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Optics Communications 275 (2007) 196–200
OPTICS COMMUNICATIONS
www.elsevier.com/locate/optcom

A novel fiber Bragg grating interrogating sensor system based on AWG demultiplexing

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Received 8 December 2006; accepted 21 February 2007

Abstract

A fiber Bragg grating (FBG) interrogating technique based on the relative intensity–demodulating and the demultiplexing of an arrayed waveguide grating (AWG) is presented in this paper. The analytical simulation and the experiment validate the feasibility of this setup. Both theoretical and experiment results show that the shift of the Bragg wavelength of the FBG sensors can be precisely interrogated by the relative intensity reading of two-adjacent-channels of the AWG-based demultiplexer. Errors caused by the light source fluctuation and micro-band losses can be reduced with the relative technique. This technique potentially offers a low-cost, compact, and high-performance solution for the interrogation of FBG distributed sensors.

Keywords: Fiber optic sensors; Fiber Bragg grating; AWG; Relative intensity demodulating

1. Introduction

Fiber Bragg gratings (FBGs) have been used extensively in telecommunication industry for various kinds of optical devices such as optical add/drop multiplexers, laser stabilizers and optical amplifier gain flattering filters for their excellent optical properties, small sizes, low cost and natural compatibility with optical fiber. In addition, FBG sensors have been received broad attention because of their versatile applications in strain, temperature and pressure measurements. The intrinsic advantages of FBG sensors, such as high sensitivity, immunity from electromagnetic interference, wavelength-encoded operation, and large multiplexing capability, enable its wide applications in measurements or monitoring [1,2].

For measuring the wavelength-encoded temperature or pressure changes of FBGs, different kinds of interrogation techniques have been reported. But the majority of interrogation system are based on tunable Fabry–Perot filters [3], Mach–Zehnder interferometers [4–7], and FBG filters [8–11]. There all requires expensive components and equipments to the measurements. Thus it is necessary to find novel techniques to convert the wavelength-encoded signal into other readable signals by cost-effective methods. Recently, it has been demonstrated that discrete measurements of Bragg wavelengths of FBGs can be taken using a thermal-tuning arrayed waveguide grating (AWG) monitored by an array of photo-detectors [12]. Due to AWG's solid state nature, compared to the moving parts of a scanning filter, long-term loss of accuracy caused by mechanical fatigue can be neglected. This method of thermal-scanning, however, requires some time to finish the searching process of the peak positions from the intensity profile.

In this paper, we propose an AWG as both a demultiplexer of multi-FBGs and an array of edge filter to precisely interrogate the wavelength shifts of the FBGs in a distributed sensor system, by using each pair of two-adjacent-channels of the AWG to monitor each FBG, respectively. The experiment results prove that this relative intensity–demodulating device has advantages of high sensitivity, immunity from the light source power fluctuations

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0030-4018/$ - see front matter
doi:10.1016/j.optcom.2007.02.063

and the uneven power distributions of the source spectrum and micro-bend attenuations of sensing FBGs.

2. Sensor structure and principle

A typical experimental setup of our FBG sensor system based on the relative intensity–demodulating and wavelength–demultiplexing of an AWG is shown in Fig. 1. It includes a broadband source, a cluster of distributed fiber Bragg gratings, a coupler or a circulator, a $1 \times N$ AWG-based demultiplexer, photo-detectors, and a series of electronic circuits and data processing. Light from the broad-band source is coupled into a cluster of FBGs by the coupler, and the reflected lights from the FBGs are coupled back into the AWG. Each channel of the AWG is detected by a photo-detector, and each pair of two-adjacent-channel signals is processed by a Ratio output. Using the relative intensity technique, undesirable effects due to possible source fluctuation and micro-bend attenuations should be corrected. The long-term measurement resolution will be significantly increased.

We take the analysis of the wavelength shift caused by temperature as an example. Fig. 2 illustrates the operating principle of the interrogating setup. Assuming that the Bragg wavelength of a sensing FBG is in middle of the central wavelength of channel k $(1 \leqslant k \leqslant N-1)$ and the central wavelength of channel $(k+1)$ of the AWG at temperature T_1, the optical power received by detector k

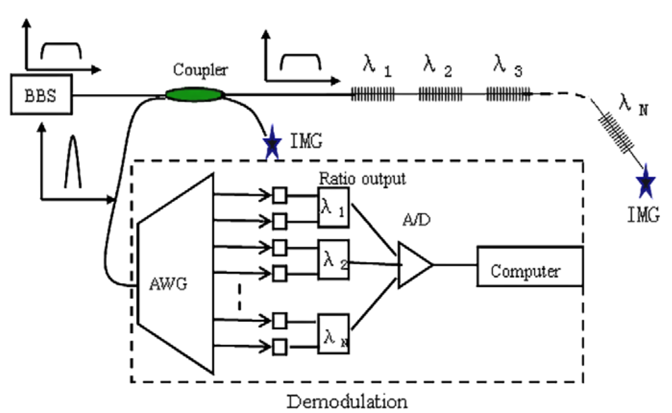

Fig. 1. Placement of device.

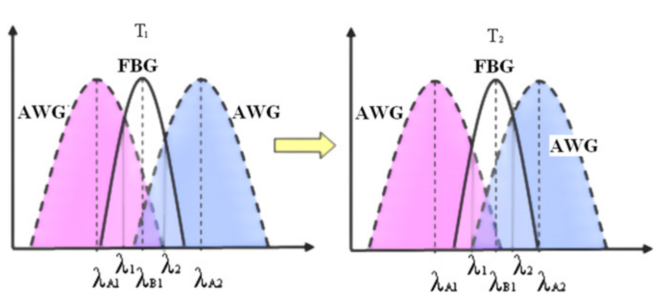

Fig. 2. The change of spectrum.

is equal to that of detector $(k+1)$ if the reflecting spectrum of FBG is absolutely symmetrical. When the FBG temperature increases, the Bragg wavelength of the FBG will shift to long wavelength. Thus, the superposition area of the transmission spectrum of channel k and the reflection spectrum of the FBG will decrease, while that of the spectrum of FBG and the spectrum of channel $(k+1)$ will increase. While the temperature decreases, the Bragg wavelength of the FBG will shift to short wavelength. Thus, the superposition area of the transmission spectrum of channel k and the reflection spectrum will increase, and that of the spectrum of FBG and the spectrum of channel $(k+1)$ will decrease. Apparently, the power ratio will increase. From the above analysis, it can be seen that the shifts of Bragg wavelength can be measured by monitoring the power ratio of AWG.

3. Analytical simulation

To explain and evaluate the feasibility of the above technique for wavelength interrogation, an analytical simulation is executed as follows. The normalized transmission function of a AWG channel with a Gaussian pass-band can be approximately given by [13]

$$T_{\mathrm{AWG}}(k,\lambda) = T_0 \exp\left(-\frac{(\lambda-\lambda_k)^2}{2\sigma^2}\right), \tag{1}$$

where T_0 is the normalized coefficient of its transmission spectrum, σ determines the full width at half maximum (FWHM) of AWG channels, while λ is the wavelength of a light source and λ_k is the center wavelength of channel k, respectively. Likely, the reflected spectrum function of a FBG can be approximately described by a Gaussian function:

$$R_{\mathrm{FBG}}(\lambda) = R_0 \exp\left(-\frac{(\lambda-\lambda_{\mathrm{FBG}})^2}{2\sigma_{\mathrm{FBG}}^2}\right), \tag{2}$$

where λ_{FBG} is the center wavelength of the FBG, R_0 is the normalized coefficient of the reflection spectrum, and σ_{FBG} determines the FWHM of the FBG, $\sigma = \frac{\mathrm{FWHM}}{2\sqrt{2\ln 2}}$.

In order to obtain the transmission power of AWG output channels, the product of the functions described by Eqs. (1) and (2) and light source intensity must be integrated across the source spectrum. It gives

$$P(k) = (1-L)\int_0^{\infty} I_s(\lambda)\cdot R_{\mathrm{FBG}}(\lambda)\cdot T_{\mathrm{AWG}}(k,\lambda)\cdot \mathrm{d}\lambda, \tag{3a}$$

$$P(k+1) = (1-L)\int_0^{\infty} I_s(\lambda)\cdot R_{\mathrm{FBG}}(\lambda)\cdot T_{\mathrm{AWG}}(k+1,\lambda)\cdot \mathrm{d}\lambda, \tag{3b}$$

where $P(k)$ and $P(k+1)$ are respectively the powers detected by photo-detector (k) and photo-detector $(k+1)$. L is the total attenuation factor of the whole system, and $I_s(\lambda)$ is the intensity of the light source. From Eqs. (1) and (2), the value of $I_s(\lambda)\cdot R_{\mathrm{FBG}}(\lambda)\cdot T_{\mathrm{AWG}}(k,\lambda)$ is very