Downstream Transmission in a WDM-PON System Using a Multiwavelength SOA-Based Fiber Ring Laser Source

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***Abstract*— We have demonstrated the application of a multiwavelength fiber ring laser as a cost-effective light source for wavelength-division-multiplexed passive optical networks for the first time. The performances of the system for downstream signal are experimentally investigated. We have achieved error-free transmission over 17 km of dispersion-shifted fiber at a bit rate of 1.25 Gb/s per channel.**

***Index Terms*— Optical fiber communications, Optical access, Passive optical networks, wavelength-division-multiplexing applications, Optical fiber lasers.**

I. INTRODUCTION

THE growth of the Internet is exponential worldwide. The type of transmitted information has changed from voice to multimedia and the amount of information is always increasing. The end users are attracted by the numerous and versatile emerging applications, such as high-definition videoconferencing, video-on-demand, high-definition television, e-learning, or high-quality audio transmission. To deliver these integrated services effectively and at affordable prices, providers strive to implement new technologies.

The use of wavelength-division-multiplexing (WDM) techniques in passive optical networks (PONs) appears to be a promising candidate to solve the bottleneck problem of broadband access for business and residential customers. WDM-PON is an attractive method to deliver high bandwidth services to the premises. This technology has the potential for large capacity, easy management, protocol transparency and upgradeability [1], [2]. However, for practical implementation, deployment costs of such systems have to be reduced. To overcome these economical considerations, several WDM-PON architectures have been proposed, particularly focusing on the development of cost-effective WDM sources. To offer services economically, the optical line terminal (OLT) installed in the central office needs to be able to accommodate as many subscribers as possible and as efficiently as feasible.

A straightforward solution consists of using an array of distributed feedback (DFB) lasers. However, this method is very expensive, especially when increasing the number of subscribers and of wavelengths. To reduce these costs, the use of optical carrier suppression and separation technique has been proposed [3]. Even if the number of DFB lasers is divided by two with this technique, problems of maintenance and inventory still remain when the number of customers increases. Recently, different techniques have attracted a lot of attention: spectrum-slicing using a broadband incoherent light source such as a light-emitting diode (LED) [4], [5] and amplified spontaneous emission (ASE)-injected uncooled Fabry-Perot laser diodes [6], [7]. While the first solution suffers from low power and high packaging costs, the last one still has problems regarding the wavelength locking under thermal drift of its lasing wavelengths over wide temperature range.

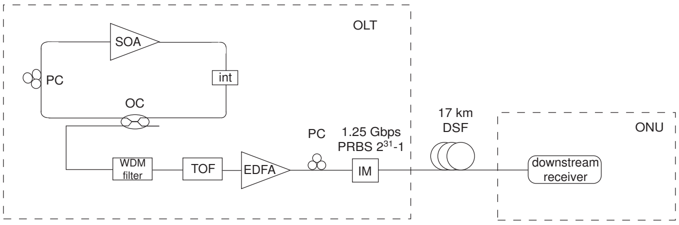

Fig. 1. Experimental set-up (PC: polarization controller, SOA: semiconductor optical amplifier, Int: interleaver, TOF: tunable optical filter, EDFA: erbium-doped fiber amplifier, IM: intensity modulator, OC: output coupler, DSF: dispersion-shifted fiber).

In this letter, we investigate a semiconductor optical amplifier (SOA)-based continuous-wave multiwavelength fiber ring laser to produce more than 40 wavelengths with 50-GHz spacing. Using this simple light source, we experimentally report and demonstrate error-free downstream transmission of 1.25 Gb/s signal per channel over 17 km of dispersion shifted fiber (DSF).

II. EXPERIMENTAL SET-UP

Fig. 1 illustrates the configuration of the WDM access system considered in our experiment. In the OLT, the light source is a multiwavelength fiber ring laser. This WDM source is composed of an SOA as gain medium, a 25/50 GHz interleaver, a polarization controller and a 50/50 output coupler. Compared to erbium-doped fiber amplifiers, SOAs have a dominant property of inhomogeneous broadening, which makes the multiwavelength generation possible. Due to SOAs broad gain spectrum, a large number of different wavelengths can oscillate simultaneously [8]. The interleaver acts as a comb filter with a periodic spectral transfer function. Its free spectral range determines the oscillating wavelength spacing.

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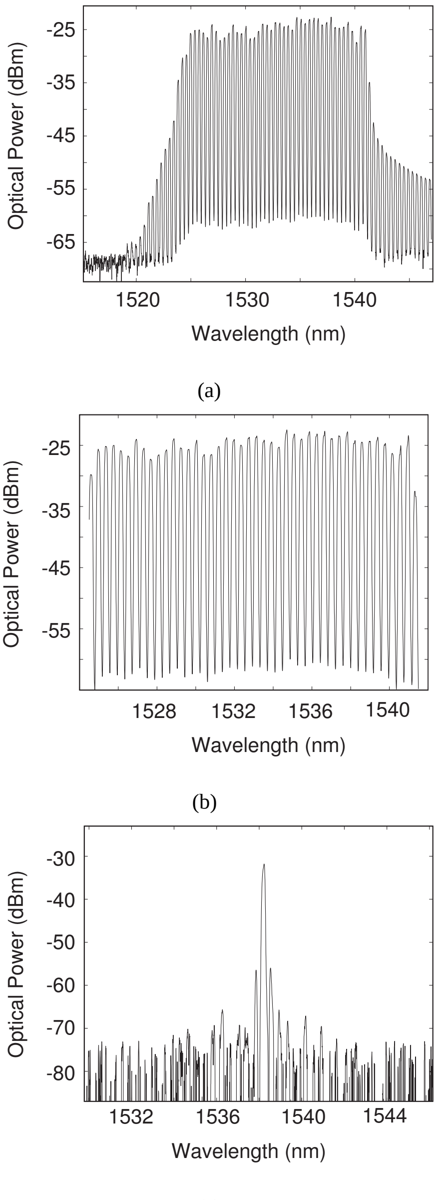
Before downstream transmission, only one wavelength is selected by a tunable optical filter. This wavelength is dedicated to a specific customer. This optical channel is amplified at the output of the bandpass filter before being externally modulated. The polarization is controlled to achieve maximum efficiency. At the output of the OLT, the signal is transmitted through the fiber. In our experiment, we used 17 kms of DSF. By using this type of fiber instead of single mode fiber (SMF), we improve the system performance by overcoming the dispersion effect. At the optical network unit (ONU), a PIN receiver is employed.

III. RESULTS AND DISCUSSION

To obtain a cost-effective light source for WDM-PON, the multiwavelength SOA-based fiber ring laser should be able to produce as many wavelengths as possible to accommodate a maximum number of customers at the premises. In our experiment, when the SOA bias current is set to 200 mA and the operation temperature is 20.5 C, the center wavelength of the amplified spontaneous emission for the SOA is located at 1455 nm with a 3-dB bandwidth of 60 nm, a small-signal gain of 22 dB, a saturation output power of 12.7 dBm, a polarization dependent gain of 0.3 dB and a noise figure of 5.6 dB at 1528 nm for an input signal power of -25 dBm. Using this layout, over 40 simultaneous wavelength lasing oscillations with a frequency separation of 50 GHz are observed, as shown in Fig. 2 (a) and (b). The spacing of 50 GHz between two successive wavelengths is imposed by the interleaver. The optical signal-to-noise ratio with the optical spectrum analyzer resolution of 0.1 nm is measured to be greater than 35 dB for all the different channels. The linewidth of the generated oscillations is 0.12 nm. Because of this large value, the transmission will suffer from chromatic dispersion. The state of polarization of light in the laser cavity has to be carefully adjusted to obtain a flat laser spectrum and also to optimize the number of emitted wavelengths. In our experiment, the multiwavelength laser output powers have good flatness even though we can observe a small power variation across the 42 wavelengths. A WDM filter is used to obtain a flat spectrum around the C band. The total output power is 3.4 dBm before the WDM filter and -2.2 dBm after. The laser output remains very stable for several hours in laboratory conditions, as are the different multiwavelength laser output powers. We can notice that a wider spectrum can be observed for a higher bias current. However, with small current changes around 200 mA, the performance of the source does not depend critically on the bias current.

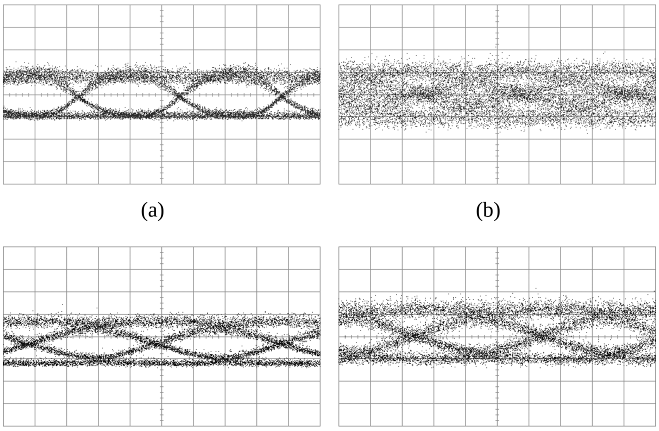
A tunable optical filter (TOF) with a bandwidth of 0.25 nm selects one wavelength (λ_1=1538.1 nm) to be amplified by an erbium-doped fiber amplifier and externally modulated by a $LiNbO_3$ intensity modulator with a 1.25 Gb/s NRZ pseudorandom binary sequence (PRBS) of length 2^{31}-1. The signal power is -25.6 dBm after the TOF and 12.7 dBm after the EDFA. The measured downstream spectrum is shown in Fig. 2(c). The downstream signal is then transmitted to the ONU through 17 km of DSF to counteract the effects of dispersion. The dispersion of this fiber is 1 ps/nm/km at 1538 nm. At the entrance of the feeder fiber, the measured signal power is 2.3 dBm. At the access node, a downstream PIN optical receiver with a 2 GHz bandwidth is used.



(c)

Fig. 2. (a) Laser output spectrum measured after the WDM filter (spectral resolution of 0.01 nm). (b) Expanded laser spectrum of (a) showing over 40 simultaneous wavelength lasing oscillations. (c) Selected wavelength for downstream transmission before the EDFA.

Back-to-back and downstream transmission eye diagrams are shown in Fig. 3. We present two situations with two different kinds of feeder fiber. Fig. 3(a) and (b) show the eye diagram obtained for back-to-back and after transmission over 20 km of conventional SMF-28 at a bit-rate of 622 Mb/s. In this case, we can notice that the influence of dispersion is large. Fig. 3(c) and (d) also show the eye patterns obtained in a back-to-back configuration and when 17 km of DSF is used at a bit rate of 1.25 Gb/s. We can easily observe the benefits of DSF: it overcomes the dispersion effect and consequently decreases the distortions. To investigate the system dependency on the


(a) (b)

(c) (d)

Fig. 3. Eye diagrams measured for (a) back-to-back (500 ps/div) and (b) downstream transmission through 20 kms of SMF (500 ps/div) at a bit rate of 622 Mb/s. Eye diagrams for (c) back-to-back (200 ps/div) and (c) downstream transmission through 17 kms of DSF (200 ps/div) at a bit rate of 1.25 Gb/s.

distribution fiber between the OLT and the ONU in the case of downstream transmission through DSF, we inserted a variable attenuator before the optical receiver. The measured BER curves are presented in Fig. 4. The curve obtained after transmission through 17 km of DSF reveals a power penalty of 1.1 dB at a BER of 10^{-9} when compared with the back-to-back case.

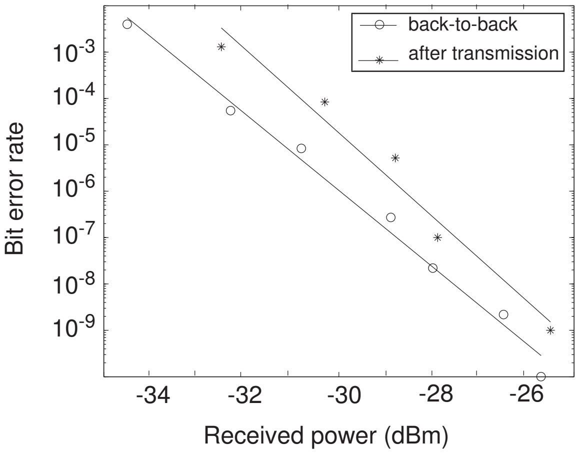


Fig. 4. Measured bit-error-rate curves.

Compared to the PONs architectures employing many laser sources at the OLT, the proposed solution is more cost-effective since it replaces multiple fixed-wavelength lasers by a simple multiwavelength fiber ring laser. It also implies less maintenance and less inventory. To the best of our knowledge, the use of SOA-based multiwavelength fiber ring laser for WDM-PON is shown for the first time. We were able to transmit 1.25 Gb/s signal per channel. However, to increase the bit rate or the transmission distance, the generated channel linewidth appears as a limitation of our system. Indeed, the transmission suffers from dispersion and so requires the use of DSF in our experiment. Reducing this linewidth would make it possible to transmit the signal through conventional SMF instead of DSF. In fact, we are still investigating how to reduce the linewidth. Our experimental results show that optimization of the cavity losses can result in a broader, more uniform spectrum. To improve the spectral flatness, a gain-equalizing filter can be added in the cavity. In order to further simplify the set-up of the multiwavelength source, a single uncoated SOA can be used to simultaneously provide both gain medium and comb filtering in the ring cavity [8].

This multiwavelength fiber ring laser could also be used as a centralized light source at the OLT for a low-cost implementation of a bidirectional WDM-PON. In this case, a solution can be to dedicate two specific wavelengths for each ONU. One wavelength will be modulated at the OLT for downstream transmission, whereas the other one will be delivered and modulated at the receiver side to provide upstream transmission [3]. It will thus relax the wavelength management required at the ONU side.

IV. CONCLUSION

We have proposed and experimentally investigated the use of a SOA-based multiwavelength fiber ring laser as light source for a WDM-PON. This configuration has generated more than 40 wavelengths with 50-GHz spacing. In the proposed network, we have demonstrated error-free downstream transmission over 17 km of DSF at a bit rate of 1.25 Gb/s per channel and the power penalty at a BER of 10^{-9} is 1.1 dB. The high simplicity and cost-efficiency of this type of source make it suitable for applications in access networks.

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LIST OF CAPTIONS

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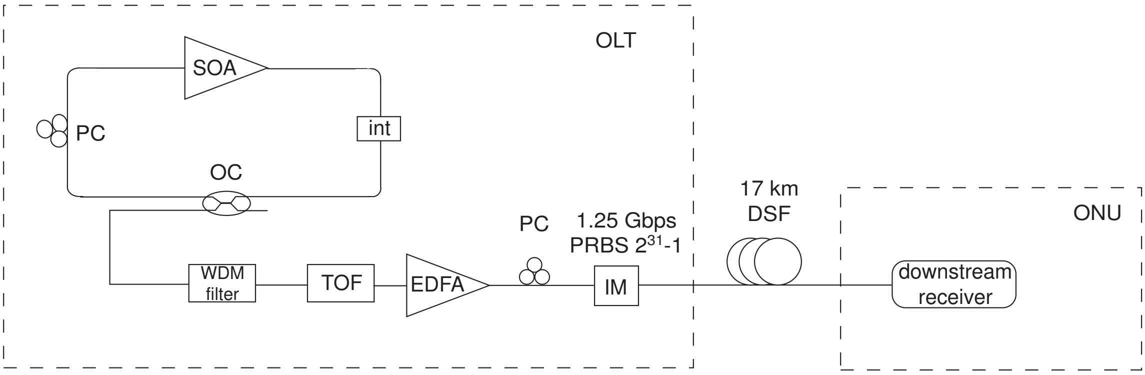
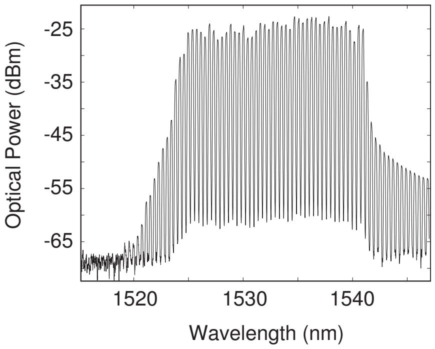
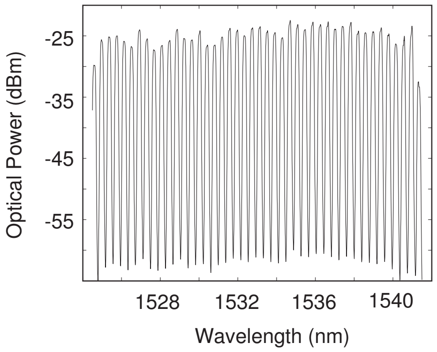
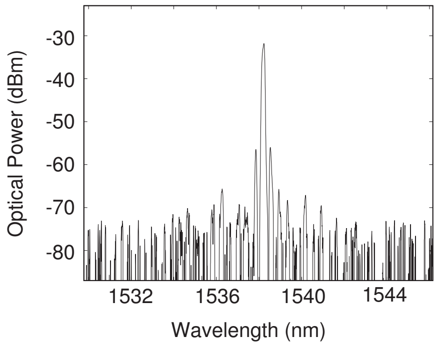

OLT
SOA
PC
int
OC
WDM filter
TOF
EDFA
PC
1.25 Gbps
PRBS 2^{31}-1
IM
17 km
DSF
ONU
downstream receiver


-25
-35
-45
-55
-65
Optical Power (dBm)
1520
1530
1540
Wavelength (nm)

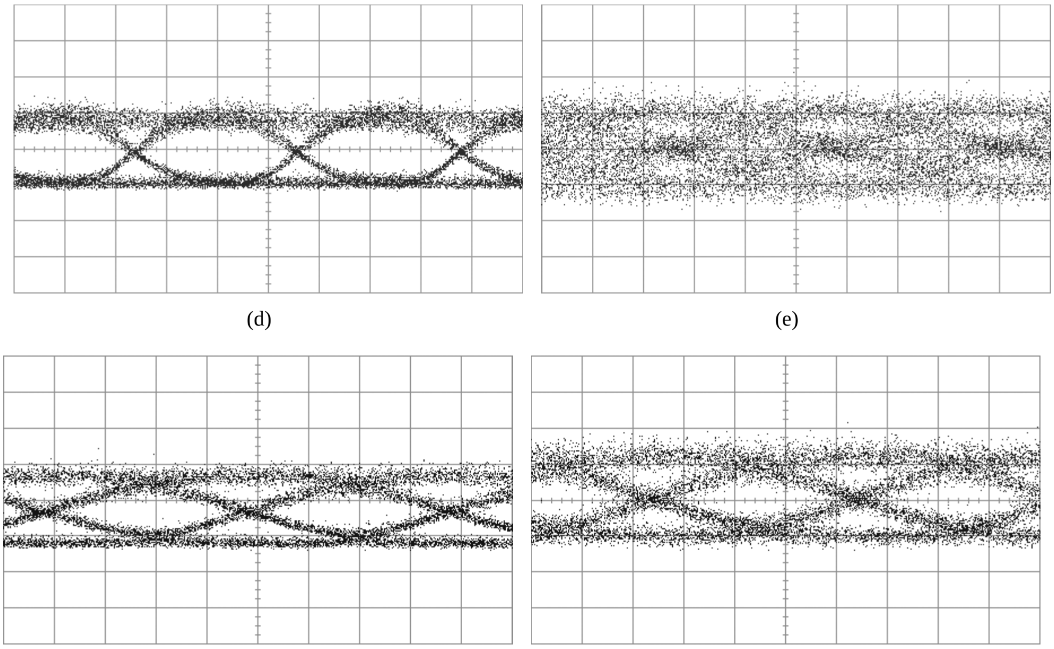
(a)


-25
-35
-45
-55
Optical Power (dBm)
1528
1532
1536
1540
Wavelength (nm)

(b)

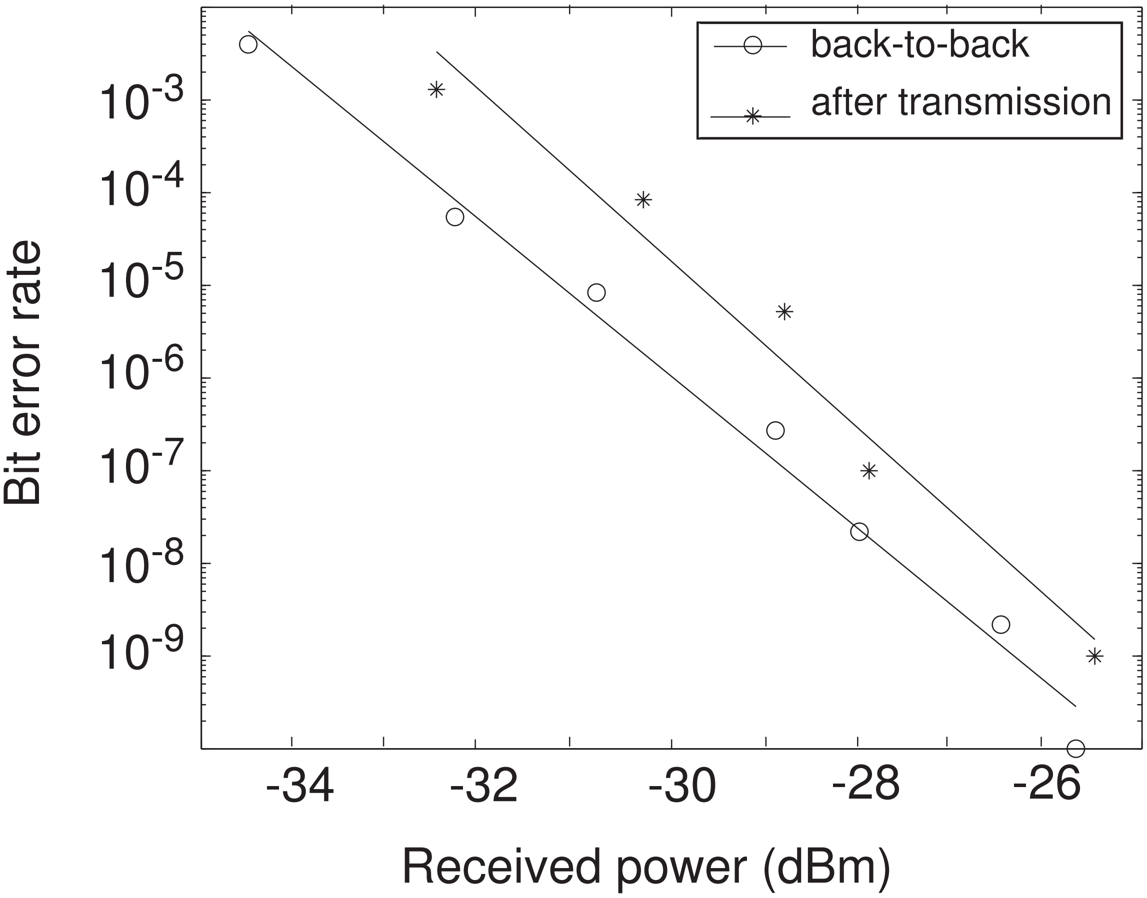

-30
-40
-50
-60
-70
-80
Optical Power (dBm)
1532
1536
1540
1544
Wavelength (nm)

(c)



(d) (e)

(f) (g)


back-to-back
after transmission
10-3
10-4
10-5
10-6
10-7
10-8
10-9
Bit error rate
-34
-32
-30
-28
-26
Received power (dBm)