from Fig. 3 that the change in the effective refractive index has a power-law dependence on UV fluence. It shows distinctly different behaviours for different dose regions, indicating that there is a gap between at least two different mechanisms of photosensitivity. In the low dose range (<20 J/cm²), the slope is approximately 0.27 and it is virtually independent of pressure. Beyond a transition region where both mechanisms operate (20-800 J/cm²), the refractive index change also exhibits power-law dependence. However, in this high-dose region, the slope is pressure dependent, increasing from 0.39 at 26 bar to 0.68 at 160 bar.

**Conclusion:** We have presented a novel highly accurate technique to measure photosensitivity in optical fibre. Experimental data on photosensitivity measurements of different fibres are presented. The experimental data indicate that there are distinct mechanisms of photosensitivity that are likely to operate in hydrogen-loaded germanosilicate fibres.

**Acknowledgments:** The authors acknowledge the financial support for this work by Telkom SA Ltd., ATC (Pty) Ltd., THRIP and RAU, and by CONACYT through the research grant 35460-U.

© IEE 2002 9 September 2002
Electronics Letters Online No: 20021046
DOI: 10.1049/el:20021046
E-mail: pls@ing.rau.ac.za
M.G. Shlyagin and VV. Spiran (Division de Física Aplicada, CICESE, Apdo. Postal 2732, 22860, Ensenada, B.C., Mexico)

**References**


**Self-healing fibre grating sensor system using tunable multiport fibre laser scheme for intensity and wavelength division multiplexing**

Peng-Chun Peng, Hong-Yih Tseng and Sien Chi

A fibre grating sensor system using a tunable multiport fibre laser scheme for intensity and wavelength division multiplexing is proposed. The power ratio (1:2:3) between each output port is used to address the sensing information. The network survivability is also considered. This fibre grating sensor system can enhance the sensing capacity and reliability.

**Introduction:** Fibre Bragg grating (FBG) sensors have attracted considerable interest because of their applications for quasi-distributed sensing in a smart structure [1]. One of the distinctive advantages provided by FBGs in a sensor system is the multiplexing capability. Several FBG multiplexing techniques have been developed, including wavelength division multiplexing (WDM), time division multiplexing (TDM), spatial division multiplexing (SDM), code division multiplexing (CDMA), and their combinations [1-4]. The WDM technique incorporated with hybrid star-bus topology or double-bus topology for an FBG sensor has been investigated [5-6]. Such research associated with network survivability would be an ongoing challenge for the practical applications of FBG sensor systems. The survivable network architectures for an FBG sensor system should be cost-effective, crosstalk-free, and output-reliable. Therefore, the capacity of a sensor network should be easily extended and the sensing accuracy should be sufficiently reliable against the noisy environments. Such performance should be considered not only for the optical network layout but also for the electronic signal processing approach.

In this Letter, we propose a self-healing FBG sensor system using a tunable multiport fibre laser scheme for intensity and wavelength division multiplexing. The proposed system can easily enhance the capacity of the sensing FBGs. To maintain the real-time monitoring and indicate the breakpoint position when a fibre link suddenly breaks, a simple self-healing function is also considered in the ring topology of each sensing FBG chain. These advantages can facilitate the remote sensing with high reliability in a smart structure.

**Principle:** Fig. 1 is a schematic diagram showing the proposed self-healing FBG sensor system. The light source of this sensor system is a tunable fibre ring laser with a Fabry-Perot (F-P) filter for wavelength selection. For WDM incorporated with intensity multiplexing, the output port of this fibre laser is a 2 x 4 coupler comprising three fibre couplers with different coupling ratios. Because of this novel arrangement, three lasing lights with identical wavelength but different output power emerge from the ring laser simultaneously. The output ratio between the different lasing branches can be designed according to the coupling ratios of the three fibre couplers. The lasing light from each output port is launched into a branch of sensing FBG chain. In contrast with [7], all the sensing FBGs in three chains can have the approximately equal peak reflectivity and need not be fabricated for specified peak reflectivity for intensity multiplexing. Consequently, the proposed multiport fibre laser can easily enhance the capacity of an FBG sensor system by using the intensity multiplexing and WDM technique.
Experiment: The multipoint fibre laser was constructed by an isolator, a 2 x 4 coupler, a F-P filter with a 35 nm free spectral range (FSR) and a 980 nm laser diode pumping a piece of Er⁺ fibre through a 980/1550 WDM coupler. The 2 x 4 fibre coupler comprised a 2 x 2 fibre coupler (50:50), a 1 x 2 coupler (40:60), and a 1 x 2 coupler (80:20). To enhance the reliability of multipoint sensing, we used a self-healing ring architecture by adding a 1 x 2 optical switch in each sensing branch. The lasing light then travelled through the 2 x 4 fibre coupler and split into three FBG branches (FBG1 at 1559.70 nm, FBG2 at 1558.74 nm, and FBG3 at 1557.23 nm) for experimental demonstration of our proposed multiplexing technique. Because of the 2 x 4 coupler, the power ratio launched into FBG1, FBG2, and FBG3 was 30%:20%:10%. The peak reflectivity of each FBG was over 99.5%. The backreflected light from each FBG sensor is also considered by adding a switch in the ring architecture. In the experiment, a three-point sensor system was used. The experimental results show that the tunable multipoint fibre laser for intensity multiplexing and WDM can enhance the OSNR and resolution of the sensor system. These advantages facilitate the electronic signal processing for a FBG sensor system and lead to a simple fibre sensor network with a large number of FBG sensing applications.

Conclusion: A self-healing FBG sensor system using a tunable multipoint fibre laser scheme for WDM incorporated with intensity division multiplexing has been proposed and experimentally demonstrated. Such a multiplexing technique can easily increase the capacity of the FBG sensor system. The network survivability of this proposed FBG sensor is also considered by adding a switch in the ring architecture. In the experiment, a three-point sensor system was shown. The experimental results show that the tunable multipoint fibre laser for intensity multiplexing and WDM can enhance the OSNR and resolution of the sensor system. These advantages facilitate the electronic signal processing for a FBG sensor system and lead to a simple fibre sensor network with a large number of FBG sensing applications.

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w = Q_{ij} \cdot 2^{m-1} + f'

(4)

We can then obtain m bits of the extracted mark simply by transforming w to binary scale.

Tamper detection: We have estimated the scheme's fragility, and found that the variable m is important to fragility. As m increases, the scheme becomes more and more sensitive to image modification. Hence, m is chosen as 4 in our work in order to achieve both tamper detection capability and tolerance towards mild modification simultaneously. In tamper detection, we generate a set of binary difference images between the marking logo image and the extracted candidate logo image in different resolutions, where binary 1 represents an error pixel, while binary 0 no error. To a specific resolution, mathematical morphology operations are applied to remove noise-like pixels and to create a compact tamper region in the difference image. Specifically, a dilation operation is applied firstly to create compact regions, then an erosion operation is applied in succession to remove the noise-like error pixel, and finally another dilation operation is applied to restore the original size of the compact regions. The structure element used in each operation is calculated carefully using order statistics [5]. We further define error detection ratio \( \lambda_i \) and error dense ratio \( \delta_i \) of the difference image in a specific resolution level I as follows:

\[
\lambda_i = \frac{\text{card}(\text{error pixel})}{\text{card}(\text{total pixel})}
\]

\[
\delta_i = \frac{\text{card}(\text{dense pixel of error detection})}{\text{card}(\text{error pixel})}
\]

(5)

where card(\cdot) denotes the cardinality of the argument set, and a pixel of error detection is dense if there is at least one error detection pixel in its surrounding eight neighbours. Using the above parameters, we define the following rules in authentication. (i) If \( \lambda_i > 0 \) for every resolution level I, the tested image has been neither maliciously tampered nor incidental distorted. (ii) If there exists some I such that \( \lambda_i > 0 \) and \( \delta_i < \alpha \), where \( \alpha \) is a preset threshold, then the tested image has encountered only incidental distortions. In experiments, we set \( \alpha = 0.5 \). (iii) \( \lambda_i > 0 \) and \( \delta_i > \alpha \) for every I, then the tested image has been maliciously tampered.

Simulation results: Many experiments have been conducted to demonstrate the effectiveness of tamper detection with the proposed scheme. The test results on 'Lena' and 'Baboon' images, both of 256 x 256 x 8 bits, are reported here. The peak signal-to-noise ratios (PSNR) of the watermarked images are 38.43 and 31.86 dB, respectively. It is noted that the PSNR is only 34.26 dB for Lena with the scheme in [2]. This 4.17 dB increase in PSNR is due to the utilisation of Watson's quantisation matrix. Fig. 1 shows the extracted watermarks from the marked image compressed by JPEG compression with quality factor a = 90, b = 70, c = 50.

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