Ultrafast Semiconductor-Based Fiber Laser Sources

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***Abstract*—In this paper, a novel ring laser platform is presented that uses a single active element, a semiconductor optical amplifier (SOA), to provide both gain and gain modulation in the optical cavity. Gain modulation is achieved by an externally introduced optical pulsed signal. This signal periodically saturates the amplifier gain and forces the ring laser to mode lock. Using this laser platform, we demonstrate picosecond pulsetrain generation at repetition rates up to 40 GHz, either in single or multiwavelength operation mode. In particular, using rational harmonic mode locking, 2.5-ps pulses were obtained up to a 40-GHz repetition rate, while output pulses and output power were constant over a 20-nm tuning range. In addition, a multiwavelength optical signal was obtained using the same laser platform with the addition of a Fabry–Pérot filter for comb generation. Multiwavelength oscillation is possible due to the broad gain spectrum of the SOA used and its inhomogeneous line broadening. To this end, 48 oscillating wavelengths were obtained at the laser output, with 50-GHz line spacing. Combining both modes of operation, it was possible to mode lock the oscillating multiwavelength signal and to obtain at the output ten wavelength channels, simultaneously mode locked at a 30-GHz repetition rate. The mode-locked channels are temporarily synchronized and exhibit almost identical spectral and time characteristics.**

***Index Terms*—Comb generation, cross-gain modulation, high speed, multiwavelength, rational harmonic mode locking, ring laser, semiconductor optical amplifier (SOA), transform-limited pulses, tunable source.**

I. Introduction

DESPITE the recent slowdown in the telecommunications market, R&D teams worldwide are trying hard to develop the technology and the systems that will allow the industry to offer cost effective and reliable solutions. With the advent of wavelength-division multiplexing (WDM) most of the available fiber capacity was unlocked. However, ultrahigh-speed optical time-division multiplexing (OTDM) is evolving rapidly and can offer distinguished advantages over the massive deployment of low-rate WDM channels of equivalent capacity. Both technologies can be combined in a hybrid format OTDM/WDM with a fewer number of channels at significant higher data rates. Optical sources capable of generating ultrashort pulse trains at high repetition rates [1]–[3] are key elements for hybrid optical networks that combine WDM and OTDM transmission techniques [4], [5].

Active mode locking is one of the key techniques for the generation of ultrashort transform-limited optical pulses and is achieved by the direct modulation of the optical field during each laser cavity round trip [6], [7]. This method is particularly important especially when synchronization between optical and electrical signals is required. At a 1.5-μm spectral window, several actively mode-locked fiber lasers employing erbium-doped fiber as the gain medium and producing transform-limited picosecond pulses at multigigahertz rates have been demonstrated [8]–[18]. The majority of these systems use loss modulation by lithium niobate electrooptic modulators due to their large electrooptic coefficient and their compact construction on low loss titanium-undiffused waveguides. Unfortunately, lithium niobate modulators are polarization-sensitive devices and as a result, laser sources using lithium-niobate modulators either have to be built from polarization preserving fiber pigtailed components [15]–[17] or with complex stabilization feedback circuits [18]–[21] or incorporating high-finesse Fabry–Perot (FP) filters [22], [23]. Similarly, the use of lightly or moderately doped Er fiber for gain results in long cavities, which make fiber lasers sensitive to small environmental perturbations, such as thermal fluctuations and acoustic vibration. Active stabilization techniques have been developed to continuously monitor and correct the driving frequency or cavity length for countering the tendency toward instability of long cavity fiber lasers.

A very promising technique of active mode locking has been demonstrated with intracavity semiconductor optical amplifiers (SOAs) to provide both gain and modulation in the cavity with the additional advantage that mode locking can be achieved via cross-gain modulation (XGM) from an external optical signal. In particular, actively mode-locked laser sources, incorporating SOAs, have been demonstrated by several research groups [24]–[28] for the generation of short optical pulses at various repetition rates. In these experiments, the SOA was used either as the gain or as the modulation element in the cavity in combination with an additional intracavity intensity modulator [11], [25], [26] or used to provide both gain and electrically controlled gain modulation [27]. Additionally, SOAs have been used also as the mode-locking elements providing gain modulation in Er-doped fiber ring lasers or storage rings [28], [29].

In this paper, we present an SOA-based fiber laser platform that has been used for short picosecond pulsetrains generation either under single-wavelength or multiwavelength operation mode. The laser platform uses a single active element, an SOA, to provide both gain and gain modulation in the fiber cavity via cross gain saturation from an external optical pulse train. This ring laser platform was first demonstrated at 10 GHz [30] and was extended to 40-GHz single-wavelength operation [31] and

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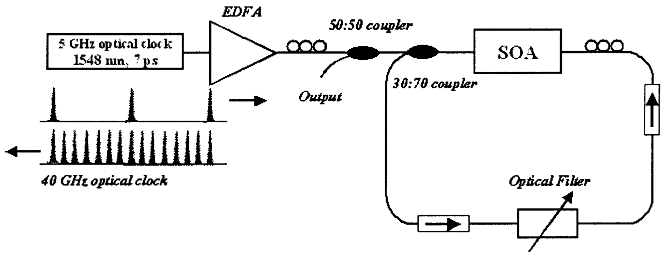

Fig. 1. Experimental setup of the semiconductor fiber ring laser.

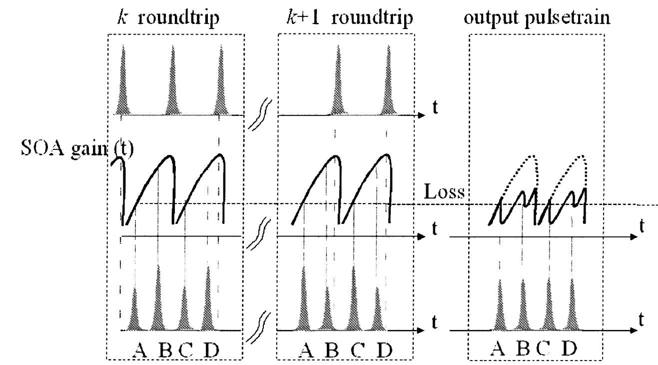

Fig. 2. Mode-locking process based on SOA gain modulation by an external pulse. Dots in the SOA gain modulation curve indicate the loss line above which the net gain is positive enabling the formation of mode-locked pulses.

30-GHz multiwavelength operation [32], exploiting further the nonlinear interaction of the optical pulses in the semiconductor. The use of a single SOA in the optical cavity in combination with the optical gain modulation yields significant performance advantages, as for example, the ultrafast modulation function, due to the fast carrier depletion of the SOA [31], the broad wavelength tunability [32]–[34], and the short picosecond pulse generation due to the nonlinear interaction of the optical signals in the SOA.

The rest of paper is organized as follows. Section II describes the experimental setup of the semiconductor-based laser source, while Section III presents experimental results for single wavelength and multiwavelength operation of the source. Finally, Section IV concludes the paper.

II. Experimental Setup of the Semiconductor Fiber Ring Laser

Fig. 1 shows the experimental configuration of the semiconductor fiber laser source. Gain was provided by a 500-μm bulk InGaAsP–InP ridge waveguide SOA with antireflection coated facets, angled at 10°. The SOA had a peak gain at 1535 nm, 400-ps recovery time, and 23-dB small signal gain when driven with 250-mA current. Faraday isolators were used to ensure unidirectional oscillation in the ring and to prevent the externally introduced signal from circulating in the cavity. The SOA exhibited 2-dB polarization gain dependence and therefore a polarization controller was inserted in the cavity. Adjustment of the polarization controller was required only at the beginning of a session for optimum pulse quality, and no further adjustments were required during operation. A tunable filter with a 5-nm bandwidth was used for wavelength selection and a 30 : 70 fused fiber coupler to insert/extract the external gain modulating and the mode-locked signal, respectively. The total length of the ring cavity was 10.5 m, corresponding to 19.05-MHz fundamental cavity frequency. The externally introduced pulses were generated from a 5-GHz gain-switched DFB laser diode operating at 1548.5 nm. These pulses were compressed down to 7 ps with dispersion-compensation fiber (DCF) before being amplified in an erbium-doped fiber amplifier (EDFA) and input into the optical cavity. A polarization controller was used to control the polarization state of the gain-switched pulses before entry into the cavity, for optimization purposes.

In the absence of the external gain-switched pulse train, the fiber ring laser source runs continuous wave (CW) and is tuned from 1523 to 1576 nm, providing approximately constant 2.0-mW output power across its tuning range. With the DFB gain switched at 5 GHz, tuned at a frequency equal to a harmonic of the fiber oscillator and with the EDFA adjusted, the ring laser source breaks into stable mode-locked operation at 5 GHz.

The principle of operation and repetition-frequency multiplication in our circuit relies on two key factors. The first is that the fast saturation of the gain of an SOA by an externally introduced picosecond optical signal is used for gain modulation in a fiber ring laser and for the generation of stable mode-locked picosecond pulses. In this instance, the externally introduced optical pulse and the comparatively slow gain recovery of the SOA define a short temporal gain window within which the mode-locked pulse is formed.

The second key factor is that by detuning the frequency $f_{\rm ext}$ of the externally introduced pulse train to $f_{\rm ext} = (N + 1/n)\delta f_{\rm ring}$, one may obtain an output pulse train at a frequency $n \cdot f_{\rm ext}$, where N is the order of harmonic mode locking of the ring laser, $\delta f_{\rm ring}$ is the fundamental frequency of the ring laser oscillator, and n is an integer number greater than one. To this end, when the repetition rate of the external pulse train is adjusted to differ by $\delta f_{\rm ring}/n$ from a harmonic of the fundamental of the ring cavity, the mode-locked pulse becomes temporally displaced by $T_{\rm ext}/n$ on each recirculation through the ring cavity with respect to its previous position. $T_{\rm ext}$ is the repetition period of the external signal. This technique for repetition frequency multiplication [35] is well described in [36] and [37] and has been found to be successful with mode-locked semiconductor lasers [36] or with Li: NbO_3 modulators in cavities with EDFAs [38], [39]. However, due to loss modulation in these experimental setups, the rational harmonic mode-locking technique produces optical pulses with uneven amplitudes for repetition rate multiplication. In addition, small perturbations in the cavity length may result in severe pulsestrain loss mainly due to the fixed temporal window of the loss modulation function.

Fig. 2 illustrates graphically the mode-locking process based on the SOA gain modulation by an external pulse in the case of two times rate multiplication. The mode-locked pulse is formed, after the insertion of the external pulse, at the time that the slowly recovering gain of the SOA balances the cavity losses, denoted by the dotted line in Fig. 2. As the mode-locked pulse transits the SOA, its gain depletes again below the loss line, to recover slowly before the next external or mode-lock pulse enters it. This mechanism results in a temporal displacement between the external and mode-locked pulses in the SOA [40]. From Fig. 2, it can be seen that after two recirculations, the mode-locked pulses are on average equally amplified due to the temporal displacement, resulting in no pulse-to-pulse pattern distortion. A decrease of the external-pulse energy or an increase in the SOA gain results in higher gain in front of the mode-locked pulse that consequently shifts it toward the first external pulse [40]. Similarly, an increase in the external-pulse energy or a decrease of the SOA gain has the opposite effect, with the mode-locked pulse trailing toward the second external pulse. In either case, the width of the mode-locked pulse increases. The most important parameters that are crucial in the formation of the mode-locked pulse for any repetition frequency are mainly the cavity loss, the pulsewidth, average power of the external pulsetrain, and the small signal gain of the SOA [41]. The SOA carrier lifetime is not crucial in the sense that gain recovery is independent of the pulse energy and pulsewidth.

In Section III, eight times rate multiplication is demonstrated, using the aforementioned ring laser platform and applying the rational harmonic mode-locking technique. In addition, multi-wavelength operation is also presented, employing a comb-generating filter in the cavity and, thus, obtaining either 48-CW lines or ten simultaneously mode locked at 30-GHz repetition rate wavelength channels. In either case, at no time is a pulsetrain loss observed as a result of the gain modulation, instead of loss modulation, and the short cavity length due to the avoidance of intracavity EDFAs or polarization sensitive components.

III. Experimental Results

A. Single Wavelength Operation

In this section, experimental results from the semiconductor fiber laser source, in single wavelength operation, are shown. The source is capable of providing nearly transform-limited 2.5-ps pulses up to 40 GHz over a 20-nm tuning range and is nearly environmentally insensitive. With the external power adjusted so that 2.0-mW average optical power is injected in the cavity and the frequency of the external pulsed signal tuned to a harmonic of the cavity, the ring laser breaks in mode-locked operation at the same frequency. The extra frequency chirp that results primarily from the saturation of the SOA was compensated using dispersion-compensation fiber (DCF), placed at the laser output.

In order to n-times multiply the repetition rate of the output pulses, the frequency of the external signal is detuned by $1/n$th of the fundamental frequency of the cavity. Fig. 3(a) and (b) shows two optical pulse streams obtained from the fiber ring laser at 30 and 40 GHz, monitored at a 40-GHz sampling oscilloscope. Fig. 3(c) and (d) displays the corresponding autocorrelation traces, while Fig. 3(e) and (f) shows the corresponding optical spectrums. The small variation in the amplitude of the autocorrelation traces is due to the small but not negligible pulse-to-pulse amplitude modulation. The autocorrelation traces were fitted with a hyperbolic secant profile and pulse duration of 2.5 ps was derived. The indicated pulsewidth–bandwidth product of the mode-locked pulse was

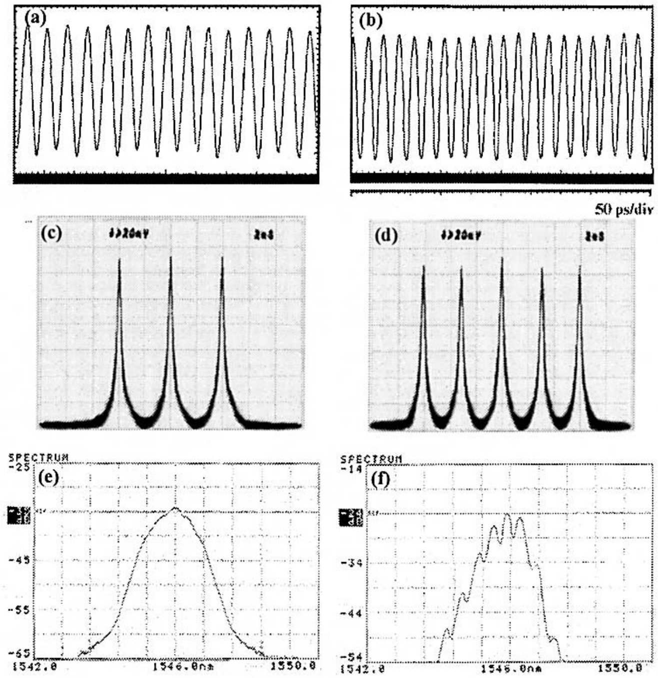

Fig. 3. (a) and (b) Optical pulse train at 30 GHz and 40 GHz repetition rate. (c) and (d) Corresponding autocorrelation traces. (e) and (f) Corresponding optical spectrums.

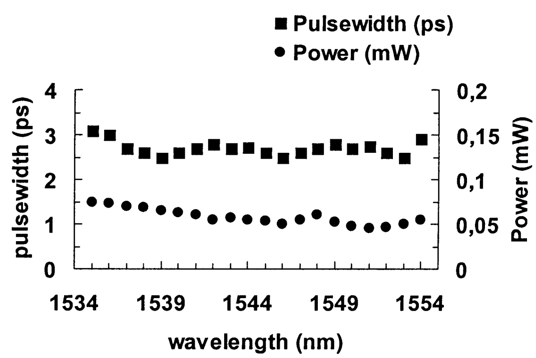

Fig. 4. Tuning curves for pulsewidth and average power of the mode-locked pulses at 40-GHz repetition rate.

found to be 0.34 and 0.35, respectively, close to that of a transform-limited squared hyperbolic secant profile.

One significant advantage that stem from the use of SOAs as the gain medium is the broad wavelength tunability that can be obtained [24], [42], [43]. Fig. 4 shows the change of the pulsewidth and the average optical power of the mode-locked source at a 40-GHz repetition rate, indicating a nearly constant pulsewidth and average power across a 20-nm tuning range. Similar tuning curves were also obtained at lower operating rates.

It was observed that by increasing the pulse energy of the external pulses in combination with an increase in the SOA current, it was possible to obtain shorter pulses from the cavity. This is a consequence of the stronger gain saturation and stronger nonlinear interaction of the mode-locked pulsetrain with the external optical signal, which subsequently results in shorter pulses. Fig. 5 shows the variation of the pulsewidth after compression with the DCF and the bandwidth of the mode-locked

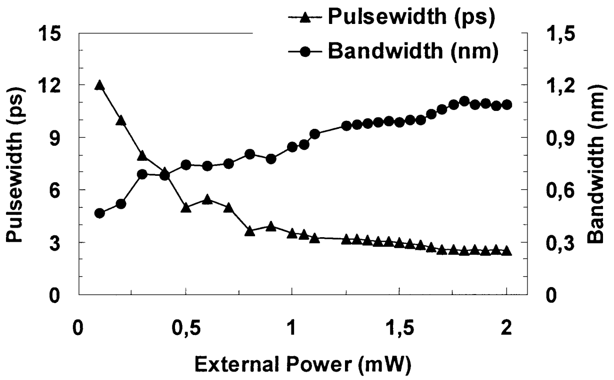

Fig. 5. Variation of the pulsewidth and bandwidth of the mode-locked pulses against the external pulse power.

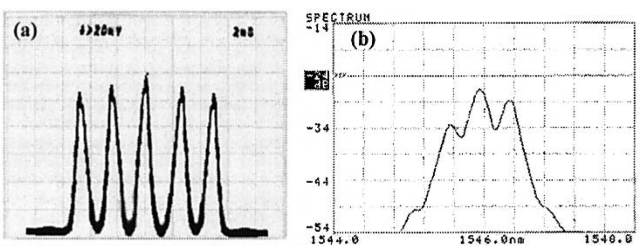

Fig. 6. (a) Second-harmonic autocorrelation trace obtained at 50 GHz, showing a 3.2-ps pulse, assuming a hyperbolic secant profile. Time base corresponds to 16.6 ps. (b) Optical spectrum of the mode-locked pulses at 50-GHz repetition rate.

pulses as the average power from the external signal is increased up to 2.0 mW for 40-GHz operation. The figure indicates that the output pulses are approximately transform limited for an average power of the external pulses between 1.8–2.0 mW.

It is worth noticing here that for obtaining higher repetition rate pulses, the power of the external signal had to be further increased. However, this results in even lower energy per mode-locked pulse, which in turn cannot supersede the linear cavity losses. The highest repetition rate obtained from the ring laser with a sufficiently high extinction ratio was 50 GHz. Therefore, by detuning the frequency of the external signal by 1/10th and slightly increasing its optical power, a 50-GHz pulsetrain is obtained. Fig. 6(a) and (b) displays the second-harmonic autocorrelation trace obtained at 50 GHz, showing a 3.2-ps pulse duration and the corresponding optical spectrum.

Alternatively, operation of the laser source can be extended to higher frequencies, when longer SOAs are employed in the cavity that exhibit a higher small signal gain and a significantly shorter recovery time. However, when not combined with shorter input pulses, it is has been verified experimentally that the use of longer SOAs results in a significant deterioration of the laser performance. This is primarily due to the fact that mode-locked pulses experience the fully recovered SOA gain and do not have adequate energy to deplete its carriers. This was particularly observed at operating frequencies up to 20 GHz by the significantly higher output power of the laser source and higher input power required to achieve mode locking. In even higher operating rates, above 20 GHz, the excess energy in the cavity prohibited mode locking, resulting

TABLE I
RING LASER PERFORMANCE RESULTS FOR VARIOUS SOAs

SOA Length (mm)	Small signal gain (dB)	Recovery time (ps)	Max. Freq. (GHz)	Min. Pulsewidth
0.5	23	400	50	2.5
0.5 (MQW)	21	120	40	2.7
1.0	28	120	25	3.5
1.5	30	80	15	3.2

in a high peak-to-background ratio of the mode-locked pulses. Table I summarizes the results obtained with different length and type of SOAs.

Performance degradation of the mode-locked semiconductor fiber laser is due to: 1) rotation of the polarization state of the optical field owing to environmental change, resulting in degradation of the performance of polarization sensitive devices and 2) cavity-length drift owing to the temperature dependence of the refractive index of glass. In order to examine the dependence on the polarization state of both external and recirculating signals, we adjusted both controllers away from their optimum position. This resulted in a variation of as much as 20% in the output power and a 25% pulse broadening, but at no time was there a mode-locked pulsetrain loss. This variation represents mild degradation of the performance of the system and is due to the low polarization gain dependence of the SOA in the saturated regime. Clearly, a polarization-independent SOA would remove this variation altogether. To examine the sensitivity of the oscillator to temperature variations we measured the RF bandwidth over which the pulsewidth of the mode-locked pulses is degraded by 25%, as the repetition frequency of the external pulsetrain was varied. This bandwidth was found to be 150 kHz, corresponding to 1.7-ps variation in the round-trip time of the ring cavity. By comparison, the differential time delay in the cavity round-trip time due to the temperature dependence of the refractive index in the core of the fiber is only 0.6 ps, with a 2 °C temperature variation, assuming a 20 ps/km·°C temperature-dependent differential delay coefficient for the fiber.

B. Multiwavelength Operation

In this section, we present experimental results of the multiwavelength operation of the semiconductor fiber laser source. For multiwavelength operation, a Fabry–Pérot etalon was inserted in the cavity. In CW operation, the intention was to obtain as many as possible oscillating lines, while in mode-locked operation to obtain the shortest possible pulses. To this end, an FP filter with a finesse of 12 and 50 GHz spacing and one with a finesse of 4.5- and 225-GHz line spacing were used for the CW and the mode-locked operation, respectively.

1) Continuous Wavelength Operation: In CW operation, oscillation occurs at slightly longer wavelengths for the high gain axis as opposed to its low gain axis. This is primarily due to the polarization gain dependence of the SOA and the high, close to the maximum permissible current that the SOA is driven. To this end, by coupling the signal to both gain axes it is possible to extend the oscillating bandwidth. Furthermore, bandwidth extension in combination with line power equalization

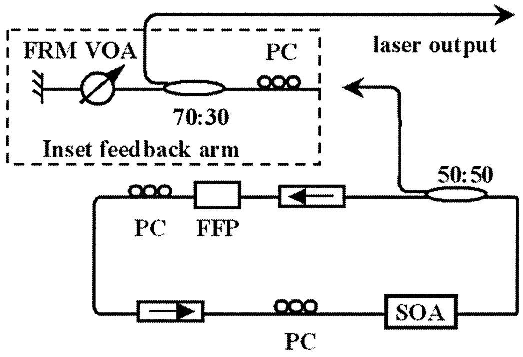

Fig. 7. Experimental setup of the semiconductor-based fiber laser optimized for CW operation. Inset shows the single-pass optical feedback arm.

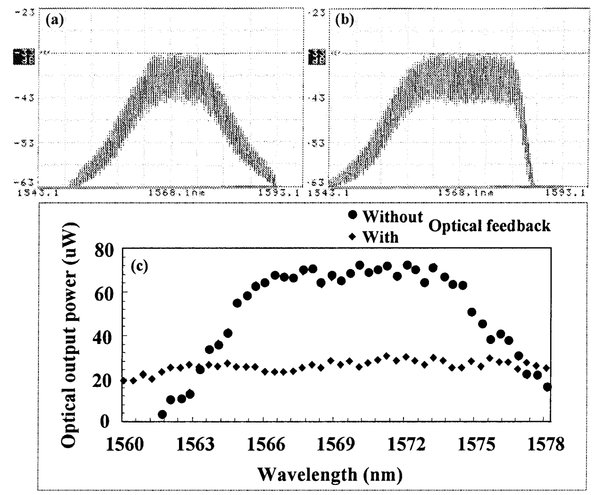

Fig. 8. Optical spectrum: (a) without and (b) with optical feedback (sweep width 5 nm/div). (c) Corresponding power distribution of output wavelengths.

can be achieved using an optical feedback technique, as detailed in [43]. Fig. 7 shows the modified experimental layout of the cavity, optimized for multiwavelength operation. Gain was provided again by a 500-μm-long bulk SOA with a 3-dB gain bandwidth close to 30 nm. The intracavity FP filter used had a finesse of 12- and 50-GHz line spacing. Inset of Fig. 7 shows the optional feedback path, which was used to further extend the oscillating bandwidth and equalize the oscillating spectrum. 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 the SOA only once and is stopped by the isolators. To this end, power equalization is possible when the laser output is used as the saturating signal in the opposite direction to the lasing signal. 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 driving current of the SOA, as well as 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. 8(a) and (b) displays the oscillating spectra of the source with the optical feedback turned "off" and "on," respectively. In particular, Fig. 8(a) shows 25 central lines spanning across a 10-nm bandwidth with a nearly equal mean power of 75 μW and less than 0.5-dB standard deviation as shown in Fig. 8(c).

With the injection of 220 μW of signal into the SOA from the feedback arm, the power spectrum equalizes and broadens to nearly 20 nm so that it consists of 48 oscillating wavelengths as seen in Fig. 8(b). The average power per line was found to be 25 μW with a standard deviation of 0.3 dB, as shown in Fig. 8(c). The driving current of the SOA was adjusted at 245 and 217 mA for optimum operation with the optical feedback path turned off and on respectively. The polarization state of the oscillating lines was examined in a polarization state analyzer, adjusting the polarization controller placed in the feedback path. It was found that all wavelengths showed greater than 97% degrees of polarization and were nearly linearly polarized even though not in the same plane.

The linewidth of the oscillating lines was also measured from the beat spectrum of the cavity modes on an RF spectrum analyzer. To this end, 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 fiber Fabry–Pérot 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. The multiwavelength source, operating in CW mode, can be used for passive or active component characterization as a relative inexpensive solution.

2) Mode-Locked Operation: The multiwavelength signal obtained previously cannot be mode locked, to obtain short multiwavelength pulsetrains at high repetition rates. This is primarily due to the narrow linewidth of the oscillating lines ($\sim$500 MHz), which does not allow the generation of short picosecond pulses and the application of the rational harmonic mode-locking technique. Therefore, the narrow FP filter was replaced with a broader one that exhibits 50-GHz linewidth and 225-GHz free spectral range. To this end, in the experimental setup of Fig. 7, the feedback path was omitted, the FP filter was replaced, and the external 5-GHz pulsed signal was introduced via a 30:70 fused fiber coupler.

Mode-lock operation is achieved with the external 5-GHz gain-switched signal turned on and its frequency tuned to a harmonic of the ring cavity. Thus, the source mode locks simultaneously at those wavelengths that experience the highest gain in the cavity. Again, by increasing the frequency of the signal generator away from this value by $1/n$th of the fundamental frequency of the ring cavity, the repetition rate of the simultaneously mode-locked channels is multiplied by n.

With these arrangements, it was possible to simultaneously mode-lock 10 wavelengths up to 30 GHz. In that case, the EDFA was adjusted to provide 1.6 mW of optical power inside the cavity. Fig. 9(a) shows the optical spectrum of the mode-locked output from the laser, showing the ten simultaneously mode-locked wavelengths at 30 GHz. The output pulses were 12-ps long and were not transform limited due to

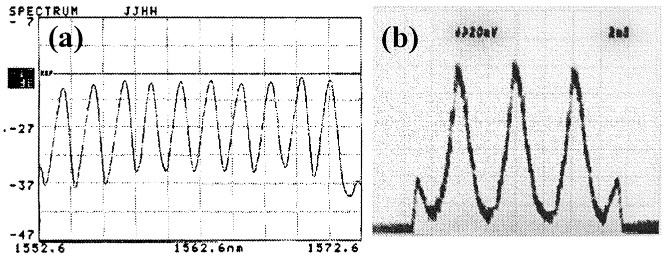

Fig. 9. (a) Spectrum of multiwavelength laser in mode-locked operation at 30 GHz. (b) Autocorrelation trace, corresponding to 6.7-ps pulsewidth. Time base in the trace corresponds to 16.6 ps.

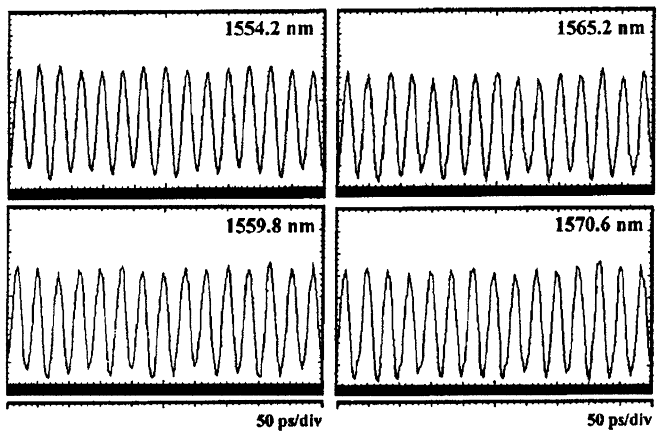

Fig. 10. Simultaneous pulse train for four wavelengths. Time base is 50 ps.

the frequency chirp imposed on them by the refractive index change of the SOA from its fast time-dependent saturation. Subsequently, these were linearly compressed with dispersion compensating fiber of total dispersion -14.25 ps/nm and were filtered with a tunable optical bandpass filter of 0.6-nm width before detection. Fig. 9(b) shows the second harmonic autocorrelation trace of the pulse train obtained at 1568.8 nm, indicating a 6.7-ps pulse duration assuming a squared hyperbolic secant profile. It was not possible to obtain good quality pulse trains for repetition rates beyond 30 GHz primarily because of the length of the recirculating mode-locked pulses and the external pulses.

Fig. 10 displays the mode-locked pulse trains, not time averaged, after filtering at $\lambda_1 = 1554.4$ nm, $\lambda_2 = 1559.8$ nm, $\lambda_3 = 1565.2$ nm and $\lambda_4 = 1570.6$ nm monitored on a 40-GHz sampling oscilloscope and shows temporal synchronization between them. Fig. 11(a) displays the variation of the pulsewidth and the pulsewidth–bandwidth product for each mode-locked wavelength. This figure shows that the pulsewidths for all ten wavelength pulse trains are within 4% of 7 ps. In addition, this figure shows that the pulsewidth–bandwidth products for all pulse trains are within 3% of 0.35, indicating that the pulses profiles are all close to the squared hyperbolic secant. It is worth noting here that the composite autocorrelation trace of the ten-wavelength pulsetrains revealed the same pulsewidth as each of the individual wavelengths, confirming their temporal synchronization. Fig. 11(b) shows the output power for each the mode-locked wavelengths indicating less than 5% variation across them. It is worth noticing from Fig. 11

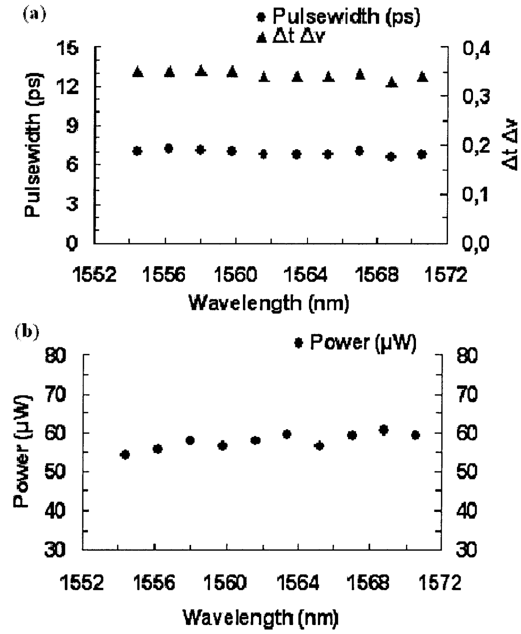

Fig. 11. (a) Variation of the pulsewidth and pulsewidth–bandwidth product versus wavelength. (b) Variation of the output power versus wavelength.

that all the mode-locked channels have nearly similar time and spectral characteristics. This is an important feature of the laser source, especially when used in OTDM/WDM transmission systems. It is worth noticing here that the use of an FP filter with a free spectral range equal to an integer multiple of the desired repetition rate would improve performance in terms of pulsewidth and possibly in terms of output power. Thus, "in principle," each of the simultaneous mode-locked channels would have the same spectral and time characteristics obtained in the single-wavelength mode of operation.

IV. Conclusion

In this paper, we presented a semiconductor fiber laser platform used to obtain short optical pulses at high repetition rates. The laser operated in both single-wavelength and multiwavelength mode. A key feature of this source that differentiates it from other similar implementations is that it uses a single active element in the optical cavity, an SOA, to provide both gain and gain modulation. Gain modulation is achieved by injecting an optical pulsed signal that periodically saturates the SOA gain.

Using this laser source, it was possible to obtain picosecond optical pulsetrains at repetition rates up to 50 GHz applying the rational harmonic mode-locking technique for rate multiplication. The laser source exhibits a 20-nm tuning range across which output pulses and average output power is nearly constant. Furthermore, the same laser source was used for multiwavelength generation, obtaining either 48 oscillating lines under CW operation mode or ten wavelength channels, each one with a 30-GHz repetition rate under mode-locked operation. It is worth noticing here that all the aforementioned results were obtain using a relative low rate optical signal and, thus, with low-cost RF electronics.

The presented laser source is suitable for hybrid OTDM/WDM optical networks and especially applicable to WDM networks or even for passive/active component characterization to replace an equivalent number of discrete laser sources or tunable laser sources. Unique features of the source are the broad tuning range, across which pulsewidth and output power is nearly constant and when used for multiwavelength signal generation, the identical spectral and time characteristics of the simultaneously mode-locked wavelengths. Finally, it is worth noticing that the presented ring oscillator possesses the integration capability, as shown in [44], due to the relative simple fiber cavity, avoiding long EDFAs for signal amplification.

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