

Development of Fiber Bragg Grating and Long Period Theory Research

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Abstract

The emergence of optical fibers and the development of various optical fiber devices have greatly promoted the development of optical communication technology, sensing technology and information technology. Communication technology based on optical fibers and their functional devices has the advantages of long distance, large capacity, and high fidelity, and is the foundation of modern communications in the world. Since LPFG was first proposed in 1996, it has become a research hotspot because of its completely different spectral characteristics from FBG. This article focuses on LPFG prepared from ordinary single-mode optical fiber, starting from the mode distribution of light waves in the optical fiber, focusing on research and analysis. Based on the theoretical basis, the study analyzes three modes in LPFG, aiming to provide a certain cognitive and interpretive basis for long-period fiber grating research.

Keywords

Optical Fiber Development; LPFG; Sensing Theory.

1. Development of Fiber Grating

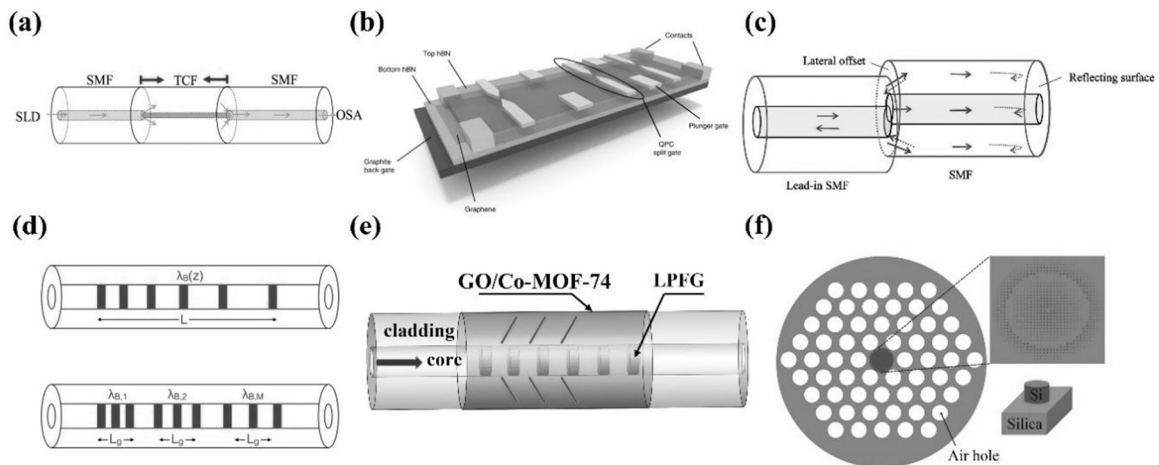


Figure 1. Schematic diagram of the structure of several different optical fiber devices

The emergence of optical fibers and the development of various optical fiber devices have greatly promoted the development of optical communication technology, sensing technology and information technology. Various optical fiber sensors such as Mach-Zehnder interferometer, Fabry-Perot interferometer, Michelson interferometer Interferometers, fiber Bragg gratings, etc. have the advantages of high sensitivity, resistance to strong electromagnetic pulse interference, low cost, and long-distance measurement in harsh environments, and have become one of the main solutions for

various sensing systems. Optical fibers and their optical fiber components already occupy an important position in real life and will play a major role in the Internet of Things, communications and sensing.

Fiber grating is a kind of diffraction grating, which is generally prepared by axially periodic modulation of the refractive index of the fiber core. It is a relatively common type of optical fiber device at present. Because of its advantages such as good wavelength selectivity, easy application and maintenance, and simple preparation, it has attracted the attention of scientific researchers as soon as it came out. In 1978, K. O. Hill and others in Canada prepared the first fiber Bragg grating (FBG) in human history in a high-parameter germanium optical fiber for the first time. The grating period of FBG is generally less than 1 μm . Because it can achieve reverse coupling of modes at a specific wavelength and has a reflection peak, it is also called a bandpass filter. FBG's optical fiber functional devices are mainly realized through this reflection characteristic. Therefore, the position of the reflection peak and the quality of its amplitude are an important performance indicator of FBG. However, the standing wave method used by K. O. Hill et al. has high requirements on the photosensitivity of the optical fiber, and the reflection peak of FBG coincides with the incident wavelength. Therefore, the promotion and application of FBG did not go smoothly in the first ten years. In 1989, G. Meltz and others in the United States proposed a new type of FBG engraving technology, which is ultraviolet exposure technology. This method can design and specify the reflection wavelength of FBG, making FBG a breakthrough in practicality. However, this method has high requirements on light source and writing platform, making it difficult to reach the level of practical application. In 1993, K. O. Hill et al. proposed a method of phase mask engraving FBG. This method greatly reduces the requirements for the light source and writing platform, making it possible for FBG to become practical. The phase mask method has become the most mature FBG engraving solution so far because of its advantages such as high repetition rate and convenient engraving, which has greatly promoted the application of FBG in the fields of communication and sensing.

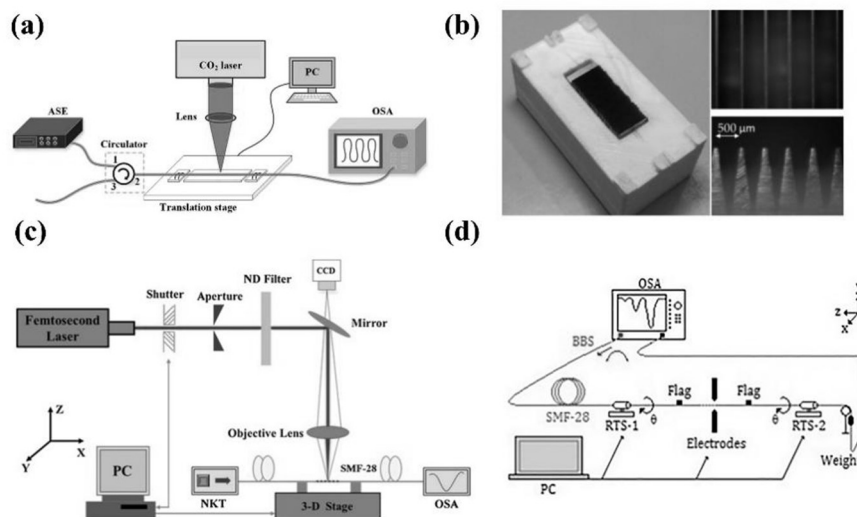


Figure 2. Schematic diagram of various LPFG engraving methods

In 1996, A. M. Vengsarkar and others used the amplitude mask method to produce a new type of fiber grating. This kind of fiber grating is called long period fiber grating (LPFG) because it has a large grating period. Different from FBG, LPFG realizes the coupling of fiber core mode and co-directional transmission mode, which redistributes the energy distribution inside the fiber and achieves the effect of mode conversion or filtering. Because it forms a loss peak in the grating transmission spectrum, it can also be called a band-stop filter. The emergence of LPFG has enriched researchers' technology for fiber mode control. In theory, a LPFG theoretical analysis system

represented by coupled mode theory has been formed, providing a solid theoretical foundation for its application in the fields of sensing and communication; in experiments Researchers have successively proposed a series of LPFG processing technologies such as CO2 laser radiation method, mechanical stress induction method, femtosecond laser direct writing method and arc discharge method, which have provided solid assistance for its practical application.

2. Research on Long Cycle Theory

2.1 Temperature Sensing Theory

In general, the coupling between the first-order cladding mode and the core fundamental mode is usually considered to be the coupling mode of LPFG. Research on LPFG's stress, temperature and refractive index sensing starts from the phase matching conditions of LPFG:

$$\lambda_D^m = (n^{co} - n_{eff}^{cl,m})\Lambda \quad (1)$$

Temperature sensitive characteristics:

$$\frac{d\lambda_D^m}{dT} = \left(\frac{dn^{co}}{dT} - \frac{dn_{eff}^{cl,m}}{dT} \right) \Lambda + (n^{co} - n_{eff}^{cl,m}) \frac{d\Lambda}{dT} \quad (2)$$

The relationship between the thermal expansion coefficient α and the period of the grating satisfies:

$$\alpha = \frac{1}{\Lambda} \frac{d\Lambda}{dT} \quad (3)$$

For optical fibers of fixed material, their thermal expansion coefficient is usually a fixed value. Another factor that affects the temperature sensing characteristics of LPFG is the thermo-optical effect of the material used to make the fiber. Changes in the thermo-optical effect will cause changes in the effective refractive index of the mode within the fiber. Since the thermal expansion coefficient α of the quartz material itself is much smaller than the temperature sensitivity factor, it can be ignored. Therefore, the thermo-optical effect is an important factor that interferes with the temperature sensing characteristics of LPFG, and the degree of interference is determined together with the fiber dispersion factor. The temperature sensitivity factor and fiber dispersion factor can be changed by changing the doping ratio of the fiber material and selecting an appropriate grating period, so that the LPFG can obtain higher temperature sensitivity.

2.2 Strain Sensing Theory

LPFG is not only sensitive to external temperature, but also highly sensitive to the stress applied to it. When external stress acts on the LPFG, the period of the grating will change slightly under the action of the stress, and the fiber itself will also undergo slight deformation. Due to the interference of the elasto-optical effect in the optical fiber, the stress exerted on the optical fiber by the outside world will also change the refractive index of the optical fiber itself, thereby affecting the coupling between modes, resulting in a resonance wavelength shift and a change in the intensity of the resonance peak in the transmission spectrum. . According to the theory of elasto-optical effect and elastic mechanics, the period and effective refractive index of optical fiber are functionally related to strain.

$$\frac{d\lambda_D^m}{d\varepsilon} = \left(\frac{dn^{co}}{d\varepsilon} - \frac{dn_{eff}^{cl,m}}{d\varepsilon} \right) \Lambda + (n^{co} - n_{eff}^{cl,m}) \frac{d\Lambda}{d\varepsilon} \quad (4)$$

Similar to the temperature sensing characteristics, the fiber dispersion factor and elasto-optical coefficients η_{tao} and η_{tacl} all play a key role in the degree of interference with the LPFG strain sensing characteristics. Generally speaking, the greater the difference between the elasto-optical coefficients of the fiber core and the cladding, the more sensitive the LPFG is to stress.

2.3 Refractive Index Sensing Theory

When the LPFG is wrapped by an external material, the refractive index of the cladding mode will be affected by the refractive index of the external material itself. Specifically, the difference in refractive index between the cladding and the external environment is regarded as the refractive index of the cladding mode.

$$\frac{d\lambda_{res}^m}{dn_{sur}} = \lambda_{res}^m \cdot \gamma^m \cdot \Gamma_{sur}^m \quad (5)$$

$$\Gamma_{sur}^m = - \frac{u_m^2 \lambda_{res}^3 n_{sur}}{8\pi r_{cl}^3 n_{cl} (n_{eff}^{co} - n_{eff}^{cl,m}) (n_{cl}^2 - n_{sur}^2)^{\frac{3}{2}}} \quad (6)$$

When the refractive index of the external material gradually increases, the mode within the fiber cladding will change, causing the coupling coefficient and phase matching conditions of the LPFG to change, ultimately causing the resonant wavelength and resonant peak intensity of the LPFG to change. When the refractive index of the external material increases close to the refractive index of the cladding, the cladding mode will disappear as it approaches infinity, and the resonance peak of the LPFG will also disappear, indicating that the refractive index of the external material has crossed the measurement range of the LPFG. When measuring the refractive index, the area where the resonant wavelength and resonant peak intensity change should be used. At the same time, the measurable range of LPFG can also be increased by changing the effective refractive index of the cladding.

3. Conclusion

This article has a clear analysis of the basic optical fiber process by studying the development process of fiber gratings. Starting from the mode distribution of light waves in the optical fiber, the study explores the three modes in LPFG and the temperature sensing theory of long period theory. , strain sensing theory, and refractive index sensing theory were deeply explored, the principle of light transmission in LPFG was analyzed and studied, and the influence of external environmental parameters on LPFG was analyzed based on the grating phase matching theory, which contributed to the theoretical research of long period fiber grating. Provide a certain basis for cognition and interpretation.

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