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Common-Path Interferometer for Characterization of Fiber Bragg Gratings

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Abstract -- A simple measurement for characterization of fiber gratings by the common-path interferometer is proposed. The complex reflection-coefficient spectrum is obtained by processing the interference spectrum. The results excellently match the data by optical network analyzer.

I. Introduction

Measurement of the group time delay is an essential technique for developing a new fiber Bragg grating (FBG) device. Although the modulation phase-shift method [1] is usually applied to measure the chromatic dispersion of a fiber grating device due to its accuracy and repeatability, it requires the complicated setup and expensive modules such as high-speed optical modulator and detectors. To simplify the dispersion measurement setup for fiber grating devices, the techniques based on the Michelson interferometers with Fourier transform spectroscopy have been proposed [2]. However, these measurement systems must be carefully isolated for good stability, because the interferometer is very sensitive to the environmental perturbations between the two discrete optical paths. In this paper, we propose a stable and accurate measurement technique for characterization of FBGs by using a common-path interferometer. This method just requires a broadband source and an optical spectrum analyzer (OSA) to scan the interference pattern in wavelength domain. Moreover, the common-path interferometer configuration can much improve the stability of the measurement system. We will demonstrate the accuracy and repeatability of group time delay measurement for the test FBGs. The results agree very well with the data measured by using the optical network analyzer (Advantest Q7760).

II. Principle of Measurement

The complex reflection coefficient measurement setup for a fiber grating consists of a Fabry-Perot interferometer which first and second reflectors are the end of the input fiber and the tested FBG respectively, as shown in Fig.1. The incident light is accurately coupled to the tested FBG by using a mechanical splice without matching oil. The ASE source and OSA have been used to obtain a wide spectral range in a single fringe scan. The reflectivity of the fiber end is so small (≈ 4%) that the Fabry-Perot interferometer can be approximated as a Fizeau interferometer. The interference spectrum of the Fizeau interferometer measured by the OSA can be expressed as

$$I_{int}(\lambda) = I_{ref} + I_{FBG} + 2\sqrt{I_{ref} I_{FBG}}\, cos\left[\frac{4\pi}{\lambda} n_{eff} L + \phi(\lambda)\right] \quad (1)$$

where I_{FBG} and I_{ref} are the intensity reflection spectra of the FBG and the reference end respectively, n_{eff} is the effective index of the core mode, and L is the effective distance between the two reflectors. The phase term $\phi(\lambda)$ is the wavelength-dependent phase delay of the test FBG. According to (1), the Fourier transformation of the measured interference spectrum consists of the -1, 0, and +1 order harmonic components. If the optical path difference $2n_{eff}L$ is large enough to avoid the overlap of the 0 and +1 order harmonic components, then the +1 order component can be conveniently calculated from the inverse Fourier transformation of the Fourier-transformed spectral data with the band-pass filtering to select only the +1 order component. Finally, we evaluate the group time delay of the tested device by differentiating the phase $\phi(\lambda)$ with respect to the angular frequency. The above-mentioned data processing procedure is summarized in Fig.2. Likewise, the intensity reflection spectrum $I_{FBG}(\lambda)$ of the test FBG can be also calculated by applying the proposed data processing with the band-pass filtering to select only the 0 order component and deducting the reflection contribution $I_{ref}(\lambda)$ of the reference end.

III. Results and Discussions

In contrast to the common-path interferometer shown in Fig.1, Skaar proposed a similar Fabry-Perot structure in which the first and second reflectors are the tested FBG and its fiber end, respectively [3]. To compare the performance difference between the two common-path interference schemes and to verify the accuracy and repeatability of our proposed measurement, we have repeatedly measured the group delay of a uniform-period FBG for five times by using the two common-path interferometers and the above-mentioned data processing technique. We performed the Skaar's measurement by coupling the broadband light from the other side of the fiber pigtail. Fig.3(a) shows the measured interference spectra I_{int} of the FBG filter, where the thin solid line is the measured result by our common-path interferometer (END-FBG) and the thick solid line is the data measured by the inverse common-path scheme (FBG-END). Fig.3(b) and (c) show the measured intensity reflection spectra and group delays of the FBG filter, where the solid lines are the results calculated by using the interference spectra shown in Fig.3(a) and the dash line is the data measured by the optical network analyzer. We notice that the group delay and reflection spectrum obtained by our proposed method are in good agreement with the measured results of the optical network analyzer. The uncertainty of this measurement is better than 0.5ps in the 10dB bandwidth of the tested FBG. For the inverse common-path configuration case, the larger error of the group time delay is observed in the wavelength range with high reflectance, although the reflection spectrum very match the data measured by Q7760. The reason is that only little amount of the light in the stop-band can transmit through the FBG and reach the second reflector (the fiber end), such that the interference between the two reflected lights is very weak. To verify the inference, we have also measured the group delay of another lower reflective FBG by using the FBG-END configuration with the bare end and higher reflective end coated a metal film. Fig.4(a) shows the measured interference spectra, where the thin and thick solid lines are respectively the measured results by using the coated end and bare end. Fig.4(b) shows the group delays of the test FBG, where the solid lines are the results calculated by using the interference spectra shown in Fig.4(a) and the dash line is the data measured by Q7760. One can see that the measured result with the stronger interference is more accurate than the data by using the bare end. Therefore, we believe our proposed common-path interferometer is better than the Skaar's configuration for FBGs with high reflectivity.

IV. Conclusion

In this paper, we have proposed a simple and accurate measurement scheme for characterization of the fiber grating devices by using the common-path interferometric technique. In this measurement, a broadband source and an OSA are used to scan the interference spectrum, and then the group time delay and intensity reflection spectrum can be obtained from the Fourier transformation of the interference pattern. We have repeatedly measured the group delay of a test FBG filter. The experimental results excellently match the data obtained by the optical network analyzer. We also compare the measurement performance with the inverse configuration proposed by Skaar to show that better accuracy can be obtained with our scheme. Because of its accuracy, repeatability, as well as simplicity in the experimental setup, we believe this technique has the potential to become a very powerful method for measuring the complex reflection spectrum during the manufacture of fiber grating devices.

References

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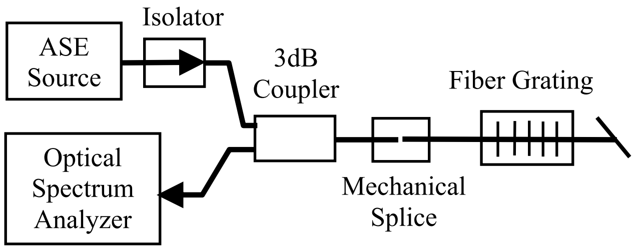

Fig.1 Common-path interferometer setup (END-FBG)

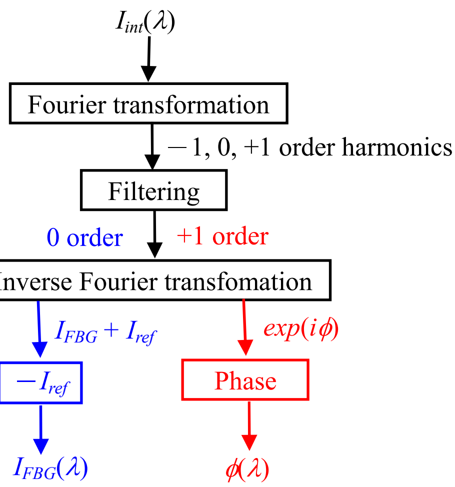

Fig.2 The proposed data processing procedure

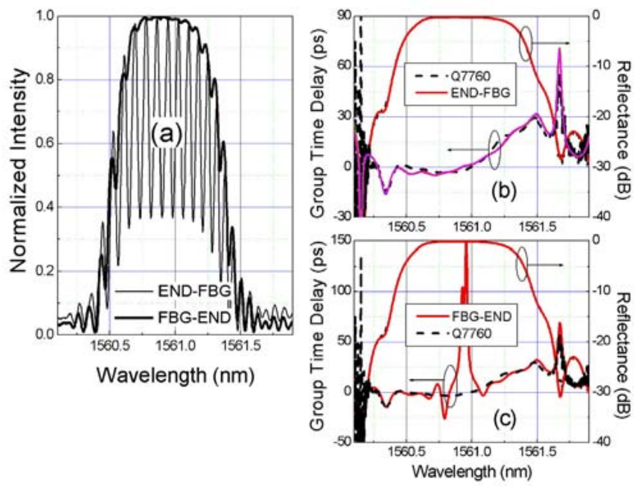

Fig.3 (a) Measured interference spectra, reflection spectra and group delays of the FBG by using (b) END-FBG and (c) FBG-END configurations, respectively.

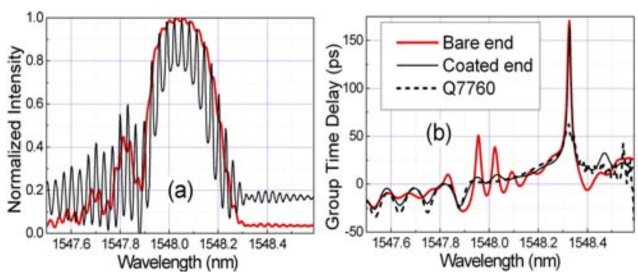

Fig.4 (a) Measured interference spectra, and (b) group time delays of the test FBG by using FBG-END configuration with various fiber ends.