High Precision, Low-Cost Interrogation System for Fiber Bragg Grating Sensors

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A low-cost electro-optic FBG interrogation system is proposed that is based on a Piezo-driven tunable fiber Bragg grating and on-line calibration with absorption spectroscopy.

1 Introduction

Fiber Bragg gratings consist of a periodic modulation of the index of refraction along the optical fiber (Fig. 1). The creation of these structures is based on the photosensitivity of optical fibers, which was found by Hill and coworkers [2]. Photosensitivity means that the index of refraction of the fiber is increased, if the material is exposed to UV radiation. The fiber Bragg gratings used in this study are manufactured in-house employing the phase mask technique. Light propagating along the waveguide is efficiently reflected by the grating, if the reflected portions from all grating planes interfere constructively with each other. This condition is known as the so called Bragg condition, i.e. the wavelength in the material, $n_{eff} \cdot \lambda_B$, has to be twice the grating period (=2Λ).

In fiber Bragg gratings strain and/or temperature variations are transformed to a shift of the Bragg-wavelength which makes them well suited as sensor elements. This characteristic also offers the possibility to create FBG-based tunable filters. Several methods for measuring the wavelength shift of FBG-sensors have been demonstrated [1,3]. They differ in system performance as well as in system complexity, robustness, and costs. In this study a signal generation scheme is investigated with respect to its potential to combine a small, portable, robust, low-cost electro-optic hardware solution with high sensor performance.

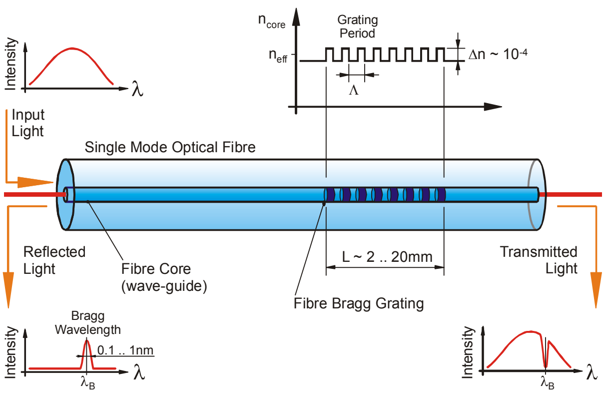

***Fig. 1** Fiber Bragg grating*

2 Signal generation scheme

Light from a broadband light emitting diode gets coupled into an SM fiber (Fig. 2). The light is first incident to FBG1 which is operated as a tunable filter and reflector because it is stretched by a piezo (PZT) driven mechanism which is controlled by a triangle voltage signal. The light at output 2 of coupler 1, which represents a tunable light source, is transmitted via coupler 2 to FBG2, the sensor grating. When the strain on FBG1 (analyzer FBG) matches the one of FBG2 (sensor FBG), a small range of wavelengths is reflected back through the second coupler to detector 1. The peak detector signal occurs at maximum overlap, and the corresponding PZT voltage can be taken as a measure for the wavelength shift and thus for the strain (or temperature) of the sensor grating.

In the proposed scheme, absorption spectroscopy is employed for wavelength calibration and for monitoring the tuning characteristics (nonlinearity, hysteresis, temperature drift etc.) of the PZT tuning element. Therefore light at output 4 of coupler 2 is transmitted through an acetylene absorption cell and the absorption spectra is observed by detector 2.

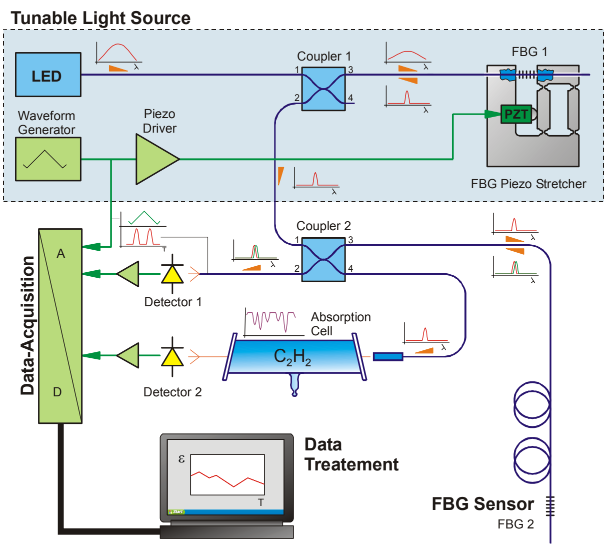

***Fig. 2** Signal generation scheme.*

3 Hardware

Fig. 3 shows the tuning mechanism for FBG1. The fiber Bragg grating is located at position 3, in the middle of positions 1 and 2, where the fiber is attached to the fixed and the movable part of the device. The movable part is guided by two flexure hinges. A low-voltage PZT actuator is used to push the movable part. It is operated in a 1:3 lever ratio, resulting in a displacement amplitude of the movable part of about 60µm. The distance of the attaching points of the fiber is typically less than 10mm resulting in a maximum achievable strain of $\Delta L/L = 6\cdot10^{-3} = 6000\mu\varepsilon$. The tuning speed is determined by the mechanical resonance frequency of the device. Stable operation with full tuning range was observed up to tuning frequencies of 100 Hz. The portable interrogation system containing the light source, the fiber couplers, the tunable fiber Bragg grating and driver/detector electronics, is shown in Fig. 4. The data is transferred to a laptop computer where signal processing is performed with a LabVIEW application software.

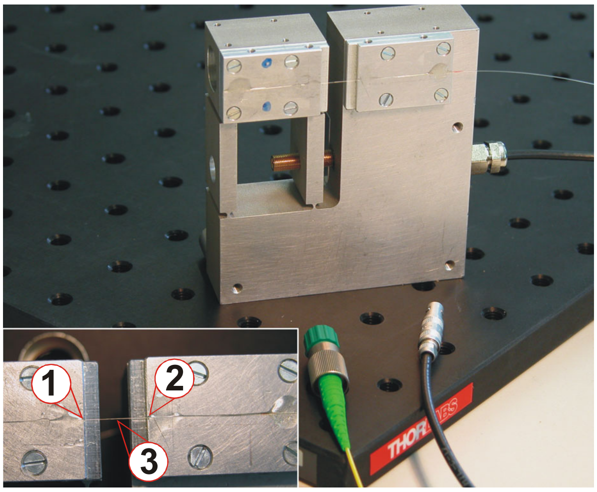

Fig. 3 *Tuning mechanism for FBG*

4 Calibration and Resolution

The system needs to be calibrated in order to convert PZT voltages to strain. Therefore a sensor FBG is suspended vertically and stretched by attaching different weights. The resulting strain is calculated from the weight and standard mechanical fiber data. Fig. 5 shows the resulting calibration curve (square symbols, left axis) together with the reflected peak wavelength, which was measured with an optical spectrum analyzer (OSA) (triangles, right axis). A second order polynomial regression to the data showed the OSA-measured wavelength to depend, as expected, only linearly on strain, whereas a small but significant quadratic term is needed for the PZT voltage. This nonlinearity is due to PZT characteristics and is corrected by our data acquisition software. The system resolution is 0.6 µε (micro-strain).

5 Conclusion

A portable, low-cost FBG interrogation system is realized. The achieved measurement resolution together with software linearization make it suitable for high precision strain sensing applications. An additional wavelength stabilization feature based on molecular absorption will be addressed in future investigations in order to improve the long term stability.

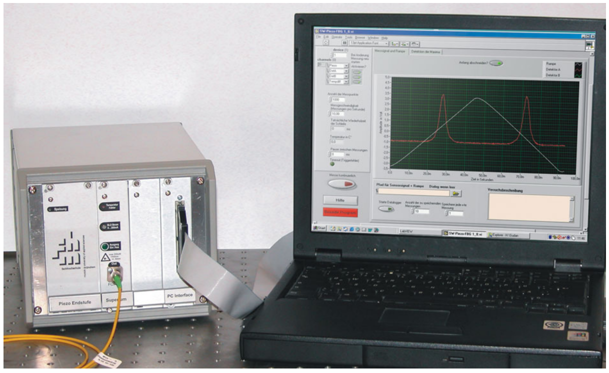

Fig. 4 *Portable interrogation unit for FBG*

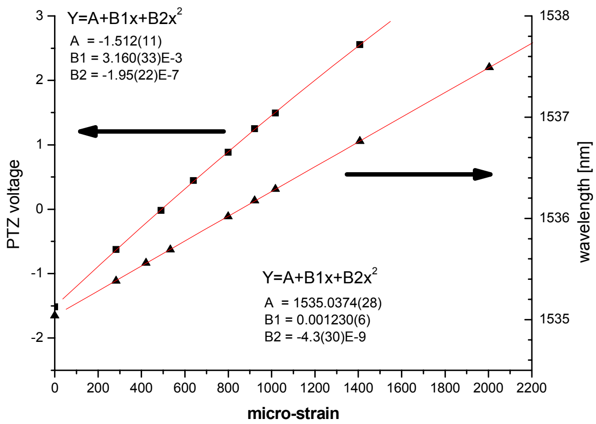

Fig. 5 *Calibration measurements (triangles: Bragg-wavelength measured with the OSA, squares: PZT-voltages at matched and tunable filter FBG)*

References

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