All fiber 1.55-μm SLM DBR fiber laser with 10-Gb/s NRZ-OOK transmission over 100-km fiber link

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The 10-Gb/s non-return-to-zero (NRZ) on-off-keying (OOK) data transmission over a 100-km transmission fiber link employing an all fiber 1.55-μm single longitudinal mode (SLM) distributed Bragg reflector (DBR) fiber laser as the signal source is demonstrated. The experimental result is comparable with that of the transmission system by using a commercially semiconductor distributed feedback (DFB) laser.

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Wavelength division multiplexed (WDM) technology has attracted significant attention due to its potential applications for high bandwidth capacity, while relaxing the requirements for ultra-high channel bit-rates and allowing for cost-effective processing of WDM channels through wavelength add/drop functionalities[1]. Current WDM networks rely on large numbers of fixed continuous wave (CW) semiconductor distributed feedback (DFB) lasers and tunable DFB lasers for providing redundancy in case of failure. Each single DFB laser acts as an optical source for a single wavelength channel, requiring dedicated current sources, temperature control, and thermal management, which lead to a high overall cost and increase space requirements in the transmitter side. Multi-wavelength fiber lasers have attracted much interest and been shown with semiconductor optical amplifiers (SOAs), Er-doped fiber amplifiers (EDFAs) or Raman fiber amplifiers (RFAs) as the gain media and various intracavity comb-generating filters. But most of these fiber lasers are not single longitudinal mode (SLM) fiber lasers, which restrict their practical applications due to multimode oscillation and mode hopping. Thus, various SLM fiber lasers have been proposed. Both SLM distributed Bragg reflector (DBR) and DFB fiber lasers, based on the fiber Bragg grating (FBG) are the simple and best candidates as the SLM fiber laser to ensure robust single-mode operation and prevent mode-hopping and exhibit ideal source characteristics being an inherently fiber compatible device. The main advantages of DBR and DFB fiber lasers over semiconductor diode lasers include a simpler fabrication, improved wavelength selectivity achieved by using current grating writing techniques and lower (one order of magnitude) temperature sensitivity. All these features, together with a reduction of production costs and perfect integrability with fiber-optics based telecom systems, make these fiber lasers very attractive as the optical source for the implementation of WDM systems[2]. They have been successfully realized in Er-doped silica-based fiber, Er/Yb co-doped silica-based fiber and Er/Yb co-doped phosphate glass fiber with the specially designed FBGs written on the fibers using 193-, 244-, 248-nm ultraviolet lights[3−12] or 800-nm femtosecond laser pulses through the phase mask method or point-by-point technique[13]. Thus, the experimental verification of whether these fiber lasers are reliable to be used in the optical fiber communication transmission link is necessary. The SLM DFB all-fiber lasers have been used to in the 4×10-Gb/s WDM transmission experiment over 200-km of standard fiber with dispersion compensation performed by chirped sinc-sampled FBG in the C band[14], and also the 10-Gb/s transmission in one channel over 73-km of standard fiber with dispersion compensation performed by chirped FBG in the L band[15]. Then, how about the performance of the SLM DBR fiber lasers in the transmission fiber link? Single frequency master oscillator power amplifier (MOPA) DBR fiber laser has been tested in a 475-km 2.5-Gb/s WDM transmission line[16].

In this letter, we demonstrated the 10-Gb/s non-return-to-zero (NRZ) on-off-keying (OOK) data transmission experiment over a 100-km transmission fiber link employing an all-fiber 1.55-μm SLM DBR fiber laser (NP Photonics) as the signal source. A commercially available semiconductor DFB laser (Agilent 8164B) was also employed as the signal source for the comparison. Experiment results show that similar performance could be achieved by using the SLM DBR fiber laser in contrast to DFB laser. This experiment demonstrates that the technology of SLM DBR fiber lasers has matured and that they are an attractive transmitter alternative to the semiconductor DFB laser.

The schematic diagram of the transmission experimental setup is shown in Fig. 1. The setup employs an all-fiber 1.55-μm SLM DBR fiber laser based on the Er/Yb co-doped phosphate glass fiber and FBG as the signal source and a commercially DFB laser for the comparison. The optical signal-to-noise ratio (OSNR) of the fiber laser is in excess of 70 dB, which is measured using the optical spectrum analyzer (OSA) (ANDO AQ6317C) and the linewidth of the laser is about 2 kHz[17]. The measured optical spectrum of the DBR fiber laser before injected into a 10-Gb/s external $LiNbO_3$ Mach-Zehnder modulator (MZM) is shown in Fig. 2(a). The degree of polarization (DOP) of the fiber laser in percentage term measured through the lightwave polarization analyzer (Agilent 8509) is as high as 100% as shown in Fig. 3(a), which indicates that the laser output is almost in stable single polarization state[18]. The polarization state of the fiber laser is adjusted using a polarization controller before being launched into the MZM. Figure 2(b) shows the output spectrum measured directly after the MZM driven by 10-Gb/s psuedo-random bit sequence (PRBS, length 2^{31}–1) generated by a pattern generator (Agilent N4901A). 10-Gb/s data signal is then amplified by an EDFA and fed into the 100.11-km transmission fiber link. The 100.11-km transmission link consists of three parts: two spans of standard single mode fiber (SSMF) with lengths of 46.35 and 43.44 km, and a span of dispersion-compensation fiber (DCF) with length of 10.32 km which is used to compensate the dispersion caused by the two spans of SSMFs in the middle position of the fiber link as the optimal place for dispersion compensation. All the fibers used in the transmission fiber link were fabricated by YOFC. An EDFA is used for compensating the fiber loss. Receiver power in this letter is defined as the input power of data and clock recovery module as shown in Fig. 1. A variable optical attenuator (VOA) is utilized here to adjust the input power of data and clock recovery module for dependence of bit-error-rate test (BERT) on receiver power measurement.

For the comparison, we also employed a commercially available semiconductor DFB laser as the signal source. The OSNR of the semiconductor DFB laser is in excess of 70 dB and the linewidth of the laser is about 2 MHz. The measured optical spectra of the semiconductor DFB laser before injected into the MZM and after the MZM are shown in Figs. 2(c) and (d). The DOP of the semiconductor DFB laser in percentage term measured through the lightwave polarization analyzer is as high as 99.8% as shown in Fig. 3(b), which also indicates that the laser output is in stable single polarization state. The DBR fiber laser has the similar optical spectra characteristics (optical power, OSNR) compared with the semiconductor DFB laser before injected into the MZM and after the MZM.

To assess whether the SLM DBR fiber laser is appropriate for the use as the signal sources for optical communication system, the bit-error-rates (BERs) and eye diagrams are measured. Before the transmission experiment, the DBR fiber laser has a warm up process about half an hour to achieve the stable operating condition. Figure 4 shows the measured BERs of back to back (BTB) transmission and after 100-km transmission plot against the received power for the transmission system,

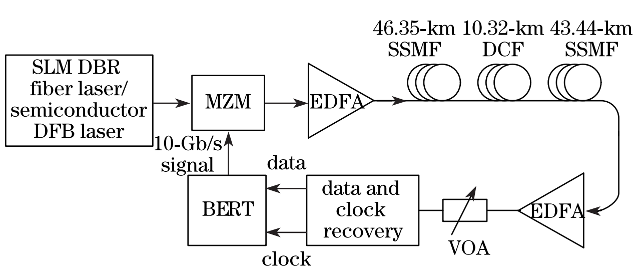


Fig. 1. Experimental setup of the 100-km transmission fiber link.

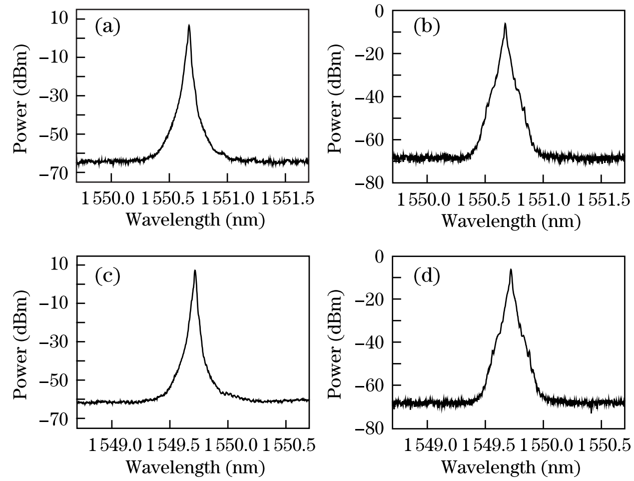
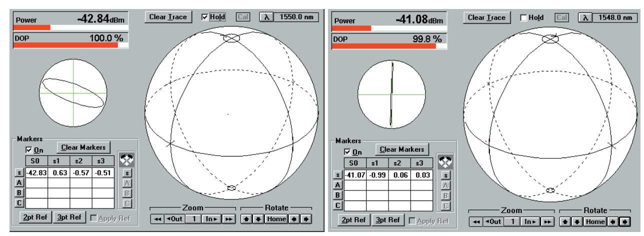


Fig. 2. Measured optical spectra (a) before and (b) after the MZM (DBR fiber laser); (c) before and (d) after the MZM (semiconductor DFB laser).



(a) (b)

Fig. 3. Polarization parameters of (a) the DBR and (b) DFB fiber lasers.

and shows a maximum power penalty of 1.5 dB at a BER of 10^{-9} operation. Figure 5 shows the corresponding eye diagrams of BTB transmission and after 100-km transmission at the BER of 10^{-9} operation measured by the wide-bandwidth oscilloscope (Agilent 86100B). No serious changes of the eye diagrams are shown before and after the 100-km transmission.

The BERs and eye diagrams measurement using the semiconductor DFB laser as the signal source was also performed. The measured BERs of BTB transmission and after 100-km transmission plot against the received power for the transmission system are also shown in Fig. 4, which shows a maximum power penalty of 1.4 dB at a BER of 10^{-9} operation. Figure 6 shows the corresponding eye diagrams of BTB transmission and after 100-km transmission at the BER of 10^{-9} operation. No serious changes of the eye diagrams are shown before and after the 100-km transmission. We can see that it has shown similar BERs and eye diagrams performance compared with the DBR fiber laser, proving the high quality of the DBR fiber laser. The experimental result using a DBR fiber laser is comparable with that of the transmission system by using a semiconductor DFB laser.

In conclusion, we demonstrate the 10-Gb/s NRZ-OOK transmission experiment over a 100-km transmission fiber link employing an all-fiber 1.55-μm SLM DBR fiber grating laser as the signal source. The SLM DBR fiber laser is demonstrated to be reliable signal source compared with the commercially available semiconductor

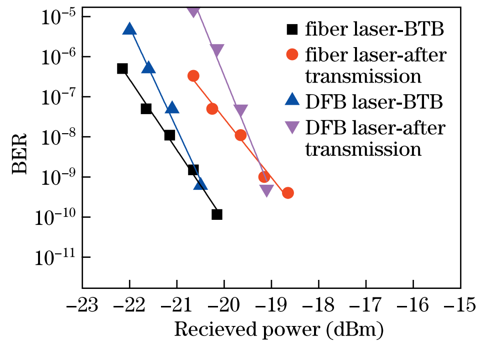


Fig. 4. Measured dependence of the BERs on receiver power with the DBR fiber laser and the DFB laser as the signal source.

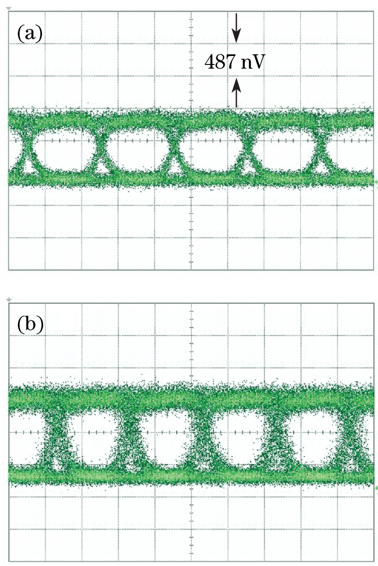


Fig. 5. Measured eye diagrams at a BER of 10^{-9} operation with the DBR fiber laser as the signal source. (a) BTB; (b) after 100-km transmission.

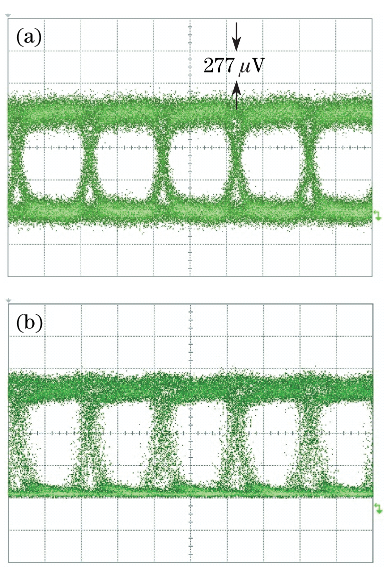


Fig. 6. Measured eye diagrams at a BER of 10^{-9} operation with the DFB laser as the signal source. (a) BTB; (b) after 100-km transmission.

DFB laser. The experimental results demonstrate that the technology of SLM DBR fiber lasers has matured and that they are an attractive transmitter alternative to semiconductor DFB laser in 10-Gb/s transmission system.

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