2008

A Tunable Multiwavelength Laser Employing a Semiconductor Optical Amplifier and an Opto-VLSI Processor

Muhsen Aljada
Edith Cowan University

Kamal Alameh
Edith Cowan University

Yong T. Lee
Gwangju Institute of Science and Technology, Gwangju, South Korea

10.1109/LPT.2008.921823
This is an Author's Accepted Manuscript of: Aljada, M. , Alameh, K. , & Lee, Y. T. (2008). A Tunable Multiwavelength Laser Employing a Semiconductor Optical Amplifier and an Opto-VLSI Processor. IEEE Photonics Technology Letters, 20(10), 815-817. Available here

IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 20, NO. 10, MAY 15, 2008

A Tunable Multiwavelength Laser Employing a Semiconductor Optical Amplifier and an Opto-VLSI Processor

Muhsen Aljada, *Member, IEEE*, Kamal Alameh, *Senior Member, IEEE*, and Yong Tak Lee

***Abstract*—We propose and experimentally demonstrate a stable tunable multiwavelength laser employing a semiconductor optical amplifier (SOA) in conjunction with an opto-very-large-scale-integration (VLSI) processor. By uploading digital phase holograms onto the opto-VLSI processor, the amplified spontaneous emission of the SOA is arbitrarily sliced and injected back into the SOA to generate multiple lasing wavelengths with a linewidth of 0.5 nm. Experimental results demonstrate a tunable multiwavelength laser with a tuning range from 1528 to 1533 nm with power fluctuations of less than 0.5 dB.**

***Index Terms*—Multiwavelength lasers, semiconductor optical amplifiers (SOAs), tunable lasers.**

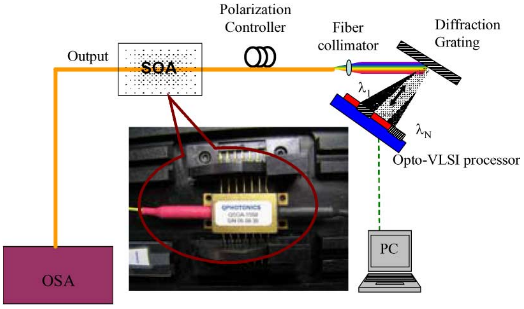

Fig. 1. Experiment setup of the proposed tunable multiwavelength laser structure.

I. INTRODUCTION

MULTIWAVELENGTH laser sources have potential applications in dense wavelength-division-multiplexed (WDM) systems, optical instrument testing and characterization, optical fiber sensors, and spectroscopy. Such light sources are particularly in-demand because they provide an efficient and economical solution to increase the flexibility of WDM systems.

Many multiwavelength laser structures have been reported including erbium-doped fiber amplifier (EDFA)-based multiwavelength fiber lasers, semiconductor optical amplifiers (SOAs), or Raman amplifier-based multiwavelength fiber lasers. However, such structures are not tunable and hence the lasing wavelengths and bandwidths could not be selected arbitrarily.

Tunable multiwavelength laser structures have recently been reported, which are based on the employment of multiple distributed-feedback (DFB) lasers [1], erbium-doped fiber (EDF) [2], and multiwavelength Raman lasers [3]. However, stable multiwavelength light sources based on EDF are difficult to realize due to the homogeneous broadening of EDFA [4]. Also, the lasing wavelength of a multiwavelength Raman laser cannot be accurately controlled because it strongly depends on the pump wavelength. In addition, the integration of multiple DFB lasers to realize a tunable multiwavelength laser is a low-yield process and hence is cost-ineffective. Multiwavelength laser structures based on fiber Bragg gratings (FBGs) have been reported including sampled Bragg gratings [5], cascaded long-period gratings [6], wideband chirped grating Fabry–Pérot resonator [7], and Michelson interferometer [8]. For most of these structures, two identical FBGs are required to avoid the generation of undesired wavelengths in the laser output. Thus, the realization of Bragg grating-based tunable multiwavelength lasers has been thwarted by the requirement for high-resolution FBGs [9]. Although several technologies and designs have been proposed over the last decade to fabricate stable, cost-effective multiwavelength laser sources, only a few have produced truly single-mode laser lines.

In this letter, we experimentally demonstrate a stable multiwavelength tunable laser that can be tuned via an opto-very-large-scale-integration (opto-VLSI) processor, operating over a tuning range from 1528 to 1533 nm.

II. MULTIWAVELENGTH TUNABLE LASER STRUCTURE AND EXPERIMENT SETUP

The structure of the proposed tunable multiwavelength laser is shown by means of an experiment setup in Fig. 1. It is based on using an SOA as a gain medium and an opto-VLSI processor as a reconfigurable WDM equalizer. The SOA used in this experiment was an off-the-shelf SOA manufactured by Q-photonics, driven by a Newport modular controller model 8000, at a maximum driving current of 300 mA. The broadband amplified spontaneous emission (ASE) generated by the SOA, as shown in Fig. 2, was collimated using a 1-mm-diameter fiber collimator and launched onto a 1200-lines/mm diffractive grating plate, which spreads the wavelength components

---

Manuscript received November 13, 2007; revised February 25, 2008.

M. Aljada and K. Alameh are with the Centre of Excellence for MicroPhotonic Systems, Edith Cowan University, Joondalup, WA, 6027, Australia (e-mail: m.aljada@ecu.edu.au; seowe@student.ecu.edu.au; k.alameh@ecu.edu.au).

Y. T. Lee is with the Department of Information and Communications, Gwangju Institute of Science and Technology, Gwangju 500-712, South Korea (e-mail: ytlee@gist.ac.kr).

Color versions of one or more of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LPT.2008.921823

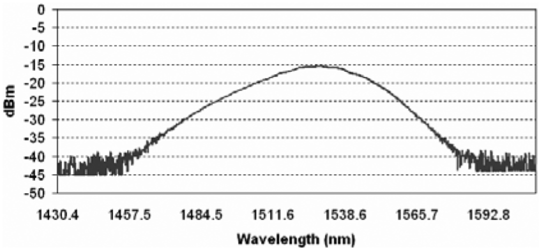

Fig. 2. ASE spectrum generated by the SOA.

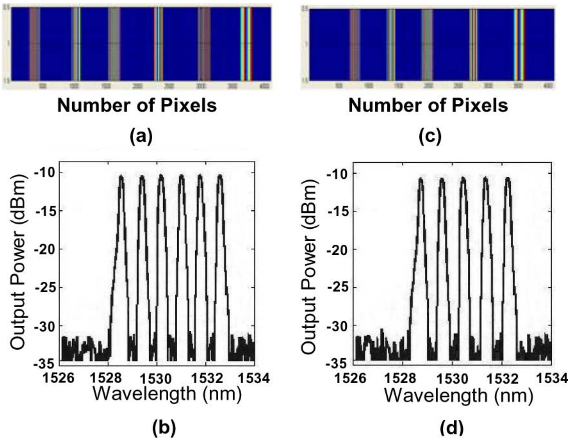

Fig. 3. (a) and (c) Digital phase holograms loaded onto the opto-VLSI processor to generate and equalize six and five wavelengths, respectively. (b) and (d) Corresponding measured spectra of SOA's output.

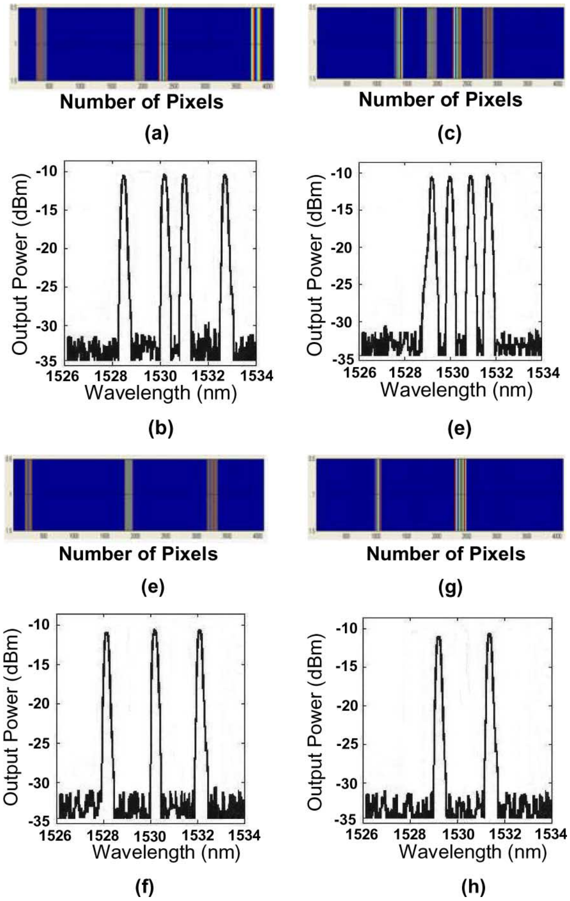

Fig. 4. Digital phase hologram loaded onto the opto-VLSI processor to generate and equalize (a) and (c) four wavelengths (e) three wavelengths, and (g) two wavelengths. (b), (d), (f), and (h) Corresponding measured SOA output spectra.

of the collimated ASE along different directions and maps them onto the active window of the opto-VLSI processor. The opto-VLSI processor comprises an array of liquid crystal (LC) cells independently and electronically driven by a VLSI circuit that generates multiphase digital holographic diffraction gratings capable of steering and/or shaping optical beams. Using LabVIEW software, a blazed grating of arbitrary pitch could be generated by digitally driving a block of LC pixels with appropriate phase levels (by changing the voltage applied to each pixel) so that an incident optical beam is dynamically steered along an arbitrary direction. The steering capability of opto-VLSI processors has previously been reported in [10]–[12]. The opto-VLSI processor used in this experiment is one-dimensional having 1×4096 pixels, 256 phase levels, 1-μm pixel size, and 0.8-μm spacing between the pixels.

A collimated optical beam illuminating a pixel block of the opto-VLSI processor can either be coupled back, through beam steering, into the fiber collimator with minimum attenuation, or steered off-track, hence attenuated. The wavelengths that are coupled into the fiber collimator are injected back into the SOA and amplified, thus generating a high amplitude WDM output optical signal. Wavelength tuning is achieved by changing the phase holograms controlling the various pixel blocks of the opto-VLSI processor.

To demonstrate the functionality and flexibility of the proposed multiwavelength tunable laser structure, characteristics such as the tunability of the lasing wavelengths, the wavelength spacing, and the number of channels were investigated simultaneously.

As shown in Fig. 3(a), the opto-VLSI processor was loaded with digital phase holograms that coupled six wavelengths, i.e., 1528.6, 1529.4, 1530.1, 1530.8, 1531.6, and 1532.5 nm, back into the collimator. Fig. 3(b) shows the measured spectrum at the output of the SOA. It is important to note that in order to achieve stable multiwavelength laser operation, the power levels of the wavelengths were appropriately equalized before they were launched into the OSA for amplification. In this structure, the polarization controller is used to achieve laser stability. Without the polarization controller, more than 3-dB interchannel fluctuations in the output WDM power levels were observed. The laser power stability was monitored for 3 h, and it was found that the power fluctuations for all wavelengths were less than 0.5 dB.

Tunability of the lasing wavelengths and spacing between the wavelengths were also investigated through changing the loaded digital phase holograms. To demonstrate this, another set of digital phase holograms was loaded onto the opto-VLSI processor to couple-back five wavelengths with nonuniform spacings (1528.9, 1529.8, 1530.5, 1531.3, and 1532.5 nm). Fig. 3(c) shows the loaded digital phase holograms, and Fig. 3(d) shows the corresponding measured spectrum at the SOA output.

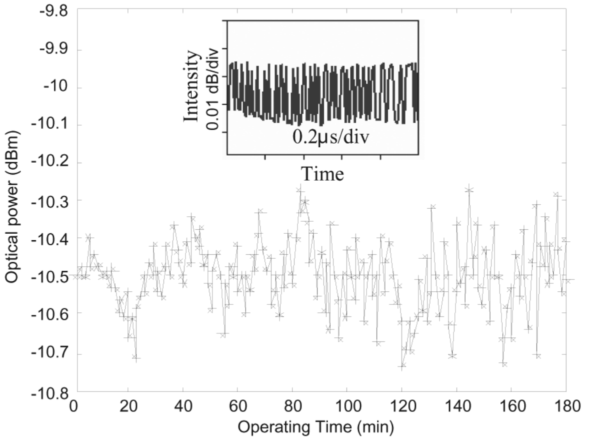

Fig. 5. Variations in laser intensity with time for a single wavelength channel (1530 nm) (Inset: microsecond time scale power fluctuation).

Fig. 4 shows different examples of digital phase holograms that were loaded onto the opto-VLSI processor and their corresponding spectra of the laser output, where four, three, and two wavelengths were generated with different spacings. A laser linewidth of approximately 0.5 nm was measured. This demonstrates the capability of the proposed multiwavelength tunable laser structure to generate arbitrary lasing wavelengths and spacings. It also demonstrates the capability of the opto-VLSI processor to equalize the output power levels of the lasing wavelengths.

Fig. 5 shows the time-domain power fluctuations measured for the lasing wavelength 1530 nm. The inset of Fig. 5 illustrates the microsecond time scale power fluctuations. It is important to point out that the biasing current applied to the SOA should be kept constant in order to achieve low laser output power fluctuations.

In this experiment, the maximum number of simultaneously generated wavelengths was six. Although the ASE spectral bandwidth could accommodate a larger number of simultaneously generated wavelengths, the small window size of the opto-VLSI processor used restricted some of the ASE wavelength components to be mapped within the active window of the opto-VLSI processor, thus prevented the wavelength components to be injected back into the SOA cavity. In addition, the tuning range is limited by the steering capability of the opto-VLSI processor. Even if the window size is large, some wavelengths might hit the opto-VLSI processor at an incident angle that is larger than half the maximum steering angle of the opto-VLSI processor. In this case, these particular wavelengths cannot be injected back into the SOA cavity, leading to a reduced tuning range. Note that the maximum steering angle is inversely proportional to the pixel size of the opto-VLSI processor. Therefore, by using an opto-VLSI processor with a large active window size and small pixel size (opto-VLSI processors of 20 mm window and 2-micron pixel pitch are commercially available), and a blazed grating plate of 600 lines/mm (rather than 1200 lines/mm), a tuning range of 40 nm can be achieved.

One of the main advantages of the proposed tunable laser structure is its wavelength stability. The only factor that affects the wavelength stability of the tunable laser structure is a malfunction in the opto-VLSI that alters the position of the steering phase holograms.

III. CONCLUSION

We have proposed and experimentally demonstrated tunable multiwavelength laser structure employing an SOA and an opto-VLSI processor, where the ASE spectrum generated by the SOA is sliced using the WDM equalization capability of the opto-VLSI processor. Experimental results have demonstrated a stable tunable multiwavelength laser with a tuning range of about 5 nm, where arbitrary wavelengths can be generated by varying the digital phase holograms loaded onto the opto-VLSI processor. The features that make the proposed tunable multiwavelength laser structure very attractive for WDM applications include simplicity, software-based tunability along the wavelength range, cost effectiveness, and compactness when the various components are integrated.

REFERENCES

[1] J. Sun, Y. Zhang, and X. Zhang, “Multiwavelength lasers based on semiconductor optical amplifiers,” *IEEE Photon. Technol. Lett.*, vol. 14, no. 6, pp. 750–752, Jun. 2002.

[2] J. Sun, J. Qiu, and D. Huang, “Multiwavelength erbium-doped fibre lasers exploiting polarization hole burning,” *Opt. Commun.*, vol. 182, no. 1–3, pp. 193–197, Aug. 1, 2000.

[3] Y.-G. Han, C.-S. Kim, J. U. Kang, U.-C. Paek, and Y. Chung, “Multiwavelength raman fiber-ring laser based on tunable cascaded long-period fiber gratings,” *IEEE Photon. Technol. Lett.*, vol. 15, no. 3, pp. 383–385, Mar. 2003.

[4] K. K. Qureshi, H. Y. Tam, W. H. Chung, and P. K. A. Wai, “Multiwavelength laser source using linear optical amplifier,” *IEEE Photon. Technol. Lett.*, vol. 17, no. 8, pp. 1611–1613, Aug. 2005.

[5] B. J. Eggleton, P. A. Krug, L. Poladian, and F. Ouellette, “Long periodic superstructure Bragg gratings in optical fibres,” *Electron. Lett.*, vol. 30, no. 19, pp. 1620–1622, Sep. 1994.

[6] X. J. Gu, “Wavelength-division multiplexing isolation fiber filter and light source using cascaded long-period fiber gratings,” *Opt. Lett.*, vol. 23, no. 7, pp. 509–510, Apr. 1998.

[7] G. E. Town, K. Sugden, J. Williams, I. Bennion, and S. B. Poole, “Wide-band Fabry–Pérot-like filters in optical fibers,” *IEEE Photon. Technol. Lett.*, vol. 7, no. 1, pp. 78–80, Jan. 1995.

[8] R. Kashyap, “A new class of fibre grating based bandpass filters: The asymmetric interferometer,” *Opt. Commun.*, vol. 153, no. 1-3, pp. 14–18, Jul. 15, 1998.

[9] X. Shu, S. Jiang, and D. Huang, “Fiber grating Sagnac loop and its multiwavelength-laser application,” *IEEE Photon. Technol. Lett.*, vol. 12, no. 8, pp. 980–982, Aug. 2000.

[10] M. Aljada, K. E. Alameh, and K. Al-Begain, “Opto-VLSI-based correlator architecture for multiwavelength optical header recognition,” *J. Lightw. Technol.*, vol. 24, no. 7, pp. 2779–2785, Jul. 2006.

[11] M. Aljada, K. E. Alameh, Y.-T. Lee, and I.-S. Chung, “High-speed (2.5 Gbps) reconfigurable inter-chip optical interconnects using opto-vlsi processors,” *Opt. Express*, vol. 14, no. 15, pp. 6823–6836, Jul. 2006.

[12] M. Aljada and K. Alameh, “Wavelength-encoded OCDMA system using opto-vlsi processors,” *OSA Opt. Lett.*, vol. 32, no. 13, pp. 1782–1784, 2007.