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A simple strain sensor using polymer fibre Bragg grating and long period fibre grating

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ABSTRACT

We develop a simple strain sensor using polymer optical fibre Bragg grating and long period fibre grating. The sensor head is formed by a polymer optical fiber Bragg grating. A long period fibre grating is used for strain related wavelength shift demodulation. This particular combination of two quite different gratings could offer very large dynamic, up to tens of thousands micro-strains, for strain sensing. The preliminary experimental results have demonstrated that this sensing scheme provides good linearity, high resolution and large dynamic range.

Keywords: Fibre strain sensor; Polymer optical fiber Bragg grating; Silica fiber Bragg grating; Long period fibre grating

I. INTRODUCTION

Fiber Bragg Gratings (FBGs) have been widely used as the sensing element for more than two decades. FBG sensor can offer important advantages, such as electrically passive operation, electro-magnetic interference (EMI) immunity, high sensitivity, and multiplexing capabilities [1, 2]. Some of the most notable successes include underwater acoustic sensing, smart structure monitoring, rotation sensing, certain chemical/biomedical sensing and temperature sensing [3].

Wavelength shift interrogation is an important issue in fiber optic strain and temperature sensing especially for FBG sensing. Most of the practical interrogation schemes are based on filters or interferometers [1, 2]. However, these schemes all require relatively complex optical and electrical circuitry. A sensor system with a simple configuration and small number of components may be needed for the applications that require moderate resolution and lower cost implementations.

Because of the small Young's modulus of polymer optical fiber (POF), POF Bragg gratings, in comparison with silica FBGs, are advantageous with much higher tunability and stress sensitivity. A simple strain tuning range of 73 nm has been achieved in PMMA-based POF Bragg grating [4]. For silica FBGs, a tuning range of 32 nm Bragg wavelength shift has been reported by uniform compression [5]. There is no way silica FBGs can reach that strain tuning capability by simply stretching the fiber. Apart from that, even the compression tuning of silica FBGs cannot reach the capability of 73 nm wavelength shifts that POF Bragg gratings have for tensile tuning. Therefore polymer Bragg gratings used in sensing has its own unique points.

Long period fibre gratings (LPFGs) are usually fabricated in the manner that the fiber is exposed through an amplitude mask with UV laser beam at 193nm or 248 nm [6]. In our work, this LPFG is fabricated by using a high-frequency CO_2 laser pulses in Corning SMF-28 fiber. In the fiber drawing process, the fiber core is frozen faster than cladding and hence the drawing tension remains permanently in the core as the residual stress. This stress modifies the core refractive index in portion to the drawing tension. The high-frequency CO_2 laser generates a thermal shock effect on the crystal lattices of SiO_2, which results in local densification and/or stress relief in the fiber core. Therefore a LPF can be fabricated because the densification and/or stress relief in the heated region would induce an index increase periodically along the axis of the fiber [7].

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In this paper, a POF Bragg grating and an LPFG combined sensor scheme has been proposed. In this sensing system, the POF Bragg grating is used as a sensor head to sense strain variation and the LPFG is used to demodulate the wavelength shift caused by the strain variation. This sensing scheme can easily measurement strain up to tens of thousands micro-strains. In addition, this scheme is also immune to source fluctuation, because it has been normalized out.

II. EXPERIMENTAL SETUP

The POF and POF Bragg grating fabrications are detailed in our previous works [8, 9]. This POF Bragg grating is written on PMMA based polymer fiber. The diameter of the fiber is 125 μm with a core diameter of 6 μm. The refractive index difference between the core and the cladding is 0.0086. The fiber is single-mode in the 1550 nm transmission window. The POF Bragg grating used here is about 5mm long with Bragg wavelength at 1525.6 nm.

LPFG has been found to be useful for a number of applications such as gain flattening of erbium doped fiber amplifiers (EDFA), band-rejection filters [6] and strain/temperature sensors [10]. The pitch of the LPFG used in this experiment is Λ = 437μm with a total number of period 45. Its spectrum is shown in Fig. 1.

The strain sensing scheme is shown in Fig. 2. Two 10GHz photo-detectors are used to detect the light power. A digital CRO is introduced into this system. The wavelength shift associated with strain variation is translated into the change of optical signal power transmitted through the LPFG. Matching oil is used for all unused end of two couplers. The desired strain variation is converted into voltage changing by two photo detectors (PDs).

III. RESULTS & DISSCUSIONS

The outputs of these two PDs are input into two channels of the digital CRO. Their ratio, V_2/V_1 , is calculated. Here V_2 is the output of the PD2 from the LPFG arm and V_1 is the output of PD1 which is the reference arm. By using ratio V_2/V_1, the source fluctuation can be easily cancelled out.

Fig. 3 shows the value of V_1, V_2 and V_2/V_1 at different tensile strain. The results display a large measurement range of 15000 με with reasonably good linearity in our proposed sensing system. This strain range is nearly two times larger than that of the sensing configuration reported in [11]. For silica optical fiber, a maximum tensile strain of roughly 1% can be applied without degrading the fiber strength and eventually breaking the fiber [5]. However, the yielding strain for our POF is about 6% [9], it indicates that the strain sensor of this proposed scheme potentially can have extremely large measurement range.

The stability of the proposed scheme shown in Fig. 2 has been studied. Good stability has been found for this sensing system. We tested the effect of intensity variations of the sensing system on the strain measurement. Fig. 3(a) clearly demonstrates the variation of the applied strain has caused signal intensity variations in both the outputs channels, i.e. both V_1 and V_2 are strain sensitive. It is clear that the intensity variation in V_2 channel is merely due to the undesirable effects such as reflectivity change under strain. However, this intensity variation could be removed by the use of the ratio, V_2/V_1 , and we could achieve improved train accuracy. Of course, any long-term variation in source output can also removed this way. Therefore, it is quite advantageous of using the ratio of V_2/V_1 instead of V_1 or V_2 alone for the strain measurement. We also tested the sensing system at slightly different ambient temperature. The data in Fig. 3 include the results corresponding to the temperature at 25.2°C and 23.2°C, respectively. Based on the results shown in Fig 3(b), the error in the strain measurement is not significant for small temperature difference.

As we all know that the resolution of strain sensing is dependent on the design of electronics and photonics. The resolution of this setting is approximately 50 με. However, this resolution may be slightly increased with the decrease of the POF Bragg grating bandwidth.

IV. CONCLUSIONS

A strain sensing system using POF Bragg grating and LPFG is proposed here. This sensing scheme is very simple and, importantly, it can achieve larger range of strain measurement. The preliminary experimental results show that we could achieve a dynamic range of about 12000 με with good linearity and accuracy. The strain measurement range is about twice that of a similar system based on the conventional silica FBG.

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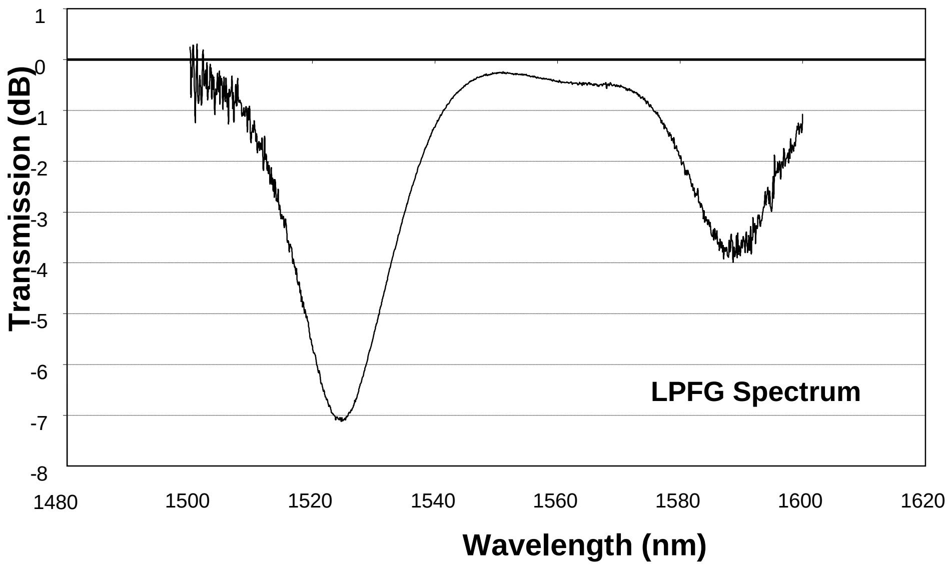


Fig. 1 Spectrum of the long period fibre gratings

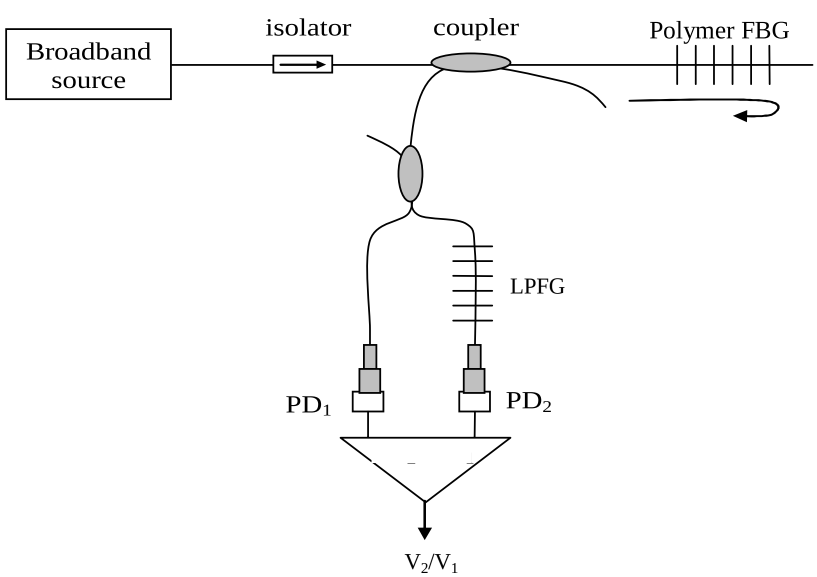
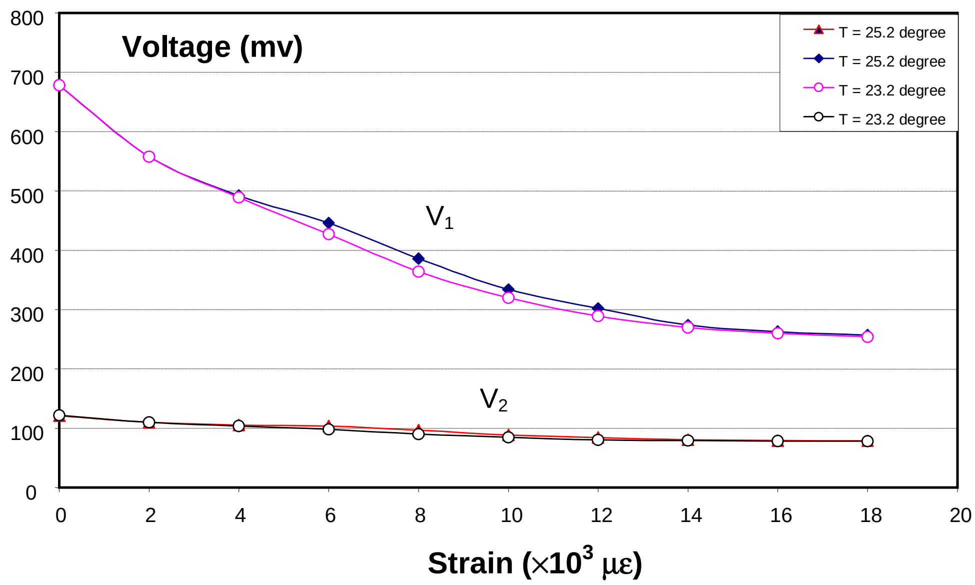
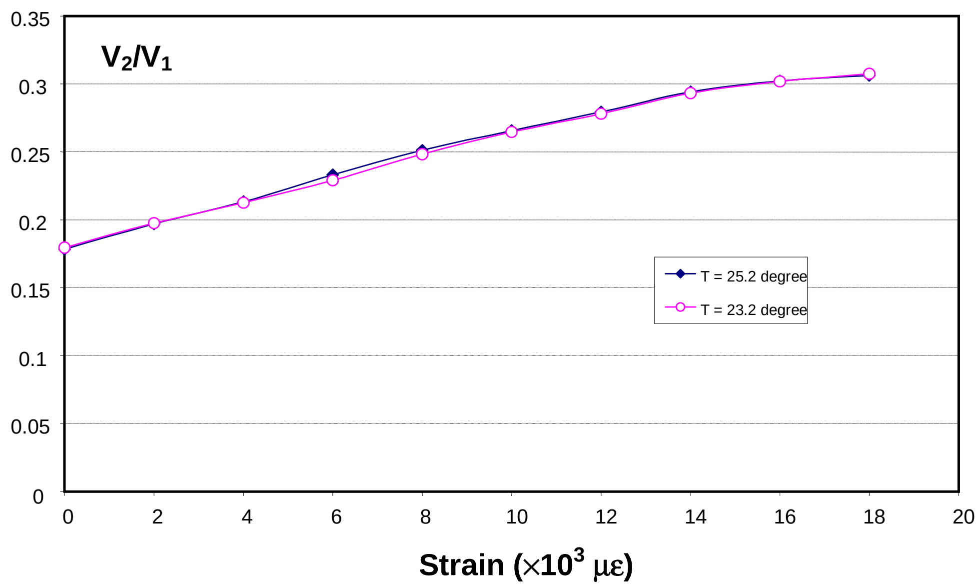


Fig. 2 Scheme of strain sensing using polymer fiber Bragg grating and long period fibre grating.



(a)



(b)

Fig. 3 Dependence of output voltage V_1, V_2 (a) and ratio of V_2/V_1 (b) on applied strain under different ambient conditions.