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Package for fiber Bragg gratings (FBG) and a comparative study on their polarization mode dispersion (PMD) at varying temperature

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A temperature-compensated material of fiber Bragg grating (FBG), which has negative thermal -expansion coefficient has been presented. The temperature coefficient of FBGs' center wavelength is less than 0.0005 nm/°C after three-layer-structure temperature-compensated package under tension. For the first time, PMD of FBG with and without temperature compensation has been detailedly studied and measured from –20 to 60°C. The measured result shows that the PMD changes a little at varying temperature, which means that the package did not affect the PMD characteristic of FBG.

Keywords: optical fiber communication, fiber Bragg grating, negative thermal-expansion material, temperature-compensated package, PMD.

1. Introduction

The increasing demands of bandwidth drive most telecommunication operators towards the deployment of large capacity transmission systems. When chromatic dispersion and loss in optical fiber no longer limit the performance of high data-rate transmission systems, polarization mode dispersion (PMD) becomes the key factor to block updating high-performance optical transmission systems and networks. In high bit rate optical communication systems beyond 10 Gbps, signal distortion caused by PMD is a major limitation on transmission distance. PMD is a distortion arising from unwanted birefringence in optical fiber and optical component [1, 2].

Fiber Bragg gratings (FBG) have developed into a critical component for many applications in fiber-optic communication and sensor systems. Advantages of fiber gratings over competing technologies include simple, all-fiber geometry, low crosstalk, high return loss or extinction, low insertion loss, and potentially low cost. They can be widely applied in dispersion compensation, higher order mode dispersion compensator, fiber grating laser, filter, optical add-drop multiplexers (OADM), EDFA gain flattening, interleaver and so on [3–6]. The temperature coefficient of unpackaged FBGs' central wavelength is 0.014 nm/°C. The shift of FBGs' center wavelength is a severe problem in practical applications. It is important to package FBGs with negative thermal-expansion material in order to decrease the shift of FBGs' center wavelength. In this paper, a novel structure to package FBGs has been studied.

The PMD of FBGs is about 0.5 ps, and the PMD coefficient of G.652 optical fiber is less than 0.1 ps/km$^{1/2}$, so PMD of FBGs becomes an important topic in optical fiber communication system. Theoretic analysis and experimental measurement had been carried out on FBG. Birefringence of UV-written gratings mainly comes from the asymmetrical absorption of photosensitive fiber, or absorption is exponential [7].

To resolve the temperature sensitivity in FBG devices, many researchers have studied various package materials and methods to compensate for the thermal effects and they have been detailedly discussed in reference [8], but the best temperature coefficient is only 0.002 nm/°C. For the first time, in this paper, the package of FBGs and PMD of temperature-compensated FBG has been detailedly studied. The temperature coefficient of FBG's center wavelength is 0.0005 nm/°C after three-layer-structure package under tension. The PMD of FBG with and without temperature-compensation has been measured from –20°C to 60°C, and some useful results have been obtained.

2. FBG package

The center wavelength of FBG can be defined [3, 4]

$$\lambda = 2 n_{\mathrm{eff}} \Lambda$$

where n_{eff} is the effect group velocity index, and Λ is the period of FBG. They will be changed under different temperature because of the changeable stress on optical fiber. And this will cause the shift of the center wavelength of FBGs simutaneously.

The center wavelength of FBG without temperature-compensation will shift at 0.014 nm/°C for standard fiber, which is unacceptable for many applications, so

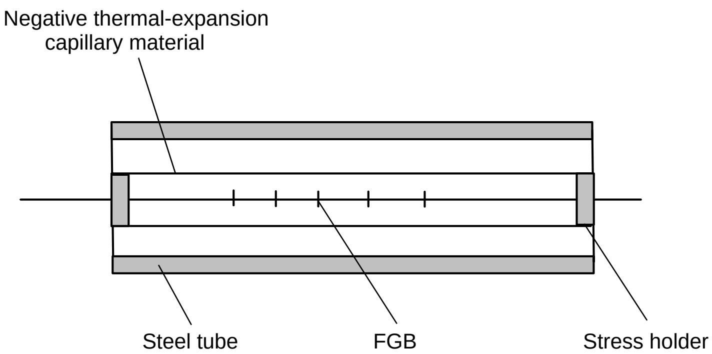

Fig. 1. Three-layer-structure package under tension for temperature-compensated FBG.

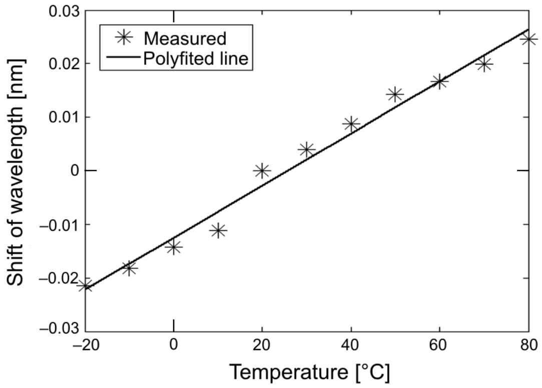

Fig. 2. Center wavelength shift of temperature-compensated FBG.

several researchers have designed packages to minimize this wavelength shift. A kind of negative thermal-expansion material which can make the temperature coefficients of FBGs' center wavelength less than 0.0005 nm/°C has been studied. The structure of packaged FBGs is shown in Fig. 1.

This is a three-layer-structure package under tension. Firstly, in order to waterproof and protect the FBGs, they are coated with a polymer; then coated FBG is packaged in the negative thermal-expansion material tube under tension, the two ends of FBG are adhered to the negative thermal-expansion material tube. For protecting packaged FBGs, the temperature-compensated FBGs are sealed in steel tube. This packaged structure can also adjust the characteristic of FBGs.

The temperature coefficient has been determined after package. The 14-cm long home-made FBGs have been used in the temperature coefficient experiment. The wavelength is measured by optical spectrum analyzer (ANDO AQ6319), the ASE of EDFA is used as the wideband optical source, the measured temperature is controlled by temperature control system (WT1-180 Weiss, Germany), the measuring range of which is from –40°C to 180°C and the resolution is 0.1°C. The measured results are shown in Fig. 2. The center wavelength shift is less than 0.0005 nm/°C from –20°C to 80°C.

3. PMD of FBG with and without temperature-compensation

PMD of FBG is one of the hot topics. FBGs were fabricated by side-written phase mask method. The UV was induced in photosensitive fiber core at one side. Birefringence of UV-written optical fiber gratings mainly comes from the asymmetrical absorption of photosensitive fiber or absorption is exponential. The normal PMD of FBG has been studied in [7].

The method tested is Jones matrix eigenanalysis (JME). The measuring setup is shown in Fig. 3. A continuously wavelength tunable laser source is used together with a commercial polarimeter to measure the Jones matrices of the packaged FBGs under test. The measured system is Agilent 8509B lightwave polarization analyzer.

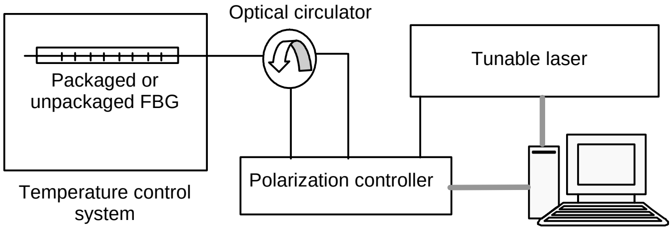

Fig. 3. Apparatus used for measurement of PMD of FBG with or without temperature-compensation using JME.

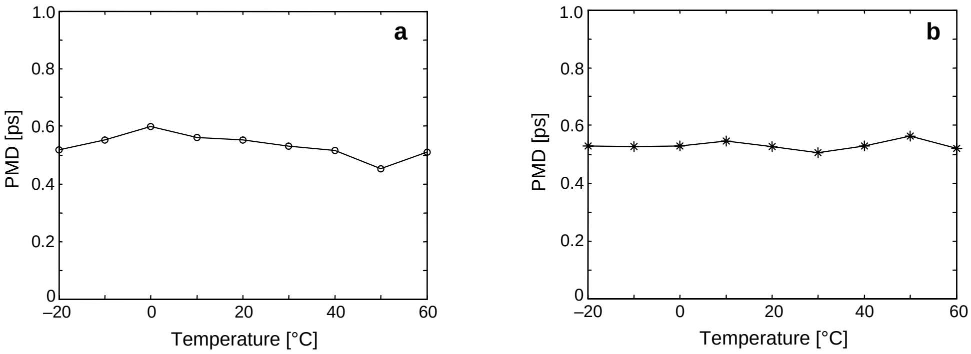

Fig. 4. Statistic PMD variance of FBG at varying temperature; temperature-compensated package (**a**) and unpackaged (**b**).

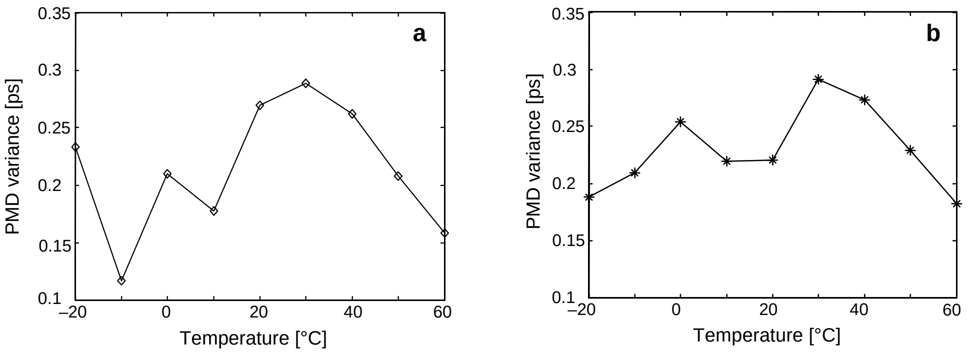

Fig. 5. Statistic PMD variance of FBG at varying temperature; temperature-compensated package (**a**) and unpackaged (**b**).

The measured system includes a computer, a polarization controller (PC), and a tunable laser (Agilent 8164A). The computer is used to control the PC and tunable laser. The computer-controlled laser can scan from 1500 to 1620 nm in a step of 0.001 nm, and the computer-controlled PC can change the polarization of input laser to test the Jones matrix of FBG with and without temperature-compensation.

The packaged or unpackaged FBGs are mounted in the temperature control system. The temperature is kept two hours before PMD is tested. The tested FBG has effective length of 140 mm, while its the center wavelength of 1546.882 nm, its being reflectivity 60% and 3 dB-bandwidth is 0.9 nm. The testing method is JME with HP8509B and the wavelength step is 0.1 nm. The 3 dB-bandwidth has been measured by optical spectrum analyzer (OSA) before the PMD of the packaged or unpackaged FBG is tested. The PMD has been measured 30 times at the same temperature. The results can be seen in Fig. 4.

From Fig. 4 we can see that both the temperature and package cause a little change in the PMD of FBG. Figure 5 shows the statistic PMD variance of packaged and unpackaged FBG at varying temperature. The measured PMD has good repeatability.

4. Conclusions

A novel negative thermal-expansion packaged material has been studied to compensate for the temperature impact on the FBGs. The temperature coefficient of FBG's center wavelength is less than 0.0005 nm/°C after three-layer-structure package under tension. PMD causes significant impairment for high bit-rate optical telecommunications systems. For the first time, PMD of temperature-compensated packaged FBG has been detailedly studied. The PMD of temperature-compensated FBG has been measured from –20°C to 60°C. The measured results show the stability of PMD of FBGs at different temperature.

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