Experimental Demonstrations of Symmetirc 40-Gb/s TWDM-PON

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Abstract—**We have experimentally demonstrated symmetric 40Gb/s TWDM-PON with long passive reach and high power budget. Directly-modulated lasers (DMLs) are used as both downstream and upstream lasers to reduce the system cost, and optical reshaping filter is used to manage the chirp of the DMLs for all the upstream and downstream channels, enabling long distance transmission without dispersion compensation. The power budget is as high as 43 dB for 100-km passive reach, supporting 64 users.**

Keywords-TWDM-PON, power budget, DML, chirp management

I. INTRODUCTION

The newly emerging bandwidth-intensive and multimedia-rich applications such as video-on-demand, 3-D TV etc are pushing forward the network upgrading progress. Next generation passive optical network – stage 1 (NG-PON1), which aims at achieving a data rate of 10 Gb/s, has been standardized by ITU-I as XG-PON. Closely follows XG-PON, Full Service Access Network (FSAN), a sub-organization under ITU-T, has proposed the conception of next generation passive optical network – stage 2 (NG-PON2) aiming at an aggregate capacity no less than 40-Gb/s and is expected to be commercially available in 2015. The initial technical candidates include 40G time division multiplexed PON (TDM-PON), wavelength division multiplexed PON (WDM-PON), orthogonal frequency division multiplexed PON (OFDM-PON), ultra-dense wavelength division multiplexed PON (UDWDM-PON) and time and wavelength division multiplexed PON (TWDM-PON). The basic requirements of backward compatibility and technique maturity in network upgrading block off the way of other technologies and select the TWDM-PON as the primary architecture. By stacking several TDM-PONs to aggregate the data rate, TWDM-PON can reuse the already deployed optical distribution network and the mature techniques in TDM-PONs.

Y. Ma et al. have reported a 4 wavelength stacked TWDM-PON system, achieving a downstream/upstream capability of 40/10 Gb/s [1]. The thermally tuned distributed-feedback (DFB) laser with a modulation data rate of 2.5-Gb/s is employed as upstream laser source and a 38-dB power budget is realized by using an APD at the receiver end.

Symmetric 40-Gb/s technologies are required for further network upgrade. Chien-Hung Yeh et al proposed to use DFB lasers and external modulators as transmitters at both ends with in-line optical amplifier to improve the loss budget, which requires the ODN to be reconstructed therefore increases the system complexity and cost [2]. DML seems to be the most proper choice of laser sources to meet the twin constraints of low-cost and high performance for the access network. However, 10-Gb/s direct modulation signal suffers from the chirp and dispersion caused signal distortion. Katsuhisa Taguchi et al. demonstrated a 40-km reach 40-Gb/s WDM/TDM-PON while the waveband of 1310 nm is used to avoid the fiber dispersion in C band [3].

In this paper, we reviewed our previous work on 40 Gb/s TWDM-PON using DML as upstream laser source in the ONU. The laser source works in C band, while the chirp and dispersion caused signal distortion is eliminated by using an optical reshaping filter at either the transmitting or the receiving end. The downstream solution is DFB laser and external modulation. To optimize the sensitivity of downstream signal, an RSOA is employed in the ONU before the PIN as pre-amplifier. 9 dB sensitivity enhancement is achieved when a PIN with a sensitivity of -17.7dBm@1e-3 is used as receiver, providing a cost-effective solution for downstream signal sensitivity improvement. As a result, we obtained a symmetric 40Gb/s TWDM-PON system with 31-dB loss budget when the chirp managing filter is employed in the ONU, while 39-dB loss budget is achieved if the filter is placed in the OLT side, which could support 25-km SMF transmission with a splitting ratio up to 1:1000 [4,5].

In order to meet the requirements of both long reach and high splitting ratio, we further optimized the network structure. The downstream transmitter is changed to DML as well. A single DI performs as the notch filter to reshape all the downstream and upstream channels thanks to its periodicity and bi-pass characters. APD takes the place of RSOA and PIN in the ONU as receiver. As a result, symmetric 40 Gb/s TWDM-PON with up to 100-km SMF transmission distance is successfully demonstrated with a splitting ratio higher than 1:64 [6]. As all the amplifying and chirp managing devices are installed in the OLT or ONU side, the proposed networks are truly passive and totally backward compatible, which provide a promising candidate for NG-PON2. The experimental details are illustrated in the following sections.

II. EXPERIMENTAL DEMONSTRATIONS

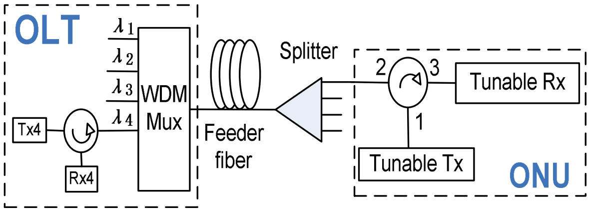


Fig.1 System configuration for TWDM-PON

Fig.1 shows the system configuration of the proposed 4 wavelengths stacked TWDM-PON. As the splitter broadcasts signals to all ONUs, so each ONU should contain a device that could select the downstream wavelength assigned to it. Similarly, the laser source in the ONU is required to be tunable because colorless ONU is preferred by operators for easier network laying and maintaining.

Fig.2 shows the experimental setup of the 25km reach PON. The downstream laser sources are four pairs of DFBs separated by 0.8 nm. A WDM multiplexer multiplexes downstream wavelengths as well as demultiplexes upstream wavelengths. In the ONU side, the downstream signal first passes through a TOF for wavelength selection and then a RSOA amplifies the signal before detected by the PIN. A DML with a thermally tuning range of ~2.9 nm performs as the upstream laser source. The same TOF reshaped the optical spectra of upstream signal to avoid the chirp and dispersion caused signal distortion. Fig.3 shows the optical spectra and eye diagrams of the original and filtered signals for comparison. The measured upstream and downstream signal sensitivities are ~-32dBm and -27dBm separately when the BER is 1×10^{-3}, which can be corrected by FEC. Fig. 4 shows the BER curves of downstream and upstream signals.

The power budget of the system is ~31 dB limited by the upstream direction as the reshaping filter introduced 6 dB extra loss. So the system could support 25km fiber transmission and 1:400 splitting ratio with a capacity of symmetric 40 Gb/s.

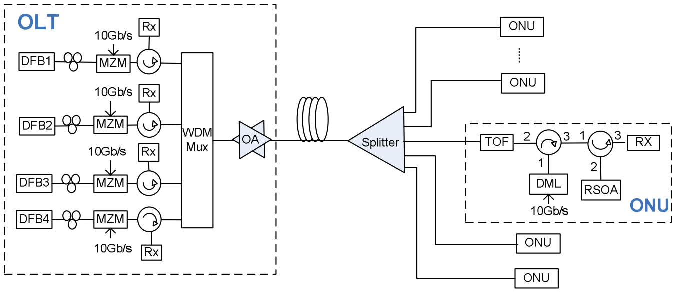


Fig.2 Experimental setup

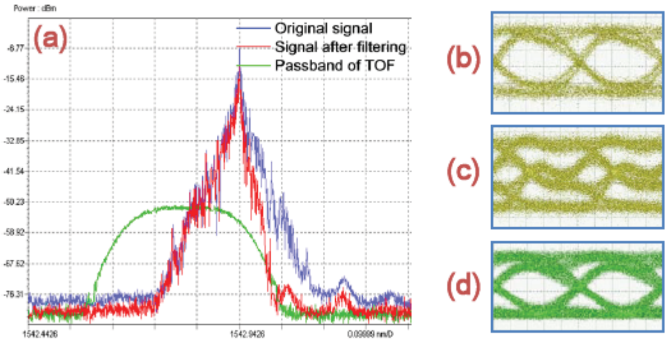
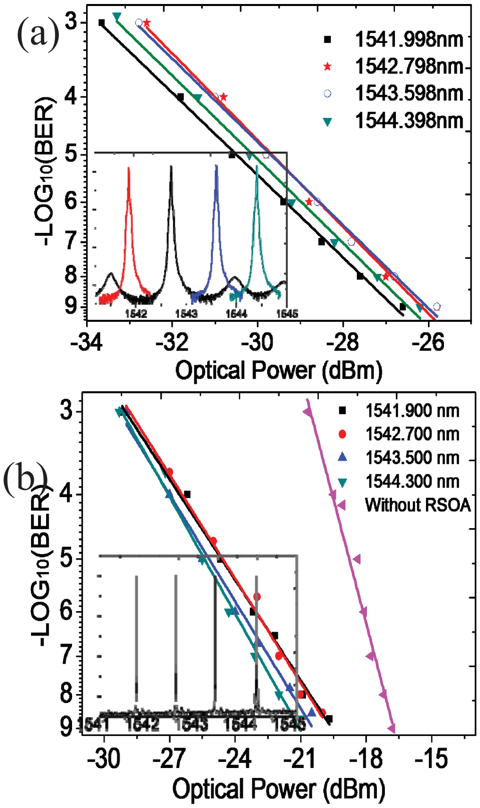


Fig.3 Optical spectra and eye diagrams of upstream signal



.Fig.4 BERs of the upstream (a) and downstream (b)10-Gb/s signals

The loss budget of the system can be further optimized by repositioning the filter used for chirp management of the DML as shown in Fig.5. As the filter is placed in the OLT side after the pre-amplifying EDFA, the insertion loss caused by the filter can be removed. Another TOF is required in the ONU side to select downstream wavelength and the ASE noise during the RSOA amplification is filtered out as well, which further optimized the downstream signal sensitivity. Finally, 39dB power budget is obtained, which could support a 25km feeder fiber and 1:1000 splitting ratio.

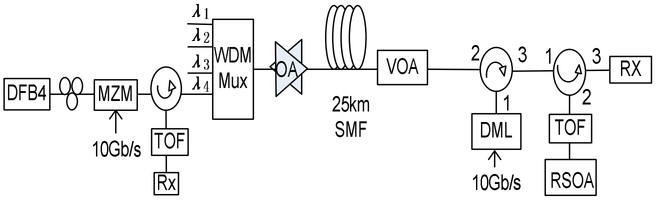


Fig.5 Experimental setup

Although the above work realizes a high splitting ratio PON which could support up to 1000 users, the transmission distance is limited to 25 km. To satisfy the requirement of long-reach PON, we changed the spectral reshaping filter to DI and the downstream laser source is replaced by DML for system simplification. Fig. 6 shows the proposed network configuration. Receiver in the ONU is an APD so the RSOA used for pre-amplifying in the previous work is not necessary any more. The DI can be regarded as a notch filter and has been proposed to use for chirp managing. Fig. 7 shows the optical spectra and eye diagrams of signal with and without DI filtering. Thanks to the periodicity and bi-pass character of the DI, all the upstream and downstream channels can be reshaped by a single device. To verify the transmission performance of the system, we varied the fiber length from 25 km to 100 km with a step of 25 km and measured the BERs of signal on both directions. The results are shown in Table.1. Note that without the spectral filtering, the sensitivity degrades first and then becomes better again when the transmission distance increases, which has been discussed in many researches such as [7] In spite of this, the DI can further increase the sensitivity in all transmission distance cases. The sensitivity of upstream signal is better than the downstream link because EDFA is used before the PIN as pre-amplifier.

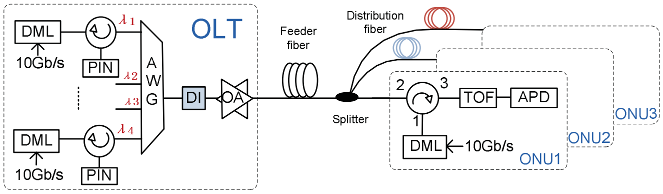


Fig.6 Network configuration of 100-km reach symmetric 40-Gb/s TWDM-PON

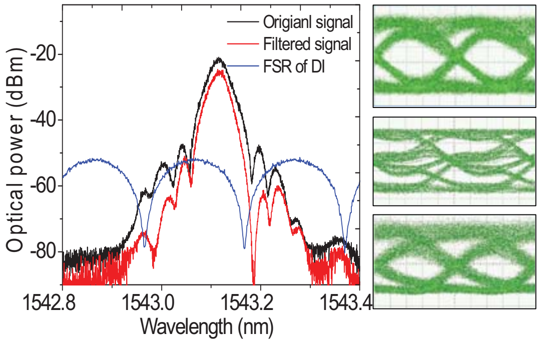


Fig.7 Optical spectra and eye diagrams of directly modulated signal

Table.1 Sensitivities of upstream and downstream signal

SMF (km)	Upstream (dBm)		Downstream(dBm)	
	Without DI	With DI	Without DI	With DI
0	-28	-39	-21	-34
25	-20	-39	-13	-32.3
50	-25	-37.5	-20	-32.3
75	-30	-37	-24	-31
100	-34	-36	-28	-30

The loss budget is 43 dB limited by the downstream link, which could support 100-km SMF transmission and 1:64 splitting ratio. By increasing the downstream launching power and improving the gain/noise performance of the preamplifier in OLT, the system loss budget could be further improved. Besides, as all the amplification and chirp managing devices are installed in the OLT or ONU side, the system is truly passive and totally backward compatible, providing a promising candidate for NG-PON2.

CONCLUSION

We proposed to use DML as laser source for 10 Gb/s direct modulation in TWDM-PON. The chirp and fiber dispersion caused signal distortion are eliminated by using filter at the transmitting or receiving end. Several symmetric 40-Gb/s TWDM-PON structures are experimentally demonstrated with various reach and splitting ratio. All the proposals are truly passive and backward compatible, which is suitable for practical application.

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