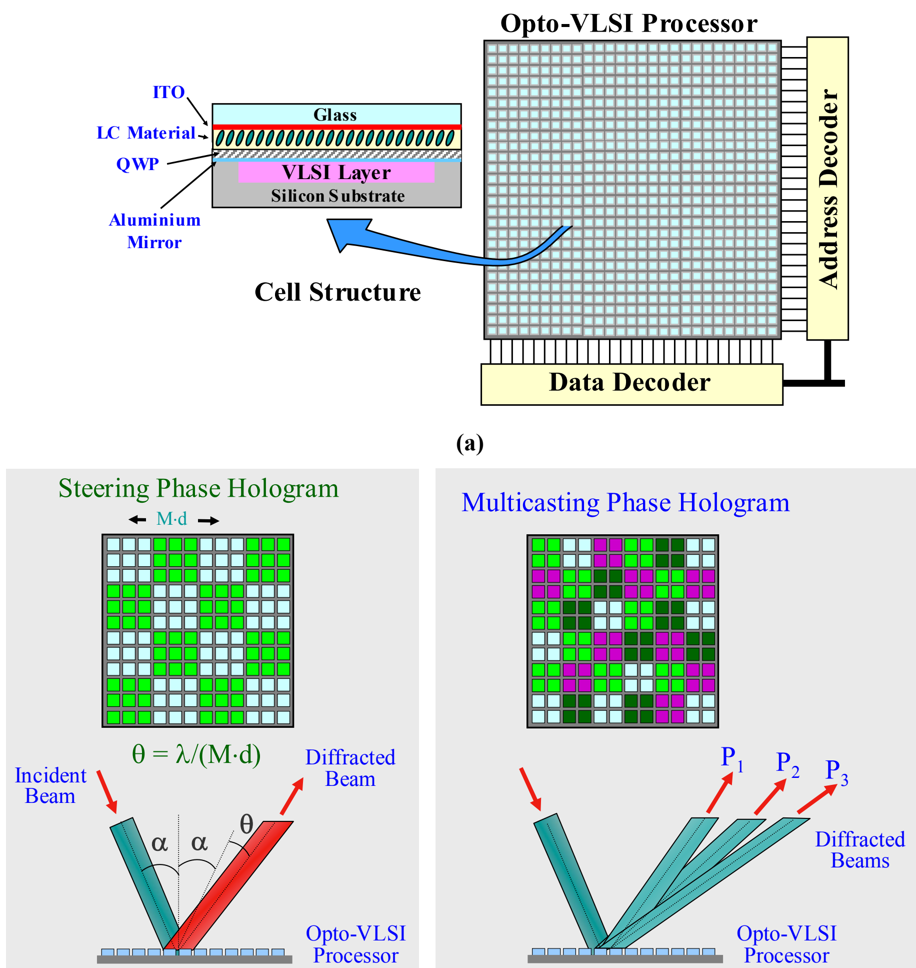

Figure 1. (a) Typical Opto-VLSI processor and an LC cell structure design, (b) steering and multicasting capabilities of an Opto-VLSI processor.

The theoretical maximum diffraction efficiency is given by [9]

$$\eta = \text{sinc}^2\left(\frac{\pi n}{M}\right) \qquad (2)$$

where $n = gM + 1$ is the diffraction order ($n = 1$ is the desired order), and g is an integer. The higher diffraction orders (which correspond to the cases $g \neq 0$) are usually unwanted crosstalks, which must be attenuated or properly routed outside the output ports to maintain a high signal-to-crosstalk performance.

3. DYNAMIC OPTICAL FILTER STRUCTURE

The basic structure of dynamic filter is shown in Fig. 2. It consists of a dispersion grating and an Opto-VLSI processor. The grating plate separates the incident signal beam into different spectral components and maps them onto the active window of the Opto-VLSI processor. The processor can be software configured such that the entire pixel array is partitioned into discreet pixel blocks. Each pixel block can hold its own phase hologram that steer an incident light beam to a desired angular position. Spectral component falling within a pixel block region can therefore either be steered back along the incidence path thus coupling it into the fiber collimator with minimum attenuation, or deliberately steered “off-track” so that its power is partially coupled back into the fibre collimator leading to a high optical attenuation for that spectral component. By reconfiguring the phase hologram of individual pixel block, the power of each spectral component can independently be adjusted, leading to tunable filter response. Variable parameters of the phase hologram include the programmable grating period and grating phase ramp profiles.

4. EXPERIMENTAL SETUP

In the experimental setup, the input port shown in Fig. 2 was driven by an ASE broadband source, while the output port was monitored by an optical spectrum analyser. The 1D Opto-VLSI processor used in the experiment had a pixel size of 1.8 mm and an active window of 4096 pixels resulting in a maximum steering angle of about 4 degrees at 1530nm. The output light from a broadband ASE source (1520nm - 1565nm) was used as input optical signal. After passing through a polarisation controller and a circulator, the optical signal was collimated at 1mm diameter and launched into a high dispersive grating plate (1200 line per mm) that mapped the different spectral components of the ASE light onto different spots on the surface of an Opto-VLSI processor, which was partitioned into three pixel blocks. A waveband falling upon a pixel block was attenuated using a phase hologram that reflected it back along its incidence path or slightly decoupled it into the fibre collimator.

A computer program was developed in MATLAB™ to dynamically optimise in real time the phase hologram needed for a filter response target by varying its period, width, position, and taking into account the intrapixel fly-back characteristics. Given the structural features of the Opto-VLSI processor used in the setup, the maximum steering angle generated without losing too much optical power is about 4 degree($d = 1.8$ μm, $\lambda = 1550$ nm, and $M = 12$).

5. RESULTS

To demonstrate the proof-of-concept for the reconfigurable multiband optical filter we show the holograms that drove the Opto-VLSI processor and the corresponding filter responses for different tuning scenarios. Figures 3(a) and (b) show the optimised phase holograms that generate the 7-band responses shown in Figure 3(c).

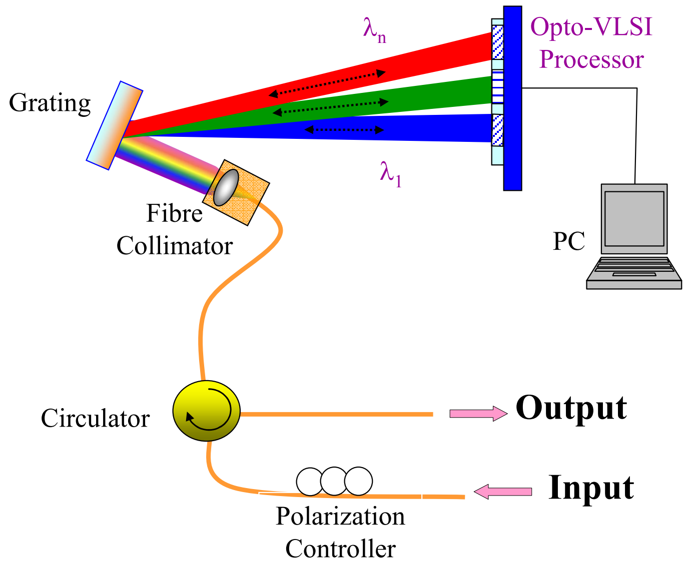

Figure 2. Dynamic optical filter using Opto-VLSI processing.

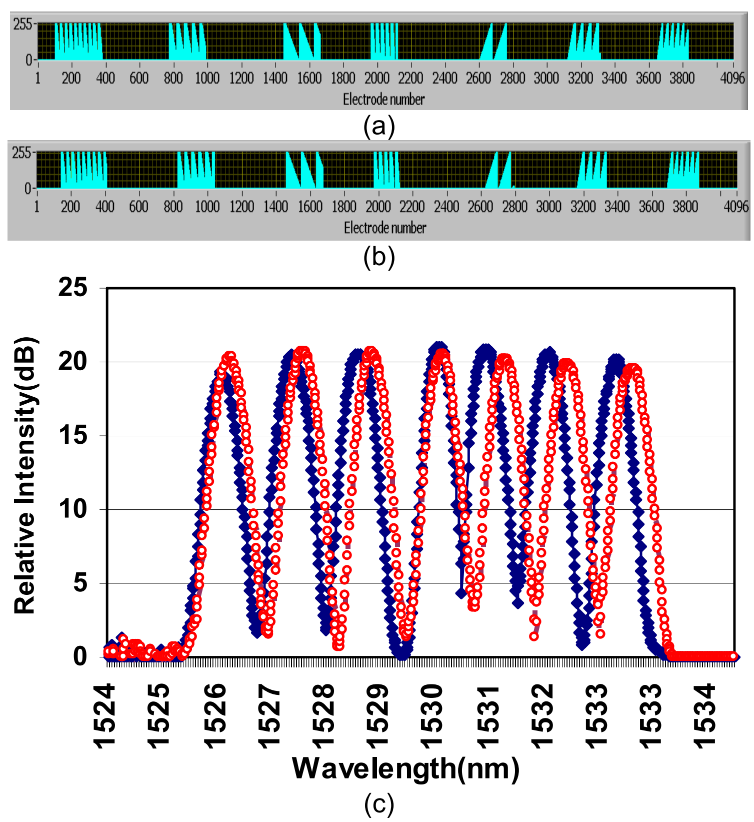

Figure 3. (a) and (b) Phase holograms, and (c) 7-band responses of the Opto-VLSI optical filter.

Note that in Figures 3(a) and (b) the phase holograms are illustrated by showing the phase level versus the pixel number, with the phase levels 0 and 256 corresponding to phase shifts of 0 and 360 degrees, respectively. It is obvious from Figure 3(c) that the centre wavelength of the passbands can arbitrarily be tuned while maintaining a passband spacing of 1.4 nm and a 3dB-bandwidth less than 0.5 nm.

Figures 4(a) and (b) show the optimised phase holograms that generate the 8- and 4-band responses shown in Fig. 4(c), respectively. A uniform passband spacing of 1.2 nm was used for the 8-band response, while the hologram shown in Fig. 4(b), was designed to realise a 4-band response with variable spacings between the passbands and with one band attenuated by 3 dB with respect to the other passbands. The measured tuning wavelength span was 10 nm. However, for a 20mm VLSI chip, a tuning range of more than 30 nm is feasible. These experimental results demonstrate the proof-of-concept for the reconfigurable Opto-VLSI multi-band filter.

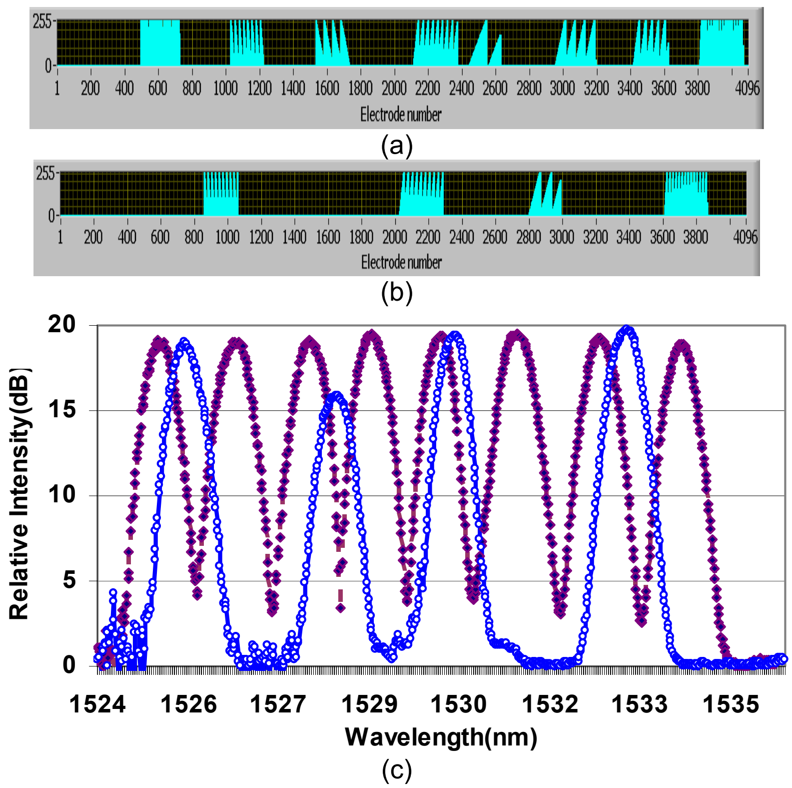

Figure 4. (a) and (b) Phase holograms, and (c) 8- and 4-band responses of the Opto-VLSI optical filter.

6. CONCLUSION

In this paper, we have reported a new reconfigurable multi-band optical filter architecture using an Opto-VLSI processor. Up to 8 passbands of bandwidth as small as 0.5-nm have experimentally been synthesised over a 10 nm wavelength span. Furthermore, each passband was independently reconfigured by driving the Opto-VLSI processor with optimised phase holograms.

7. ACKNOWLEDGEMENT

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