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Ultra-Dense WDM PON with 12.5-GHz Spaced 256 Channels

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We demonstrate an ultra-dense wavelength-division- multiplexed (UD-WDM) passive optical network (PON) where 12.5-GHz spaced 1 GbE × 256 optical channels are distributed using 12.5- and 200-GHz arrayed waveguide gratings in series. For the generation of upstream signals, we use reflective semiconductor optical amplifiers. We use two optical fiber amplifiers at the optical line terminal to amplify downstream and upstream channels.

Keywords : Passive optical network, Ultra-dense wavelength-division-multiplexing, Reflective semiconductor optical amplifier

OCIS codes : (060.0060) Fiber optics and optical communications; (060.4250) Networks; (060.4510) Optical communications

I. INTRODUCTION

As high-capacity video and data services contribute more dominantly to passive-optical-network (PON) traffic, conventional time-division-multiplexed (TDM) PONs will evolve to wavelength-division-multiplexed (WDM) PONs [1]-[3]. For WDM PONs in highly populated areas, many PONs are required, increasing the net cost. Thus it will be more economical to increase the number of optical channels for each PON. With plenty of optical channels, it will be advantageous to use optical amplifiers with low additional costs per channel. Since the gain bandwidths of optical amplifiers are finite, the channel spacing will be very narrow yielding ultra-dense (UD) WDM PONs [4].

In this paper, we demonstrate an UD-WDM PON that supports 12.5-GHz spaced 256 channels. We use distributed feedback (DFB) laser diodes with 12.5-GHz channel spacing for downstream channels. The downstream channels are reused as upstream channels using reflective semiconductor optical amplifiers (RSOAs). We use 12.5-GHz and 200-GHz arrayed-waveguide-gratings (AWGs) in series to distribute UD-WDM channels.

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II. EXPERIMENT

Our experimental setup for the 12.5-GHz spaced 256 channel UD-WDM PON is shown in Fig. 1. The optical line terminal (OLT) had 256 DFB laser diodes whose output wavelengths ranged from 1537.4 to 1562.9 nm. Four 50-GHz AWGs and three 3-dB couplers were used to multiplex the laser diode outputs into the first erbium-doped fiber amplifier (EDFA1). The EDFA1 had a total output power of 23 dBm.

During the performance measurement of each channel,

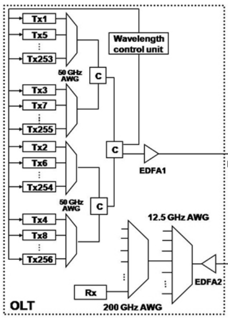
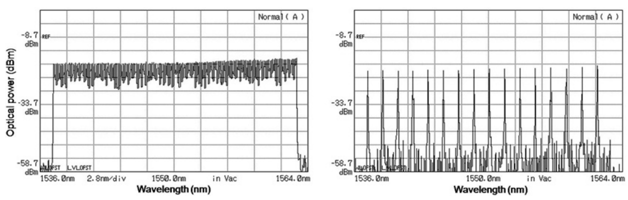
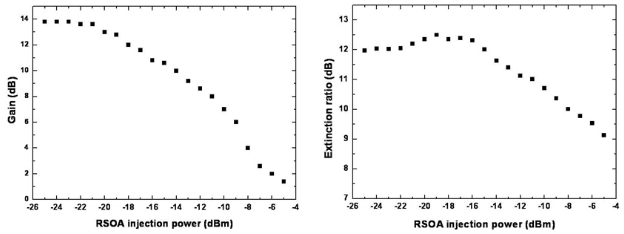


FIG. 1. Experimental setup of the UD-WDM PON. AWG: Arrayed Waveguide Grating, C: Coupler, EDFA: Erbium-Doped Fiber Amplifier, OC: Optical Circulator, OLT: Optical Line Terminal, ONU: Optical Network Unit, RN: Remote Node, RSOA: Reflective Semiconductor Optical Amplifier, Rx: Receiver, SMF: Single Mode Fiber, VOS: Variable Optical Splitter, Tx: Transmitter



(a) (b)

FIG. 2. Optical spectrum. (a) 256 WDM channels. (b) 16 channel group.



(a) (b)

FIG. 3. RSOA characteristics. (a) optical gain. (b) extinction ratio.(input light source: not modulated, 1550 nm)

only the channel under test plus its nearest two channels were directly modulated. We used a 2^7−1 pseudorandom-bit sequence in 1.25 Gb/s bit rate for the channel modulation to simulate the 1 GbE signal. We used two different modulation patterns, one was for the channel under test and the other was for the nearest two channels. The modulated channels had a 20-dB linewidth of around 16-GHz. The powerpenalty by the crosstalks between adjacent channels was negligibly small, 0.08 dB. All the channel wavelengths were monitored using a wavelength meter. A control circuit aligned the channel positions within ±400-MHz errors adjusting laser diodes temperatures.

We used two feeder fibers to suppress the coherent crosstalks between downstream and upstream channels. Conventional single mode fibers (SMFs) of 15 km were used as feeder fibers. At the first remote node (RN1), a 1×8 12.5-GHz AWG divided the 256 UD-WDM channels into 8 channel groups. The channel spacing in each group was 200-GHz, the free spectral range (FSR) of the 12.5-GHz AWG. The channel number per group was 16. The 12.5-GHz AWG had a 2.5-dB loss. The 12.5-GHz AWG does have some errors in its FSR value. The rightmost channel was shifted by 2.4-GHz to meet the AWG's peak in our experiment.

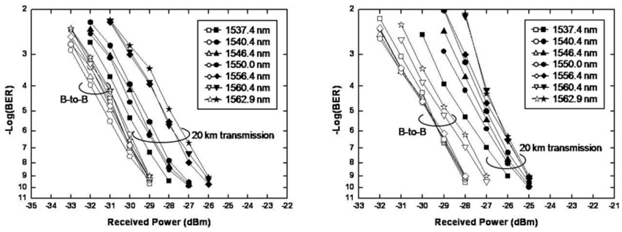
Each channel group was further transmitted over an SMF of 5 km and demultiplexed using a 200-GHz AWG at a second remote node (RN2). The 200-GHz AWG had a 2.5-dB loss. There were no additional fibers between the 200-GHz AWG and the optical network unit (ONU). The optical spectra of 256 WDM channels and a channel group are shown in Figs. 2(a) and (b), respectively.

At each optical network unit (ONU), the downstream optical channel was divided into two paths using a variable optical splitter (VOS). The first path headed for a receiver (Rx). The second path headed for a reflective semiconductor optical amplifier (RSOA) that produced an upstream channel modulated by 1.25 Gb/s [5]. The first path and second path are in the ratio of about 2:8. The RSOA gain for the first channel was 11 dB. The RSOA gain decreased monotonically to 8 dB, as the input channel wavelength was increased. Fig. 3(a) shows the optical gain of the RSOA. The ER values of the RSOA output light are plotted in Fig. 3(b). The input channel was at 1550 nm and was not modulated.

The upstream channels were multiplexed at RN1 and RN2 and transmitted through the second feeder fiber. We used EDFA2 at the OLT to amplify upstream channels. EDFA2 had a 17 dBm output power. The optical signal to noise ratio of a single RSOA output was higher than 35 dB. To simulate the presence of other upstream channels, some the downstream channels were tapped and used as the upstream channel input to EDFA2. When an even channel was under test, odd channels were tapped and vice versa.

III. RESULTS AND DISCUSSION

In Fig. 4(a) and (b), we compare the bit-error rate (BER) for downstream and upstream channels, respectively. A variable attenuator is used between OC and RN1 to change the received optical powers. Downstream and upstream channel BER curves are also sensitive to the channel wavelengths owing to the wavelength dependence of RSOA. The transmission penalties are about 3 and 2 dB for downstream and upstream channels, respectively, with respect to BER=10^{-9}. The received power just before the photodetector is -16.6~-21.8 and -9.5~-16.0 dBm for downstream and upstream channels,



(a) (b)

FIG. 4. BER curves. (a) 1.25 Gb/s downstream channels and (b) 1.25 Gb/s upstream channels.

TABLE 1. Measured margin, extinction ratios (ERs), and RSOA injection powers.
(a) 1.25 Gb/s downstream channels, (b) 1.25 Gb/s upstream channels and (c) RSOA injection powers.

(a)

Wavelength	Margin (dB)	ER (dB)
1537.4 nm	7.1	6.5
1540.4 nm	8.7	6.7
1546.4 nm	9.0	6.6
1550.0 nm	10.1	6.3
1556.4 nm	9.5	6.4
1560.4 nm	9.0	6.3
1562.9 nm	8.0	6.8

(b)

Wavelength	Margin (dB)	ER (dB)
1537.4 nm	6.7	9.5
1540.4 nm	7.9	9.5
1546.4 nm	8.3	9.7
1550.0 nm	9.1	9.8
1556.4 nm	9.7	10.1
1560.4 nm	9.3	10.0
1562.9 nm	6.9	10.3

(c)

Wavelength	RSOA injection power (dBm)
1537.4 nm	-17.3
1540.4 nm	-15.8
1546.4 nm	-14.2
1550.0 nm	-13.3
1556.4 nm	-12.6
1560.4 nm	-11.4
1562.9 nm	-10.5

respectively.

The power margins of downstream and upstream channels are about 7.1~10.1 and 6.7~9.7 dB, respectively. Measured power margin, extinction ratios (ERs) and RSOA injection powers are shown in Table. 1.

Our UD-WDM PON needs a temperature control for the 12.5-GHz AWG at RN1. Since UD-WDM PONs will be used in highly populated areas, it will be easy to use small electrical powers at remote nodes if needed.

Unfortunately, a cyclic 12.5-GHz AWG is not available in our experiment. If a 1×8 cyclic 12.5-GHz AWG is used in RN1, the channel spacing in each group would be 100-GHz and the channel number per group would be 32. The 12.5-GHz AWG in real networks should be designed more carefully to minimize the FSR errors. However, when the UD-WDM PON channels are not routed to other networks, slight changes of the channel spacing can be permitted.

IV. CONCLUSION

We have demonstrated an UD-WDM PON having 12.5-GHz spaced 256 channels. We have used AWGs in series to distribute UD-WDM channels over 20 km. The downstream channels were re-modulated using RSOAs in 1.25 Gb/s. The power margins are more than 7.1 and 6.7 dB for downstream and upstream channels, respectively.

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