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Prediction of power transmission coefficient and the aspect ratio of a single mode trapezoidal index fiber by using splice loss technique

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ABSTRACT

Based on the splice loss analysis between two perfectly aligned single mode step and trapezoidal index fibers, we propose a simple empirical relation of power transmission coefficient in terms of normalised frequency and aspect ratio, using a recently reported Marcuse type formulation of spot size for trapezoidal index fiber. The relation is verified, after comparison with standard results from basic equations. Our empirical relation should find wide use by the system users to predict power transmission coefficient for known opto-geometrical parameters without the knowledge of spot size. Also, a simple graphical technique to predict an unknown aspect ratio of a trapezoidal index fiber is suggested and justified.

1. Introduction

Very recently, considerable amount of interests are generated on investigation of single mode fiber (SMF) having trapezoidal index profile (TIP). In this context, a novel, accurate and straightforward empirical relation of the normalised spot size of a circular core trapezoidal index single mode fiber (CCTISMF) considering Gaussian approximation is very recently reported in terms of normalised frequencies and aspect ratio of the trapezoid [1]. Also, using this simple relation, maximum Kerr nonlinear optical processes [2] in sub-wavelength diameter CCTISMFs have been predicted. Moreover, using the same relation [1], far-field characterization of CCTISMFs is reported [3]. It may be recalled that, very recently, effect of optical nonlinearity on first higher order cut-off frequency in CCTISMFs and other profiles has been investigated [4] using Chebyshev technique. It is well known that, trapezoidal index fiber has combined merits of step and triangular index profiles [5,6]. The former has the rigidity for monolithic material distribution and the latter possesses the dispersion-shifted criteria, shifting the zero dispersion wavelengths from 1.3 μm to 1.55 μm [6]. At the latter wavelength, glass shows lowest loss.

The above stated empirical relation [1] follows Marcuse formalism developed for step [7] and graded-index [8] fibers. Then, it is shown to predict the splice loss, excellently, for transverse and angular misalignments between two identical CCTISMFs [1]. However, if a trapezoidal index fiber with an unknown aspect ratio is supplied, there should be an easily acces-

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sible method capable to predict the particular value of the aspect ratio. This will help to have the accurate characterization of such fiber. Such work is not reported, so far, in literature to the best of our knowledge.

In order to determine the arbitrary aspect ratio of a supplied CCTISMF, as mentioned above, we choose splice loss technique out of many other propagation characteristics. This loss has great importance in the context of optical communication as its knowledge is essential for proper optical power budgeting. Several models have been proposed for the proper estimation of the splice loss at the joint between the two fibers. The distribution of optical power at the splice, mainly, depends upon the proper joining of two conventional and non-conventional SMFs of identical profiles. But, splice loss at the joint between two fibers, also, arises due to mismatch of the fiber profiles [9]. To predict the power transmission coefficient (PTC) from one fiber to another and, hence, the splice loss, accurate knowledge of modal spot size is essential. In addition to computing this loss, the accurate value of spot size, obtained from electromagnetics of these fibers, in turn, helps to predict other propagation characteristics like bending loss, dispersion etc. of single mode conventional fibers [9,10] and other optical properties of photonic crystal fiber (PCF) like bend-resistant large mode area [11], dispersion properties [12], transmission properties [13], splice loss [14] etc. Side by side, in the context of large birefringence of PCF, tremendous interest has, also, been generated, very recently [15,16].

Some pioneering works have been reported [7,17–20] where the splice loss has been calculated considering the splicing between two identical SMFs in the presence of transverse and angular mismatches at the joint. In a recent work, a numerical model has been framed to calculate the splice loss between a photonic band gap fiber and a SMF [21]. A methodology of making effective low-loss fusion splicing between two PCFs has been reported [22], recently. In another very recent article [23], an analytical approach has been applied to achieve low-loss splicing of index-guiding micro-structured optical fibers and SMFs by controlled air-hole collapse. A novel refractive index sensor has been developed by large lateral misalignment fusion splicing between two single mode abrupt tapers [24]. For the accurate knowledge of the field and spot size, it is well-known that, Gaussian approximation for the fundamental mode is preferred since it is simple and shows a close resemblance with the exact form of the field. Hence, using this form, accurate values of the PTC at the splice can be estimated [7,25]. In earlier literature [17–19], some non-Gaussian forms of the fundamental mode have been considered to calculate the splice loss in a deeply involved manner. But, the expressions for splice loss are not simple due to intricate involvement of Bessel and modified Bessel functions. Also, it may be relevant to mention that the analysis of splice loss is, significantly, exploited in designing fiber optic volumetric sensor [26,27] for the measurement of the volume of liquid.

In this paper, our objective is, first, to predict an unknown PTC for any arbitrary aspect ratio and normalised frequency of a given CCTISMF and then to predict an unknown aspect ratio for a given PTC, graphically. The entire analysis is based on the Gaussian approximation of the fundamental mode in both types of fibers. Here, first, we calculate the normalised spot size for the step profile using Marcuse relation [7] and that for the trapezoidal index fiber for a particular value of normalised frequency using the recently proposed empirical relation [1]. Then, for various aspect ratios, we calculate the PTC at the splice between single mode step and trapezoidal index fibers without considering any transverse or angular misalignment at their joint. We propose a simple empirical relation to determine the PTC for a particular value of aspect ratio for a wide range of normalised frequencies to accommodate all aspect ratios in single mode region. Then, we justify its validity by comparing our results with those obtained from an already established formulation [1]. Finally, we present a graphical method to simply predict an unknown aspect ratio of the CCTISMF corresponding to a known value of PTC.

2. Analysis

2.1. Basic framework

The refractive index distribution $n(R)$ of a graded index fiber [9] is given as

$$n^2(\mathrm{R}) = n_1^2\left[1-\delta f(R)\right], \quad \text{for} \;\; 0 < R \le 1,$$

$$= n_1^2\left[1-\delta\right] = n_2^2, \text{for } R > 1 \tag{1}$$

where $R = r/a$ is the normalised core radius; r is the radial coordinate and a is the core radius; n_1 is the refractive index of the core axis and n_2 that of the cladding; $f(R) = R^q$ is the profile shape function and $\delta = \frac{{n_1}^2-{n_2}^2}{{n_1}^2}$. Further, q is known as the profile exponent; $q = 1$, 2 and ∞ correspond to triangular, parabolic and step index fibers, respectively.

The profile function $f(R)$, for trapezoidal index profile under consideration is given (1) as

$$f(R) = 0, \text{for} 0 \; < R \le S$$

$$= \frac{R-S}{1-S} \quad \text{for } S < R \le 1 \tag{2}$$

where S is known as the aspect ratio of the CCTISMF, which is the ratio of the width of the trapezoid to core radius. Further, $S = 1$ and 0 correspond to step and triangular index profiles, respectively.