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Modes Effective Refractive Index Difference Measurement in Few-mode Optical Fiber

Jing Zhang[1]*, Zhifang Wu[2,3], Tianye Huang[2,3], Xuguang Shao[2] and Ping Shum[2,3]

*1 National Metrology Centre, Agency for Science, Technology and Research (A*STAR), Singapore*
2 School of Electrical and Electronics Engineering, Nanyang Technological University, Singapore
3 CINTRA CNRS/NTU/THALES, UMI 3288, Research Techno Plaza, 50 Nanyang Drive, Level 6, Singapore
**Corresponding author: Zhang_jing@nmc.a-star.edu.sg*

Abstract

We studied the measurement and data analysis of modes effective refractive indexes for few-mode optical fiber and found that measuring refractive index difference from the modes interference pattern was affected by dispersion in the optical fiber. A comprehensive method of accurate measurement of modes effective refractive index differences in few-mode optical fiber was developed. It consists of the measurements of the FBG reflection spectrum and the modes interference spectrum, the simulation of interference with dispersion effect in the interferometer configuration, and the data optimization to match with the measured modes interference. The results show much improvement in the few-mode optical fiber characterization.

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Keywords: modes, effective refractive index difference, few mode fiber

1. Introduction

Few-mode optical fibers have been a hot research area in the past few years. The few mode optical fiber can potentially increase the transmission capacity of a single optical fiber by mode-division multiplexed transmission [1]. The characterization methods and tools for single mode optical fibers are mature; however, the characterization

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx

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of a few-mode optical fiber is much more challenging due to the co-existing of more than one modes than the characterization of a single mode optical fiber.

The effective refractive indices of the modes, and effective refractive index differences between the modes are important characteristics for few-mode optical fibers. By measuring the reflection spectrum of the fiber Bragg grating (FBG) fabricated in the few-mode fiber, some discrete information of effective refractive indices of the modes at their resonance wavelengths can be obtained. However, it can't provide a full view of the modes effective refractive indices across the wavelengths. The interferometer configuration was used to measure the index difference in few-mode optical fibers by some researchers [2][3]. The mode interference in the interferometer configuration caused the intensity change across the wavelengths. Based on the techniques, one could conclude the modes effective refractive index.

Optical low coherence interferometry (OLCI) was proposed for FMF characterization by R. Gabet et al.. The different LP modes could be obtained accurately in a single measurement in combination with a numerical method called "time-wavelength mapping" [4]. Michael A. Galle et al. simultaneously measured first and second order dispersion in short length few mode fibers by using virtual reference interferometry [5]. Multimode dispersion was also measured based on the time-of-flight method [6][7], however, this method couldn't be used for short distance fiber characterization.

In this study, we simulated the interference phenomenon between the modes in few-mode optical fiber, and found that the interference pattern was not only determined by the index difference but also affected by the relative dispersion between the modes. Hence, the method of obtaining refractive index difference from the modes interference pattern is valid only when there is no or minimum dispersion in the optical fiber. We propose a comprehensive method of accurate measurement of modes effective refractive index differences in few-mode optical fiber, consisting of the measurements of the FBG reflection spectrum and the modes interference spectrum, the simulation of interference with dispersion effect in the interferometer configuration, and the data optimization to match with the measured modes interference.

2. Methodology

2.1 Fiber Bragg Gratings

The comprehensive method started with the measurement of the reflection spectrum of a fiber Bragg grating (FBG) fabricated in the few-mode fiber. The few-mode fiber sample is a high Ge-doped Silica optical fiber. The core size of the fiber was about 5 μm. The refractive index of the core and cladding were about 1.49 to 1.44, respectively. Figure 1 shows the index profile of the few-mode fiber. A suitable pitch (530.08 nm) of FBG was chosen so that the reflection peaks by all the modes would be within the wavelength range of 1520 nm to 1620 nm, which range was covered by our tunable laser source and optical spectrum analyzer. Figure 2 shows the reflection spectrum measured from the FBG fabricated in a piece of few-mode fiber sample. There are five peaks in the spectrum. The peaks at the wavelengths of 1575.132nm, 1553.912nm and 1532.76nm correspond to the fundamental mode and the two higher orders modes interacting with the FBG, respectively. The two peaks in between are caused by the coupling between the two adjacent modes in the FBG.

The FBG fabrication process caused slight increase of the refractive index in the fiber. We use the effective refractive indexes calculated from the from the FBG measurement to estimate the effective refractive indexes of the three modes in the few-mode fiber. Figure 3 shows the calculated effective index of the three modes in the few mode fiber from three FBG samples at different pitches. The calculated effective refractive indexes from the three FBG samples form three lines representing the modes across the wavelengths.