A WDM-PON with DPSK modulated downstream and OOK modulated upstream signals based on symmetric 10 Gbit/s wavelength reused bidirectional reflective SOA

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A WDM-PON with DPSK modulated downstream and OOK modulated upstream signals based on symmetric 10 Gbit/s wavelength reused bidirectional reflective SOA

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We investigate a wavelength-division-multiplexing passive optical network (WDM-PON) with centralized lightwave and direct detection. The system is demonstrated for symmetric 10 Gbit/s differential phase-shift keying (DPSK) downstream signals and on-off keying (OOK) upstream signals, respectively. A wavelength reused scheme is employed to carry the upstream data by using a reflective semiconductor optical amplifier (RSOA) as an intensity modulator at the optical network unit (ONU). The constant-intensity property of the DPSK modulation format can keep high extinction ratio (*ER*) of downstream signal and reduce the crosstalk to the upstream signal. The bit error rate (*BER*) performance of our scheme shows that the proposed 10 Gbit/s symmetric WDM-PON can achieve error free transmission over 25-km-long fiber transmission with low power penalty.

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Time-division-multiplexed passive optical network (TDM-PON) has already been deployed to meet the huge bandwidth demand of broadband services, but it suffers from the bandwidth sharing. Wavelength division multiplexed passive optical network (WDM-PON) has been proposed to increase the bandwidth utilization of the optical fiber, and it is emerging as a promising key technology for the future fiber-to-the-home (FTTH)[1,2].

Differential phase-shift keying (DPSK) signal has high spectrum efficiency and great chromatic dispersion tolerance, which can broaden the bandwidth and expand the transmission distance over fiber[3]. At present, most optical signals can support on-off keying (OOK) format, however lately other modulation formats, such as phase shift keying and quadrature amplitude modulation format, are increasingly supported[4-6] .

The wavelength reused technique is a cost-effective solution in WDM-PON systems. There is no optical source in the optical network unit (ONU). The downstream wavelength signals are remodulated with uplink data, and then sent upstream towards the central office (CO). In these systems, both the upstream and downstream channels use the same wavelength for improving the wavelength utilization efficiency[7-9]. The reflective semiconductor optical amplifier (RSOA) has been proposed as an uplink colorless transmitter and modulator in the ONU due to its high optical gain, wide optical bandwidth and good integration capability[10-13]. The main problem in the wavelength reused networks is the imperfect removing of the modulated input light, which results in residual downstream signal in the upstream signal[12].

Some WDM-PONs based on RSOA with OOK modulation as downstream signal have been proposed to reduce the remodulation noise to the upstream signal. However, those schemes require high injection power and relinquish the extinction ratio (*ER*) of the downstream data[10,14,15].

For downstream transmission, phase-modulated links have several advantages compared with the intensity-modulated links, such as the constant intensity of the DPSK modulation format which could keep high *ER* in both directions. Hence, reducing various nonlinear effects and dispersion during transmission can improve the system power budget[16,17]. Moreover, an optical phase modulator with a single $LiNbO_3$ crystal is generally cheaper than a Mach-Zehnder intensity modulator. Thus, these modulation schemes are expected to play key role in future broadband access networks.

In this paper, a 25-km-long colorless WDM-PON with centralized lightwave and direct detection is investigated. The system is demonstrated for symmetric 10 Gbit/s DPSK downstream signals and OOK upstream signals, respectively. The DPSK modulated downstream signal is used as a seeding wavelength for upstream transmission. This scheme follows the 10GE-PON standard set up by the full service access network (FSAN) group.

Fig.1 shows the proposed lightwave centralized WDM-PON architecture using DPSK downstream signals and OOK upstream signals. At the CO, there are *N* distributed laser sources, followed by phase modulators

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(PMs). For down-link, the 193.1 THz carrier signal generated by a CW laser is modulated by a $LiNbO_3$ PM using 10 Gbit/s non-return-to-zero (NRZ) downstream data to generate the desired DPSK downstream signal. The modulated DPSK WDM signals are multiplexed by the arrayed waveguide grating (AWG) in the CO, and the aggregate signal is sent over 25-km-long single-mode fiber (SMF) for downstream transmission. The fiber used here has attenuation of 0.2 dB/km, chromatic dispersion of 16.75 ps/(nm·km) and dispersion slope of 0.075. In the remote node (RN), the WDM signals are de-multiplexed by an AWG where signals with various wavelengths are sent to different optical network units (ONUs). At the ONU, using a 3 dB optical splitter, half of the DPSK modulated signal is fed to a DPSK balanced receiver with receiver sensitivity enhancement of 3 dB which is a delay interferometer followed by a balanced detector. The phase-modulated DPSK signal is converted to the intensity-modulated signal by a Mach-Zehnder delay interferometric (MZDI) demodulator, and then it is detected by a direct detection PIN receiver. For up-link, the other half of the downstream modulated signal is directly remodulated by the reflective semiconductor optical amplifier (RSOA) to generate the 10 Gbit/s NRZ OOK upstream signal. The RSOA used here has reflectivity values at input and output facets as 5×10^{-5} and 0.99, respectively. As the seeding power of RSOA has a significant effect on its modulation characteristics, a variable optical attenuator (VOA) is used to keep an adequate optical power at the input of RSOA to operate it in the gain-saturation regime. The remodulated OOK signal is then launched back through an AWG at the RN via 25-km-long SMF to the CO where it is demultiplexed by an AWG and received by a PIN receiver in the CO.

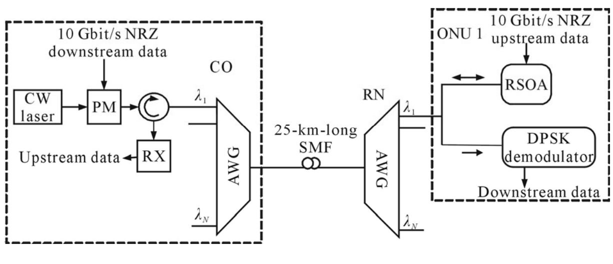

Fig.1 Schematic diagram of the proposed WDM-PON architecture

The WDM-PON system is simulated using a commercial OptiSystem package from Optiwave. The bit error rate (*BER*) curves of downlink 10 Gbit/s DPSK modulated signals at back-to-back (BTB) and after 25-km-long SMF are shown in Fig.2, and the corresponding eye diagrams are shown in the inset of Fig.2. The results show a clear eye opening which means that error free transmission can be achieved. The downlink 10 Gbit/s DPSK signals can achieve a *BER* performance of 1.7×10^{-9}, and the 25-km-long transmission curve is very close to that of the BTB.

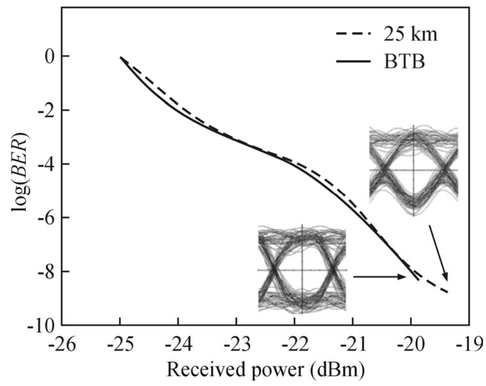

Fig.2 *BER* curves of downlink 10 Gbit/s DPSK modulated signals at BTB and after 25-km-long SMF (Insets are the corresponding eye diagrams.)

Fig.3 shows the *BER* curves at BTB and after 25-km-long SMF and the corresponding eye diagrams of the 10 Gbit/s upstream OOK signals. The OOK signal is generated from the remodulation of the downlink DPSK signal. The results show that the eye diagram after 25 km is thicker compared with that at BTB. Moreover, it can be seen from Fig.3 that the 10 Gbit/s uplink OOK signals can achieve a receiver sensitivity of −13 dBm at *BER* of 3.8×10^{-7}, and the power penalty varies from 0.4 dB to 3 dB with declining received power after 25-km-long transmission. Therefore, 25-km-long SMF transmission can be achieved with negligible power penalty and without any signal amplification or dispersion compensation. The results show that the power penalty for the uplink is greater than that for the downlink which is expected. This is due to dispersion, Rayleigh backscattering (which as identical wavelengths are used for downlink and uplink transmission) and other nonlinear effects resulting from the presence of residual phase modulation of the seeding DPSK signal. The power penalty can be reduced by keeping the received power between −14 dBm and −13 dBm.

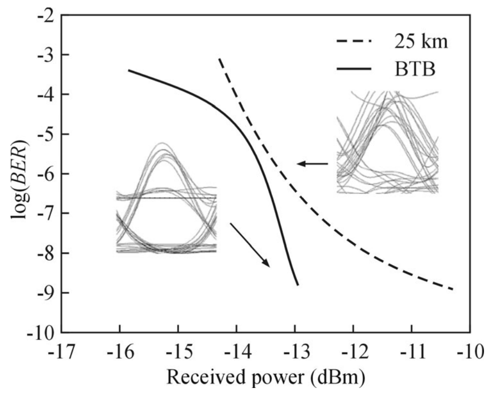

Fig.3 *BER* curves of 10 Gbit/s upstream OOK signals at BTB and after 25-km-long SMF (Insets are the corresponding eye diagrams.)

We propose and investigate a 10 Gbit/s symmetric bidirectional WDM-PON system with centralized lightwave and direct detection. A DPSK modulated signal is transmitted over 25-km-long SMF as downstream. For upstream link, the DPSK downstream signal is remodulated by an RSOA at the ONU. The crosstalk to the upstream signal is reduced by employing the constant envelope DPSK modulated signal in downlink transmission. The results show that symmetric 10 Gbit/s WDM PON can be realized, and the effect of dispersion is negligible. Hence, this scheme is a practical solution for next generation wavelength reused WDM-PONs.

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