1115

Fibre Grating Pressure Sensor with Enhanced Sensitivity Using a Glass-Bubble Housing

M. G. Xu, H. Geiger, and J. P. Dakin

Optoelectronics Research Centre, University of Southampton

Southampton SO17 1BJ, United Kingdom

Abstract

A fibre Bragg grating pressure sensor with enhanced sensitivity has been demonstrated, using a grating housed in a glass bubble. This configuration increases the pressure sensitivity and effectively reduces the thermal crosstalk by a factor of 4. A pressure resolution of 0.5% over a full measurement range of 14 MPa has been achieved. This concept could lead to a range of sensors using fibre gratings with mechanical amplifiers to enhance sensitivity.

Introduction: Fibre grating sensors are of considerable interest for a number of sensing applications [1]. However, the thermal sensitivity of the fibre grating sensor may complicate its use as a pressure or strain gauge. This thermal crosstalk problem has been resolved by various methods. These include compensating for temperature using a second grating in a different material[2]; simultaneously measuring strain and temperature using two superimposed fibre gratings[3]; positioning surface-mounted fibre gratings to cancel the thermal response[4]; and making the fibre grating temperature-independent using a chirped fibre grating in a tapered fibre[5]. However, such correction methods are likely to work better if the measurand-sensitivity can be enhanced. In this letter we describe a novel fibre grating pressure sensor using a glass-bubble housing (see Fig.1). Because of the greater mechanical compliance of the hollow glass bubble, a much higher sensitivity is achieved.

Theory: When the glass bubble is pressurised, the fractional change in the diameter of the glass bubble $\Delta d/d$ due to a pressure change ΔP is given by[6]:

$$\frac{\Delta d}{d} = -\frac{d(1-\mu)}{4Et}\Delta P \quad (1)$$

where E, μ, and t are the Young's modulus, Poisson's ratio, and wall thickness of the glass bubble, respectively. Assuming good bonding between the fibre and the glass bubble, the pressure-induced strain in the grating is equal to the fractional change in the diameter of the bubble $\Delta d/d$. Then the pressure sensitivity, defined as the fractional change in Bragg wavelength $\Delta\lambda_B/\lambda_B$, is given by[1]:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1-p_e)\frac{\Delta d}{d} = 0.17\frac{d(1-\mu)}{Et}\Delta P \quad (2)$$

where p_e=0.22 is the effective photoelastic constant for silica[1]. It can be seen from Eq.(2) that the pressure sensitivity can be enhanced by choosing a larger or thinner-walled bubble. However, a compromise has to be made between the desired pressure sensitivity and the maximum measurement range, limited by the collapse of the bubble. The observed implosion pressure for the bubble we used was 14 MPa.

Experiment and results: Fig.1(a) depicts the experimental setup. Light from a 1300 nm fibre-pigtailed ELED was coupled via a fibre coupler into the sensing element shown in Fig.1(b). The sensing element was installed within a cavity of a high pressure vessel. Pressure was applied using a hydraulic pump and measured using a commercial precision pressure transducer (Druck PDCR 960). The fibre grating was installed in a glass bubble blown in a Pyrex glass capillary tube. The fibre outside the grating region was bonded using UV-curing cement into short sections of the residual capillary tube attached to the bubble. Since the mechanical compliance of a glass-bubble is much higher than that of a solid-glass fibre grating, the glass bubble acts as a mechanical amplifier. Pressure sensitivity is therefore enhanced, whereas the temperature sensitivity is not enhanced, due to the similar thermal expansion coefficients of the fibre grating and the glass bubble. The pressure-induced Bragg wavelength was accurately monitored using a wavelength tracking system based on an acousto-optic tunable filter. This system has been previously demonstrated for precise tracking of Bragg wavelength shift of fibre grating sensors[7,8] and for monitoring fringe shifts in interferometric sensors[9].

Fig.2 shows the measured pressure response of the fibre grating, housed within a 5.5mm diameter glass bubble of approximately 500μm wall thickness. Using values of 7×10^{10} N/m^2 for Young's modulus, and 0.2 for Poisson's ratio, the predicted pressure sensitivity from Eq.(2) was -24×10^{-6}/MPa. The measured pressure sensitivity was -21.2×10^{-6}/MPa, which matches well with that theoretically predicted. Since the pressure sensitivity of a normal fibre grating is only -5.1×10^{-6}/MPa [10], the pressure sensitivity has been enhanced by more than a factor of 4 for this particular glass bubble. In addition, the temperature sensitivity of the sensor was measured to be 6.1×10^{-6}/°C, a typical value for a normal fibre grating[10]. Hence, the effect of thermal crosstalk has been reduced by a factor of 4, so less thermal compensation will be required. The dynamic response (see Fig.3) was also measured. The Bragg wavelength was tracked over 80 seconds as a periodic pressure pulse of 6.8MPa (peak-to-peak) was applied. The measured pressure resolution was 68.8kPa (10psi), corresponding to a pressure resolution of 0.5% over the full measurement range to the implosion limit. For higher pressure measurement, a smaller or thicker-walled bubble could be used. Alternatively, the pressure sensitivity could be increased further by choosing a larger sphere of the same wall thickness.

Conclusion: We have demonstrated a new technique to enhance the pressure sensitivity of fibre Bragg grating sensors using a glass-bubble housing. For the initial experiment, the sensitivity was increased by a factor of 4, but could be further improved by optimising the glass bubble design. This is believed to be the first report on using mechanical amplifiers to enhance the sensitivity. Such concepts could form the basis of various fibre grating sensors.

Acknowledgements

The Optoelectronics Research Centre is a U.K. government funded (EPSRC) Interdisciplinary Research Centre. The authors wish to thank M.L.Caplin for blowing the glass bubbles.

References

1. Morey, W.W., Meltz, G., and Glenn, W.H.: "Fibre optic Bragg grating sensors", 1989, *Proc. SPIE*, **1169**, pp.98-107.

2. Morey, W.W., Meltz, G., and Weiss, J.M.: "Evaluation of a fibre Bragg grating hydrostatic pressure sensor", 1992, Proc. OFS'8, Monterey, USA, Postdeadline Paper PD-4.4

3. Xu, M.G., Archambault, J.L., Reekie, L, and Dakin, J.P.: "Discrimination between strain and temperature effects using dual-wavelength fibre grating sensors", *Electron. Lett.*, 1994, **30**, pp.1085-1087.

4. Xu, M.G., Archambault, J.L., Reekie, L., and Dakin, J.P.: "Thermally-compensated bending gauge using surface mounted fibre gratings", *Int. J. Optoelectronics.*, 1994, **9**, pp.281-283.

5. Xu, M.G., Dong, L., Reekie, L., Tucknott, J.A., and Cruz, J.L.: "Temperature-independent strain sensor using a chirped Bragg grating in a tapered optical fibre", *Electron. Lett.*, 1995, **31**, (10), pp.823-825.

6. Xu, M.G., and Dakin, J.P.: "A novel hollow-glass microsphere sensor for monitoring high hydrostatic pressure", 1992, *Proc. SPIE*, **1795**, pp.2-7.

7. Xu, M.G., Geiger, H., Archambault, J.L., Reekie, L., and Dakin, J.P.: "Novel interrogating system for fibre Bragg grating sensors using an acousto-optic tunable filter", *Electronics Lett.*, 1993, **29**,(17), pp.1510-1511.

8. Geiger, H., Xu, M.G., Eaton, N.C., and Dakin, J.P.: "Electronic tracking system for multiplexed fibre grating sensors", *Electronics Lett.*, 1995, **31**, (12), pp.1006-1007.

9. Xu, M.G., Geiger, H., and Dakin, J.P.: "Interrogation of fibre-optic interferometric sensors using an acousto-optic tunable filter", *Electronics Lett.*, 1995, **31**, (17), pp.1487-1488.

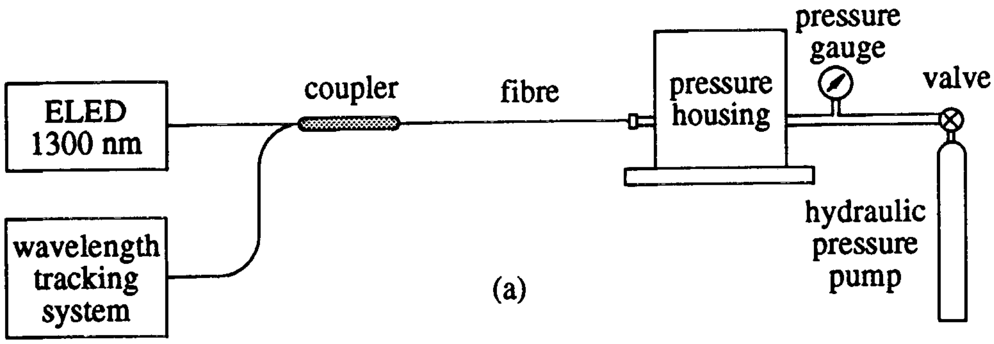
10. Xu, M.G., Reekie, L., Chow, Y.T., and Dakin, J.P.: "Optical in-fibre grating high pressure sensor", *Electronics Lett.*, 1993, **29**, (4), pp.398-399.

Figure captions

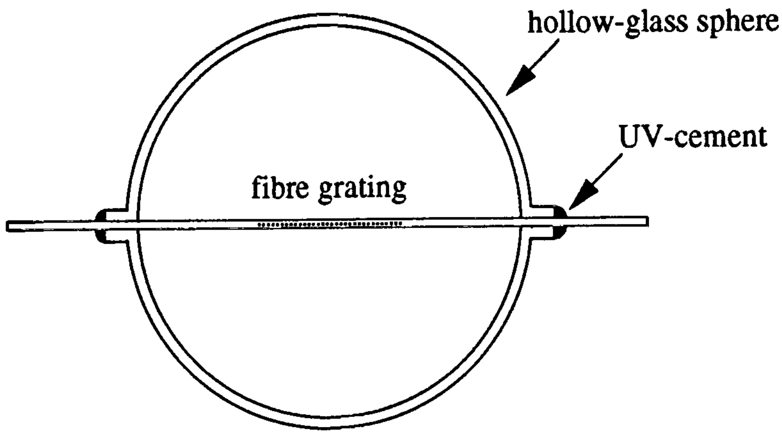
Fig.1 (a) Schematic of experimental setup. (b) Sensing element: fibre grating housed in a glass-bubble.

Fig.2 Tracking of pressure sensor. A linear fit of the measured data gave a enhanced pressure sensitivity of -21.2×10^{-6}/MPa.

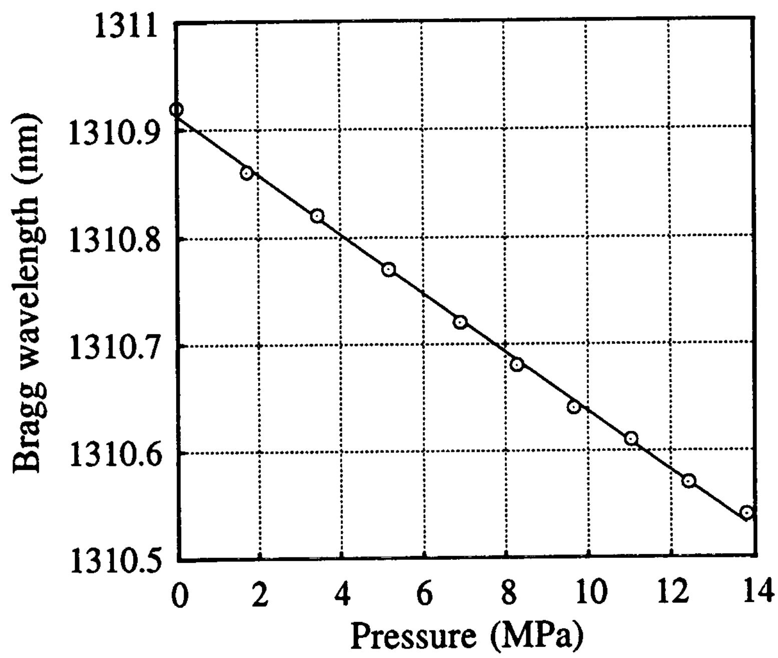
Fig.3 Dynamic pressure monitoring when a pressure pulse of 6.8MPa was applied.


ELED
1300 nm
wavelength
tracking
system
coupler
fibre
pressure
housing
pressure
gauge
valve
hydraulic
pressure
pump

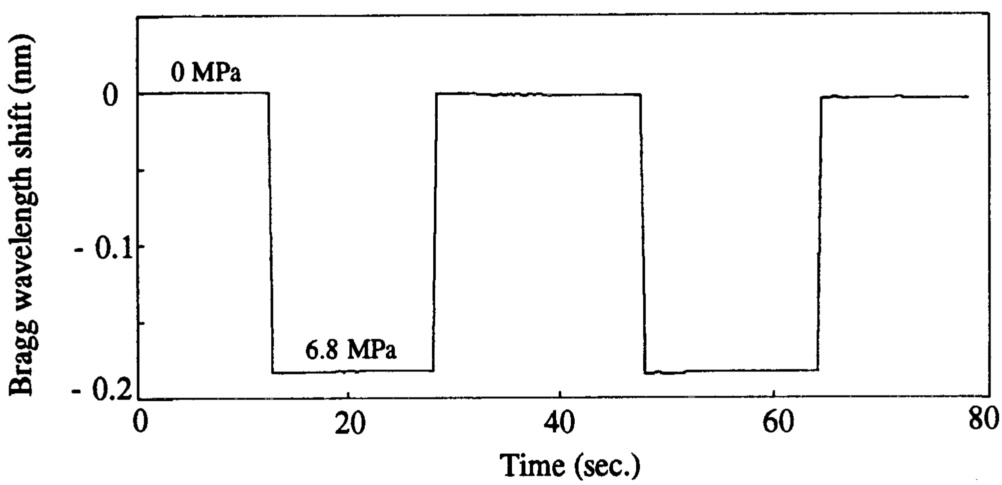
(a)


hollow-glass sphere
UV-cement
fibre grating

(b)



1311
1310.9
1310.8
1310.7
1310.6
1310.5
Bragg wavelength (nm)
0
2
4
6
8
10
12
14
Pressure (MPa)



Bragg wavelength shift (nm)
0 MPa
6.8 MPa
0
- 0.1
- 0.2
0
20
40
60
80
Time (sec.)