Multiwavelength Laser Source Using Linear Optical Amplifier

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***Abstract*—We propose and demonstrate a high-performance multiwavelength ring laser based on a linear optical amplifier (LOA) for potential applications in dense wavelength-division-multiplexing communication systems. Experimental results indicate that the inhomogeneous gain medium provided by the LOA reduces the gain competition and leads to stable multiwavelength lasing. Thirty-eight wavelengths covering $C + L$-band with 0.8-nm channel spacing are generated at room temperature. Simultaneous tuning of multiwavelengths is demonstrated and a stability test shows a power fluctuation of less than 0.2 dB during a 3-h test.**

***Index Terms*—Linear optical amplifier (LOA), multiwavelength laser.**

I. INTRODUCTION

MULTIWAVELENGTH laser sources have potential applications in instrument testing, sensing, and wavelength-division-multiplexing (WDM) systems. These types of light sources are attractive as they provide an efficient and economical way to increase the transmission capability of WDM systems. There are many methods to generate simultaneous multiwavelength outputs. Examples include multiwavelength Raman lasers [1], [2], multiwavelength generation using semiconductor optical amplifiers (SOAs) [3], and multiwavelength erbium-doped fiber lasers [4], [5]. However, stable multiwavelength light sources based on Er^{3+}-doped fibers are difficult to obtain due to homogeneous broadening of lasing modes. Multiwavelength Er^{3+}-doped fiber lasers were reported, either by immersing the Er^{3+}-doped fibers in liquid nitrogen [5] or using specially designed twin-core Er^{3+}-doped fiber [6]. Higher channel count and room-temperature operation multiwavelength lasers based on SOAs have also been reported [7].

This letter proposes and demonstrates a simple configuration of a multiwavelength laser source based on linear optical amplifiers (LOAs) [8]. LOAs and SOAs are semiconductor devices and, thus, have the advantages of small size and direct modulation. The LOA used in this work operates in the $C + L$-band and provides an inhomogeneous gain medium in the laser ring cavity. A significant difference between LOAs and SOAs is that in LOAs, a vertical-cavity surface-emitting laser is integrated, perpendicularly, along the entire length of the amplifier, serving as a ballast to provide a constant gain to the amplifier [8], helping to clamp the gain competition in a laser cavity. A comparison between an LOA and an SOA for their transient response verified that SOA-based multiwavelength laser sources are more prone to power fluctuations when compared to LOA-based sources. Power stability test of a single channel of the multiwavelength laser source using LOA is also reported in this letter. For comparison, the result of the multiwavelength laser with the LOA replaced with an SOA is also reported.

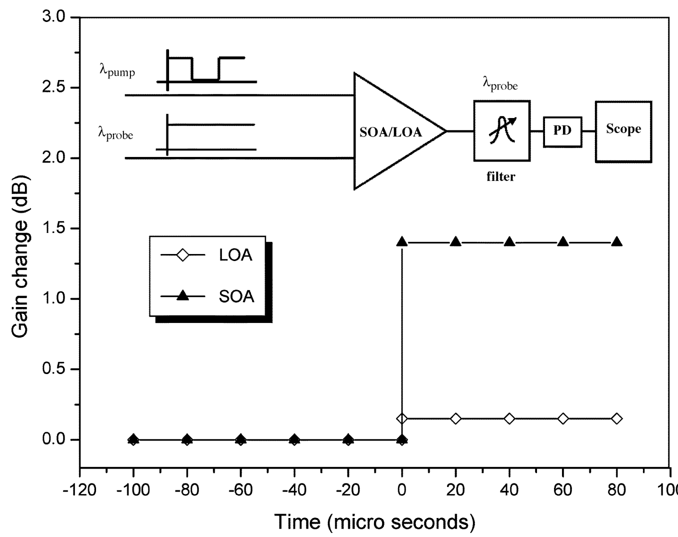

Fig. 1. Gain transient of the probe signal when pump signal is turned OFF for SOA and LOA. Inset shows the configuration of the pump and probe technique. Note: PD: Photodetector.

II. EXPERIMENTS AND RESULTS

In order to find out whether an LOA-based laser source has negligible mode competition compared to the SOA-based laser source, the switching transient response of the LOA was measured and was compared with that of an SOA. For this measurement, a pump and a probe technique as reported in [8] and shown in the inset of Fig. 1 was used but the comparison made in this letter was done by operating the two devices at the same value of gain. The SOA was operated 2 dB below its saturation output power at a biasing current of 102 mA, whereas, the LOA was operated at 4 dB below its saturation output power at a biasing current of 130 mA. The pump beam at a wavelength of 1545.2 nm was modulated at a frequency of 20.9 kHz to simulate adding and dropping of wavelengths in a WDM system. The probe beam at a wavelength of 1548.0 nm was monitored

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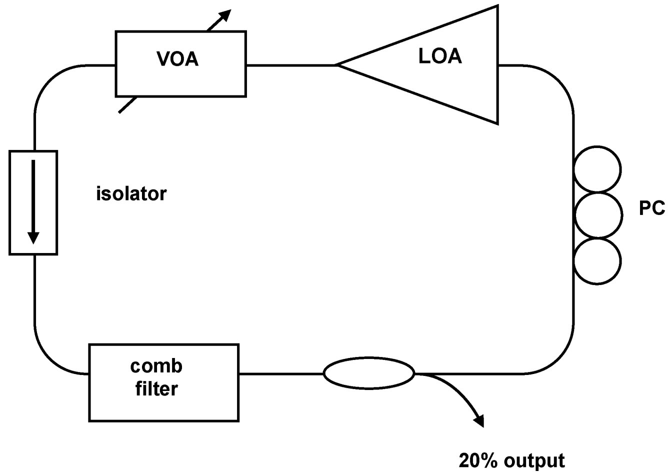

Fig. 2. Experimental setup of the multiwavelength ring laser. Note: VOA: Variable optical attenuator. LOA: Linear optical amplifier. PC: Polarization controller.

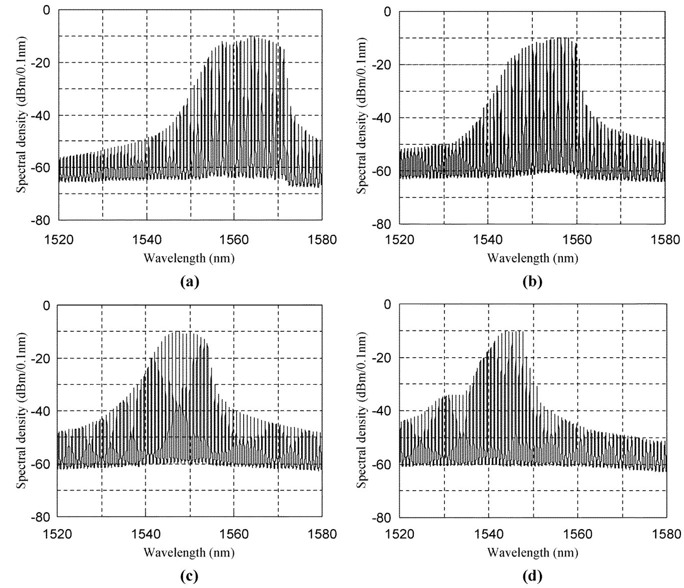

Fig. 3. Multiwavelength spectra tuning with variable optical attenuator. The attenuation levels are (a) 0, (b) 3, (c) 5, and (d) 7 dB.

at the falling edge of the pump beam. At the output of the LOA or the SOA, the surviving channel, i.e., the probe beam was measured, after being filtered with a narrow-band tunable filter, with a fast photodetector. In the case of SOA, at the falling edge of the pump beam the probe beam jumps instantly by more than 1.4 dB, where as in the case of LOA, the probe beam changes by less than 0.15 dB, as shown in Fig. 1. This clearly demonstrates that the effect of adding or dropping wavelengths on the surviving wavelengths is negligible in the case of LOA when compared to an SOA. It also revealed that the LOA is not susceptible to instantaneous input power changes, which makes it a superior choice over SOA. LOA is not only useful for dynamic WDM systems but can also be used as a gain medium in a laser source configuration where different wavelengths should be amplified by the laser cavity gain media and the gain or loss of one wavelength should not affect the other wavelengths.

Fig. 2 shows a schematic diagram of the proposed configuration of the laser. It consists of an 80 : 20 coupler, a polarization controller (PC), a polarization-independent isolator, a thin film etalon filter, and an LOA. The thin film etalon filter has a free-spectral range of 100 GHz and exhibits absolute wavelength accuracy of $+/-1.25$ GHz over a temperature range from 0 °C to 70 °C. The operation wavelength of the etalon filter is from 1525 to 1620 nm and its insertion loss is 1.4 dB. The LOA is designed to operate in the C-band and has a typical bandwidth gain flatness of 1.4 dB. The optical isolator in the cavity ensures unidirectional operation of the ring cavity and avoids any unwanted reflections. The PC adjusts the polarization in the laser cavity to achieve high signal-to-noise ratio (SNR). The laser output is taken from the 80 : 20 fiber coupler, which provides 20% for the output and 80% for the feedback function. The total length of the cavity was approximately 3 m and the round-trip loss of the cavity was estimated to be less than 3.2 dB.

The output spectrum of the multiwavelength laser is shown in Fig. 3(a), which shows more than 38 wavelengths within both the C- and L-band (with at least 20-dB SNR) with a channel spacing of 0.8 nm. The laser wavelength spacing was controlled by the cavity's comb filter (thin film etalon filter). About 20 lasing wavelengths in the L-band exhibited optical SNR of greater than 40 dB. Although the LOA used in the cavity was designed for C-band, but the carrier density of the LOA decreased due to strong optical feedback (80%) and shifted the gain profile toward the L-band (red shift) of the spectrum [9]. Therefore, the lasing spectrum of the LOA-based ring laser can be tuned by varying the loss in the laser cavity.

A variable optical attenuator with a dynamic range of 40 dB in the 1550-nm region was inserted inside the multiwavelength laser cavity. The multiple lasing wavelengths were tuned simultaneously as the attenuation level was adjusted. As the attenuation level was increased, the multiwavelength comb blue shifted (to shorter wavelength region). Fig. 3(b)–(d) shows the output spectra of the multiwavelength laser when the attenuation levels were set to 3, 5, and 7 dB, respectively. Other parameters such as the biasing current applied to the LOA, and the output coupling ratio were kept constant during the tuning process. The experimental results have demonstrated a maximum tuning range of 22 nm (1548∼1570 nm), which corresponded to the shift of the longest lasing wavelength as the attenuation level was increased from 0 to 7 dB. The maximum shift of shortest lasing wavelength was around 22 nm (1526∼1548 nm). This is a very effective method for wavelength tuning.

In order to measure the stability of the laser source, a single laser channel was filtered out and its output power was observed for 3 h using an optical power meter. The measurements were recorded after 1 h of the initial startup of the setup to allow for the LOA current driver circuitry to be stabilized. The optical SNR of the lasing output was very large (>50 dB), higher than previously reported multiwavelength sources. The power fluctuation measured with a power meter was less than 0.2 dB, as shown in Fig. 4(a). The inset (i) shows the spectrum of a single wavelength channel obtained by using a thin film tunable filter with a 3-dB bandwidth of 0.14 nm and working in C-band, while the inset (ii) shows the microsecond time scale power fluctuation. The LOA in the cavity was than replaced with

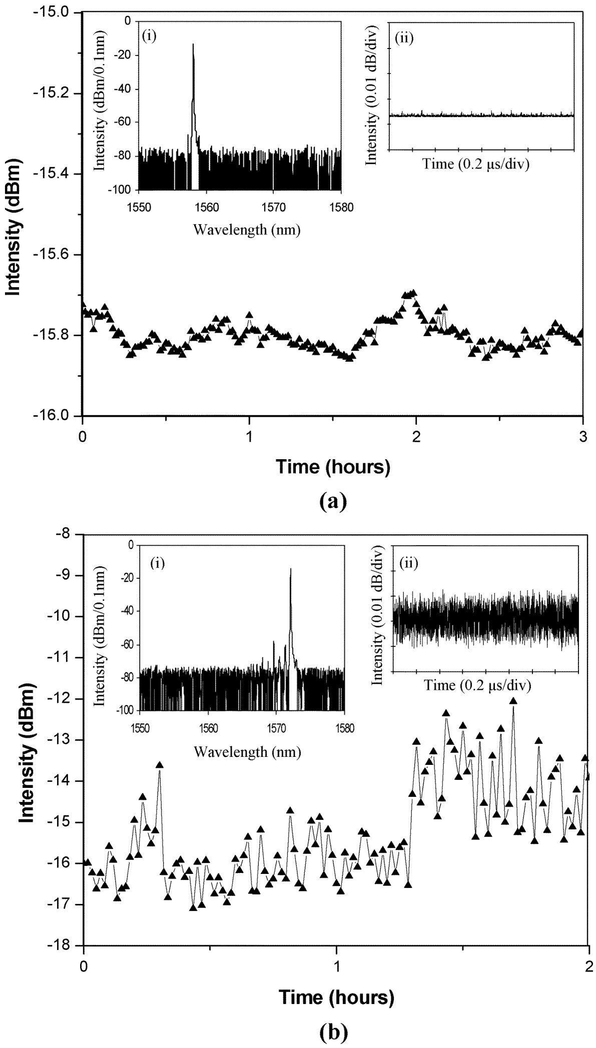

Fig. 4. (a) Variation of intensity with time for a single wavelength channel for an LOA-based ring laser. Inset (i) shows the spectrum of a single filtered channel from the output of the LOA-based ring laser. Inset (ii) shows the microsecond time scale power fluctuation. (b) Variation of intensity with time for a single wavelength channel for an SOA-based ring laser. Inset (i) shows the spectrum of a single filtered channel from the output of the SOA-based ring laser. Inset (ii) shows the microsecond time scale power fluctuation.

an SOA in order to compare the performance of the ring laser using two different gain media. The stability test was conducted for 2 h and it was found that the power fluctuation was over 5 dB, as shown in Fig. 4(b). The inset (i) shows the spectrum of a single wavelength channel obtained by using a tunable grating filter with a 3-dB bandwidth of 0.22 nm and working in L-band, while the inset (ii) shows the microsecond time scale power fluctuation. This comparison has demonstrated that an LOA-based multiwavelength ring laser is very stable when compared to an SOA-based laser source.

III. Conclusion

We have demonstrated a multiwavelength operation of an LOA-based ring laser working at room temperature. A total of more than 38 lasing wavelengths were obtained with the channel spacing of 0.8 nm. By using an optical variable attenuator in the cavity, simultaneous tuning of multiwavelengths was achieved with a tuning range of around 22 nm. With an increase in the attenuation level, the lasing wavelengths shifted toward the shorter wavelength region. It was also observed that the power fluctuation of a single wavelength channel was less than 0.2 dB, which makes this source a good choice for dense WDM applications and component characterization.

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