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Refractive index retrieving of polarization maintaining optical fibers

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ABSTRACT

In this paper, the cross-section images, of two different types of polarization maintaining (PM) optical fibers, are employed to estimate the optical phase variation due to transverse optical rays passing through these optical fibers. An adaptive algorithm is proposed to recognize the different areas constituting the PM optical fibers cross-sections. These areas are scanned by a transverse beam to calculate the optical paths for given values of refractive indices. Consequently, the optical phases across the PM optical fibers could be recovered. PM optical fiber is immersed in a matching fluid and set in the object arm of Mach-Zehnder interferometer. The produced interferograms are analyzed to extract the optical phases caused by the PM optical fibers. The estimated optical phases could be optimized to be in good coincidence with experimentally extracted ones. This has been achieved through changing of the PM optical fibers refractive indices to retrieve the correct values. The correct refractive indices values are confirmed by getting the best fit between the estimated and the extracted optical phases. The presented approach is a promising one because it provides a quite direct and accurate information about refractive index, birefringence and beat length of PM optical fibers comparing with different techniques handle the same task.

1. Introduction

Polarization maintaining (PM) optical fibers began to attract researcher attention at early eighties. It is widely employed to deliver a certain polarization state of light. This characteristic qualifies the PM optical fibers to be used in coherent communications, fiber-optic gyroscope and integrated optics [1]. Also, PM optical fibers can be used as sensors for temperature and strain [2–4]. The launched polarization states of light waves along the propagation in PM optical fiber are maintained with nearly neglected cross-coupling of optical power coupled in different polarization modes [1]. PM optical fibers are working in the same way; the cores are surrounded by areas of high-expansion glass called “stress rods” that makes the core under localized tension. This tension causes two different indices of refraction; one of the higher index which is parallel and the other is perpendicular to the direction of the applied stress. So, this structure generates two propagation axes; slow and fast axes which are parallel and perpendicular to the direction of the applied stress, respectively. This means that there is an induced birefringence due to this tension [1]. The increase of the applied stress to the core leads to an increase of the difference in the refractive index between the two axes (an increase of the birefringence) [1,5].

Mostly, PM optical fibers is one of three types: Bow-Tie, PANDA or elliptical jacket which depends on stresses rods shape [1]. One of the features of PM optical fibers is their symmetry around only two orthogonal axes perpendicular to the fiber central axis, which are known as slow axis and fast axis. When polarized light is launched along one of these axes it travels by a velocity differs from that of the other axis. This prevents cross-coupling of the light between the two axes. It would require a perturbation capable for making a significant change between the transmitted velocities of the light along the fast and slow axes [1]. The difference in velocities of the two polarized light components causes the resultant polarization state to vary along the propagation axes of the fiber. The beat length is the distance over which this polarization rotates through 360° [1,6].

The determination of the optical fiber refractive index profile is a topic under investigation for over three decades by several research groups worldwide. There are many techniques has been used to reach this target. As a brief review on these techniques we can mention, refracted near field method [7–9], differential interference contrast microscopy [10–12] and quantitative phase microscopy [13,14]. These techniques are applied for axially symmetric optical fiber, but they are not exposed to refractive index profile investigation of PM optical fibers (axially asymmetric). Computerized tomography technique is used to structural study of PM optical fibers. Abe et al. [15] have been proposed a method for measuring the axial residual stress profile in PM optical fibers depending on the optical retardations that travel laterally through the fiber. Applying a numerical inversion of the obtained data

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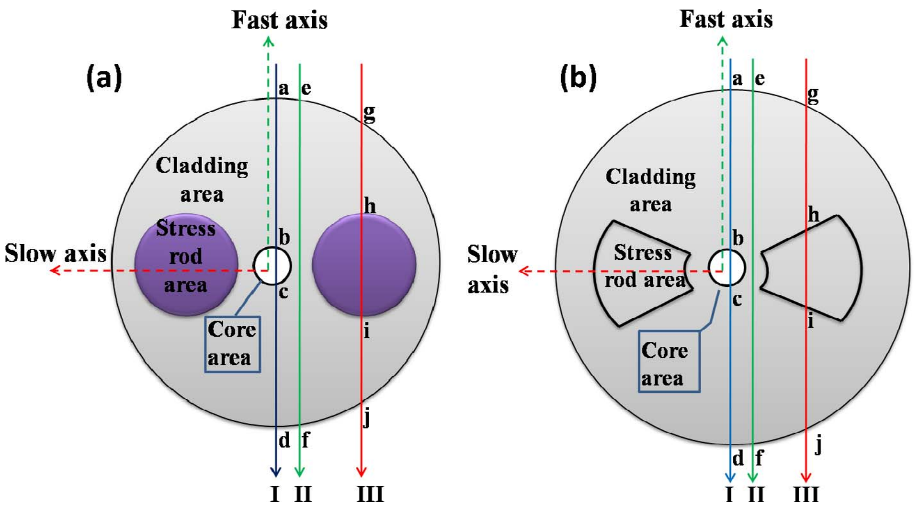

Fig. 1. A schematic diagram illustrating different parallel rays when traversing (a) PM PANDA optical fiber and (b) PM Bow-tie optical fiber cross-sections.

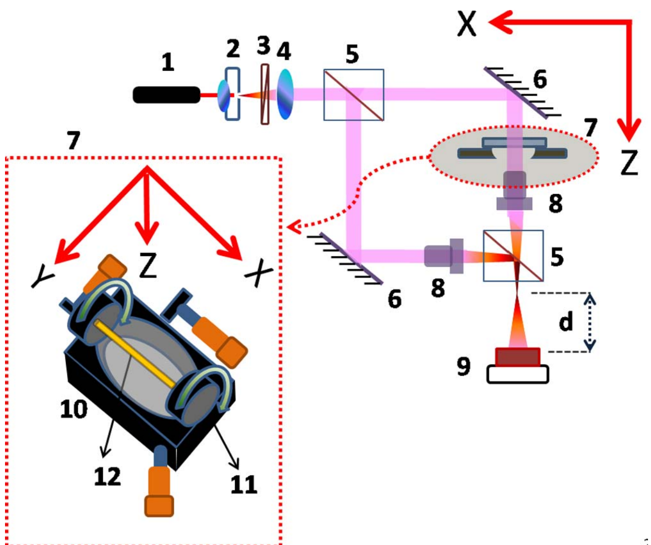

Fig. 2. A schematic diagram of the experimental set-up for Mach-Zehnder interferometer, where; 1 – He-Ne laser source, 2 – spatial filter, 3 – Polarizer, 4 – collimating lens, 5 – beam splitter, 6 – mirror, 7 – Three direction movement slide holder, 8 – microscope objective, 9 – CCD camera, 10 – 3-D slide holder, 11 – Rotating holder and 12 – PM optical fiber sample.

the stress profile is reconstructed. Park et al. [16] used high resolution photo elastic tomography they were able to determine two-dimensional axial stress profile of PM optical fiber. They have been demonstrated an expression of stress-induced anisotropy. The main concern of that work is determining the stress profile distribution of the PM optical fibers under investigations no information has been given to determine refractive indices profiles of the fibers. Kniazewski et al. [17] have been proposed an experimental phase shifting digital photo elasticity method and used the data obtained from this method as input data for topographic procedure to determine the 3-D axial stress distribution in PM optical fibers. In this method stress distribution in PM optical fiber has been employed indirectly, via mathematical relations, to get two-dimensional refractive index profile. Up to our knowledge, this work demonstrates the refractive index profile extracted from stress distribution for PANDA PM optical fiber, for the first time. The average values of the refractive indices have been given with no information about the errors generated in the presented refractive index profile.

Interferometric based techniques present a direct and accurate tool to recover refractive index of tiny optical elements. These techniques have been developed and enhanced to be faster and more precise in the last decades, whereas the digital cameras and computer programs are contributed seriously in capturing, analyzing and carrying out the calculations [18–20]. A rapid development in the field of digital holography and image processing has contributed strongly in facilitating, accelerating and accurateness of the analysis process [21–24]. It is well known that interference systems can be classified according to the number of the interfered beams where we have two beam or multiple beam interference systems [25]. In two beam interference system, when inserting the fiber under investigation in the object arm the beams traversing the fiber suffer optical phase variations. Many theories have been proposed, employing this optical phase variation, to recover the refractive index profiles of the optical or irregular fibers [26–28]. This can be achieved by analyzing the interference fringes to extract the optical phase difference caused by the fibers [29–31].

Most of interferometric based applications are performed on axially symmetric optical fibers. In this case, one can obtain symmetric fringes shift around the fiber central axis. Which means that, when the fiber is placed in the path of the object beam always, we get the same shape of the fringes shift regardless the rotation angle of the fiber around its optical axis. Little work using interference technique to study PM optical fiber has been presented [6,32]. When PM optical fibers are inserted in the object arm of a two beam interference system, fringes shift caused by the fiber is observed. The shape of this shift depends on the angle between the traversed rays and the fast axis of the fiber. This means that we get different fringes shape with fiber rotation around its central axis.

In this work, interferometry has been employed to investigate PM optical fibers. We propose a development in interference technique to be faster and able to give information about the refractive indices of PM optical fibers, directly. The proposed development is beginning by capturing the real image of the PM optical fiber cross-section and the experimentally obtained interferograms. An adaptive prepared software is able to predict theoretically the optical phase difference, based on cross-section image, as well as the experimental optical phase difference from the interferograms. We have the facility to monitor the estimated optical phase difference, when the fiber is rotating around its axis in order to reproduce the experimentally obtained shape. A comparison between the two phases could provide the correct refractive indices of the PM optical fiber under study. We think that, the conjunction between the recovered phase based on cross-section image and the extracted phase from the interferograms is an important development to retrieve the refractive index of PM optical fibers in a direct way.

2. Theory

In this approach, we begin with cross-section image of the PM