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Opto-VLSI-based Tunable Linear-Cavity Fibre Laser

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***Abstract*— A novel approach using an Opto-VLSI processor to achieve a tunable fibre laser is presented. The Opto-VLSI based fibre laser is able to tune wavelengths and maintain a high Side-Mode Suppression Ratio (SMSR) even when the output optical power is low. Experimental results show a continuously tunable fibre laser source with a tuning range as high as 30 nm and a SMSR exceeding 30 dB.**

***Index Terms*— Opto-VLSI, erbium doped fibre, fibre laser, tunable laser, linear cavity.**

I. INTRODUCTION

Fibre lasers have unique capabilities, including narrow linewidth, easy implementation into a fibre system, high output power and high Side Mode Suppression Ratio (SMSR). These capabilities make them attractive for applications such as Wavelength Division Multiplexed (WDM) systems, spectroscopy, biotechnology and fibre sensor networks. For example, optical systems that require wavelengths to be evenly spaced, such as WDM, need a laser source where the output wavelength can be discretely tuned [1]. Several tunable fibre laser structures have been reported [2-8], most of them are based on erbium-doped fibre amplifiers (EDFAs) and employ one or a combination of components or techniques for wavelength selection or tuning, including Fibre Bragg Gratings (FGB) [2 - 4], etalon based filters like Fabry-Perot cavity [5 - 6] and acousto-optic based tunable filters [7].

This paper proposes and demonstrates a novel continuously linear-cavity tunable fibre laser employing an Opto-VLSI processor as the wavelength selection mechanism. The advantages of this system include (i) no mechanically moving parts, (ii) the ability to realise multiple tunable lasers using a single Opto-VLSI processor, and (iii) the ability to select any wavelength from the whole available spectrum provided from an erbium doped fibre.

Experimental results demonstrate almost-continuous tuning over the 30 nm ASE spectrum range of an EDFA, output optical power fluctuations less than 1.5 dB and an SMSR of more than 30 dB, without the need of gain-flattening filters.

II. OPTO-VLSI PROCESSOR

An Opto-VLSI processor is a device which comprises the following parts: spatial light modulator or Liquid Crystal on Silicon (LCoS), electronics driver and a software interface. The LCoS is composed of pixels which can be controlled individually via a software interface.

Figure 1 shows the pixel layout of an Opto-VLSI processor and the VLSI structure for each pixel. The liquid crystal molecules are twisted when a voltage is applied across the top and bottom electrodes, thus inducing a phase shift to an incident light. The voltage is applied by the electronics driver which converts the information from the software interface into voltage levels. The software interface is designed to generate a digital phase hologram for achieving laser beam steering and thus wavelength tunability.

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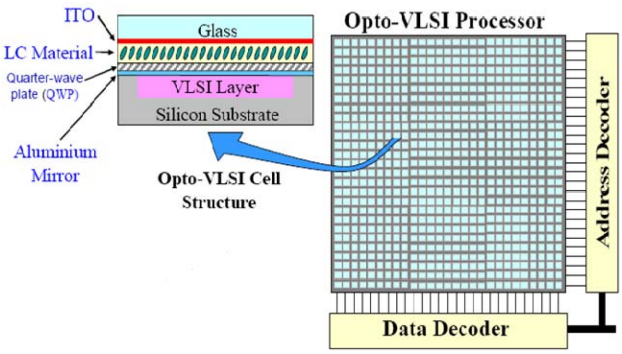
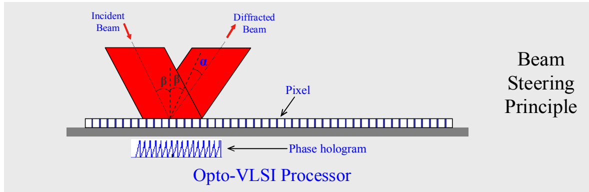


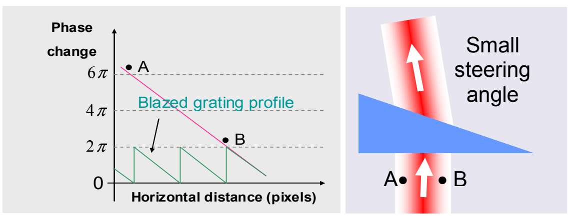
Figure 1. Pixel layout on the Opto-VLSI processor and internal cross-section view of pixel structure.



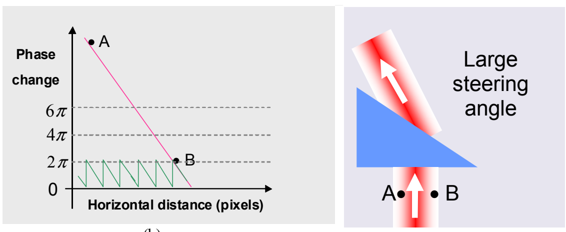
(c)

Figure 2 (c). Incident light experiences beam steering when a digital phase hologram is applied to the Opto-VLSI processor.

When a voltage profile is produced across a specific pixel block of the Opto-VLSI processor, a digital phase hologram or a blazed grating is created. The blazed grating behaves in a similar way to how a prism interacts with a laser beam by causing a change in its phase. As the laser beam exits a prism, due to a path difference inside of the prism, it is steered by an angle, which depends on the prism's angle. An Opto-VLSI can emulate the prism effect by changing the period of the blazed grating (digital phase hologram) as illustrated in Figure 2. The amount of steering experienced by a laser beam incident on the Opto-VLSI processor depends on the period of the blazed grating, as shown in Figures 2 (a-b). By optimising the blazed grating profile the appropriate steering angle enables the system to select the desired wavelength for lasing.



(a)



(b)

Figure 2 (a) and (b). Comparison of different blaze grating profiles versus the corresponding phase change.

III. EXPERIMENTAL SET UP

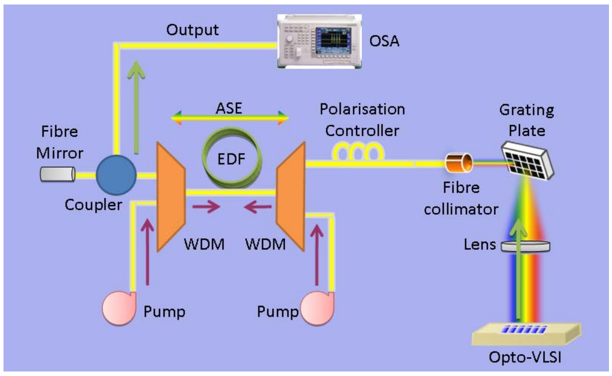


Figure 3. Architecture of the fibre laser employing an Opto-VLSI processor.

Figure 3 shows the layout of the proposed fibre laser, which is illustrated through the experiment that was set up. The section of Erbium-doped Fibre (EDF) had a length of 5 m and an erbium concentration of 820 ppm. The peak core absorption was 16 dB/m measured at 1530 nm. Two 980 nm laser diodes, each of maximum output optical power 168 mW, were used for optically pumping the EDFA. The light from both pump diodes was launched via a 1550/ 980 nm WDM multiplexer. A fibre mirror was placed on one end of the cavity with a maximum insertion loss of 0.8 dB. To remove the background noise generated by the EDF, the output coupler was placed near the fibre mirror. The laser output was extracted from the 10% port of the output 10:90 fibre coupler, which was connected to the Optical Spectrum Analyser (OSA) for laser performance monitoring. The remaining 90% was sent to a fibre mirror, which was one of the reflecting ends of the lasing cavity. The polarisation controller was used to appropriately align the polarisation of the Amplified Spontaneous Emission (ASE) with the fast axis of the LC molecules of the Opto-VLSI processor, so that high beam steering efficiency is achieved and also laser operation in single polarisation mode is maintained. The wavelength tuning of the fibre laser was performed by the Opto-VLSI processor which had a pixel size of 15 µm, and a total area of 512 x 512 pixels.

In order for the ASE to spread over the active window of the Opto-VLSI processor for wavelength selection, a fibre collimator, a grating plate and a lens were used, as illustrated in Fig. 3. The ASE was collimated to a beam diametre of 0.5 mm, which was then incident onto the grating plate of 1200 lines/mm and a blazed angle of 70° at a wavelength of 1530 nm. This grating plate was chosen because it produces a high-power first order beam. The grating plate acted as a demultiplexer to separate the ASE so that the Opto-VLSI processor can select the appropriate wavelength for re-injection into the lasing cavity. A lens with a focus length of 10 cm was placed between the grating plate and the Opto-VLSI processor to map the demultiplexed ASE spectrum over the Opto-VLSI processor's active window.

When combining the Opto-VLSI processor with a fibre collimator, grating plate and a lens, as seen in Fig. 3, an optical filter was created which enabled the discrimination between wavelengths within the ASE spectrum. This was the main mechanism for the tunability. Wavelengths from the ASE spectrum were selected without the need of scanning through the whole tunable range. This was achieved by changing the location of the digital phase hologram via the software interface developed with LabView. Digital phase holograms were created through periodic voltage profiles of 10 x 512 pixels in size and with a total of 256 voltage levels, as illustrated in Fig. 2.

IV. RESULTS

The experiments intended to demonstrate the unique capabilities of the Opto-VLSI processor to continuously tune throughout the ASE spectrum when the output power is low, while maintaining a high SMSR. The power control was achieved by lowering the available ASE level which was controlled by reducing the optical output from the two laser diode pumps.

Figure 4 shows a typical measured laser output at 1552.5 nm. Figure 5 shows different laser outputs generated at various wavelengths by simply changing the phase hologram uploaded onto the Opto-VLSI processor. The SMSR for all lasing wavelengths was more than 30 dB.

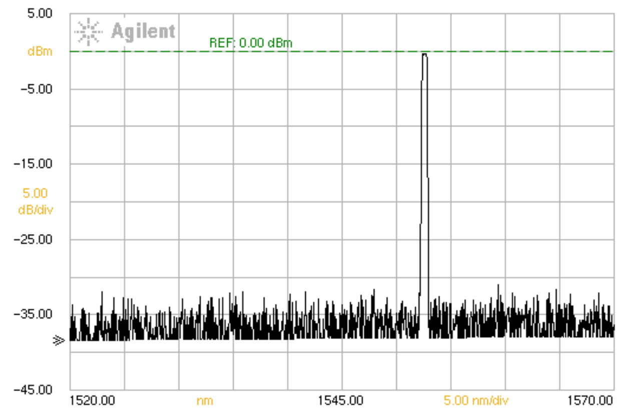


Figure 4. Fibre laser output measured with an OSA to be close to 1 mW and a SMSR of more than 30 dB.

The tuning capability of the fibre system is also shown in Fig. 5. As it can be seen, the system was able to select any wavelength within the 1531–1561nm spectrum while maintaining a SMSR of more than 30 dB. The system could be continuously tuned through this range.

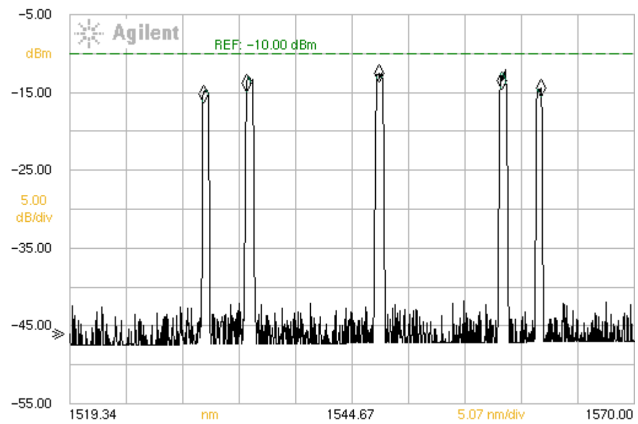


Figure 5. Measured laser spectrum for different phase holograms, demonstrating a 30 nm tuning range through the reconfiguration of the Opto-VLSI processor. The SMSR is more than 30 dB throughout the tunable range.

Figure 6 shows the measured linewidth of fibre laser. Typically, the FWHM linewidth was less than 0.1 nm. This value was obtained with the aid of an OSA. Fig. 6 shows that for a laser output power of less than 100 µW the linewidth was less than 0.1 nm, while Figure 7 confirms that when the laser output power was nearly 1 mW the linewidth was also less than 0.1 nm. These two Figures provide further evidence of the ability of the system to maintain the linewidth quality of the output when the output power is varied through changing the optical pump power.

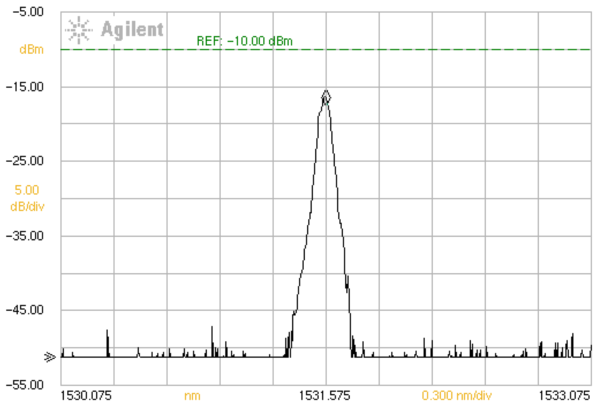


Figure 6. Linewidth of fibre laser source measured with an OSA. The maximum output power is less than 100 µW and the linewidth is less than 0.1 nm.

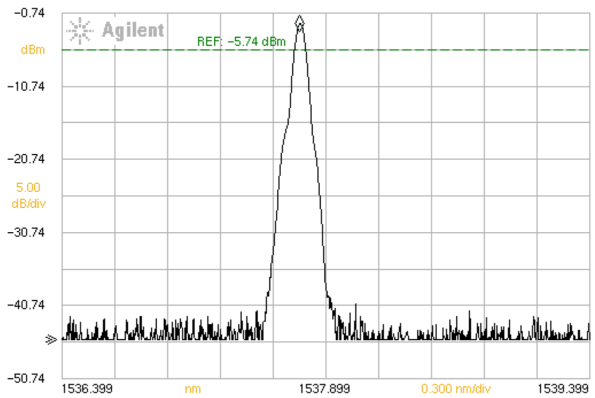


Figure 7. The measured linewidth is less than 0.1 nm and the maximum output power is nearly 1 mW.

In addition, the laser's output wavelength was successfully tuned through the full 30-nm ASE spectrum range, exhibiting power fluctuations of less than 1.5 dB and a minimum SMSR exceeding 30 dB, without the need of gain-flattening filters.

V. CONCLUSION

This paper has proposed and demonstrated the concept of a new tunable fibre laser structure employing an Opto-VLSI processor in conjunction with optical components within a linear optical gain cavity. The Opto-VLSI processor has been reconfigured electronically to allow the fibre laser system to continuously tune through the available ASE spectrum and select the desired wavelength for further amplification. For low optical pump powers (or gains), the Opto-VLSI processor has been able to select and re-inject wavelengths for amplification into the lasing linear-cavity, while maintaining a high SMSR exceeding 30 dB and a laser linewidth below 0.1 nm.

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