Multiwavelength and Power Equalized SOA Laser Sources

N. Pleros, C. Bintjas, M. Kalyvas, G. Theophilopoulos, K. Yiannopoulos, S. Sygletos, and H. Avramopoulos

***Abstract*—Multiwavelength and power-equalized operation is demonstrated in a semiconductor optical amplifier ring laser that uses a fiber Fabry–Pérot filter. By using single-pass optical feedback, the power-equalized oscillating spectrum is broadened so that simultaneous oscillation of 52 lines spaced at 50 GHz is achieved. The lines had 500 MHz width were power-equalized to within 0.3 dB and the extinction was better than 32 dB.**

***Index Terms*—Multiwavelength source, optical feedback, ring-cavity lasers, semiconductor optical amplifiers.**

I. Introduction

Wavelength-division-multiplexing (WDM) technology is now well established and transmission and network systems are being deployed rapidly worldwide. As the channel count continues to increase across the spectrum from S- to L-band, so has the interest in laser sources that can provide simultaneous, multiwavelength operation. Applications for such sources include use in WDM transmitters, or passive and active component characterization and may be used instead of an equivalent number of discrete laser sources or tunable laser sources to reduce cost, electronic driver real estate or the complexity in measurement procedures. For example multiwavelength laser sources are ideal for the characterization of optical amplifiers where the gain profile must be saturated across its whole spectrum for reliable measurements, or polarization mode dispersion and polarization-dependent loss measurements that are usually carried out with tunable sources. Multiwavelength operation has been demonstrated using a number of techniques including spectrum slicing in LEDs [1], amplified spontaneous emission from erbium-doped amplifiers (EDFAs) [2], supercontinuum generation in fiber [3], femtosecond pulses [4] as well as in erbium-doped fiber (EDF) oscillators that use an intracavity grating [5] and a fiber Lyot filter [6]. Recently, multiwavelength operation was also shown in semiconductor optical amplifier (SOA) cavities [7]–[9].

This communication presents a study of different implementations of multiwavelength laser sources with power-equalized output, which use a combination of SOAs and a fiber Fabry–Pérot (FFP) filter. We show that with a regular ring cavity including two SOAs, it is possible to obtain simultaneous 38-line oscillation at 50-GHz nominal line spacing across a 15-nm spectral window, with less that 0.5-dB power variation between them. We also propose and demonstrate a novel to our knowledge technique that extends the power-equalized oscillating spectrum. It relies on the simple addition of a one-pass feedback arm in the output of the source. With this it is possible to extend the oscillating window to 21 nm and allow the simultaneous oscillation of 52 lines. In this configuration the line width is 500 MHz, the power variation across the 52 lines is less than 0.3 dB and the extinction between them is better than 32 dB and the total power is 1.7 mW. The source may be a relatively inexpensive option for passive and active component characterization.

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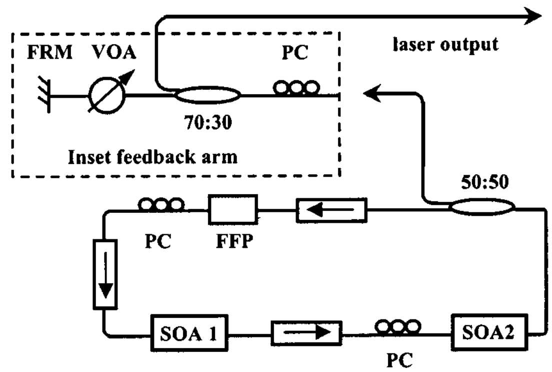


Fig. 1. Experimental setup and inset showing the feedback arm.

II. Experiment

Multiwavelength oscillation in a laser source that uses an SOA [7]–[9] is possible because of its broad gain spectrum and heterogeneous spectral broadening. If the laser cavity employs a single SOA that has polarization gain dependence, oscillation occurs at slightly longer wavelengths for the high gain axis as opposed to its low gain axis. By coupling the signal to both gain axes it is, therefore, possible to extend the oscillating bandwidth. The oscillating bandwidth and power may be further increased with the addition of a second SOA which has a peak gain slightly offset. Optimization of the cavity losses and adjustment of the drive currents for the two SOAs, can result in a broad, uniform oscillating spectrum.

Fig. 1 shows the experimental layout of the cavity that was used. Gain was provided by two bulk, 500-μm-long commercially available (Opto Speed, S.A.), InGaAsP–InP ridge waveguide SOAs, with facets angled at 10° and antireflection coated. SOA 1 provided peak small signal gain of 22 dB at 1530 nm with 1.5-dB polarization dependence, when driven with 250-mA dc current. SOA 2 provided peak small signal gain of 23 dB at 1522 nm with 1.9-dB polarization dependence, when driven with a 250-mA dc current. Polarization controllers were used

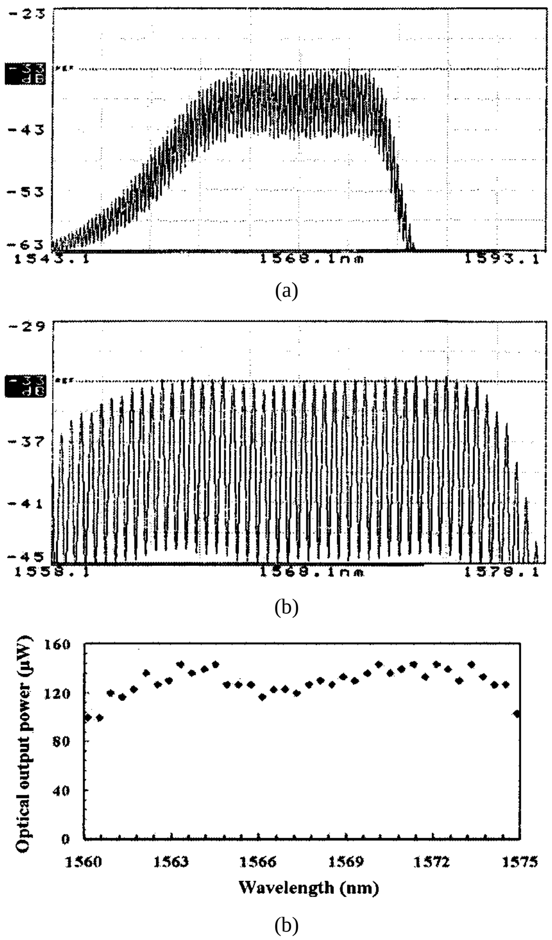


Fig. 2. Optical spectrum at (a) sweep width 5 nm/div (b) sweep width 2 nm/div, and (c) power distribution of output wavelengths.

before the SOAs to adjust the input state of polarization and isolators were used to ensure unidirectional oscillation in the ring and to avoid undesirable reflections. The oscillating spectrum was defined by a FFP filter with free spectral range 47.75 GHz, finesse 8.1 and 1.7-dB insertion loss. A 50:50 fused fiber coupler provided the output from the source.

With the drive currents adjusted for SOA 1 at 207 mA (20-dB small signal gain at 1532 nm) and at 229 mA for SOA 2 (22-dB small signal gain at 1524 nm), the source oscillates across a broad spectral range shown in Fig. 2(a) and (b). The 38 central lines span across 15 nm and provide nearly equal power with a mean of 127 μW and less than 0.5-dB standard deviation shown in Fig. 2(c). The total output power from the source was 5.5 mW. The linewidth of the oscillating lines was below the 0.16 nm resolution limit of our optical spectrum analyzer and for this reason it was deduced by measuring the beat spectrum of the cavity modes on an RF spectrum analyzer. Assuming a Lorentzian line shape, the linewidth was found to be 500 MHz. The extinction between the lines was measured after amplification in an EDFA using a second FFP filter (5.2-GHz bandwidth) and was found to be 32 dB. It is expected that the extinction obtained directly from the source will be significantly better than this.

It is worth noting that multiwavelength operation may be obtained with a single SOA too. For example if only SOA 2 is used in the cavity, a flat oscillating spectrum of 10 nm is obtained with 25 simultaneously oscillating lines.

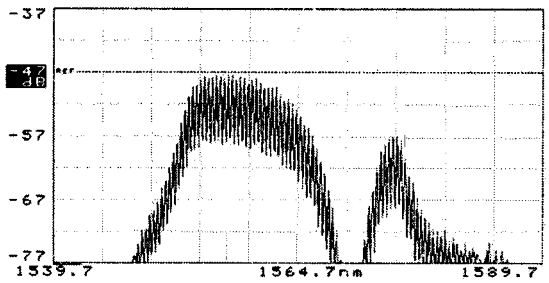
III. Source With Single Pass Feedback

In order to extend the power-equalized oscillating spectrum, single-pass optical feedback was employed with the setup shown in the inset of Fig. 1. With this arrangement part of the output signal obtained through the 50:50 coupler, is returned back to the laser via a Faraday rotator mirror (FRM) and a 70:30 coupler, while a variable optical attenuator (VOA) is used to adjust its optical power into the oscillator. The feedback signal travels in the backward direction through SOA 2 only once and is stopped by the isolators.

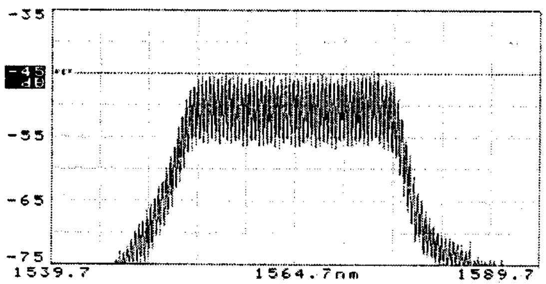
The oscillating signal experiences more losses in traveling from SOA 2 to SOA 1 than from SOA 1 to SOA 2 and to obtain a wide oscillating spectrum SOA 1 must be driven at a lower current than SOA 2. SOA 2 is deeply saturated and without feedback the oscillating spectral profile is strongly featured especially when attempting to couple to both TE and TM axes in order to broaden the spectrum. If an appropriate level of this featured spectral profile is used as saturating signal in the opposite direction to the lasing signal, equalization of the power of the oscillating wavelengths can be achieved. Essentially the more intense lines saturate the SOA more, causing a uniform distribution of the gain across wavelength. Optimization of the cavity losses, the power of the feedback signal, the currents driving the SOAs and the polarization controllers in the cavity, results in a broad and equalized spectrum. Use of the FRM is beneficial because it ensures that the feedback signal is orthogonal to the oscillating signal and simplifies the polarization adjustments.

Fig. 3 shows the oscillating spectra of the laser source with the drive currents for SOA 1 and SOA 2 adjusted at 182 and 215 mA, respectively. Fig. 3(a) displays the output in the absence of the feedback and shows a broad, but highly featured profile. With the injection of 235 μW of signal into SOA 2 from the feedback arm, the power spectrum equalizes and broadens to nearly 21 nm so that it consists of 52 oscillating wavelengths as seen in Fig. 3(b). Fig. 3(c) shows in more detail 49 of these 52 oscillating wavelengths and Fig. 3(d) shows their power distribution that has a mean of 33 μW and standard deviation of 0.3 dB. The total output power was 1.7 mW. The performance of the source does not depend critically on the current or feedback power values. For example with current changes of up to 10 mA on either SOA, or variations in the feedback of up to 30 μW, there is no change on the number of oscillating lines but there is a small increase to 0.6 dB in the power variation across the 52 lines. The line width was found to be 500 MHz and the extinction between the lines after amplification was better than 32 dB. These figures may be improved if a narrower Fabry–Pérot filter is used. The polarization state of the oscillating lines was examined in a polarization state analyzer (Instruments Systems, model RPA 2000-125). All wavelengths showed greater than 97% degree of polarization and were nearly linearly polarized even though not in the same plane.

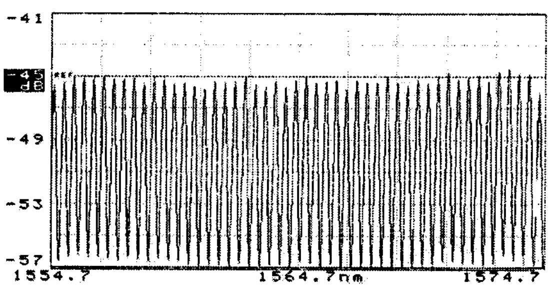
The feedback technique has even more pronounced effects for a cavity with a single SOA, in which case a flat oscillating spectrum of 50 simultaneously oscillating lines across 20 nm can be achieved. This should be compared to the performance of the same oscillator operating without feedback that can only sustain oscillation of flat lines across 10 nm.



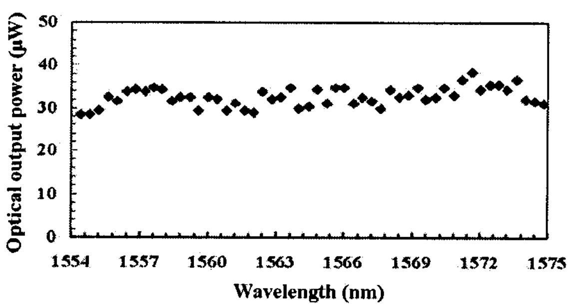
(a)



(b)



(c)



(d)

Fig. 3. Optical spectrum: (a) without and (b) with optical feedback (sweep width 5 nm/div). (c) With optical feedback (sweep width 2 nm/div). (d) Power distribution of output wavelengths with feedback.

IV. Conclusion

In summary, we have presented a study for the demonstration of multiwavelength power-equalized laser sources that use SOAs with a FFP filter. We have shown that in a regular ring cavity that includes two SOAs, it is possible to obtain simultaneous 38-line oscillation at 50-GHz nominal line spacing across a 15-nm spectral window, with less that 0.5-dB power variation between them. We have also proposed and demonstrated a novel technique for extending the power-equalized oscillating spectrum that relies on single pass feedback of the output signal into the source. With this technique it is possible to extend the oscillating window to 21 nm and allow the simultaneous oscillation of 52 lines, with 500-MHz line width, power variation of less than 0.3 dB across the 52 lines and better than 32-dB extinction between them. The sources demonstrated here remain stable for hours in laboratory conditions and may be useful for component characterization.

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References

[1] M. H. Reeve, A. R. Hunwicks, W. Zhao, S. G. Methley, L. Bickers, and S. Homung, "LED spectral slicing for single-mode local loop applications," *Electron. Lett.*, vol. 24, pp. 389–390, 1988.

[2] J. S. Lee, Y. C. Chung, and D. J. DiGiovanni, "Spectrum-sliced fiber amplifier light source for multichannels WDM applications," *IEEE Photon. Technol. Lett.*, vol. 5, pp. 1458–1461, Dec. 1993.

[3] E. Yamada, H. Takara, T. Ohara, K. Sato, T. Morioka, K. Jinguji, M. Itoh, and M. Ishii, "A high SNR, 150 ch supercontinuum CW optical source with precise 25 GHz spacing for 10 Gbit/s DWDM systems," in *Optical Fiber Communication Conf.*, 2001, Paper ME2-1.

[4] B. C. Collings, M. L. Mitchell, L. Boivin, and W. H. Knox, "A 1022—Channel WDM transmitter," in *Eur. Conf. Optical Communication*, 1999, Postdeadline Paper PD1-3.

[5] N. Park, J. W. Dawson, and K. J. Vahala, "Multiple wavelength operation of an Erbium-doped fiber laser," *IEEE Photon. Technol. Lett.*, vol. 4, pp. 540–541, June 1992.

[6] N. Park and P. F. Wysocki, "24—Line multiwavelength operation of Erbium—Doped fiber—Ring laser," *IEEE Photon. Technol. Lett.*, vol. 8, pp. 1459–1461, Nov. 1996.

[7] H. Shi, G. Alphonse, J. Connolly, and P. Delfyett, "20 × 5 Gbit/s optical WDM transmitter using single-stripe multiwavelength modelocked semiconductor laser," *Electron. Lett.*, vol. 34, pp. 179–181, 1998.

[8] K. Vlachos, K. Zoiros, T. Houbavlis, and H. Avramopoulos, "10 × 30 GHz pulse train generation from semiconductor amplifier fiber ring laser," *IEEE Photon. Technol. Lett.*, vol. 12, pp. 25–27, Jan. 2000.

[9] N. Pleros, C. Bintjas, M. Kalyvas, G. Theophilopoulos, K. Vlachos, and H. Avramopoulos, "50 channel and 50 GHz multiwavelength laser source," in *Eur. Conf. Optical Communication*, 2001, Paper WE. P.16.