Spectral characterization of fiber Bragg grating with etched fiber cladding*

ZHOU Qian(周倩), **NING Ti-gang**(宁提纲), **PEI Li**(裴丽)**, **and LI Chao**(李超)
Key Lab. of All Optical Network and Advanced Telecommunication Network, Ministry of Education, Beijing Jiaotong University, Beijing 100044, China

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A new method is presented to tune Bragg wavelength slightly by using hydrofluoric acid to etch fiber cladding. The spectral characteristics before and after etching and the change properties of Bragg wavelength are studied. Cladding modes are reduced during the etching process. High-order cladding modes are converted into radiation modes, and energy of cladding modes is coupled to the outside. As the cladding radius decreases, the Bragg wavelength shifts to longer direction. Experimental results show that this method can tune Bragg wavelength slightly, and the tunable range is 0.002 −0.120 nm.
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Fiber Bragg grating is a diffraction grating where the refractive index of core has periodic modulation. The fiber Bragg grating has many good optical properties, such as small size, small splice loss, compatibility with optical fiber, and it can be embedded in smart materials. Its resonant wavelength is more sensitive to changes in the external environment, such as the temperature, strain, refractive index and concentration. So it has been widely used in fiber optical communications and fiber sensor systems in recent years[1-4]. Currently, we usually produce fiber Bragg grating by phase mask technique, but the Bragg wavelength of fiber grating is limited by phase mask period, so it lacks flexibility. In order to tune Bragg wavelength, we usually use piezoelectric ceramic tuning method, mechanical tuning method, electric tuning method, magnetic tuning method and thermal tuning method[5-11], but these methods need complex system structures or mechanical equipments for a certain tuning range. Recently a refractive index tuning method with side-polished technology is proposed[12-14], where materials with different refractive indices were overlaid on the polished area of a side-polished FBG to achieve the Bragg wavelength tuning. However, this method not only requires complicated side-polished technology on one side of fiber Bragg grating cladding, but also requires to cover different materials. The methods described above can obtain a certain tuning ability, from a few nanometers to more than several tens of nanometers, but they need complex systems, cumbersome technologies or expensive equipments more or less. However, when we need to slightly tune Bragg wavelength, the above methods can't be applied.

In this paper, a method of slightly tuning Bragg wavelength using hydrofluoric acid to etch fiber Bragg grating cladding is presented. Different fiber Bragg gratings with different cladding radii are obtained. The spectral characteristics before and after etching and the change properties of Bragg wavelength are studied. This approach can tune Bragg wavelength through reducing the cladding diameter. It can make the minimum tunable range of Bragg wavelength up to 0.002 nm and the maximum tunable range up to 0.120 nm.

Phase matching conditions of core mode and cladding mode can be described as follows:

$$\lambda_{\text{Bragg}}(z) = 2n_{\text{eff,co}}(z)\Lambda(z) \ , \tag{1}$$

$$\lambda_n(z) = [n_{\text{eff,co}}(z) - n_{\text{eff,cl},n}(z)]\Lambda(z) \ , \tag{2}$$

where $\lambda_{\text{Bragg}}(z)$ is Bragg wavelength, $n_{\text{eff,co}}(z)$ is the effective refractive index of core, $\lambda_n(z)$ is the resonant wavelength of the n-order cladding mode, $n_{\text{eff,cl},n}(z)$ is the effective refractive index of the n-order cladding mode, and $\Lambda(z)$ is the grating pitch.

As a distributed feedback reflector, the transmission spec-

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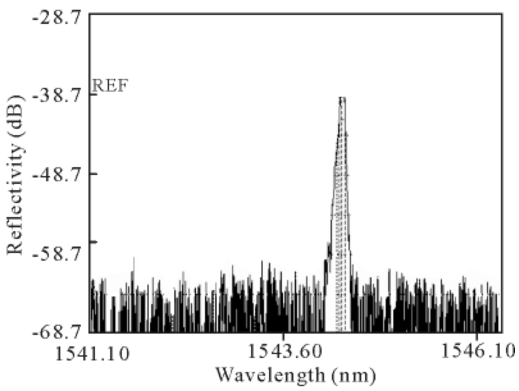
** E-mail: lipei@bjtu.edu.cn

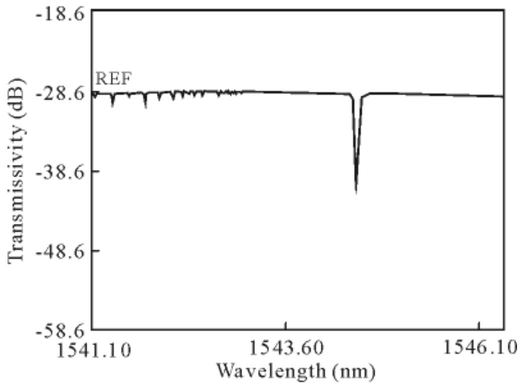
trum of fiber Bragg grating includes core mode resonance peak and cladding mode resonance peaks. If phase matching conditions change, the Bragg wavelength will change. Core mode of fiber Bragg grating consists of forward core mode and backward core mode, and it only has some connection with the effective refractive index of core usually. Under the phase matching condition, the forward core mode is coupled to the backward core mode. The core mode can also be coupled to counter propagation cladding guided modes and cladding radiation modes under the phase matching conditions. Cladding mode is not only related to the effective refractive index of core, but also depending on the effective refractive index of cladding. The effective refractive index of cladding mode depends on the refringence between the intramural cladding and the extramural cladding. Therefore, mode characteristics of fiber Bragg grating depend on the refractive indices of core, intramural cladding and extramural cladding. When the refractive index of extramural cladding is less than that of intramural cladding, cladding modes include cladding guided modes, and the core mode may be coupled to these cladding guided modes[15]. When the refractive index of extramural cladding is greater than that of intramural cladding, there is no cladding guided mode, the core mode may be coupled to radiation modes, and the power will be taken away from fiber by these radiation modes[16-19].

From the above analysis, it shows that the changes in refractive index of extramural cladding will cause the changes in effective refractive index of cladding modes. The cladding radius is reduced greatly through using hydrofluoric acid to etch fiber Bragg grating cladding, and the cladding mode is influenced by the changes in refractive index. The increase of changes causes the drift of resonant wavelength of cladding propagation mode.

In the experiment, the fiber Bragg grating was produced by phase mask technique. Fig.1 shows the reflection spectrum and transmission spectrum of no-etched fiber Bragg grating cladding. It indicates that the Bragg wavelength is 1544.329 nm, the bandwidth is 0.044 nm, and the transmission spectrum peak is 11.2 dB.



(a)



(b)

Fig.1 Spectra of no-etched fiber Bragg grating cladding: (a) Reflection spectrum; (b) Transmission spectrum

Fig.2 shows the experiment device. We put the fiber Bragg grating in 40% hydrofluoric acid solution, and after a period of etching, the cladding radius decreases to tens of microns. In the experiment, the spectrum analyzer was used to monitor the changes in fiber Bragg grating reflection spectrum during the etching process in real time. The cladding radius is reduced greatly through this etching process, higher order cladding modes are converted into radiation modes, and core mode will be coupled to radiation modes, making the energy coupled to the outside.

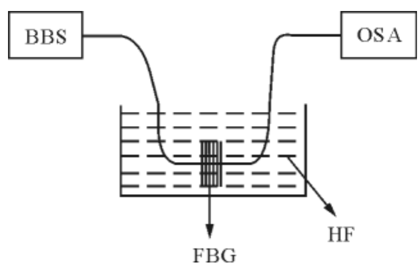


Fig.2 Experiment device

After 30 min etching, the reflection spectrum and transmission spectrum of etched fiber Bragg grating cladding are shown in Fig.3. It indicates that the Bragg wavelength is 1544.414 nm, the bandwidth is 0.046 nm, and the transmission spectrum peak is 10.2 dB. The Bragg wavelength shifts by 0.084 nm to longer direction, the bandwidth is essentially unchanged, and the transmission spectrum peak is reduced by 1 dB. This is because the main energy of core mode concentrates in the fiber core, then the core mode resonance peaks are affected less by the external environment, and the core mode resonance peaks shift slightly after etching. But cladding modes are greatly influenced by the external environment. With the changes of etching time, cladding radius decreases, and the energy of cladding mode is coupled to the outside, thus increasing the loss of cladding modes; higher order cladding modes are converted into radiation modes, and the cladding modes of fiber Bragg grating decrease; the cladding mode resonance peak shifts to longer wavelength.

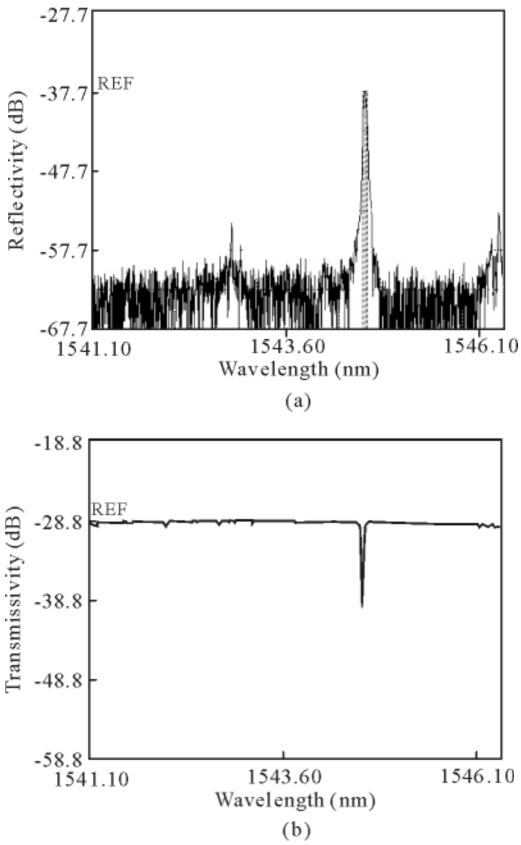


Fig.3 Spectra of etched fiber Bragg grating cladding: (a) Reflection spectrum; (b) Transmission spectrum

During the experiment, we observed the reflection spectrum of fiber Bragg grating every two minutes, and measured the cladding radius. Fig.4 shows the Bragg wavelength changes with the etching time. We can see that Bragg wavelength shifts gradually to the longer direction with the increase of etching time, there is a basic linear relation between them, and the Bragg wavelength shifts by 0.006 nm to longer direction every two minutes. Fig.5 shows the Bragg wavelength changes with cladding radius. From Fig.5, cladding radius decreases by 3.2 μm, and Bragg wavelength shifts by 0.006 nm to longer direction. The cladding radius of single-mode fiber used in the experiment is 62.5 μm. After 30 min etching, cladding radius becomes 14.5 μm. When the etching time is up to 40 min, the light through fiber Bragg grating is totally reflected, and we can not observe reflection spectrum or transmission spectrum of fiber Bragg grating on the spectrum analyzer. After calculation, the etching cladding radius rate of hydrofluoric acid is about 1.6 μm/min. When the cladding radius changes by 1 μm, Bragg wavelength shifts by about 0.002 nm to longer direction.

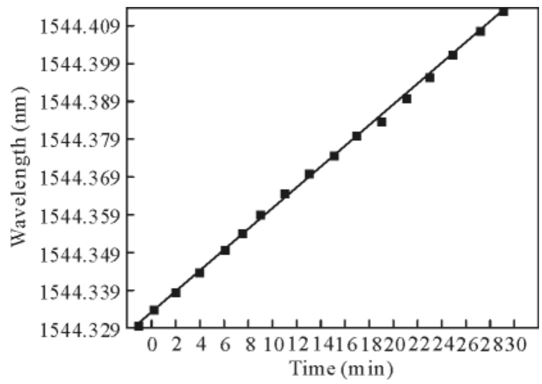


Fig.4 Bragg wavelength variation with etching time

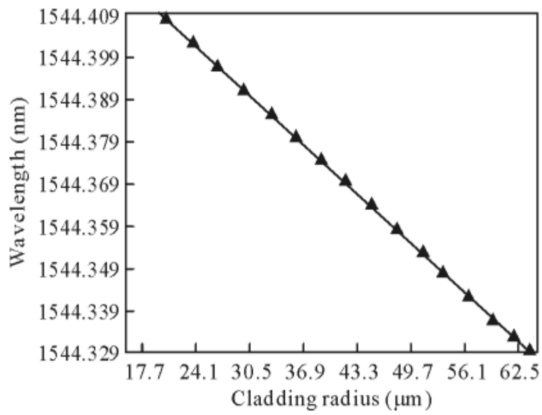


Fig.5 Bragg wavelength variation with cladding radius

In practice, when we need to tune Bragg wavelength slightly, we can use hydrofluoric acid to etch fiber Bragg grating cladding. We can control the etching time according to the required tuning range of Bragg wavelength. The tunable range is from 0.002 nm to 0.120 nm.

A method of slightly tuning Bragg wavelength using hydrofluoric acid to etch fiber Bragg grating cladding is presented. The spectral characteristics before and after etching and the change properties of Bragg wavelength are studied. Cladding modes are reduced during the etching process, high order cladding modes are converted into radiation modes, and the energy of cladding modes is coupled to the outside. As the cladding radius decreases, the Bragg wavelength shifts to the longer direction. Experimental results show that this method can tune Bragg wavelength slightly, and the tunable range is 0.002−0.120 nm.

Etched fiber Bragg grating is more sensitive to the external environment, so it can be used in refractive index sensing. The temperature and stress sensing experiments based on etched fiber Bragg grating are in progress.

References

[1] A. D. Kersey, M. A. Davis, H. J. Patrick, M. LeBlanc, K. P. Koo, C. G. Askins, M. A. Putnam and E. J. Friebele, J. Lightwave Technol. **15**, 1442 (1997).

[2] B. O. Guan, H. Y. Tam, S. L. Ho, H. C. Weng and X. Y. Dong, Electron. Lett. **26**, 1018 (2000).

[3] Q. Y. Chen, S. H. Shi, Z. Y. Zhang, K. Fang and X. J. Zhou, Journal of Optoelectronics • Laser **22**, 677 (2011). (in Chinese)

[4] K. Zhang and S. Wang, Journal of Optoelectronics • Laser **23**, 15 (2012). (in Chinese)

[5] W. Guo, K. Liu and Y. Q. Huang, Journal of Optoelectronics • Laser **11**, 23 (2000). (in Chinese)

[6] D. Z. Yang, D. J. Feng, J. Wang, M. S. Jiang and Q. M. Sui, Tunable Chirped Fiber Bragg Grating based on Two-fixed-end Compressive Bar without Central Wavelength Shift, the Pacific Rim Conference on Lasers and Electro-Optics, 1 (2009).

[7] P. Lu, L. Q. Men and Q. Y. Chen, Journal of Applied Physics **106**, 013111 (2009).

[8] G. R. Vargas and R. R. Panepucci, Wavelength Monitoring using a Thermally Tuned Micro-ring Resonator, 10th International Conference on Numerical Simulation of Optoelectronic Devices (NUSOD), 83 (2010).

[9] X. N. Yu, C. C. Sun and Q. Zhang, Journal of Tsinghua Univ-ersity (Science and Technology) **45**, 456 (2005). (in Chinese)

[10] W. G. Zhang, G. Y. Kai, X. Y. Dong, S. Z. Yuan and Q. D. Zhao, Acta Optica Sinica **23**, 164 (2003). (in Chinese)

[11] Z. X. Qin, Q. K. Zeng, Y. Xiang, D. J. Feng, S. Z. Yuan, G. Y. Kai, Z. G. Liu and X. Y. Dong, Acta Optica Sinica **21**, 1421 (2001). (in Chinese)

[12] L. Zhen, C. Zhe, V. K. S. Hsiao, J. Y. Tang, F. L. Zhao and S. J. Jiang, Optics Express **20**, 10827 (2012).

[13] L. H. Liu, Z. Chen, C. H. Bai and Z. Li, Acta Photonic Sinica **36**, 865 (2007). (in Chinese)

[14] L. Zhen, V. K. S. Hsiao, C. Zhe, J. Y. Tang, F. L. Zhao and H. Z. Wang, IEEE Photon. Technol. Lett. **22**, 1123 (2010).

[15] A. Vengsarkar, P. Lemaire, J. Judkins and V. Bhatia, J. Lightwave Technol. **14**, 58 (1997).

[16] V. Mizrahi and J. Sipe, J. Lightwave Technol. **11**, 1512 (1993).

[17] H. Patrick, A. Kersey and F. Bucholtz, J. Lightwave Technol. **16**, 1606 (1998).

[18] D. Stegall and T. Erdogan, IEEE Photon. Technol. Lett. **11**, 343 (1999).

[19] Z. A. Jia, L. Zhang, X. G. Qiao and C. Ma, Journal of Optoelectronics • Laser **19**, 315 (2008). (in Chinese)