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The system of L-band 2×10 Gb/s WDM transmission over conventional single mode fibre with 600 km by chirped fibre Bragg gratings dispersion compensation*

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A chirped fibre Bragg grating according to ITU-T suggested L-band (2nd channel $\lambda_1 = 1570.83$ nm; 80th channel $\lambda_2 = 1603.57$ nm) with more than 1800 ps/nm single channel dispersion compensation is presented in this paper, of which the cladding mode loss, the delay curve ripple and the power fluctuation of the reflected spectrum are less than 0.5 dB, 50 ps and 0.25 dB, respectively. With this new FBG as dispersion compensation device, a 2×10 Gb/s wavelength division multiplexing (WDM) L-band transmission of 600 km based on conventional single mode fibre (G.652 fibre) is performed without forward error correction. The bit error rate (BER) is less than 10^{-12} and the power penalties of the 2nd and 80th channel of L-band are 1.8 dB and 2.0 dB, respectively.

Keywords: chirped fibre Bragg grating, dispersion compensation, L-band, conventional single mode fibre (G.652 fibre)
PACC: 4280S, 4281D, 4230Q

1. Introduction

With the increasing demand of information transmission bandwidth by users and the profit pursuing by IT merchants, the capacity of fibre communication system as the main information transmission medium has also been improved continually. The communication waveband in common use of quartz fibre focuses mainly on the low loss window of ∼1550 nm: that is, S-band ($1480-1530$ nm), C-band ($1530-1565$ nm) and L-band ($1570-1610$ nm). Recently the capacity of practical point-to-point fibre communication system has reached up to 160×10 Gb/s which means that more than 19,000,000 digital speech channels can be transmitted with bi-directions in two fibres simultaneously, and the capacity of point-to-point transmission system in the lab has reached up to 10.92Tb/s which means that more than one billion digital speech channels can be transmitted with bi-directions in two fibres simultaneously.[1,2] However, the bit rate over a single wavelength is limited to within 40Gb/s because of polarization mode dispersion (PMD); dense wavelength division multiplexing (DWDM) should be adopted in order to support such high bit rate. As the fully developed optical amplifiers now, erbium-doped fibre amplifiers (EDFAs) have a very limited operational range of C-band. If the length of erbium-doped fibre (EDF) can be increased five times more, the Er^{3+} ions distribution can be stabilized in low energy state so that L-band EDFA called gain-shift EDFA (GS-EDFA) can be realized by both directional pumping.[3−5] However, the length increase of EDF would result in more fibre loss, the accumulated amplified spontaneous eradiation (ASE), decreased pump transform efficiency of amplifier and increased noise coefficient.[6−10]

Either G.655 or G.656 fibre transmitted over L-band should use special method to compensate the dispersion and it is difficult to realize because of the large dispersion of common silicon-based fibre over L-band. Considering the practical situation of using G.652 fibre as the main fibre (over 70%) laid in fibre transmission systems in China, this paper proposes an L-band fibre transmission system over G.652 fibre by using chirped fibre Bragg grating (CFBG) as disper-

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sion compensation device.[11,12] A CFBG according to ITU-T suggested L-band with more than 1800 ps/nm single channel dispersion compensation is presented in this paper, of which the cladding mode loss, the delay curve ripple and the power fluctuation of the reflected spectrum are less than 0.5 dB, 50 ps and 0.25 dB, respectively. With this new fibre Bragg grating (FBG) as dispersion compensation device, a 2×10 Gb/s wavelength division multiplexing (WDM) L-band transmission of 600 km based on G.652 fibre is performed without forward error correction (FEC). The bit error rate (BER) is less than 10^{-12} and the power penalties of 2nd and 80th channel of the L-band are 1.8 dB and 2.0 dB, respectively.

2. CFBG manufacture

The phase mask manufacture is difficult because of the large dispersion of L-band fibre. After detailed analysis, trial-manufacture and test, it is clear that the time-delay ripple coefficient of fibre gratings can be directly affected by the phase difference between phase mask units.[13,14] Actually fibre gratings are composed of several F-P cavities which are made between chisel stripes of two adjacent fibre gratings. In the situation of same fibre gratings length, the larger dispersion compensation is wanted, the smaller period difference of two adjacent F-P cavities is demanded, which means that the ripple increases with the increased F-P effect.[15−18] The effect is very distinct to phase mask made by electron beam scan method because it is composed of more than 100 different fibre gratings with the length of 1mm and if we want to increase the dispersion compensation in the same length, $\Delta\lambda$ should be decreased so that the period difference of two adjacent F-P cavities can be smaller and F-P effect can be increased and finally the ripple increases. In order to diminish the ripple coefficient of time-delay and cladding mode loss of fibre gratings, optimized apodizer method should be adopted,[19,20] In addition, the dispersion character of fibre gratings should present nonlinearity in order to compensate dispersion slope while composing fibre dispersion which increases the difficulty of phase mask manufacture. After repeated optimization design and trial-manufacture, the phase mask of two wavelengths in L-band (2nd, channel $\lambda_1 = 1570.83$ nm; 80th channel $\lambda_2 = 1603.57$ nm) is obtained finally. The reflected spectrum and dispersion characteristic curve of L-band CFBG made by this phase mask and swing mask using high-level golden section method and Hamming function are shown in Figs.1 and 2.

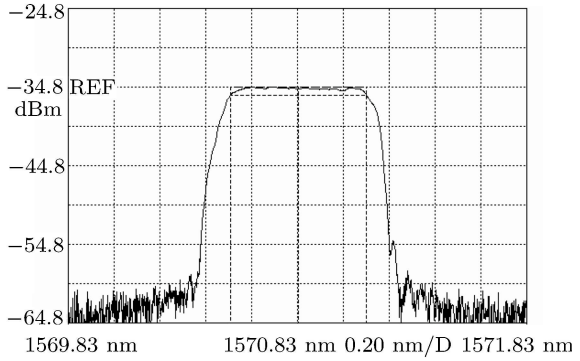


Fig.1. Reflection spectrum of FBG.

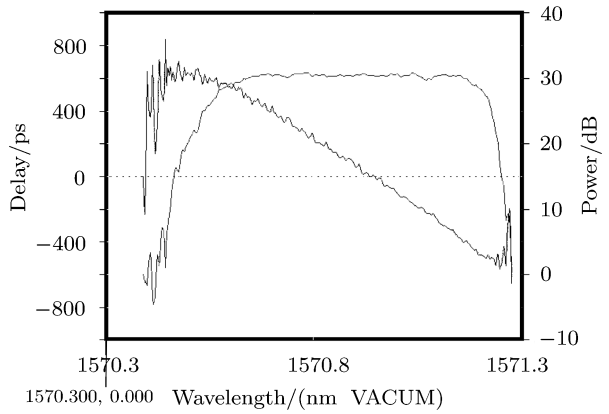


Fig.2. Dispersion characteristic curve of FBG.

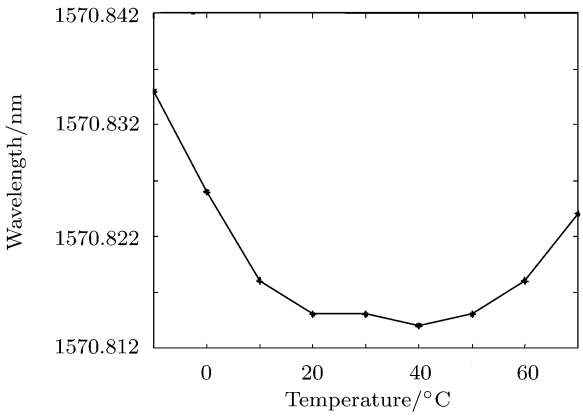


Fig.3. Wavelength vs temperature.

The temperature coefficient of this CFBG can decrease below 0.001nm/°C and can be used practically by long time research of FBG annealing characteristics which is the basis of dispersion compensation of high speed and long distance fibre transmission realized by CFBG. Fig 3 shows the typical temperature characteristics of CFBG encapsulation.

With the test of CFBG encapsulation, we can find that the power ripple of reflected spectrum is ±0.23 dB, ripple coefficient of time-delay is ±30ps, dispersion compensation is 1803ps/nm (single channel) and temperature coefficient of centre wavelength is less than 0.001 nm/℃.

3. Experimental system

The 2×10 Gb/s WDM 600km Transmission system is realized over G.652 fibre by using CFBG as dispersion compensation device. Because of the EDFA gains are severely uneven over L-band, especially for the selected two wavelengths of 2nd and 80th channels of L-band in this experiment, the gain difference could reach about 5 dB and the EDFA gain at 1603.57 nm had decreased extremely. Therefore, it is difficult to realize transmission over the two wavelengths without L-band gain equalizer. After many repeated experiments, the L-band 2×10 Gb/s WDM 600 km transmission system was realized without FEC over G.652 fibre by using CFBG to compensate fibre dispersion and dispersion slope finally. The system construction and BER test result were shown in Figs.4 and 5 respectively. The laser output power with 2nd and 80th wavelength channel of the L-band were modulated by $LiNbO_3$ phase modulator, and injected into G.652 fibre with length of 100 km via multiplexer (MUX), optical amplifier 1 (OA1), optical circulator (OC1) and dispersion compensation modular1. Output power of the fibre then repeats five sections of the optical fibre amplifier and dispersion compensation module, and input into BER analyser via OA13 and demultiplexer (DEMUX) to analyse the BER characteristics of the system. From Fig.5, one can obtain that the BER of L-band 2×10 Gb/s WDM less than 10^{-12} over 600km G.652 fibre, which is the basis of application. It had not been reported by literatures all over the world that the L-band 10 Gb/s WDM 600km transmission system can be realized without FEC over G.652 fibre by using CFBG.

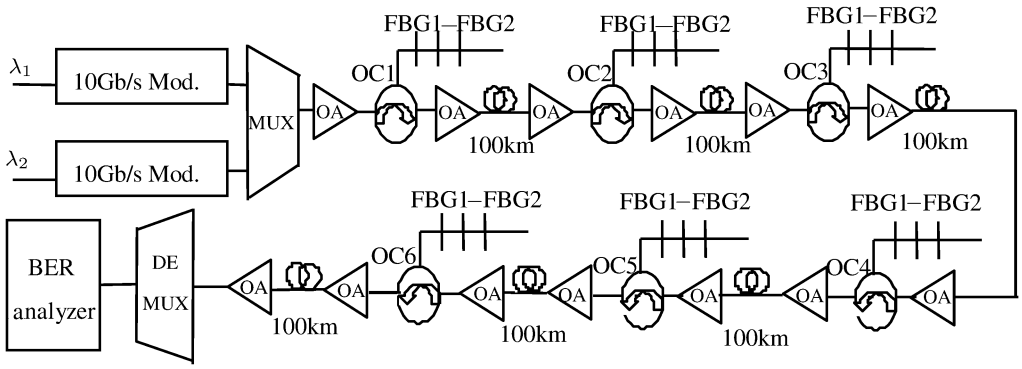


Fig.4. Diagram of the L-band 2×10 Gb/s WDM Transmission system, it realized over G.652 fibre with 600km by chirped fibre Bragg gratings dispersion compensation.

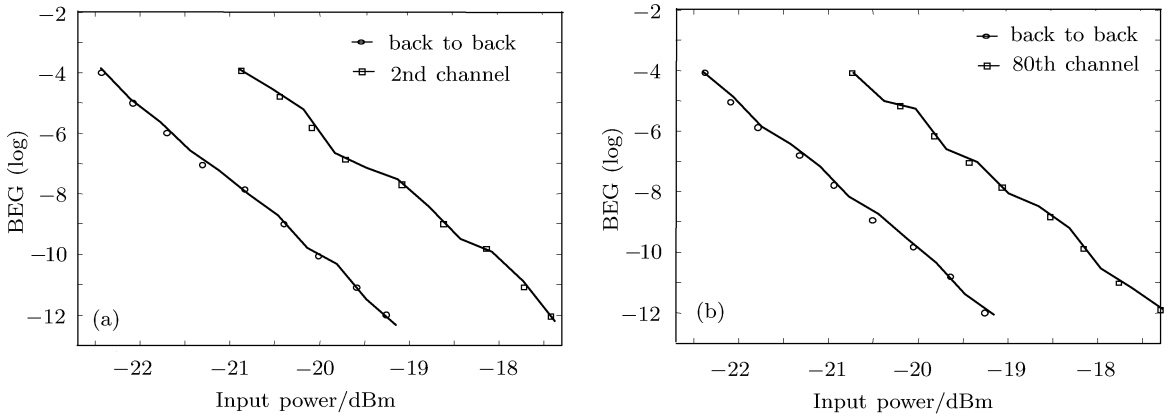


Fig.5. BER characteristics curves. (a) 2nd channel of L-band (1570.83 nm) Power penalty is 1.8 dB. (b) 80th channel of L-band (1603.57 nm) Power penalty is 2.0 dB.

4. Conclusion

A CFBG according to ITU-T suggested L-band with more than 1800 ps/nm single channel dispersion compensation is presented in this paper, of which the cladding mode loss, the delay curve ripple and the power fluctuation of the reflected spectrum are less than 0.5 dB, 50 ps and 0.25 dB respectively. With this new CFBG as dispersion compensation device, a 2×10 Gb/s wavelength division multiplexing (WDM) L-band transmission of 600 km based on G.652 fibre, as far as we know, is first performed without FEC. The bit error rate (BER) is less than 10^{-12} and the power penalties of λ_1 and λ_2 are 1.8 dB and 2.0 dB respectively.

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