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Bragg grating tuned fiber laser system for measurement of wider range temperature and strain

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Abstract

A Bragg grating-tuned fiber laser-based sensor system has been developed to measure over a wide range of temperatures (22–500 °C) and strain (0–1200 με) using both a normal grating and a chirped grating as optical feedback elements and Er^{3+}-doped fiber as the active gain medium. A high reflectivity normal Bragg grating was written into a specially fabricated high temperature sustaining Sb–Ge co-doped photosensitive fiber and a chirped grating was inscribed into a commercial B-Ge co-doped fiber, due to its higher photosensitivity. The shift in the laser wavelength was monitored in this system when the normal grating was temperature or strain-tuned, with it also forming the active element of the sensor head of the system. The root mean square (RMS) error values of the active sensor system were found to be 2.6 °C and 28.3 με over the above measured ranges of temperature and strain, respectively.
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1. Introduction

Fiber Bragg grating (FBG)-based sensor devices have shown themselves to be important components in a range of sensor applications [1,2] over the past several years, because of their mechanical robustness, the use of a wavelength-encoded measurement information, and a potential multiplexing capability over a single optical fiber. In passive FBG-based sensor systems, a spectrally broadband source is required to cover the wavelength range over which the Bragg grating is measurand-tuned.

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Due to the narrow-band nature of the Bragg wavelength, the output power reflected from this type of source is often quite weak, leading to a poor signal-to-noise ratio (SNR) of the measurement system, especially in noisy environments, thus reducing the potential accuracy available with current detection systems. A laser-based sensor system can, however, provide significant improvements in the SNR, with the signal amplification occurring in the optical, rather than in the electronic domain. Also the narrow linewidth of the laser signal allows the detection of much smaller shifts in the laser wavelength, arising as a result of temperature and strain changes, thus making the device highly sensitive to small perturbations of the measurand.

Several laser-based approaches have been reported to measure strain and temperature, for example using a mode-locked interrogation technique in the laser cavity for strain measurement [3], a laser-based sensor system for temperature measurement using a combination of a normal grating (type I or type IIA) and a chirped grating to form the laser cavity [4,5], or using multiple Bragg gratings in a laser configuration to measure the strain and temperature [6]. However, in all the laser-based sensor schemes proposed, the temperature range has normally been limited up to ~300 °C (and more recently increased to 440 °C), which mainly arises from the narrow bandwidth of the chirped grating which was used as one of the cavity reflectors to achieve tunable laser action [5] and also from the limitations on the availability of the high temperature sustainable photosensitive fiber required, in which to inscribe the normal gratings used as the sensing element of the laser system.

In this paper, building upon prior work by the authors, a Bragg grating-tuned fiber laser-based sensor system has been demonstrated to measure successfully and independently both a wider range of temperature from room temperature (~22 °C) to 500 °C and strain values from zero to 1200 με, respectively. The laser-based sensor system employs a similar approach to previous work [4,5] to form the laser cavity using Er^{3+} doped fiber as the active gain medium, but it incorporates a high temperature sustaining normal grating (RB_1) as the sensor head and the tuning element of the laser, written into a specially fabricated Sb–Ge co-doped fiber to achieve temperature measurement as high as 500 °C, and extend the sensor range to allow for strain measurement of 0–1200 με demonstrated at a fixed temperature (~22 °C). Also a chirped grating (RB_2) with a wider bandwidth (~10.80 nm) was used to achieve the tunable laser action over the measurand range used. The normal grating forms one of the end reflectors of the laser cavity, designed to have sufficiently high reflectivity (of ~92.6%) for lasing to occur (even after annealing at 525 °C for 11 h to remove the transient, unstable characteristics of the grating) and also to act as the active element of the sensor head, this being measurand-tuned for the determination of both the measured parameters. The chirped grating forms the second reflector in the laser cavity, replacing a broadband mirror in the laser cavity configuration as reported by Alavie et al. [6], thus creating a *full-in-fiber* based laser system for a range of potential sensor applications. This also overcomes the requirements, in situations where a chirped grating is not used, that both the (wavelength-matched) normal gratings used to form the laser cavity respond to the same measurand e.g. to measure temperature and/or strain [7], by allowing the laser wavelength which changes with the measurand to be tuned continuously [8].

2. Theoretical background

The laser oscillation takes place at the Bragg wavelength of the normal grating, RB_1 (which is exposed to the measurand) when the gain medium is externally pumped to overcome the cavity losses and also the cavity resonance condition, below, is satisfied:

$$\lambda_L = \frac{2nL_C}{m}, \tag{1}$$

where λ_L is the resonant laser wavelength, n is the refractive index of the gain medium, L_C is the laser cavity length and m is a positive integer [9]. Each value of m (which satisfies the resonance condition) is a longitudinal mode of the cavity, where the difference between each longitudinal mode is given by the cavity mode spacing of the laser. For Er^{3+} fiber length of ~96 cm, the cavity mode

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