Using four wavelength-multiplexed self-seeding Fabry-Perot lasers for 10 Gbps upstream traffic in TDM-PON

Chien-Hung Yeh*[1], Chi-Wai Chow[2], Chia-Husan Wang[2], Fu-Yuan Shih[2], Yu-Fu Wu[3] and Sien Chi[2,3]

[1]*Information and Communications Research Laboratories,*
Industrial Technology Research Institute, Chutung, Hsinchu 31040, Taiwan
[2]*Department of Photonics and Institute of Electro-Optical Engineering,*
National Chiao Tung University, Hsinchu 30010, Taiwan
[3]*Department of Electro-Optical Engineering, Yuan Ze University, Chungli, Taoyuan 32003, Taiwan*
**Corresponding author*: depew@itri.org.tw

Abstract: In this paper, we propose and experimentally investigate a simple self-injection Fabry-Perot laser scheme on each optical network unit (ONU) for 10 Gbps TDM passive optical networks (PONs). Based on the proposed four wavelength-multiplexed 2.5 Gbps lasers, the 10 Gbps uplink traffic can be achieved at a cost-effective way. The network architecture and performance have also been analyzed and discussed.

OCIS codes: (060.2330) Fiber optics communications; (060.4510) Optical communications.

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1. Introduction

Due to the great capacity and high flexibility of fiber communications, fiber to the home (FTTH) is considered as a promising technology in the last mile access system. It is undoubted that the FTTH network can provide the future-proof infrastructure with respect to the bandwidth and application demands for the next generation communication. Passive optical network (PON) is emerging network architecture for FTTH due to its cost-effectiveness [1]-[3], since there is no active component, such as switch or router, between the head-end office and end user in the PON. Telecom carriers have begun to deploy the time division multiplexing (TDM) PON, such as Broadband PON (BPON), Ethernet PON (EPON) and Gigabit PON (GPON) in accordance with the current movement of data, voice and video (triple-play) services leading to the rapid growth of all kinds of multimedia applications [4]-[6]. However, the bandwidths of the present TDM-PONs might not be large enough to satisfy the extensive bandwidth requirements of the future triple-play services for end-users, and thus present TDM-PONs should be upgraded. Nowadays, the standardization of the next-generation 10 Gbps TDM-PONs, including 10G-EPON and 10G-GPON, have been discussed for providing the upcoming enormous bandwidth requirements [7]-[9]. A simple and cost-effective evolution from the present TDM-PONs to next-generation high-speed TDM-PONs is attractive and desirable without changing the current fiber access infrastructure. The 10 Gbps downstream signal can be used in the optical line terminal (OLT) for broadcasting information and this can be deployed easily using distributed feedback laser diode (DFB-LD) with external modulation, since the cost in the OLT is shared by all the customers in a TDM-PON. However, using DFB laser with 10 Gbps external modulation in optical network unit (ONU) is expensive and not practical, since the cost of the ONU is paid solely by the user. In addition, 10 Gbps burst-mode receiver (Rx) is still hard to perform for receiving uplink signal.

In this paper, we propose a simple 10 Gbps TDM-PON architecture using four wavelength-multiplexed 2.5 Gbps self-injected directly modulated Fabry-Perot laser diodes (FP-LDs) [10] in each ONU acting as the upstream signal to increase to bandwidth to 10 Gbps. The proposed ONU module does not require external light injection sending from the OLT. In addition, four 2.5 Gbps burst-mode Rxs is more easy to construct in OLT for receiving the upstream signal. The synchronization of these four directly modulated FP-LDs and the Rxs can be performed in media access controller (MAC) layer protocol. Moreover, the performances of the proposed access architecture with both upstream and downstream traffics are discussed and analyzed.

2. Architecture design

Figure 1 presents the proposed 10 Gbps TDM-PON architecture with both downstream and upstream traffics. In the OLT, the downstream signal (λ_{down}) uses a DFB-LD for broadcasting and sharing of information to each ONUs. In the remote node (RN), a 1×N passive optical splitter (SP) is used for distributing the whole traffic to each ONU. In each ONU, we use four FP-LDs, a 2×4 wavelength demux/mux (WDM) and a fiber reflected mirror (FRM) to generate the four wavelength-multiplexed 2.5 Gbps signals (λ_1 to λ_4). Besides, a 1×4 WDM and four 2.5 Gbps (λ_1 to λ_4) burst-mode Rx are used in the OLT to receive the four wavelength-multiplexed upstream signals from the ONU.

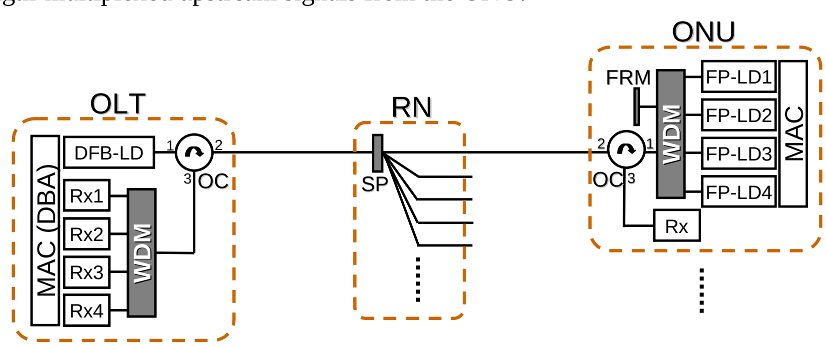

Fig. 1. Proposed 10 Gbps TDM-PON architecture using self-injected Fabry-Perot laser scheme on each ONUs for 10 Gbps upstream.

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The 10 Gbps upstream traffic is performed by using four wavelength-multiplexed 2.5 Gbps self-injection FP-LDs. In this proof-of-principle experiment, we use 1.5 μm FP-LD to simulate the 1.3 μm FP-LD due to the unavailability of the 1.3 μm FP-LD. The FP-LD has multi-longitudinal-mode output with ~45% front-facet reflectivity. Each 10 Gbps ONU contains four FP-LDs connected with a 2×4 WDM and a FRM, as shown in Fig. 1. The FRM has ~99% reflectivity from 1525 to 1565 nm. The polarization dependence of the FRM is < 0.5 dB. The multi-longitudinal-mode FP-LD is aligned to the corresponding filter mode of the WDM used in the ONU. In the ONU, the filtered longitudinal mode will be reflected by the FRM and injected into the FP-LD. Hence, the FP-LD will lase at single longitudinal mode due to self-seeding. Based on the seed-seeding operation, four lasing wavelengths λ_1 to λ_4 on ONU will lase simultaneously. Thus, 10 Gbps upstream signal can be obtained by directly modulating the 4 wavelength-multiplexed FP-LDs from λ_1 to λ_4 with electrically demultiplexed 2.5 Gbps data. Furthermore, a MAC having dynamic bandwidth allocation (DBA) function can be equipped at the OLT to allow efficient bandwidth sharing for each ONUs. The coding of forward error correction (FEC) could also be applied for upstream modulation to retrieve more coding gain and reduce power budget. WDM in the ONU and OLT will increase the optical power budget penalty of the uplink signal. As the WDMs in the OLT and ONU will introduce insertion losses, optically pre-amplifier Rx at the OLT can be used to improve the power budget of the system. As the temperature of different ONUs can vary a lot, temperature control inside each ONU is required in order to ensure the four wavelengths launching into the OLT can be wavelength de-multiplexed and received properly. Besides, wavelength control is also required so that nearly the same set of wavelengths can be produced by different ONUs. This scheme offers some advantages when compared with the previous proposed scheme using orthogonal frequency division multiplexed (OFDM) signal [11]. This is because the high speed digital signal processing circuits for the generation and detection of OFDM signal are still expensive. The proposed scheme provides an advantage of upgrading the present GPON which is TDM in nature to the 10 Gbps PON by only modifying the equipments at the OLT and ONU. The fiber link between the OLT and ONU can still be used and no extra optical components are needed.

Figure 2 shows the wavelength plans of (a) the conventional EPON/GPON and (b) the proposed 10 Gbps TDM-PON. In the conventional architecture, downlink and uplink signals are 1490 nm DFB-LD and 1310 nm multi-mode FP-LD, respectively, and video service uses 1550 nm DFB-LD. In the proposed 10 Gbps TDM-PON, we use four wavelengths ranging from 1310 to 1320 nm for 10 Gbps upstream traffic based on the proposed self-injected FP-LD laser module, while the other wavelength allocations are the same. This shows that our proposed scheme can upgrade the present TDM-PONs without modification of the wavelength plan.

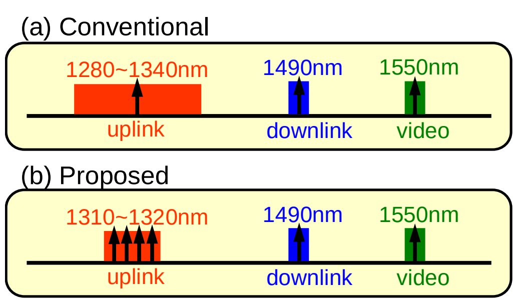

Fig. 2. The using wavelength plans in the (a) conventional EPON/GPON and the (b) proposed 10 Gbps TDM-PON.

3. Experiments and discussions

Figure 3 shows the experimental setup of the proposed PON architecture for 10 Gbps upstream traffic. In this experiment, the proposed self-seeding FP-LD module in the ONU can

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be achieved by using a FRM, a 1×2 coupler (CP), a WDM, a polarization controller (PC) and multi-mode FP-LD. In the proof-of-principle experiment, the WDM is a Gaussian-shaped optical filter having a 3-dB bandwidth of 0.4 nm. Its insertion loss is about 4 dB. The WDM could be an arrayed waveguide grating (AWG) in the proposed architecture. The variable optical attenuator (VOA) can be used to emulate PON split-ratio in the proposed architecture. The transmission length for both upstream and downstream signals is 25 km single mode fiber (SMF) without dispersion compensation. To measure the optical output performance, a power meter (PM) and optical spectrum analyzer (OSA) with 0.01 nm resolution are used in this experiment.

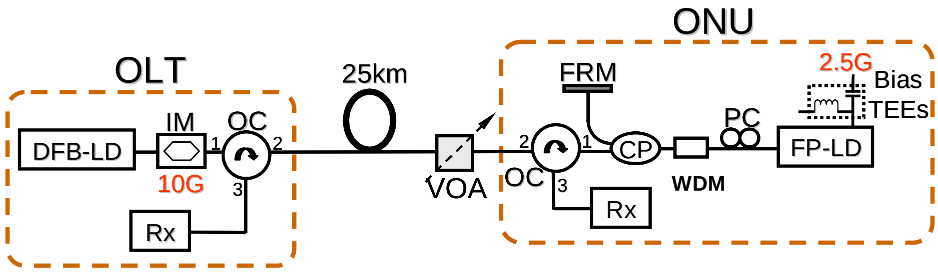

Fig. 3. Experimental setup in the proposed scheme. OC: optical circulator; Rx: receiver; IM: intensity modulator; WDM: wavelength mux; PC: polarization controller; CP: 3 dB coupler; FRM: fiber reflected mirror.

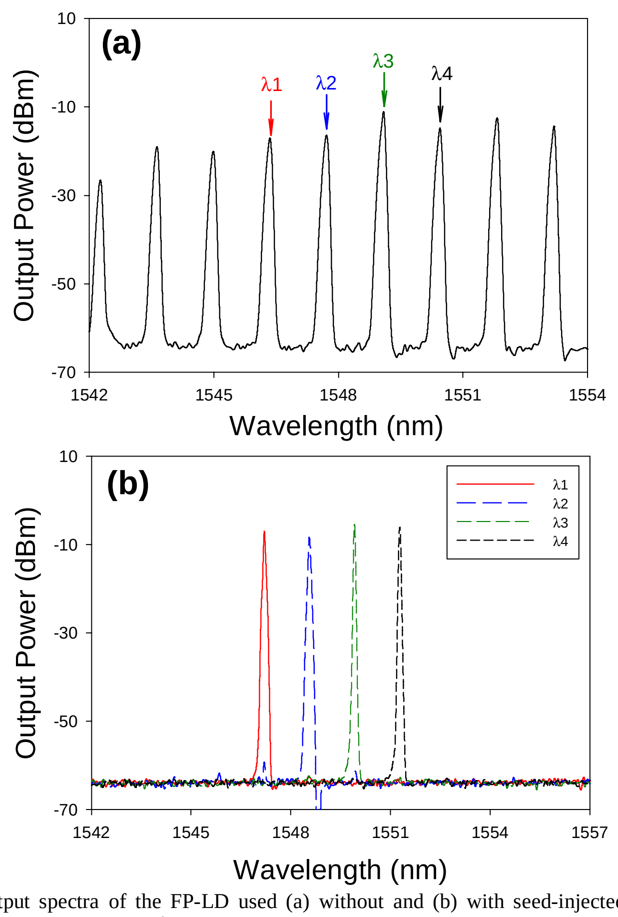

Fig. 4. Output spectra of the FP-LD used (a) without and (b) with seed-injected operation, while the bias current is 21 mA at room temperature.

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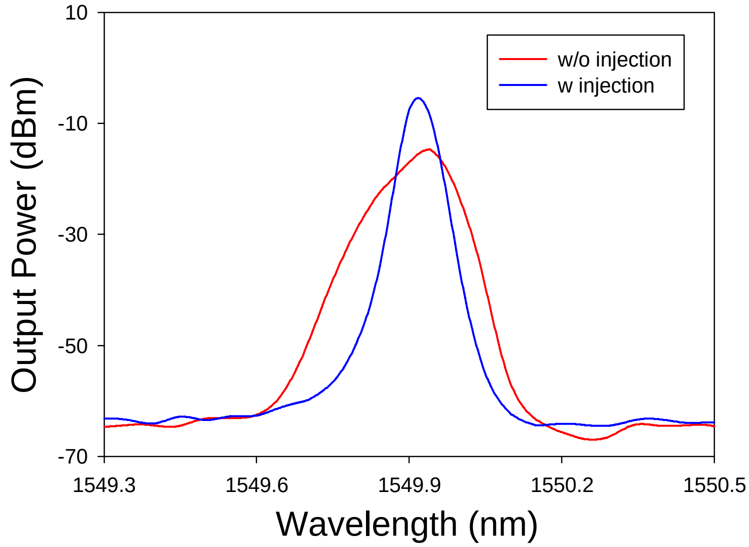

Fig. 5. Output spectra of the FP-LD without and with seed-injected operation, for the lasing wavelength of 1549.90 nm.

Figure 4(a) shows the free run output spectrum of the FP-LD without self-seeding when the bias current is 21 mA at room temperature, and the FP-LD has ~1.4 nm mode spacing. In the experiment, we choose four similar FP-LDs for the proposed 10 Gbps upstream source. The four lasing wavelengths (λ_1 to λ_4) are 1547.2, 1548.6, 1549.9 and 1551.3 nm, with the output powers of −6.6, −8.1, −7.2 and −7.3 dBm, respectively, are shown in Fig. 4(b). The side-mode suppression ratios (SMSRs) of the four lasing wavelengths are lager than 45 dB, as also shown in Fig. 4(b). In addition, we also measure the output wavelength and power stabilities of the lasing wavelength (for example λ_1). During the observation time of 30 minutes, the wavelength variation and the power fluctuation for the proposed wavelength-multiplexed laser are 0.04 nm and 0.65 dB, respectively. After two hours observing, the stable output of the laser is still maintained.

Figure 5 shows the output spectra of FP-LD without (red line) and with (blue line) self-injection at the lasing wavelength of 1549.90 nm, while the bias current is 21 mA at room temperature. Comparisons of the output linewidths without and with self-injection, the linewidth of FP-LD will be narrower after self-injection. In addition, using optical injection can increase the relaxation oscillation frequency [12], hence increasing the speed of direct modulation to 2.5 Gbps.

In the experiment, we select the lasing wavelength λ_1 for the evaluation. The self-seeding FP-LD is directly modulated at 2.5 Gbps with non-return-to-zero (NRZ) pseudo random binary sequence (PRBS) to produce the upstream optical on-off keying (OOK) signal. A single-mode DFB-LD (λ_{down}) of 1560 nm is used to simulate the 1490 nm downstream signal. The λ_{down} is fed to a lithium niobate intensity modulator (IM) to generate a 10 Gb/s OOK downstream traffic. The bit error rate (BER) curves for both downstream and upstream signals at back-to-back (BTB) and the transmission of 25 km SMF without dispersion compensation are shown in Fig. 6(a) and 6(b), respectively, with the corresponding eye diagrams. The power penalties of downlink and uplink traffic are measured and less than 0.2 and 0.3 dB, respectively, at BER at 10^{-9}. The clear open eyes of the received signals also suggest that the transmission distance can be further extended for future extended reach or long reach PON [13]. The high SMSR, the clear eye diagrams and the negligible receiving power penalty of this proposed 10 Gbps TDM-PON architecture reveal that the proposed scheme can be a potential candidate for the next-generation 10 Gbps TDM-PONs.

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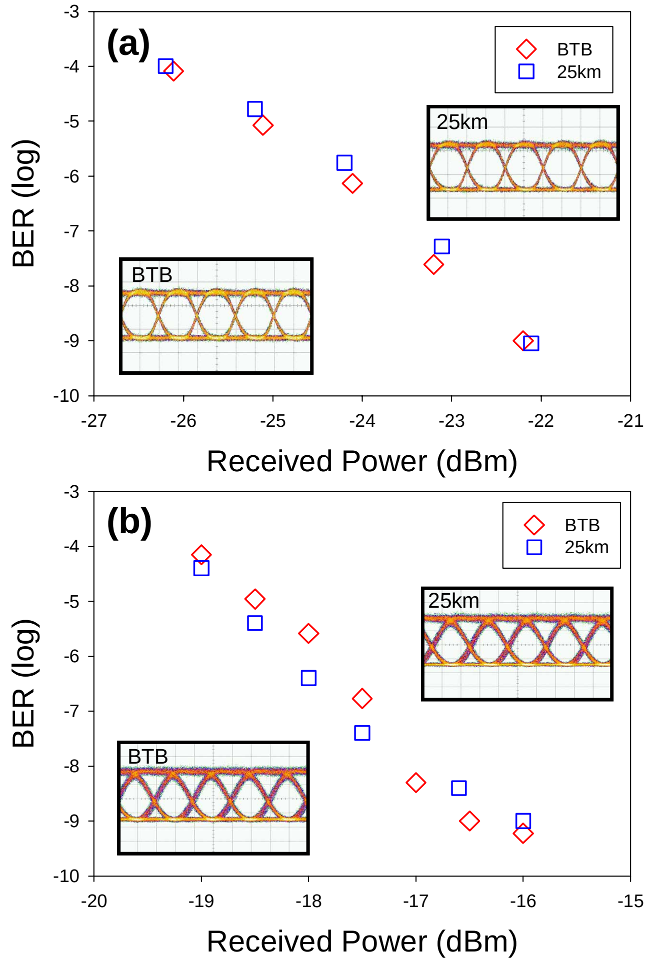

Fig. 6. BER spectra and corresponding eye diagrams for the (a) downstream and (b) upstream traffic with BTB and over 25 km transmission length.

4. Conclusion

This work presents and experimentally demonstrates a simple and cost-effective 10 Gbps TDM-PON architecture for increasing the bandwidth without changing the conventional PON infrastructures. 10 Gbps upstream traffic is achieved by using four wavelength-multiplexed 2.5 Gbps self-seeding FP-LDs. BER measurements are performed for both upstream and downstream signals, showing negligible power penalty over transmission of 25 km SMF without dispersion compensation. Moreover, the wavelength and output power performances of the proposed ONU are also discussed and analyzed. We believe that the proposed 10 Gbps TDM-PON would be a promising solution for next generation PON applications.

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