Real-Time 50Gb/s Upstream Transmission in TDM-PON with Class E1 Power Budget Using Ge/Si Avalanche Photodiode and Bismuth-Doped Fiber as Preamplifier

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Abstract: We experimentally demonstrate a real-time 20km transmission of 50Gb/s NRZ upstream signal in TDM-PON using a BDFA preamplifier and a Ge/Si APD receiver. The sensitivity of -27.8dBm is achieved due to the low noise figure of the BDFA. © 2023 The Author(s)

1. Introduction

As the demand for transmission capacity of fiber access networks continues increasing, currently deployed XG(S)-PON cannot meet the requirement of future services. In order to solve this capacity crunch, 50G TDM-PON has been defined by ITU-T to be one of the most promising candidates for next generation fiber access network system. The downstream line rate is 50Gb/s based on NRZ modulation format, while the upstream have three different rates: 12.5Gb/s, 25Gb/s and 50Gb/s. By far, it is challenging for the 50Gb/s upstream link to meet class C+ 32dB power budget. Economically, ONUs are cost-sensitive and their transmitter output power is limited. To meet the link budget requirement, OLT receiver sensitivity has to be sufficiently high. It has been proposed that by using semiconductor optical amplifier (SOA), the sensitivity could be effectively improved [1]. By further optimizing the receiver FIR filter, a sensitivity of -27dBm was achieved for 50Gb/s upstream burst-mode signal [2]. However, due to the relatively large noise figure (NF) of the SOA, it is difficult to further improve the receiver sensitivity.

The bismuth-doped fiber amplifier (BDFA) that capable of amplifying signals across the O-band has been intensely studied in the recent decade, because of its unique features such as high gain, low noise, larger gain bandwidth. A flattop O+E band BDFA with 116nm gain bandwidth has been reported in [3]. BDFAs are suitable for the preamplification of upstream signals from all ONUs at the central office side. In this case, the small optical signal at the OLT receiver could be amplified without severe SNR degradation. More importantly, the photon lifetime of bismuth ions is on the order of millisecond, so the high-speed burst-mode signal can get amplified almost without any distortion of the temporal waveform. Also, because of the preamplifier works in the pump unsaturated regime, the pump recycling technique of fiber amplifiers [4] can be used to dramatically reduce the cost and power consumption per link. By further applying space-division multiplexing scheme for fiber amplifiers [5], even the active fiber can be shared between different OLT ports.

In this work, we experimentally demonstrated a real-time 20km fiber transmission of 50Gb/s upstream burst-mode signal at a central wavelength of 1309.6nm reaching class E1 33dB power budget. A low-noise BDFA was employed as the preamplifier at the OLT side and a 50G Ge/Si APD was used as the photodetector. The sensitivity was improved to be -27.8dBm without any optical bandpass filter (BPF). This result is 4.1dB better compared to using a APD receiver alone. The optical signal-to-noise ratio (OSNR) of the amplified signal is over 23dB thanks to the ultra-low noise figure of the BDFA. The eye diagrams before and after the BDFA were also measured and the extinction ratio (ER) and TDEC parameters are characterized.

2. O-band bismuth-doped fiber amplifier characterization

The schematic setup of the BDFA is shown in Fig. 2(a), which is a backward pumped configuration. The gain fiber is an 80-meter-long bismuth-doped fiber fabricated in-house, capable of providing 15dB of gain around 1310nm wavelength [6]. The core diameter is 7μm and the refractive contrast between core and cladding is 6×10^{-3}, ensuring it is at single-mode operation in O-band. The pump at a wavelength of 1195nm was coupled into the gain fiber through a WDM in reverse direction. The input signal travels through an isolator and get amplified in the Bi-doped fiber. The measured ASE spectra is shown in Fig. 2(b), the gain peak is around 1310nm. The green area shows the upstream wavelength range of 50G PON defined by G.9804.3, which is 1290nm-1310nm. This wavelength range allows the

WDM coexistence with existing XG(S)-PON. We measured the gain and noise figure of the BDFA at different input signal power across the 50G PON upstream wavelength, the results are shown in Fig. 2(c) and 2(d), respectively. The pump power was fixed to be 500mW. We can see that the small signal gains were between 12dB to 16dB around 1300nm. The highest gain appears at the wavelength of 1307nm that is 15.2dB. Because of this amplifier was working at pump strongly unsaturated region, the noise figures were only around 4dB for different input power levels.

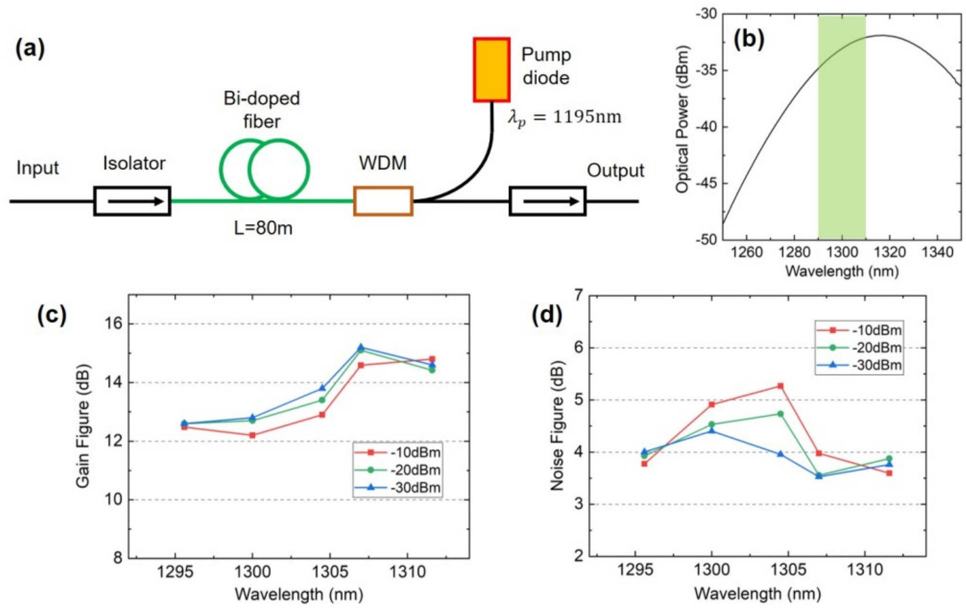

Fig. 1. (a) Schematic setup of the backward pumped BDFA, (b) measured ASE spectra of the BDFA, gain figure (c) and noise figure (d) of the BDFA at different input signal powers with a pump power of 500mW.

3. Experimental setup and results

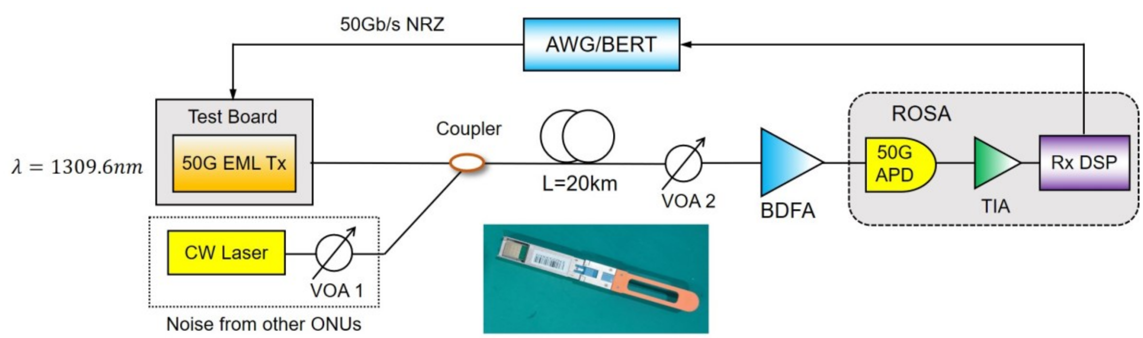

Fig. 2. Experimental setup for 50Gb/s upstream transmission with 20km SMF using a BDFA as preamplifier, (inset) photo of the commercial SFP56-DD type packed 50G EML transceiver.

The experimental setup of the 50Gb/s upstream transmission is shown in Fig. 2. The transmitter and receiver are fully packaged transmitter optical subassembly (TOSA) and receiver optical subassembly (ROSA), integrated on a multi-rate SFP56-DD transceiver, as shown in the inset of Fig. 2. This SFP56-DD transceiver incorporated a commercial DSP that can be programmed to support 25Gb/s NRZ, 50Gb/s NRZ, 50Gb/s PAM4 or 100Gb/s PAM4 modes. In this experiment, we set up the transceiver in 50Gb/s NRZ mode. The TOSA was built with a commercial electro-absorption modulator laser (EML). The ROSA was built with a high bandwidth Ge/Si APD, which has a higher bandwidth-gain product than traditional III-V material based APD, and a transimpedance amplifier (TIA). 50Gb/s NRZ burst-mode electric signal was generated from a programmable arbitrary waveform generator (AWG), and fed into the transmitter side. The laser wavelength selected in this experiment is 1309.6nm, which is inside the gain band of the BDFA. Currently, there is no 50G PON OLT available to create the BWmap to arrange time slots for multiple ONUs. Here we adopted an alternative way described in [7]. A CW laser at the same wavelength was employed to emulate the noise from other ONUs. We used a variable optical attenuator (VOA) to control the output power. Assuming there are 64 ONUs under the same OLT port, the output noise power of -40dBm should be a reasonable value. The modulated optical signal and the noise was combined by an optical coupler and transmitted through 20km of G.652 single-mode fiber. We used the BDFA described above with a pump power of 500mW to amplify the received signal. The 3dB bandwidth of the APD receiver used in the experiment is larger than 30GHz [8]. After further amplified by a 50G TIA, the signal was sent into the DSP unit. Only regular equalizers (FFE+DFE) were used to compensate the inter-symbol interference. The data stream after the DSP was sent back to the bit error rate tester (BERT).

The measured BER curve of 50Gb/s upstream transmission is shown Fig. 3(a). By using BDFA preamplifier, the sensitivity of 20km transmission is -27.8dBm with BER of 10^{-2} for the LDPC FEC limit, which is 4.1dB better than the result of APD receiver alone. The output power of the EML was measured to be 5.6dBm, therefore a total link budget of 33.4dB is achieved. We can see that at the upstream wavelength, the sensitivity after 20km transmission is slightly better than the back-to-back case. This is because the fiber dispersion at 1309nm is negative, the positive chirp of the transmitter could create some gain in receiver sensitivity after transmission. It is note that there is no optical BPF added in this experiment. A narrow BPF can be used to eliminate the ASE noise from the BDFA. In addition, we can further optimize the DSP equalizer algorithm for the receiver sensitivity improvement. We employed a real-time oscilloscope to characterize the eye diagram of the NRZ signals. The eye diagram of the signal generated from the transmitter is shown in Fig. 3(b), the ER and TDEC were 7.5dB and 2.3dB, respectively. After 20km of fiber transmission, the result is shown in Fig. 3(c), the TDEC degraded to be 2.4dB. Figure 3(d) shows the eye diagram of the small signal after BDFA amplification, the ER degraded to be 6.8dB and TDEC remained the same. We also measured the optical spectra of the signal before and after BDFA, the results are shown in Fig. 3(e). After amplification, the peak power increased from -27.9dBm to be -14.1dBm. The OSNR of the amplified signal is 23.2dB, corresponding to a BDFA noise figure of 4.5dB only.

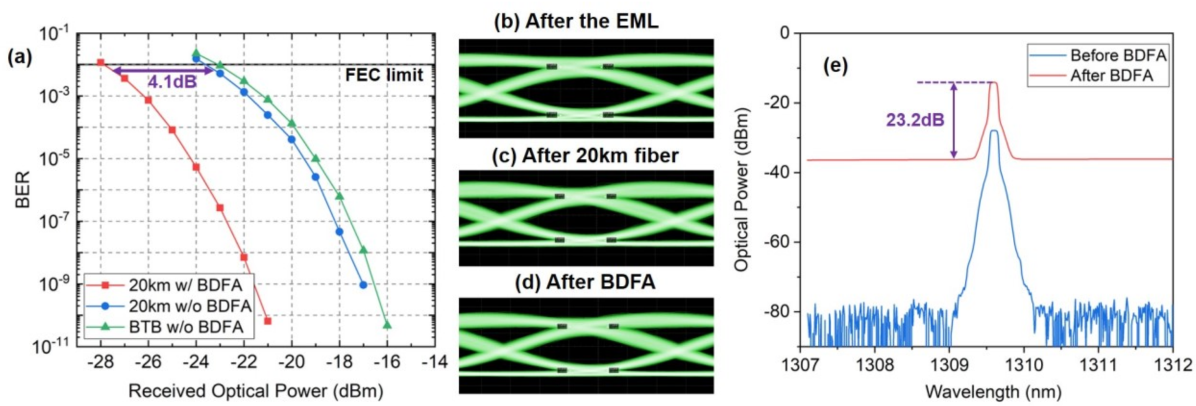

Fig. 3. (a) BER performances for 50Gb/s upstream signal, measured eye diagram of 50Gb/s NRZ signal (b) after the EML, (c) after 20km fiber transmission, (d) after BDFA amplification, (e) optical spectra of the small signal before and after amplification.

4. Conclusions

We have experimentally demonstrated a real-time 20km fiber transmission of 50Gb/s upstream burst-mode signal at 1309.6nm wavelength using a low-noise BDFA as preamplifier and a 50G Ge/Si APD receiver, with a realistic commercially built transceiver module as prototype reference. The receiver sensitivity is improved to be -27.8dBm without using any optical filter. This work paves the way for the future implementation and standardization of 50Gb/s upstream transmission in TDM-PON.

5. References

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