Wavelength division multiplexing passive optical networks (WDM PONs) with downstream DPSK and upstream remodulated OOK using injection-locked Fabry-Perot laser diodes (FP-LDs)

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Abstract—A wavelength division multiplexing-passive optical network (WDM-PON) system has been investigated, based on the injection locked Fabry-Perot laser diode (FP-LD). The system has been demonstrated without dispersion compensation for both 10Gbps differential phase-shift keying (DPSK) downstream signal and 2.5Gbps on-off keying (OOK) upstream signal respectively. Error free transmission over 50-km is achieved by tailoring the parameters of the FP-LD. The BER performance of our system shows that the injection locked FP-LD is a low cost effective colourless transmitter for high-speed WDM-PONs.

The rapid growth in Internet traffic is continuing to fuel the penetration of fiber into the access network section. Future broadband access networks need to offer cost-effective, high transmission capacity support for the rapidly growing number of new broadband subscribers. WDM-PONs are an attractive option due to their high capacity, easy management, network security, protocol and bit rate transparency, and easy upgradability [1-4].

WDM-PONs offer virtual point-to-point connections with a high degree of data security and higher per ONU bandwidth, low splitting loss, and maximum link reach as opposed to current time division multiplexing (TDM) systems such as EPON and GPON systems. However, the network complexity and its subsequent cost have been the most critical issues for practical deployment. Current research is focused on increasing the operating speed and maximum reach (or splitting ratio) of WDM PON cost-effectively. A differential phase-shift keying (DPSK) signal has high spectrum efficiency and great chromatic dispersion tolerance, which can increase the bandwidth and extend transmission distance over fiber [5]. At present, most optical signals can support an on-off keying (OOK) format. However, lately other modulation formats, such as phase shift keying and quadrature amplitude modulation format are increasingly supported.

A low cost optical network unit (ONU) for WDM-PON is desirable. The wavelength re-use scheme with the Fabry Perot Laser Diode (FP-LD) has lately been evaluated for deployment in WDM-PON [6-11]. There is no optical source in the ONU, downstream wavelength signals are re-modulated with uplink data, and then sent upstream towards the CO. In these systems, both upstream and downstream channels use the same wavelength for improving the wavelength utilization efficiency.

FP-LD has been proposed as an uplink colorless transmitter and modulator in the ONU. The FP-LD is injection-locked with the downstream wavelength at the ONU, where the original downstream data can be mostly blocked while the upstream data can be sent on the same injection-locked wavelength by concurrently directly-modulating the FP-LD [8]. For downstream transmission, phase-modulated links present several advantages over intensity modulated links, as the constant-intensity nature of the DPSK modulation format reduces various nonlinear phenomena during transmission, hence improving the system power budget [12]. Thus these modulation schemes are expected to play a key role in future broadband access networks.

In this paper, a 50-km-reach colorless DWDM-PON without dispersion compensation has been demonstrated, employing a 10Gb/s DPSK downstream signal and a 2.5Gb/s OOK re-modulated upstream one.

Figure 1 shows the proposed WDM-PON architecture using downstream DPSK and upstream OOK signals. For down-link, the 193.1THz carrier signal generated by a CW laser is differential phase-shift keying (DPSK) modulated, using 10Gb/s non-return to zero (NRZ) downstream data to generate the desired downstream signal. The modulated DPSK signal is multiplexed by the AWG in the CO and transmitted over 50km bidirectional single-mode fiber (SMF). A 1×64 AWGs are used in this work, hence a 1:64 split ratio is achieved. This agrees with the proposed solution for next-generation PON stage 2 (NG-PON2) by the full service access network (FSAN) in 2012.

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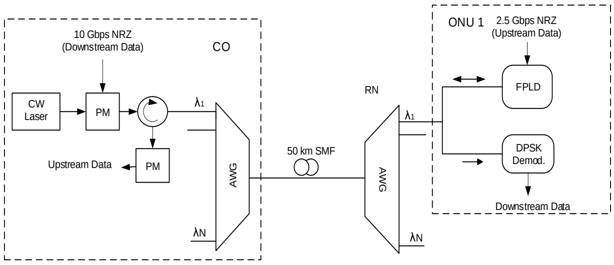

Fig. 1. The proposed WDM-PON architecture; PM: Phase modulator.

A circulator is used in the central office (CO) to separate the downstream and upstream traffic. The DPSK signals are de-multiplexed by the AWG at the remote node (RN) where various wavelength signals are sent to different ONUs. At the Optical network unit (ONU), using a 3-dB optical splitter, half of the DPSK modulated signal is demodulated using a DPSK demodulator and received by a 10-GHz PIN photodetector. For up-link, the other half of the downstream DPSK modulated signal is launched into the FP-LD for mode-locking and generating the 2.5Gb/s NRZ upstream ON–OFF Keying (OOK) signal. The re-modulated OOK signal is then launched back through the same fiber path, via the 50-km SMF to the 2.5-GHz receiver in the CO.

The WDM-PON system was simulated using a commercial package [13]. Figure 2 shows the variation of output power of the FP-LD with different bias currents. The total output powers of FP-LD were −18.4, −15.9, −13.6, −12.4 and −11 dBm, respectively when the bias currents were 5, 12.5, 20, 27.5 and 35 mA. Thus, the attained output power increases gradually with an increase in the bias current. In this work, the threshold current and facet reflectivity of FP-LD utilized were 16 mA and 99%, respectively. The BER performance of FP-LD at different bias currents under different CW injection power is shown in Fig. 3. It can be seen from Fig. 3 that to achieve acceptable BER results, the bias current should be larger than 15 mA and the injection power should be larger than −20 dBm for launching into FP-LD driving at 25 mA, 35 mA and 45 mA, as shown in Fig. 3. Moreover, while the bias currents of injection-locked FP-LD were 25 mA, 35 mA and 45 mA, their corresponding BER curves were similar in the same injection range. Hence, to improve the BER performance in the injection-locking FP-LD based ONU, the larger bias current and CW injection power were required.

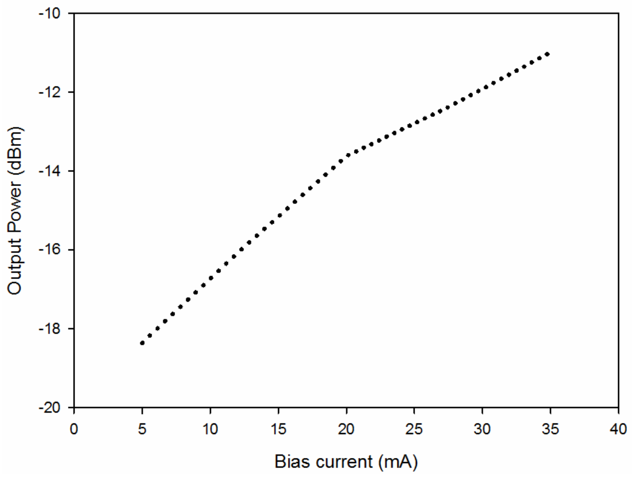

Fig. 2. Output power versus Bias current for FP-LD.

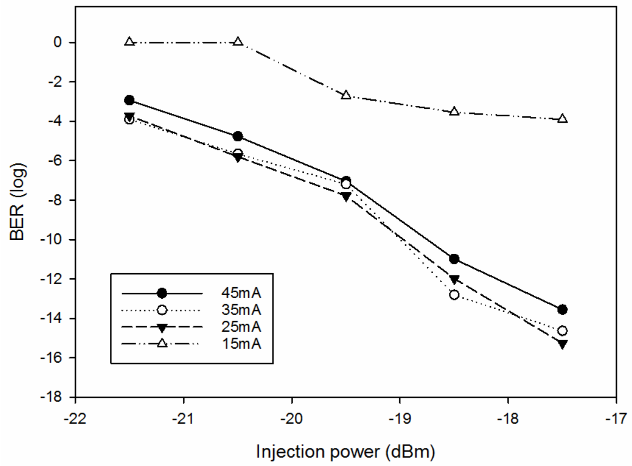

Fig. 3. BER performance of FP-LD at different bias currents under different CW injection power.

Figure 4 shows the bit-error-rate (BER) measurements of the 10-Gb/s downstream DPSK signal. Figure 5 shows the BER measurements of the 2.5-Gb/s upstream OOK signal. The OOK signal was generated from the re-modulation of the downstream DPSK signal, which has propagated through the 50-km SMF before the re-modulation at the ONU. Then, the upstream signals also transmitted through the same 50-km SMF before being detected by the 2.5-GHz PIN photodetector in the CO. We can observe that a BER of < 10^{-9} can be achieved with a negligible power penalty after 50-km SMF transmission without any dispersion compensation. It can be seen from Fig. 5 that the effect of the downstream signal phase modulation introduced to the upstream signal is negligible.

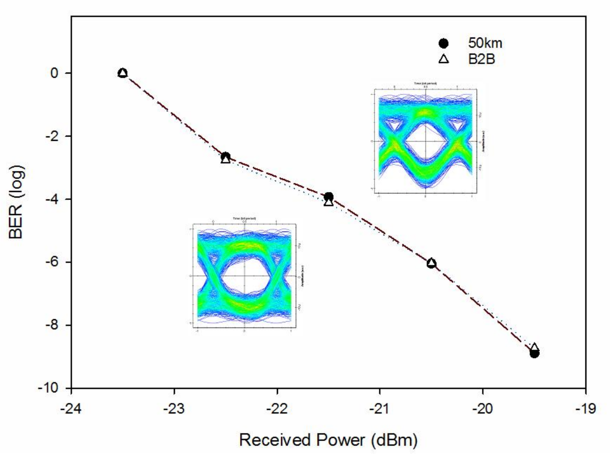

Fig. 4. BER measurements for Downlink. Insets: Corresponding eye diagrams.

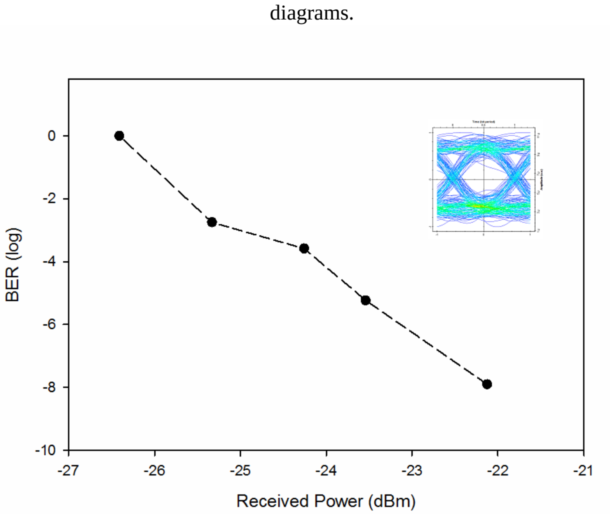

Fig. 5. BER measurements for Uplink. Inset: Corresponding eye diagram.

In conclusion, we have proposed and investigated a WDM-PON system utilizing an injection-locked FP-LD in each ONU for colorless operation. A 10-Gb/s DPSK signal was used for down-link and a 2.5 Gb/s OOK signal for up-link, respectively. In this work, the CW injection power of -20 dBm and a bias current of 25 mA, for the injection-locked FP-LD were required for error free 50-km fiber transmission. The results show that the effect of the phase modulation introduced to the upstream signal is negligible, hence this scheme is a practical solution for next generation wavelength reuse WDM-PONs.

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