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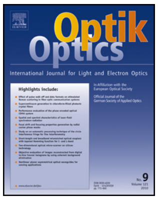

Full length article

Coupling efficiency between ball lens capped laser diode chip and single mode fiber

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ABSTRACT

Laser diodes are one of the key devices in the optical fiber communication system. Alignment and coupling is an application prerequistite between laser diode and single mode fiber. Coupling efficiency is analyzed theoretically between laser diode, ball lens and single mode fiber. The theory coupling efficiency with working distance are obtained under different optical system parameters, such as, the separation between the laser diode and the ball lens, refractive index and diameter of ball lens. Alignmnet and coupling experiments are done on the optical system for the coupling efficiency with working distance, and the maximum coupling efficiency is located at 2400 μm. The simulation to get high coupling efficiency, namely minimize spherical aberration, the laser diode should be put as close to the ball lens as possible and choose the ball lens with high refractive index and small diameters, which can be explained by Gaussian lens law.

1. Introduction

Optical fiber communication system is one of the baisic of the information society, it is suitable for large capacity, high speed transmission with long distance. Laser diode, optical fiber, and photodetector are the baisic components of optical fiber communication system. It can be work, a stable interconnection with high coupling efficiency between the laser diode and the single mode fiber, the single mode fiber and the photodetecter is a prerequsite [1–3]. According to the optical mode field character, a laser diode has a large light beam divergence angle (30°–50°) perpendicular to the junction plane, and a single mode fiber has a small circular light beam (the core diameter is 4–9 μm). They are dismatch, the light from laser diode is poor coupling to the single mode fiber. For tightly coupling a laser beam efficiently into single mode fiber (SMF), a ball lens have been applied for shaping and focusing the laser beam into a end plane with diameter less than 10 μm due to its small size, low cost, ease of alignment and ease of encapsulate [4,5]. Coupling efficiency as a key parameter in coupling optical system will be influenced by lens aberrations, component misalignment, and fresnel reflection losses. The beam propagation method (BPM), a powerful optical technique for modeling physical optics, telecom components, integrated optics, micro optics [6,7], has been adopted to model specific optical system. Study of the coupling efficiency between the laser diode and a single mode fiber in optical fiber communications is an crucial research [8]. Hence, Wagner et al. presented an analytical mode to explore the effect of fiber mode mismatch, lens aberration and fiber misalignment for coupling effieicny [9]. Sami D. Alaruri reported fiber coupling efficiency calculations by using Huygens integral and Gaussian beam physical optics propagation

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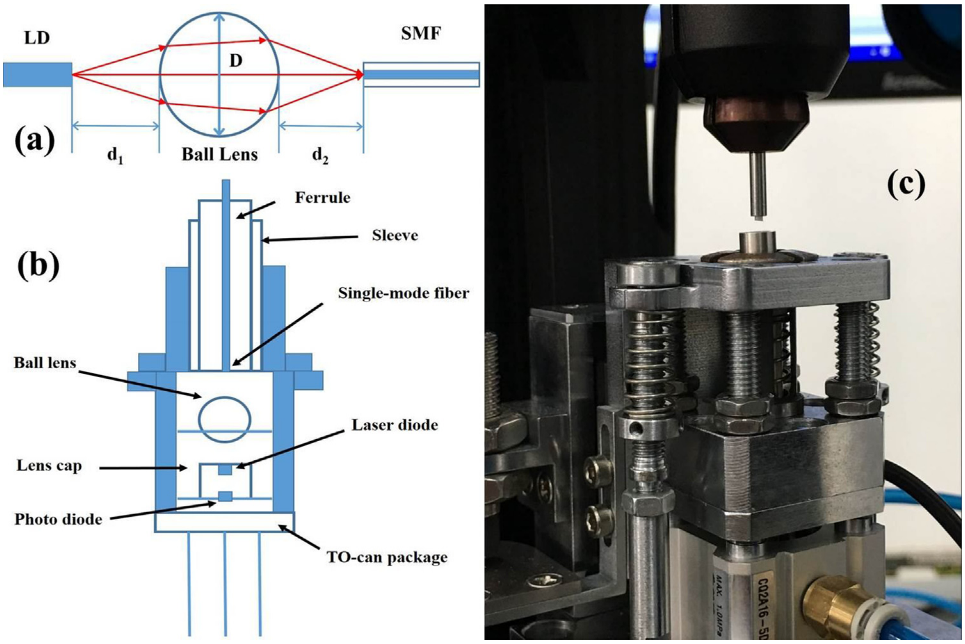

Fig. 1. (a) Schematic of ball lens coupling component of laser diode to single mode fiber; (b) A typical laser diode module with ball lens and single mode fiber; (c) Image of laser diode module experimental facility.

features in Zemax [10]. Robert Gale Wilson conclued that fine discretization of the distances of source and fiber from the lens could impact the coupling efficiency after comparing two method of conventional optical analysis and exact solution of Maxwell's equations [11].

In this paper, the coupling efficiency of various optical configuration have been acquired by regulating its system parameters. We have explored the effect of the laser beam waist radii, distance of laser diode and lens, refractive index and diameter of ball lens on coupling efficiency.

2. Configuration of the optical system and numerical simulation method

Fig. 1(a) exhibits the coupling component in optical coupling system. The configuration of the optical system is illustrated in Fig. 1(b), which is a typical ball-lens capped laser diode chip into SMF. The beam propogation method (BPM) [12,13] is employed to obtain the coupling efficiency for the coupling optical system. According the assumption of Gaussian optical field distribution, the output optical field from laser diode:

$$\psi_l(x,y)=\sqrt{\frac{2}{\pi}}\frac{1}{\sqrt{\omega_{lx}\omega_{ly}}}\exp[-(\frac{x^2}{\omega_{lx}^2}+\frac{y^2}{\omega_{ly}^2})] \qquad (1)$$

where ω_{lx}, ω_{ly} are the waist radii on X and Y directions. The BPM calculates the three-dimensional space optical field in a series of evenly spaced planes by applying finite difference technique to solve the scalar or semi-vectorial Helmholtz equation:

$$[\frac{\partial^2}{\partial x^2}+k_0^2(n^2-\upsilon^2)]A(x,y)=\pm 2jk_0\upsilon\frac{\partial A_k(x,y)}{\partial y} \qquad (2)$$

Where $k_0=2\pi/\lambda_0$ is the propagation constant calculated at the reference wavelength λ_0, n is the computation space refractive index, ν is the beam propogation speed, $A(x,y)$ is the electrical field amplitude envelope. The coupling efficiency η describes the degree of matching between the spot sizes and distributions of the laser and fiber mode fields, which can be expressed by following equation:

$$\eta=\frac{|\iint F_r(x,y)W^*(x,y)dxdy|^2}{\iint F_r(x,y)F_r^*(x,y)dxdy\iint W(x,y)W^*(x,y)dxdy} \qquad (3)$$

where $F_r(x,y)$ is the mode field of the single mode fiber, $W(x,y)$ is the mode field deriving from optical output filed of ball lens, and the * symbol represents complex conjugate. The calculated parameters are listed in Table 1 for ball lens coupling system.