12th Optoelectronics and Communications Conference/16th International Conference on Integrated Optics and Optical Fiber Communication (OECC/IOOC2007)
Technical Digest, July 2007, Pacifico Yokohama

12C1-3

10 Gb/s WDM transmission at 1064 and 1550 nm over 24 km PCF with negative power penalties

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Abstract

We achieved the first 10 Gb/s WDM transmission at 1064 and 1550 nm over a 24 km photonic crystal fiber (PCF) with negative power penalties by using the pre-chirp technique with a conventional Z-cut LN modulator.

1. Introduction

Photonic crystal fibers (PCFs) are very attractive transmission media since they have unique features unavailable with conventional single-mode fibers, namely they can be endlessly single-mode and are capable of dispersion tailoring [1,2]. The ultra wide single-mode region of PCF has provided the possibility of building communication systems with a bandwidth of over 160 THz [3]. Progress on reducing the optical loss of PCF has generated several reports on transmission experiments using PCFs [3-5]. On the other hand, the construction of a high-speed network such as a 100G Ethernet [6] is attracting a lot of attention with the rapid growth of data-centric services. A new optical communication band at 1000 nm in a PCF is very attractive for high-speed networks. This is because we can use ytterbium (Yb^{3+}) doped fiber amplifiers (YDFA), which have a broad bandwidth in the 1 – 1.2 μm wavelength range [7]. Recently, we achieved a 10 Gb/s transmission at 1064 nm over a 24 km PCF with a negative power penalty by using the pre-chirp technique [5].

This paper reports the first 10 Gb/s WDM transmissions at 1064 and 1550 nm over a 24 km PCF.

2. Properties of PCF and experimental setup

We fabricated a 24 km PCF that had 60 holes and the structural parameter d/Λ was 0.5. Here, d and Λ denote the hole diameter and pitch, respectively, and Λ was 7.6 μm. The effective core areas at 1064 and 1550 nm were 44 and 50 μm^2, respectively. The optical losses were 0.94 and 0.49 dB/km at 1064 and 1550 nm, respectively. The zero dispersion wavelength (λ_0) was 1184 nm, and the dispersions at 1064 and 1550 nm were -20 and 33 ps/(nm.km), respectively, which corresponds to group velocity dispersions (β_2) of 12 and -42 ps^2/km, respectively.

Figure 1 shows our experimental setup. The light sources were a DFB fiber laser operating at 1064 nm and a DFB laser diode (LD) operating at 1550 nm. The input light at each wavelength was modulated at 10 Gb/s with a 2^{31}-1 PRBS by using a Z-cut LN intensity modulator. Here, we used an NRZ format. The optical signals at both wavelengths were multiplexed with a WDM coupler and guided into a 24 km PCF. The input powers into the 24 km PCF were set at 7.5 and 3.8 dBm at 1064 and 1550 nm, respectively. The transmitted optical signals were demultiplexed with a WDM coupler. The signals at 1064 nm were amplified with another YDFA and detected with a PIN photodiode. The signals at 1550 nm were also detected with a PIN photodiode. We did not use a preamplifier at 1550 nm.

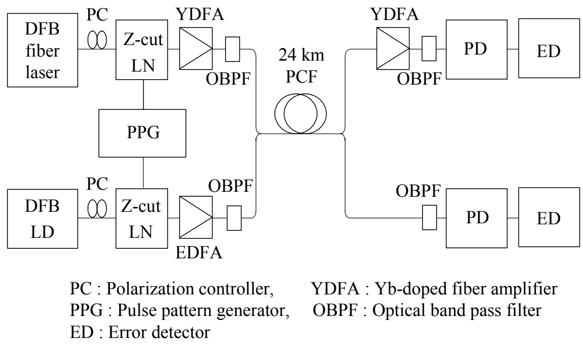

Fig. 1. Experimental setup

3. Results and discussion

Figure 2(a) shows the bit error rate (BER) characteristics of the transmission at 1064 nm. The received power was measured at the input of the YDFA. The solid lines with filled and open circles show the baseline BER and the BER after the 24 km transmission, respectively. A BER of 10^{-11} was achieved when the received optical power was -24 dBm. We also confirmed an improvement in the BER performance after the transmission, namely a "negative power penalty" of -0.5 dB at a BER of 10^{-9}. Since the β_2 (=12 ps^2/km) was positive at 1064 nm, and the chirp parameter C of the LN modulator was -0.7, the $\beta_2 C$ value became negative. Therefore we can expect to observe pulse narrowing after the transmission as a

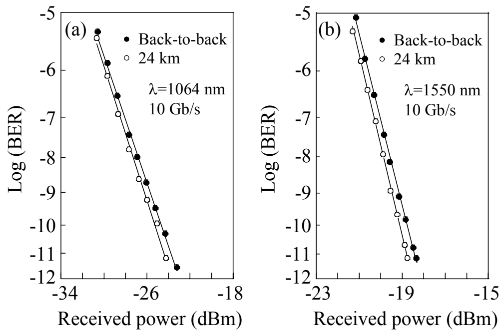

Fig. 2. BER characteristics

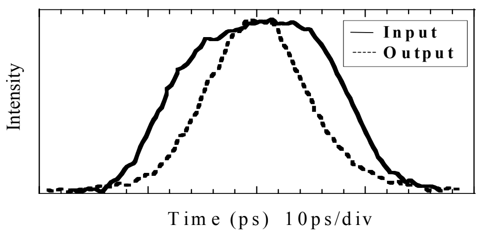

Fig. 3. Measured pulse waveforms at 1550 nm

result of the pre-chirp effect [8]. In fact, there was pulse narrowing after the transmission and we confirmed that this was the main reason for the negative power penalty of -0.5 dB [5].

Figure 2(b) shows the BER characteristics of the transmission at 1550 nm. Since the β_2 value (= -42 ps^2/km) was negative at 1550 nm, we effectively changed the chirp parameter C of the LN modulator at 1550 nm to +0.7 by shifting its DC bias voltage by V_π in order to achieve the pre-chirp effect. Therefore, we measured the BERs with the inverse polarity condition at 1550 nm. A BER of 10^{-11} was achieved when the received optical power was -18.8 dBm. We also confirmed a negative power penalty of -0.3 dB at a BER of 10^{-9} after the transmission. To obtain a quantitative analysis of the BER improvement at 1550 nm, we measured the pulse waveforms using a sampling optical oscilloscope and a fixed data pattern of <1010101.....>. Figure 3 shows the measured normalized waveforms. As seen in the figure, pulse narrowing was observed after the 24-km transmission. We calculated the root-mean-square (RMS) widths from Fig. 3 and obtained a pulse broadening factor $f_b(=\sigma/\sigma_0)$ of 0.90. Here σ and σ_0 are the RMS widths of the output and input pulses, respectively. Therefore, the dispersion-induced power penalty δ_d is roughly estimated to be -0.5 dB from Eq. (1) [9].

$$\delta_d = 10 \log_{10} f_b = 10 \log_{10} (\sigma/\sigma_0) \quad (1)$$

In addition, when we returned the chirp parameter C of the LN modulator to -0.7, we observed pulse broadening. Therefore, we consider the observed negative power penalty at 1550 nm to be also mainly the result of the pulse narrowing caused by the pre-chirp effect.

Figure 4 shows the variation in the f_b value with wavelengths calculated by using Eq. (2) [8], the dispersion characteristics of the PCF and the experimental parameters (T_0=50 ps, m=1.5, z=24 km), where we assume that the input pulse is a chirped super Gaussian (m=1.5) pulse.

$$f_b = \left[1 + \frac{\Gamma(1/2m)}{\Gamma(3/2m)} \frac{C\beta_2 z}{T_0^2} + \frac{\Gamma(2-1/2m)}{\Gamma(3/2m)} \frac{(1+C^2)(m\beta_2 z)^2}{T_0^4} \right]^{1/2} \quad (2)$$

Here Γ is the gamma function, and T_0 is the half-width at the 1/e-intensity point of the input pulse. We assumed that C is -0.7 for $\lambda < \lambda_0$ and +0.7 for $\lambda > \lambda_0$ in order to employ the pre-chirp technique. The chirp parameter C of the LN modulator is effectively changed to + 0.7 by shifting its DC bias voltage by V_π. As shown in Fig. 4, f_b is not larger than 1 for all wavelengths between 1060 and 1600 nm. This indicates that we can expect to realize 10 Gb/s transmission over a 24 km PCF with negligible BER degradation in the 1060 to 1600 nm wavelength region by using the pre-chirp technique with a conventional Z-cut LN modulator.

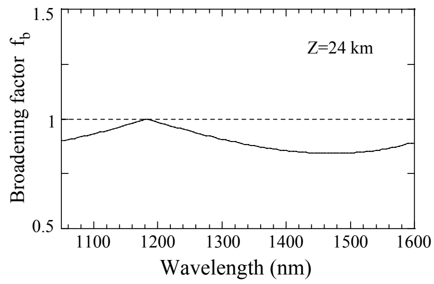

Fig. 4. Calculated broadening factor

4. Conclusion

We achieved 10 Gb/s WDM transmission at 1064 and 1550 nm over 24 km with negative power penalties by employing the pre-chirp technique with a conventional Z-cut LN modulator. We also showed theoretically that we can expect to realize 10 Gb/s transmission over a 24 km PCF with negligible BER degradation in the 1060 to 1600 nm wavelength range by using the pre-chirp technique.

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