2007

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Experimental demonstration of a tunable laser using an SOA and an Opto-VLSI Processor

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Abstract: In this paper we propose and experimentally demonstrate a tunable laser structure cascading a semiconductor optical amplifier (SOA) that generates broadband amplified spontaneous emission and a reflective Opto-VLSI processor that dynamically reflects arbitrarily wavelengths and injects them back into the SOA, thus synthesising an output signal of variable wavelength. The wavelength tunablility is performed using digital phase holograms uploaded on the Opto-VLSI processor. Experimental results demonstrate a tuning range from 1524nm to 1534nm, and show that the proposed tunable laser structure has a stable performance.

OCIS codes: (250.5980) Semiconductor optical amplifier

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1. Introduction

Tunable laser sources are key elements for WDM-based optical communications network architectures because they provide maximum flexibility in wavelength selection and more efficient utilisation of the wavelength resources.

#83050 - $15.00 USD Received 14 May 2007; revised 28 Jun 2007; accepted 15 Jul 2007; published 19 Jul 2007

Immense efforts have been made in searching for laser media which have broad emission band in designing of a tunable laser system. Indeed, CW tunable solid-state [1] [2] and chemical dye lasers [3] [4] have been developed to satisfy the practical requirements to some extent. The drawbacks of these systems are the inherent large noise due to fluctuations of pump power or dye jet, and the requirement of a complicated pump system, which leads to a large system volume and susceptibility to environmental influences [5].

Tunable laser structures based on the use of an active medium in conjunction with a tunable filter [6], a special configuration employing two optical circulators and optical bandpass filter [7], tunable twin-guide (TTG) structure [8], and erbium-doped fiber lasers (EDFLs) by utilizing cascaded fiber Bragg grating (FBG) cavities [9], [10] have been demonstrated. Semiconductor Optical Amplifiers (SOAs) SOAs have been widely used in wavelength division multiplexed (WDM) fiber-optic systems as power boosters, wavelength converters, optical routing switches, and logic gates [11]. Being small size and electrically pumped, an SOA is significantly less expensive than an EDFA and can be monolithically integrated alongside other optical and electronic components to provide a compact solution for access markets. Moreover the high optical nonlinearity of SOAs makes them attractive for all-optical signal processing, such as all-optical switching and wavelength conversion, clock recovery, signal demultiplexing, and optical pattern recognition.

In this paper, we experimentally demonstrate a tunable laser structure with 10 nm tuning range based on the use of a semiconductor optical amplifier as an active medium and an Opto-VLSI processor as a tunable optical filter. The Opto-VLSI processor dynamically selects the lasing wavelength and injects it back into the SOA so it gets amplified. The wavelength selection is performed using optimised digital phase holograms. The advantages of the proposed structure include the simplicity of the wavelength tuning operation and the ability to integrate the various components of the structure into a compact cost-effective module.

2. Opto-VLSI processor

A reconfigurable Opto-VLSI processor comprises an array of liquid crystal (LC) cells driven by a Very-Large-Scale-Integrated (VLSI) circuit that generates digital holographic diffraction gratings to steer and/or shape optical beams [12] ,[13], as illustrated in Fig. 1(a). Each pixel is assigned a few memory elements that store a digital value, and a multiplexer that selects one of the input voltages and applies it to the aluminum mirror plate. An Opto-VLSI processor is electronically controlled, software-configured, polarization independent, cost effective because of the high-volume manufacturing capability of VLSI chips as well as the capability of controlling multiple optical beams simultaneously, and very reliable since beam steering is achieved with no mechanically moving parts [12], [13]. These attractive features make the Opto-VLSI technology attractive for reconfigurable optical networks.

Figure 1(a) also shows a typical layout of the Opto-VLSI processor. Indium-Tin Oxide (ITO) is used as the transparent electrode, and evaporated aluminum is used as the reflective electrode. By incorporating a thin quarter-wave plate (QWP) layer between the liquid crystal and the VLSI backplane, a polarization-insensitive Opto-VLSI processor can be realized. The ITO layer is generally grounded and a voltage is applied at the reflective electrode by the VLSI circuit below the LC layer to generate stepped blazed gratings for optical beam steering [12, 13].

Figures 1(b)-1(d) illustrates the steering capability of an Opto-VLSI processor of pixel size d, driven by blazed gratings [Fig. 1(b)] which correspond to phase holograms [Fig. 1(c)]. If the pitch of the blazed grating is $q \times d$, (where q is number of pixels per pitch), the optical beam is steered by an angle Θ that is proportional to the wavelength, λ, of the light and inversely proportional to $q \times d$, as shown in Fig. 1(d). A blazed grating of arbitrary pitch can be generated using MATLAB or LabView software by digitally driving a block of LC pixels with appropriate phase levels by changing the voltage applied to each pixel, so the incident optical beam is dynamically steered along arbitrary directions.

#83050 - $15.00 USD Received 14 May 2007; revised 28 Jun 2007; accepted 15 Jul 2007; published 19 Jul 2007

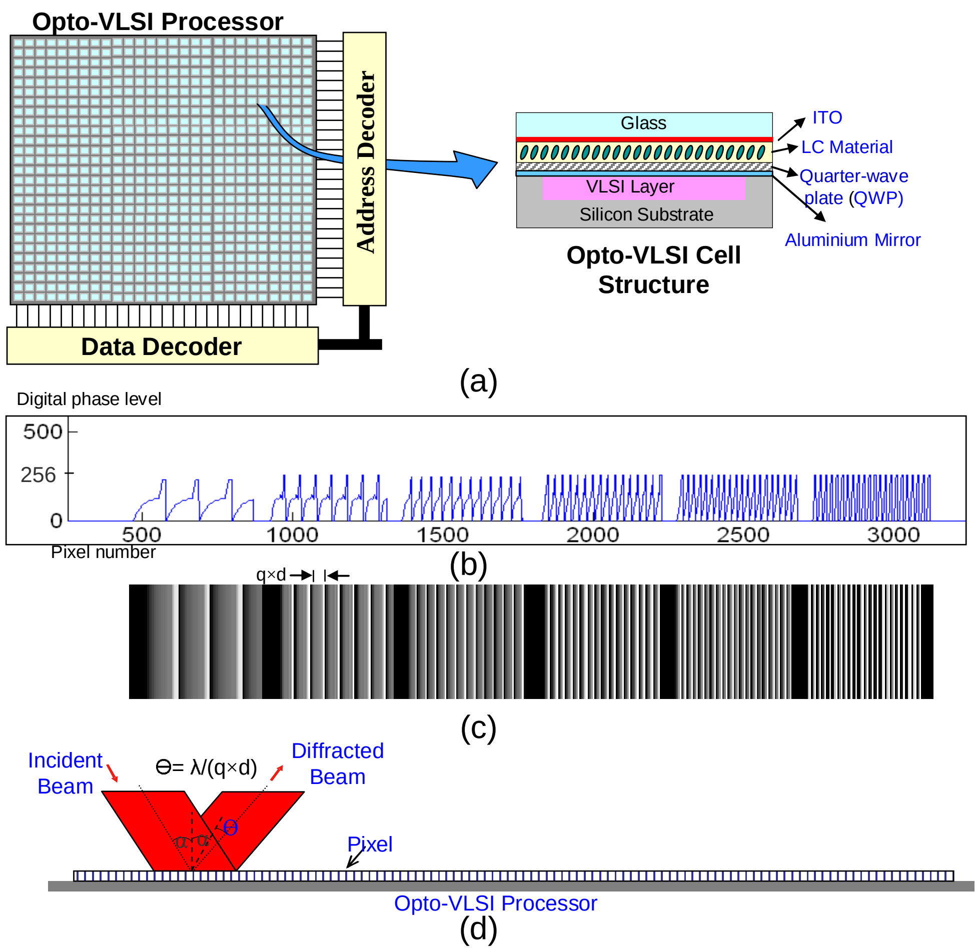

Fig. 1. (a). Opto-VLSI processor and LC cell structure design.(b) Phase level versus pixel number for blazed grating synthesis, (c) corresponding steering phase holograms of the various pixel blocks, and (d) principle of beam steering using an Opto-VLSI processor.

3. Tunable laser structure

The proposed tunable laser structure shown in Fig. 2 is based on using an SOA as a gain medium and an Opto-VLSI processor as a tunable optical filter. The broadband amplified spontaneous emission (ASE) of the SOA is collimated and launched to a diffractive grating plate that spreads the wavelength components of the collimated ASE along different directions and maps them onto the active window of the Opto-VLSI processor. An optimized digital hologram is generated to independently steer the incident wavelength components along arbitrary directions. A specific wavelength can be coupled back through beam steering into the fibre collimator with minimum attenuation, while all other wavelengths are steered off-track and hence attenuated. The coupled wavelength is injected back into the SOA and amplified thus generating a high amplitude output optical signal. Wavelength tuning is achieved by changing the phase hologram uploaded onto the Opto-VLSI processor.

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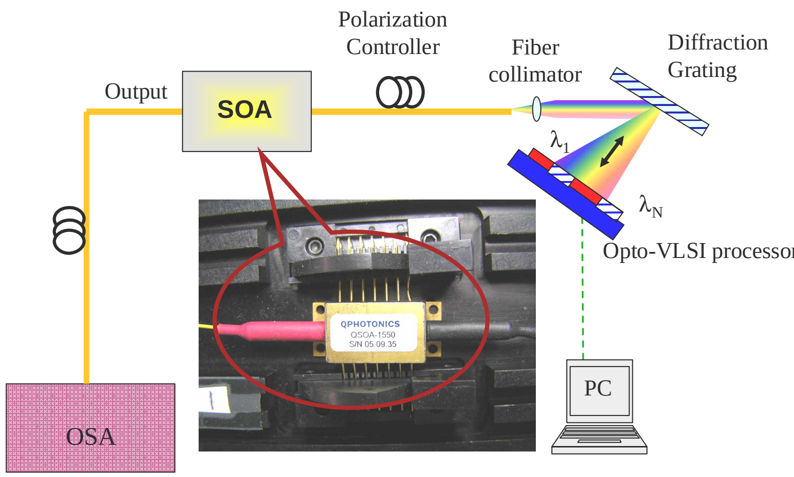

Fig. 2. Proposed tunable laser structure.

4. Experiment setup

The SOA used in this experiment was an off-the-shelf SOA manufactured by is Qphotonics. Figure 2 shows the experiment set up and Fig. 3 shows a photograph of the experiment set up. The SOA was driven by a Newport modular controller model 8000 at a driving current of 400 mA. The broadband ASE generated by the SOA, shown in Fig. 4, was collimated using a 1-mm-diameter fibre collimator, and the collimated beam was launched onto a 1200 lines/mm diffractive grating plate. The latter spread the wavelength components of the collimated beam along different directions and mapped them onto the active window of the Opto-VLSI processor. The Opto-VLSI processors used in this experiment was one-dimensional having 1×4096 pixels and 256 phase levels, with 1μm pixel size, and 0.8 μm dead spacing between each pixel. Labview software was used to generate optimized digital holograms that independently steer the incident wavelength components along arbitrary directions.

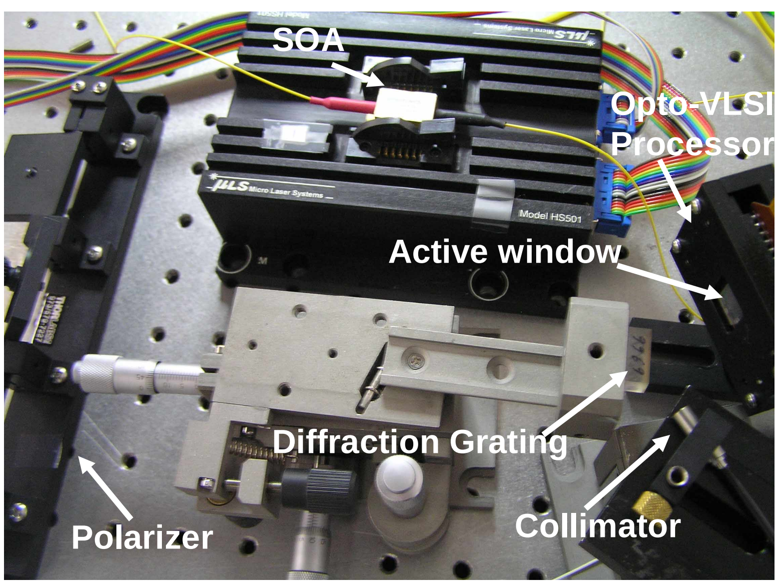

Fig. 3. Photograph of the experimental setup used to demonstrate the principle of the tunable laser structure.

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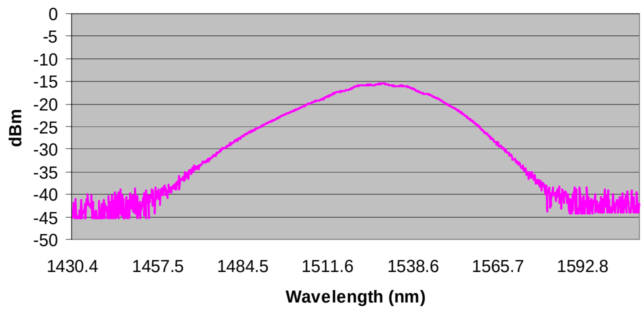

Fig. 4. ASE spectrum generated by the SOA. Driving current = 400 mA.

To demonstrate the principle of the proposed tunable laser structure, three scenarios were investigated, in which the Opto-VLSI processor was loaded with digital phase holograms that couple back, respectively, the wavelengths 1524.8 nm, 1527.1nm and 1532.5nm into the collimator with minimum attenuation. Figures 5(a), 5(b) and 5(c), show the loaded digital phase holograms for selecting the output wavelengths, and the measured SOA output spectrum for each selected wavelength.

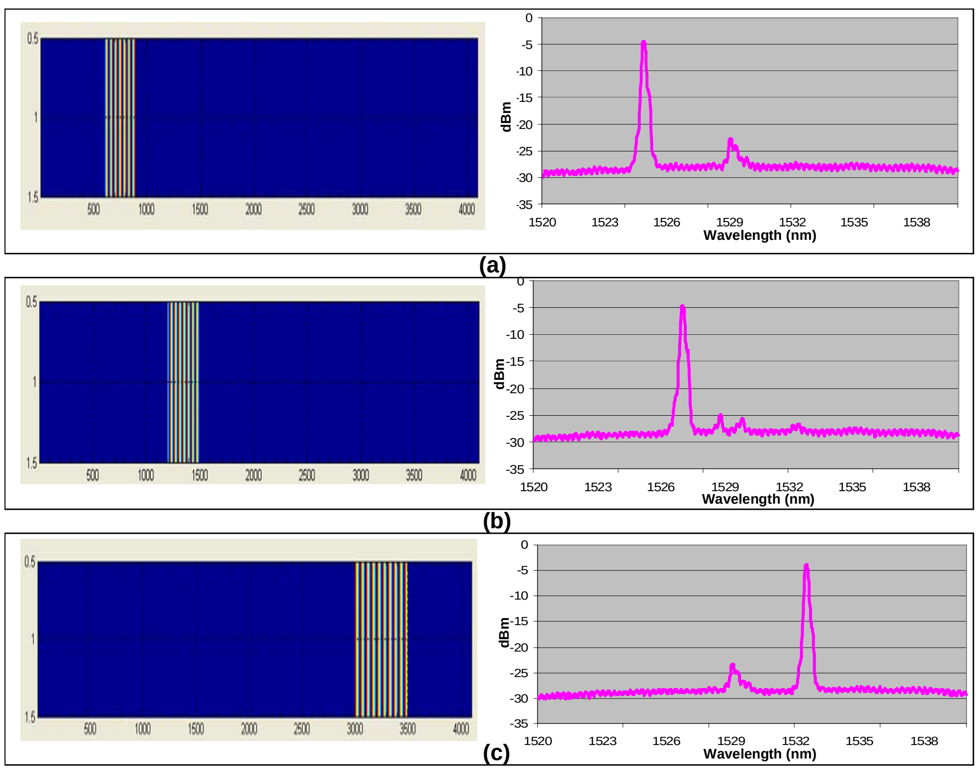

Fig. 5. Digital phase hologram loaded onto the Opto-VLSI processor and measured SOA output spectrum for generating an output wavelength at (a) 1524.8nm, (b) 1527.1nm and (c) 1532.5nm.

Figure 5 demonstrated the concept of laser tuning using the capability of an Opto-VLSI processor to steer specific wavelengths and couple them back into the SOA active cavity.

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It is noticed in Fig. 5 that in addition to the output wavelength, there was an output wavelength at 1529 nm of power 20 dB below the lasing wavelength. This was attributed to a small-power zeroth order diffracted beam which was amplified by the SOA cavity.

Figure 6 shows the measured output spectrum for realising single-wavelength tuning through hologram optimisation. A tuning range of 10 nm was achieved for the used Opto-VLSI processor, which has an active window size of around 7.3 mm. It is important to notice from Fig. 4 that the measured 3-dB bandwidth of the ASE spectrum of the SOA is around 40 nm. It is important to note that the scalability of the tuning range depends on the broadband spectrum of the SOA, the size of the active window, and the pitch of the grating plate. Therefore, by employing an Opto-VLSI processor of active window size 20mm and a blazed grating plate of 600 lines/mm, a tuning range of 40 nm can be achieved.

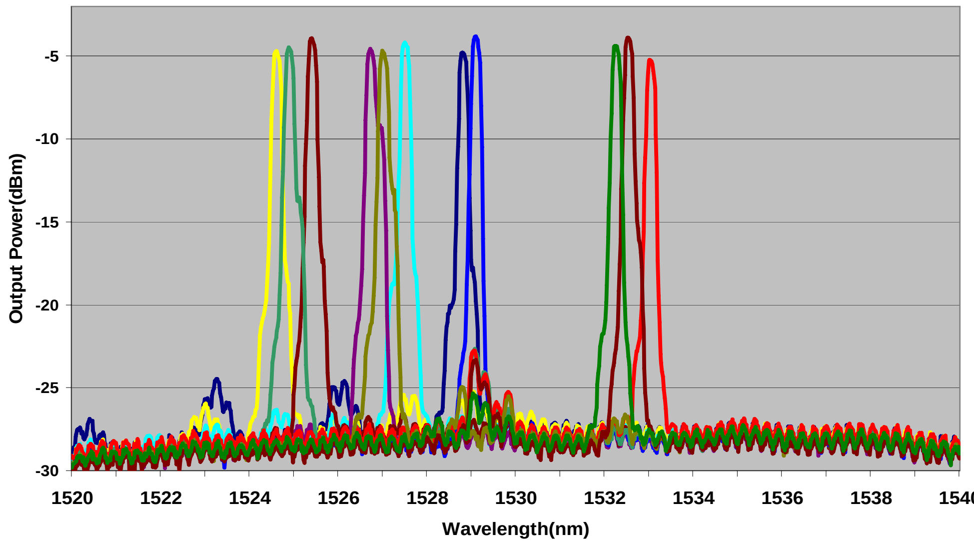

Fig. 6. Measured output spectrum, demonstrating single-wavelength tuning through hologram optimisation.

5. Conclusion

We have proposed and demonstrated a novel tunable laser structure employing a semiconductor optical amplifier (SOA) and an Opto-VLSI processor. To realise wavelength tuning, an arbitrary narrow waveband of the broad amplified spontaneous emission spectrum generated by the SOA has been coupled back into the active cavity of the SOA for amplification using an optimised phase hologram uploaded onto the Opto-VLSI processor. Experimental results have demonstrated that by varying the phase hologram of the Opto-VLSI processor, stable laser performance with a tuning range of 10 nm can be attained.

Acknowledgment

This work is supported by the Office of Science and Innovation, Government of Western Australia.