

Design of FBG Demodulation System Based on Arrayed Waveguide Grating

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Abstract

Array waveguide grating(AWG) is a kind of role scattered light passive device base on the plane wave circuit technology. A broadband laser beam can be divided into multi-beam laser light by wavelength. In this paper, the characteristics of AWG are used and based on previous studies. Using an array waveguide grating fiber Bragg grating (FBG) demodulation method, and the mathematical model of FBG is set up in theory. With the simulation analysis, the linear relationship between the AWG dual channel optical power ratio and the FBG central wavelength is obtained. The linear relationship was verified by experiments.

Keywords: *Array waveguide grating; Fiber Bragg grating; Demodulation system*

1. Introduction

The biggest problem of practical application of optical fiber Bragg sensing system is the demodulation of the sensing signal. Accurate detection of the wavelength shift of fiber Bragg grating is the key to the practical application of the fiber Bragg grating demodulation system. In the sensing process, the sensing information of the fiber Bragg grating is received by the wavelength encoding. The change of the sensing signal is obtained by wavelength demodulation. So the tracking and analysis of the central reflection wavelength of the sensing grating is the core of the demodulation system, and to a large extent determined the resolution, reliability, and cost of the system. In the laboratory, the spectrometer can not meet the requirements of the wavelength resolution above. But in practice, we should use the excellent characteristics of fiber Bragg grating to develop a new type of sensor demodulation system with high sensitivity, good stability, high energy efficiency and high performance ratio to replacing expensive spectral analyzer in laboratory. And it used to measure and monitor the field of engineering structure. For this purpose, people have made a deep research on the demodulation technology of fiber grating sensor signal. And a lot of demodulation methods are proposed. FBG sensor demodulation method: spectrometer measurement, grating matching method[1], can be tuned Fabry Perot method[2], non balanced Mach Zehnder interferometer tracking method[3], tunable light source method and so on. Currently on the market, most of the spectrum analyzer rely on imports, the cost is expensive and the domestic production of the product function is not perfect. It is an important problem that we need to find a practical demodulation scheme which can meet the high resolution, wide tuning range, and low price, which has the real time change signal. Therefore, this paper will use the array waveguide grating (AWG)[4] role dispersion characteristics to achieve the FBG sensing signal demodulation.

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2. System Principle

The system uses AWG to realize the dynamic multiplexing of FBG, and it was proposed by A and B[5]. Figure 1 is a block diagram of the FBG demodulation system for AWG.

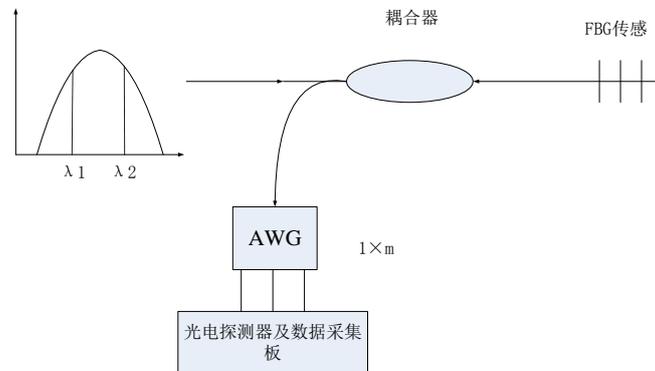


Figure 1. FBG Demodulation System with AWG

The demodulation principle is the use of the adjacent two channels of the side of a FBG sensing demodulation. The whole sensing system is composed of a broad band light source, a light coupler, a AWG, a multiple photodiode and a data processor. The light emitted by the broadband light source is entered into the FBG sensing array by a coupler and a single mode fiber, and the reflected wavelength of the FBG sensor array is entered into the AWG by the coupler. And the light is divided into narrow band light of different wavelength into multiple channels. The demodulation schematic diagram is shown in Figure 2.

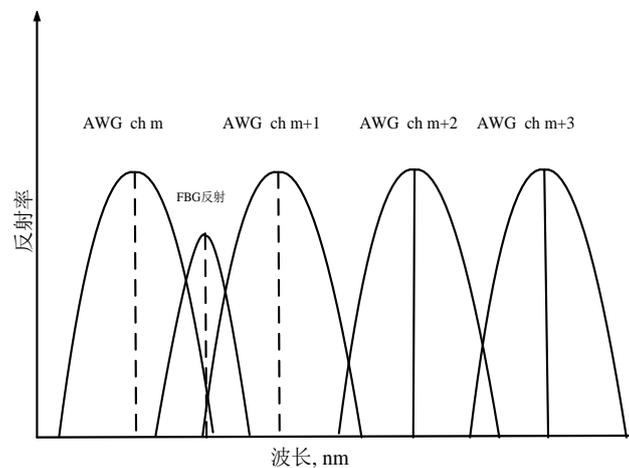


Figure 2. AWG Output Channel and FBG Reflectivity Demodulation

Figure 2 shows that the most important feature of this system is spatially separated wavelength signals by AWG. The raw data is obtained by checking the intensity signal of each channel of AWG. The central wavelength of the input signal is processed by the central processing system. For this method, in order to detect the center wavelength of λ FBG, the reflection spectrum of FBG is narrower than that of AWG. As shown in Figure 2, the λ_m represents the central wavelength of the m channel of AWG.

The FBG reflection spectrum can be obtained by solving the coupled mode equation of the grating. It has an analytical expression for uniform grating. To conclusion of

universality, the FBG reflection spectrum is expressed by Gauss approximation. The advantage is to use Gauss to fit the actual measurement of the FBG reflection spectrum data processing, and it has a good operability. The expression of the grating reflection spectrum under the Gauss approximation is as follows.

$$B(\lambda) = b \cdot \exp \left[-4 \ln 2 \frac{(\lambda - \lambda_{FBG})^2}{\Delta \lambda_{FBG}^2} \right] + b_0 \quad (1)$$

In the formula, b represents the peak of the reflection spectrum of the grating, and the b_0 represents the background noise term. In the paper, the influence of AWG transmission spectrum on wavelength detection will be discussed. And according to the conclusion, the AWG is designed to meet the requirements of the system. So we uses Gauss's far field diffraction of the beam in the free transmission area to modify the calculation in this paper. Using Fourier optics, the expression of AWG channel m is obtained. In the form of expression (1), the transmission spectrum is approximated by Gauss, and it be written as

$$A_m = a_m \cdot \exp \left[T \frac{(\lambda - \lambda_{Amc})^{2n}}{(\Delta \lambda_{Amc})^{2n}} \right] + a_{m0} \quad (2)$$

In the formula, a_m is the m channel transmission peak, a_{m0} is the background noise term, n is the order of the Gauss function, and λ_{Amc} is the central wavelength of the m channel.

AWG is affected by the environment, especially temperature. The change of temperature directly leads to the change of the central wavelength and the bandwidth of 3dB. The main detection error of wavelength detection based on AWG is the variation of the central wavelength of AWG channel and the bandwidth of 3dB. And these two parameters are most influenced by environmental temperature. Therefore, this method proposed the requirement of temperature control for AWG.

3. Simulation Analysis

According to the above principle, the numerical analysis by software is shown in Figure 3. The curve 3 represents the FBG reflection spectrum, the center wavelength is 1547.89nm, the bandwidth is 1nm and the peak intensity is 1. Curves 1 and 2 represent two adjacent channels of AWG. Adjust the channel wavelength range, so that the peak of the FBG reflection spectrum just in the junction of wavelength of two adjacent channels of AWG. At this point, the overlap area of the grating reflection and AWG two channel spectrum is equal, so the power value is equal.

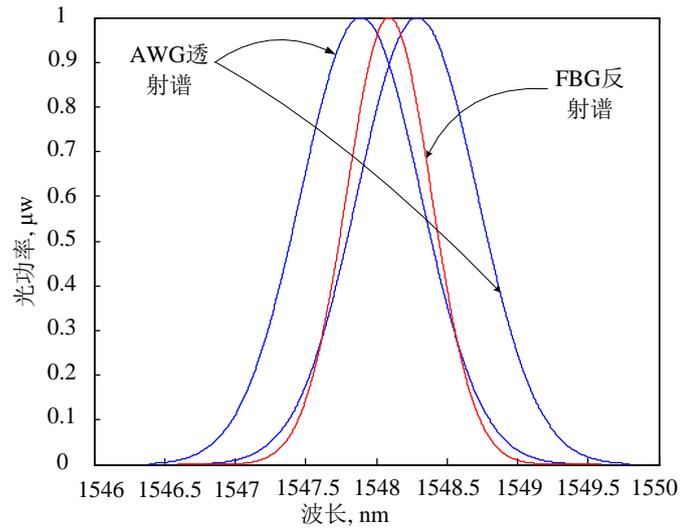


Figure 3. The Spectrum of FBG and AWG in Simulation

When the external variable changes, such as temperature or stress, FBG reflection spectrum will drift, such as temperature or stress. The overlap region of FBG reflection spectra and the two adjacent channel spectral of AWG were changed. Similarly, the light intensity will change. The integral of the overlapping part is the output light intensity. The relationship between the ratio of two light intensity and the wavelength of FBG is shown in Figure 4.

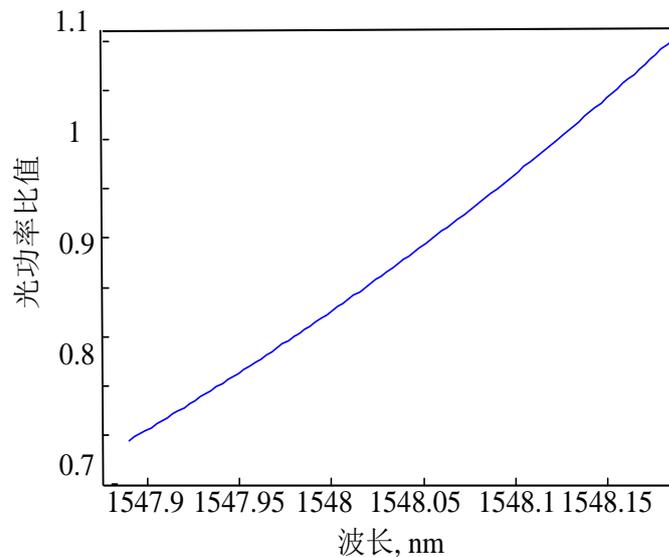


Figure 4. The Relationship between the Optical Power Ratio and the Central Wavelength of FBG

In the Figure 4, we can see that the linear change of optical power with wavelength can be obtained by numerical analysis. It will be further verified by experiments.

4. Photographs and Figures

The sensing system based on AWG consists of a broadband light source, an optical coupler, a AWG, and a multiple photodiode. The simulation block diagram of the experimental system is shown in Figure 5.

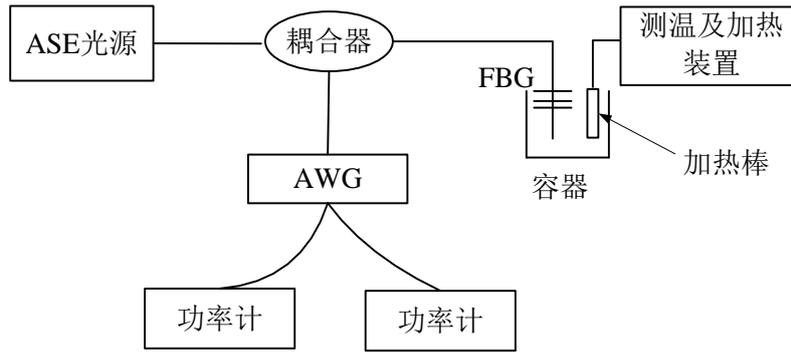


Figure 5. AWG Wavelength Demodulation

The light emitted by the broadband light source is entered into the FBG sensing array by a coupler and a single mode fiber. The reflective wavelength of the FBG sensor array is then entered into the array waveguide grating AWG by a coupler. And the characteristics of AWG can be divided into different wavelength of the incident light into multiple channels. The change range of DFB's central wavelength λ_m ($1 < m < N$) is between the two channels of the adjacent AWG. So it can avoid the mutual interference of demodulation. It is also assumed that the wavelength of each FBG is sufficiently large to make them independent. At the same time, the distance between two adjacent FBG is greater than that of AWG two. Experimental system is shown in Figure 6:

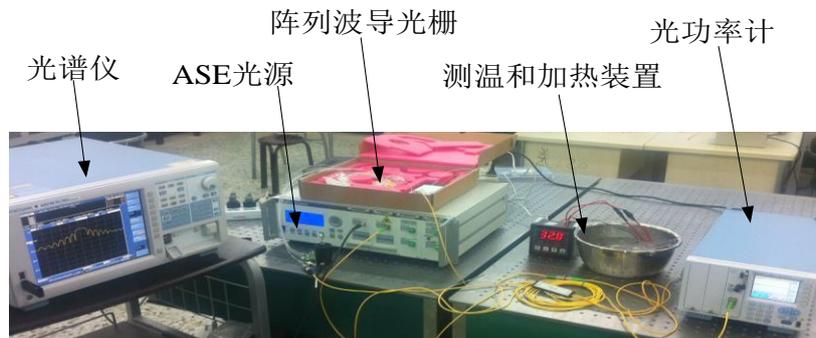


Figure 6. AWG Wavelength Demodulation System in Kind

AWG 26 and 28 channels were used in the experiment. The central wavelength of the 26 channel transmission spectrum is 1548.720nm, and the central wavelength of the transmission spectrum of the 28 channel is 1550.310nm. Their transmission spectra are shown in Figure 7.



Figure 7. AWG Dual Channel Transmission Spectrum

Because of the large 3dB bandwidth of the transmission spectrum of AWG, the grating temperature sensor is used in the experiment, and the grating is bare. The center wavelength is 1550.000nm and the bandwidth is close to 1nm. The reflection spectrum of the grating read by the spectrometer is shown in Figure 8.

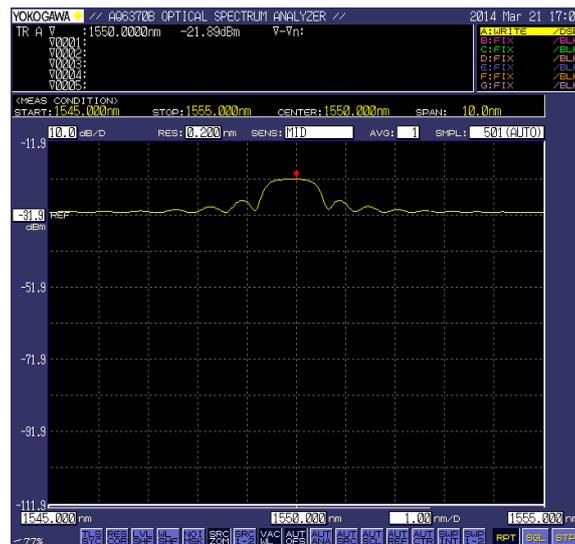


Figure 8. Reflection Spectra of Fiber Bragg Grating Sensor

5. Data Processing

By processing the raw data, We can get the relationship between the ratio of the two power meter and the temperature of grating. The relationship of the optical power of the AWG26 channel with temperature is shown in Figure 9.

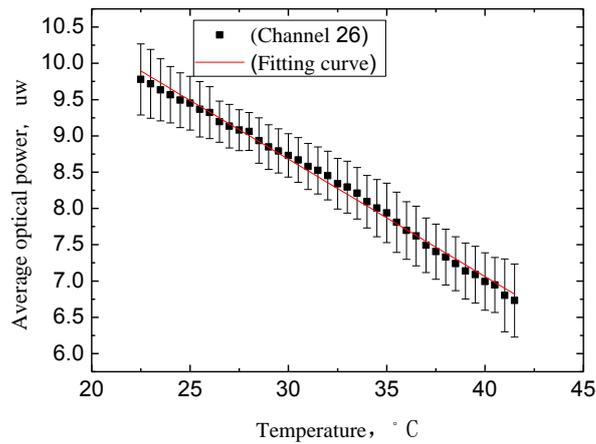


Figure 9. The Optical Power of FBG Reflected Spectrum through the AWG28 Channel

From Figure 9, we can know that the fitting degree of the curve is 0.994, and the fitting effect is very good. The fitting equation is $y = 13.5 - 0.162x$ and the sensitivity was $0.162 \mu\text{W}/^\circ\text{C}$.

The relationship of the optical power of the AWG28 channel with temperature is shown in Figure 10.

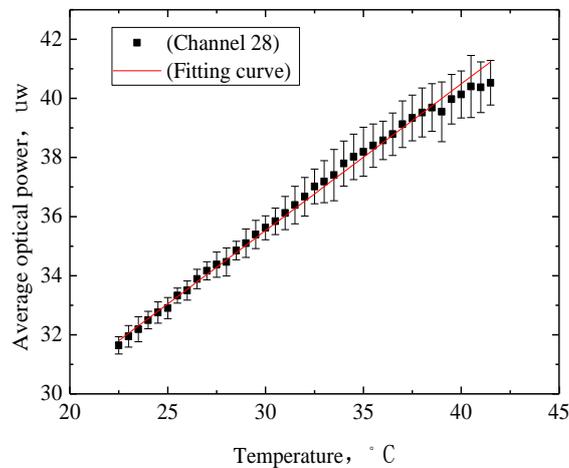


Figure 10. The Optical Power of FBG Reflected Spectrum through the AWG28 Channel

From Figure 10, we can know that the fitting degree of the curve is 0.996, the fitting effect is very good. The fitting equation is $y = 20.7 + 0.496x$ and the sensitivity was $0.496 \mu\text{W}/^\circ\text{C}$.

The relationship between AWG26 and AWG28 channel optical power is shown in Fig. 11.

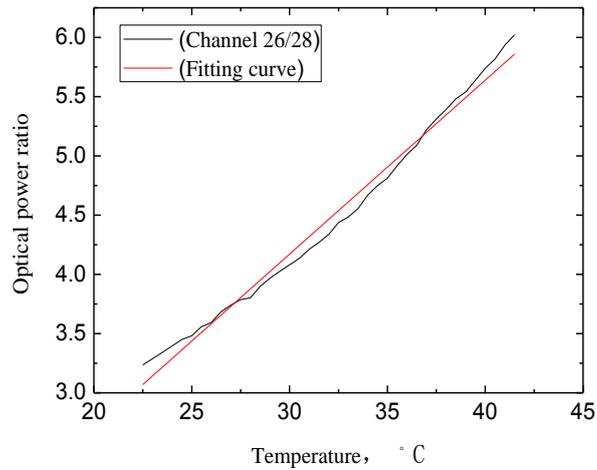


Figure 11. The Relationship between the Optical Power Ratio and the Central Wavelength of Fiber Bragg Grating

We can see from Figure 11 that the curve fitting is 0.988. The fitting equation was $y = -0.234 + 0.147x$ and the sensitivity was $0.147 / ^\circ C$. In the experiment, because of the 3dB bandwidth of the transmission spectrum of the AWG and the reflection spectrum of the temperature sensor is close to the 1nm, and they have some fluctuation, which affects the accuracy of the experiment results. This is an important reason for the fitting effect of Figure 11.

6. Conclusion

The feasibility of the FBG demodulation system based AWG demodulation system is verified by simulations and experiments. The sensitivity of the two channels of AWG is $0.162 \mu W / ^\circ C$ and $0.496 \mu W / ^\circ C$. The sensitivity of the power ratio of the two channels is $0.147 / ^\circ C$.

Acknowledgments

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