The Characteristics in the Sensitivity of Microfiber Fabry-Perot Interferometric Transducers

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Abstract. We inscribe a Fabry-Perot (FP) resonator in the microfiber utilizing the 193-nm UV exposure and the phase mask technique. Some new characteristics in contrast to the conventional counterparts are measured, which are attributed to the index change in the grating and the dispersion of the effective grating length, respectively. The FP spectral dependencies on external strain, temperature, and refractive index are investigated. Our fabricated structures can have potential of acting as ultrasonic transducers and photo acoustic imaging.

1. Introduction

For sensing, the ordinary fiber inducing to the external environment changes need to carry out special processing, which gives birth to the side of polishing type fiber, the corroded fiber and the microfiber. L. M. Tong et al. fabricated an optical fiber with a 50 nm diameter, forming a smooth and uniform optical waveguide as “microfiber” in 2003 [1]. Microfibers with sub wavelength diameters have been caught in great research interests due to their light confinement, surface optical intensity, mechanical strength, compactness and large waveguide dispersions [2]. Microfibers can be realized by heating the ordinary fiber. Due to the lateral direction of the sub wavelength waveguide, the evanescent field effect is the most advantageous characteristic, which allows an obvious interaction between the core fiber and the surrounding environment as transducers [3]. On the other hand, because of Fiber Bragg Grating (FBG) is equipped with intrinsic selectivity of wavelength, Fabry-Perot (FP) interferometric transducer based on FBG has unique properties [4]. The structure of FP interferometric transducer uses FBG instead of traditional high reflectivity mirror, which simplifies the traditional complex structure into simple linear structure and provides convenience for element packaging and array manufacturing [5-7]. The two FBG structure not only simple structure, wavelength division multiplexing capability, convenient manufacture, but also FP resonator can be obtained with high sensitivity and long the cavity compared with the traditional dissipative type short cavity fiber [8-9].

In recent years, compared with the fiber FP interferometric transducer produced by the traditional fusion method, the microfiber FP interferometric transducer can provide a higher mechanical strength by directly engraving the grating in the optical fiber [10]. In addition, the symmetrical structure is considered to be the simplest method to solve the double sensitivities in temperature and stress of single FBG sensing, which avoids the problem both mutual restraint of sensitivity and detection precision in the dynamic stress sensing system of single FBG interferometry transducer[11-12]. Two FBGs FP interferometric transducers are used as an important structure in many fields, such as a filter, a resonant cavity of fiber laser, a hydrophone to detect sound waves and so on [13-14]. Combining the microfiber
Bragg grating with the Fabry-Perot resonator can greatly reduce the volume of the device and realize the temperature, stress, vibration, curvature, acoustic wave, concentration, refractive index and other parameters of the sensing measurements. The microfiber FP interferometric transducer has shown many new physical phenomena and has been extended to biomedical applications [15-16].

Besides the small size, the fabricated structure exhibits a high index contrast in the periodic structure and has potential in the application of quantum dynamic experiments. Even though, the milling procedure is relatively complex and time consuming because of the low efficiency of nanostructure. To improve the mechanical properties of microfiber devices, high manufacture efficiency with no distinct physical damage is required.

In this paper we fabricate a microfiber-based FP resonator by the use of 193-nm UV exposure. The responses of FP spectrum to external strain, temperature, and external refractive index are investigated. The research results are valuable for future applications of the related devices.

2. Fabrication Of Microfiber Fabry-Perot Interferometric Transducers

In the experiment, we use 193nm excimer laser to output ultraviolet laser as shown in Figure 2-1. The output pulse power is 3mJ and the repetition rate is 200Hz. Methods using fused tapered multimode fiber made of the microfiber with low loss and no obvious loss peak. The slight change in the diameter of the microfibers can effect on vary of the effective refractive index. The second FBG once engraved with the first FBG is not match; the reflection wavelength will drift a lot, which cannot produce resonance phenomenon. Therefore, it is necessary to use auxiliary light to ensure that Fabry-Perot cavity is located in the uniform area of the whole microfiber.

![Figure 2-1. The fabrication of microfiber grating Fabry-Perot interferometer.](image)

The transmission spectrum of microfiber Fabry-Perot interferometer is shown in Figure 2-2, whose diameter is d=6.1μm and length is L₀=5mm. A and B represent the interference fringes of each order mode, respectively. The central wavelengths of the interference peaks in the fundamental and high order modes appear at 1543.101 nm (HE₁₁ mode) and 1530.465 nm (HE₂₁ mode) respectively. The transmission depths are 24.131dB and 5.816dB, respectively. The bandwidth of Fabry-Perot interferometer is much narrower than that of the M-Z interferometer with microfibers, which is determined by the multi-beam interference principle. The peak spacing and bandwidth of the interference peaks are determined by the effective cavity length and the reflectivity of mFBG. The smaller the effective cavity length is, the higher the reflectivity is. Then the peak spacing of interference fringes is greater with the smaller the bandwidth.
3. Experiments and Results

3.1. Response to Temperature

The microfiber Fabry-Perot interferometer is sensitive to temperature. According to the formula of interference peak:

\[ 2n \left( L_0 + 2L_{\text{eff}} \right) = m \lambda \]  \hspace{1cm} (1)

Through differentiating (1), the temperature response of the microfiber Fabry-Perot interferometer can be expressed as:

\[ \frac{d\lambda}{dT} = 2n \frac{d}{dT} \left( L_0 + 2L_{\text{eff}} \right) + 2(L_0 + 2L_{\text{eff}}) \frac{d\bar{n}}{dT} \]

\[ = \lambda_n (\alpha + \beta) \]  \hspace{1cm} (2)

Where, \( \alpha = \frac{1}{L_0 + 2L_{\text{eff}}} \frac{d}{dT} \left( L_0 + 2L_{\text{eff}} \right) \) indicates the thermal expansion coefficient, \( \beta = \frac{1}{\bar{n}} \frac{d\bar{n}}{dT} \) indicates the thermal light coefficient. Obviously, it can be seen that the temperature can cause changes in the interference peaks. The microfiber Fabry-Perot interferometer is measured using temperature measurement system, as shown in Figure 3-1. In order to improve the accuracy of the measurement, the temperature of electric furnace rises from 40°C to 140°C continuously at room temperature. The wavelength drift is recorded during continuous warming. Figure 3-2 shows the wavelength drift of the interference peak with different modes, which is caused by temperature. It can be seen from Figure 3-2 that the higher order interference peak wavelength drifts more as the temperature increases. It is due to that the higher order mode has a larger fiber evanescent field distribution. Then it shows obvious changes with temperature rising and perceives temperature changes outside more easily.
It can be seen from Figure 3-3 that the interference peaks in the fundamental and high order modes show linear increment with the same peak spacing when the temperature gradually increases. Not like the refractive index which has big difference, the temperature sensitivity is 12.6 pm/°C and 12.3 pm/°C, respectively. The temperature sensitivity of an ordinary Bragg grating is 10 pm/°C at 1550nm. It is clear that the temperature sensitivity of microfiber Fabry-Perot interferometer is almost close to that of ordinary grating. It is due to the fact that the SiO₂ material has a similar thermal-light coefficient.

4. Conclusion

We have proposed and demonstrated a necessary condition for the ultrasonic transducers needed based on microfiber grating for photo acoustic imaging [16]. In this paper, the fabrication method, the spectral characteristics and the sensitivity of Fabry-Perot interferometric transducers based on Bragg gratings are studied. First, the theory and the output spectrum of the microfiber grating Fabry-Perot interferometric transducers are discussed. Second, the influence of reflectivity and cavity length on the output spectrum of fiber grating Fabry-Perot interferometric transducers is obtained. Third, through to the microfiber Fabry-Perot interferometric spectral analysis, it found that the different mode interference on peak temperature and refractive index sensing measurement shows different characteristics, and further to the causes of these similarities and differences between the sensitivity of parameters is analyzed.
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