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Coupling of a laser diode to single mode circular core trapezoidal index fiber via hyperbolic microlens on the fiber tip and construction of empirical relations to determine the optimum back focal length

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ABSTRACT

The fiber tip based hyperbolic microlens coupling efficiency of circular core trapezoidal index single mode fiber and a laser diode is theoretically studied. The corresponding analytical expressions are formulated considering ABCD matrix for hyperbolic microlens following paraxial approximation and also Gaussian field distributions are considered for both the source and the fiber. Here, we study for two different light-emitting wavelengths of practical importance for such fibers. Then, we construct simple empirical formulations to find out the optimum back focal length as function of normalized frequency and aspect ratio of such fibers for optimal excitation of fiber. These handy relations should guide system designer in designing hyperbolic microlens directly on the tip of such fiber carrying the information signal with no need of dependence on rigorous methods to estimate the optimum back focal length.

1. Introduction

In optical communications systems, state of the art performance is achieved by efficient coupling between fiber and the laser diode (LD). In particular, various lensing schemes for highly efficient laser coupling are required in high-bit-rate, long-distance optical fiber transmission systems. The recent semiconductor laser packages are seen to use microlensed fibers [1]. The microlense formation directly on the tip of single mode fiber (SMF), has come into use because of their ability to produce high coupling efficiency by matching the microlens transformed modal spot sizes of the LD and SMF. Moreover, microlens-ended fibers could find great usefulness in future biomedical applications, particularly, in endoscopic imaging applications [2,3].

In this respect, the hemispherical microlenses are not ideally suitable to collect all the available radiation emanating from a laser source, mainly, because of fiber truncation, mode-mismatch, spherical aberration, and Fresnel reflections [4]. However, microlensed fiber consisting of graded index section with hyperbolic end shape is proposed for excitation by LD with large

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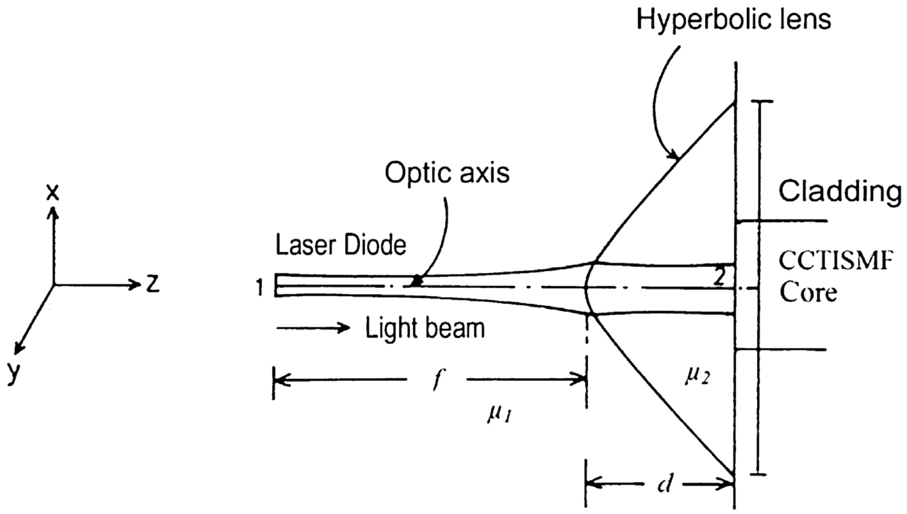

Fig. 1. The coupling scheme between laser diode to CCTISMF involving hyperbolic microlens on the fiber tip.

working distance and minimum loss [5]. The most suitable microlens on an SMF tip with reference to other conventional types is hyperbolic microlens (HML) [4–14]. The coupling of the circular core step index and power law SMF involving HML with the LD has, already, been reported in literature [9–12]. Also, the coupling of the step index elliptic core SMF and the LD via HML has also been reported [15–17]. Beside these, an approximate ABCD matrix has been formulated to calculate coupling efficiency using parabolic lens [18]. In spite of considerable studies, on various microlens types developed on the tip of graded index and also step index SMFs, such study is yet to be reported concerning coupling of circular core trapezoidal index single mode fiber (CCTISMF) and an LD involving an intermediately HML on the fiber tip. The CCTISMF possesses both the merits of triangular and step index profiles [19]. The step index profile has rigidity and the other profile possesses merit of dispersion shifting. So, such investigation should invite attention of system designers involving trapezoidal index fiber. In addition, accurate knowledge of optimum launch optics corresponding to varying values of aspect ratio is essential. Side by side, a complementary investigation is recently made available in the context of the effect of the trapezoidal profile structure on the operating characteristics of Raman sensitive fiber amplifiers [20].

Now, we first, theoretically, find out the excitation efficiencies between semiconductor LDs of two wavelengths of light of practical interest [7] and a CCTISMF with different normalized frequencies and aspect ratios using HML at the tip of such fibers. Here, we use simple ABCD matrix technique [10] considering paraxial approximation for HML to estimate analytical expression for coupling efficiencies concerning such fiber. In this connection, Gaussian distribution is taken for both, the fiber and the source. Finally, we formulate two empirical relations for calculating optimum back focal length (OBFL) for maximum coupling in between LDs and CCTISMF with different normalized frequencies and aspect ratios involving HML corresponding to these two wavelengths of light from LDs. The fiber designers are able to mould and shape the desired HML on the fiber tip by using these two important empirical relations according to their needs to attain optimum coupling condition based on CCTISMF.

2. Analysis

2.1. Preview

The coupling scheme [12] between CCTISMF involving HML on the fiber tip and LD is shown in Fig. 1. Here, μ_1 represent the refractive index of incident media and μ_2 that to microlens media; the distance from tip of the HML to the laser source is represented by the back focal length *f*. In our analysis, for both the source and fiber, we take Gaussian field distributions. We also appoximate the intensity profiles of the emitted optical beams from LD having elliptical shape by Gaussian spot sizes w_{1x} and $w_{1y,}$ respectively in the X and Y directions, X being perpendicular and Y parallel to the junction plane respectively. Evolution of spot sizes from LD output face at the fiber input face is computed from well known ABCD matrix technique in Gaussian beam transmission and known ABCD matrix for HML. Moreover, we use some usual approximations in our analysis like, no transmission loss etc. Also we adjust the distance between LD and nearest point of HML equal to microlens focal length to achieve absence of spherical aberration [4–7].