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ScienceDirect
Optics & Laser Technology 40 (2008) 1082–1090
Optics & Laser Technology
www.elsevier.com/locate/optlastec

Automatic determination of refractive index profile, sectional area, and shape of fibers having regular and/or irregular transverse sections

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Received 5 July 2007; received in revised form 27 November 2007; accepted 29 January 2008
Available online 18 March 2008

Abstract

A new method based on a mathematical model and a computer program is suggested to determine the refractive index profile of fibers having regular and/or irregular transverse sectional shape. Microinterferogram of both multiple-beam Fizeau fringes and the duplicated image from two-beam interference microscope are used for the determination of refractive index profile, cross-sectional area and shape of three different types of fibers. To confirm the suggested model, the calculated area and the shape of the transverse section of these fibers are compared with those results obtained using conventional methods.

Keywords: Irregular fiber; Refractive index profile; Interferometry

1. Introduction

It is widely recognized that the main characteristics of physical properties of fibers can be related to their refractive index profiles. In other words, the values of refractive indices of the fibers give useful information about the structural parameters of these fibers. Also, they provide information about the microscopic parameters such as oscillation energy, dispersion energy, and the molecular polarizability. So it is important to establish not only easy and simple but also efficient and accurate methods and tools for measuring the refractive index profiles. The interferometric methods represent easy and precise tools for investigating the fibers. Different interferometric methods have been applied successfully to measure the refractive indices of natural and synthetic fibers [1–13].

It is well known that there are many natural and synthetic fibers having different cross-sectional shapes and areas due to their nature and fabrication. These geometrical parameters are important and necessary for the determination of the refractive indices of fibers.

Many authors described different interferometric techniques to overcome the difficulty of irregular transverse sections of fibers [1–4,14,15]. Simmens [1] described a technique using the Babinet compensator to determine the optical properties of fibers of constant weight per unit length but irregular sectional shape. Hamza [2] introduced a method to measure the mean refractive indices and birefringence of fibers with irregular transverse sections by a complementary technique using double beam interference and scanning electron microscopy. Hamza et al. [3,4] applied multiple-beam Fizeau fringes to obtain mean refractive indices and birefringence of fibers with irregular transverse sections. Hamza et al. [14] applied variable wavelength microinterferometry to determine the dispersion curves of irregular fibers. Hamza et al. [15] suggested a method to determine the regular and/or irregular transverse sectional shape and area of homogeneous fibers. In this method, the transverse sectional shapes of the fibers are determined by measuring the thickness profiles and varying the angle of rotation for these fibers.

In this paper, we developed an accurate and simple method with the aid of automatic fringe analysis not only

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0030-3992/$ - see front matter
doi:10.1016/j.optlastec.2008.01.022

to measure the mean refractive indices but also to obtain the refractive index profile for natural, synthetic, and optical fibers with regular and/or irregular transverse sections. Also in this work, we are able to calculate the transverse sectional area of the fiber with any cross-sectional shape.

2. Theoretical considerations

A mathematical model will be derived to determine the refractive index profile of fibers in case of two- and multiple-beam interferometric methods. In these methods, the fiber under study is immersed in a suitable liquid with refractive index different from that of the fiber (Fig. 1(a)). Due to this difference the interference fringes will be deformed across the fiber as shown in Fig. 1(b). The shape of the deformed fringes depends on the refractive index and the thickness of the fiber. In case of multiple-beam interference fringes, the equation that governs the shape of the deformed fringes [16] can be written as follows:

$$2\Delta S = \Delta m\lambda \tag{1}$$

where ΔS is the change in the path difference due to the passing of light through the fiber and Δm is the change in the fringe order which is given by

$$\Delta m = \frac{z}{h} \tag{2}$$

where z is the fringe shift across the fiber and h the interfringe spacing.

Therefore,

$$\Delta S = \frac{z\lambda}{2h} \tag{3}$$

where ΔS is a function of the refractive index of the fiber and the optical path length through it. To obtain the refractive index profile according to this equation we must know the fringe shift across the fiber and this optical path length. The accuracy of measuring these two parameters determines the accuracy of the produced refractive index profile.

2.1. Measuring the fringe shift (Z)

In order to obtain precise values for the fringe shift z, the experimental microinterferogram for fringes along the fiber are processed using a prepared computer program. Using this program we obtain precise contour lines of the fringes, from which we can automatically measure the shift z with high accuracy.

2.2. Determination of the total path length of light through the fiber

When the fiber is immersed in two liquids of different refractive indices, two different values of the fringe shift are obtained. Suppose the shift z_a is obtained using the first liquid and z_b when using the second liquid. The two equations that describe the fringe shift in the two cases using multiple-beam interferometer [6] are

$$nl_a - n_0 l_0 = \frac{z_a\lambda}{2h_a} \tag{4}$$

where n is the fiber mean refractive index, l_a the optical path length into the fiber at position x, l_0 the optical path length at the same position x if the fiber is not existing, n_0 the liquid refractive index, z_a the fringe shift due to the fiber at position x (see Fig. 2a), λ the light wavelength, and h_a the interfringe spacing, and

$$nl_b - n_0^* l_0 = \frac{z_b\lambda}{2h_b} \tag{5}$$

where n_0^* is the refractive index of the second liquid, l_b the optical path length into the fiber at the same position x, z_b the fringe shift using the second liquid at position x (see Fig. 2b), and h_b the interfringe spacing.

Eqs. (4) and (5) contain four unknowns' l_a, l_b, l_0, and n, and so we cannot solve them by algebraic methods. To solve these equations we interpret some experimental assumptions. These assumptions (in case of two- and multiple-beam interference fringes) are based on the experimental fact that the small change in the immersion liquid refractive index causes a slight change in the optical path length through the fiber, while it causes a large change

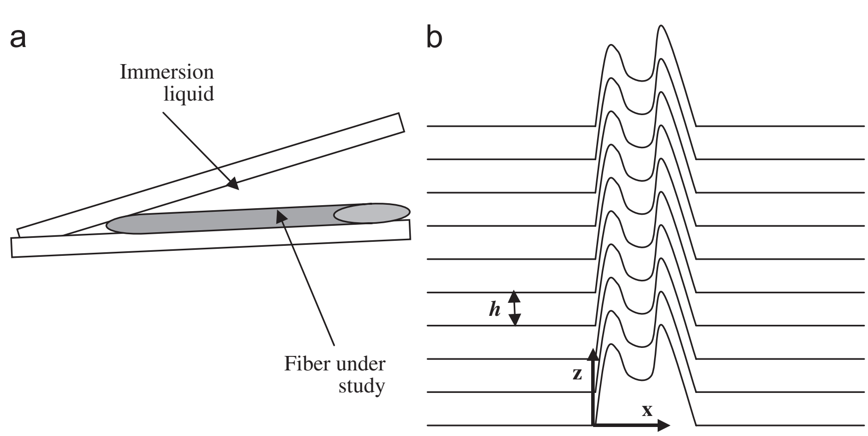

Fig. 1. (a) Liquid wedge interferometer containing a fiber with irregular transverse section. (b) The shape of the deformed Fizeau fringes across the fiber.