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A New Optical Coupling Scheme from Laser Diodes to Single-Mode Fibers for Low Cost Telecommunication Modules

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A new fiber coupling scheme using thermally over-expanded core(TOEC) fiber was proposed and demonstrated. In the coupling experiment between 1.3μm FP-LD and the proposed TOEC fiber with a tapered hemispherical microlens, superior performances such as a long working distance, a high coupling efficiency, and large misalignment tolerances were verified experimentally.

I. INTRODUCTION

The advance of the Information Super Highway requires low cost telecommunication modules since a significant part of the module price is taken up by packaging costs. The direct coupling scheme with lensed fibers is one conceivable means to economically achieve high coupling efficiency without employing expensive components [1]. Usually a coupling loss of 1-3 dB at a working distance of a few μm has been reported using aspherically ended single mode fibers[2-5]. However, aligning and packaging for such structures are very difficult and time-consuming. Therefore, a new LD to fiber coupling scheme with a high coupling efficiency, a long working distance, and a large misalignment tolerance is desirable. A design proposed by Shiraishi and coworkers seems to fulfill the purpose, where coupling loss is 4.2 dB at 160 μm working distance [6,7]. The only drawback of the method is the difficulty of making the complicated fiber lens.

We propose a new direct coupling scheme from laser to thermally over-expanded core (TOEC) fiber. The fabrication process for TOEC fiber is schematically illustrated in Fig.1(a) and (b). The conventional single-mode fiber is locally heated until the fiber core is excessively expanded so as to loose beam guiding property. Then only 1-2 mm of the thermally over-expanded core is left and a lens shape is formed at the end of TOEC fiber using arc discharge. The dopant profile of the TOEC fiber can be controlled by the diffusion temperature and time [8]. Since there is only one cleaving step after the heat treatment, the fabrication is simpler and easier than the previous processes [6,7].

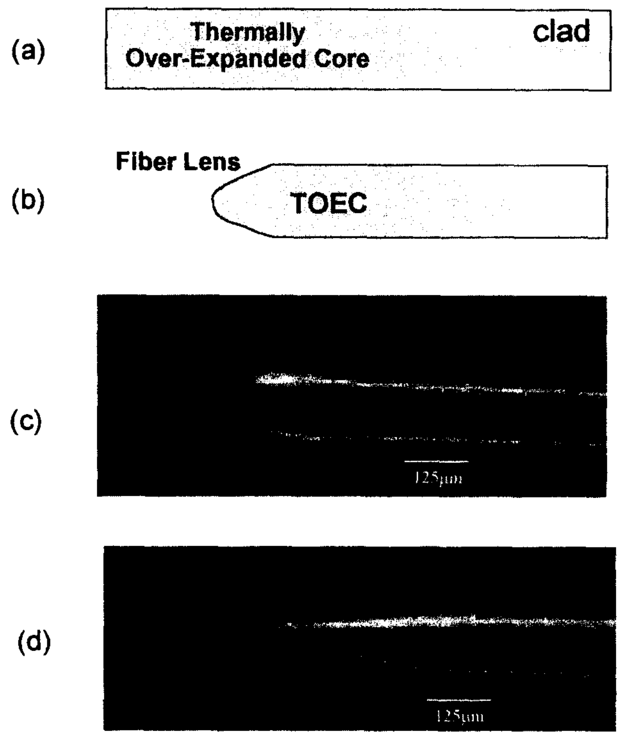

FIG. 1. The fabrication processes of a thermally over-expanded core (TOEC) fiber lens. (a) The diffusion of core dopant by local heating, (b) microlensing by arc discharge. A fabricated TOEC fiber with parabolic fiber lens is shown in (c). A standard single-mode fiber with tapered hemispherical lens in (d) was also prepared in order to compare with the coupling performances of TOEC fiber in (c). The Corning SMF-28 fiber was used in these experiments.

II. EXPERIMENT AND RESULTS

The LD used in the experiment is a 1.3μm MQW PBH-LD with far-field divergence angle of 28° × 30°

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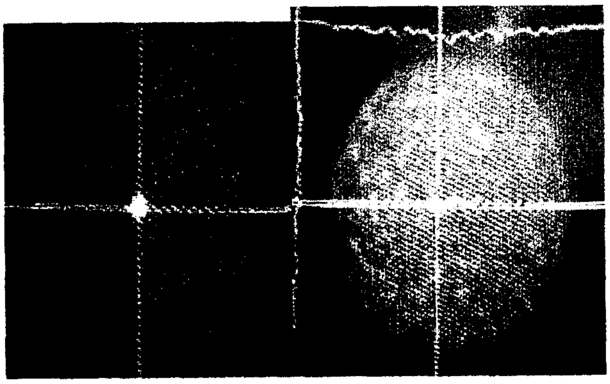

FIG. 2. The near-field patterns from the cleaved fiber facets of (a) a normal SMF-28 fiber and (b) a TOEC fiber.

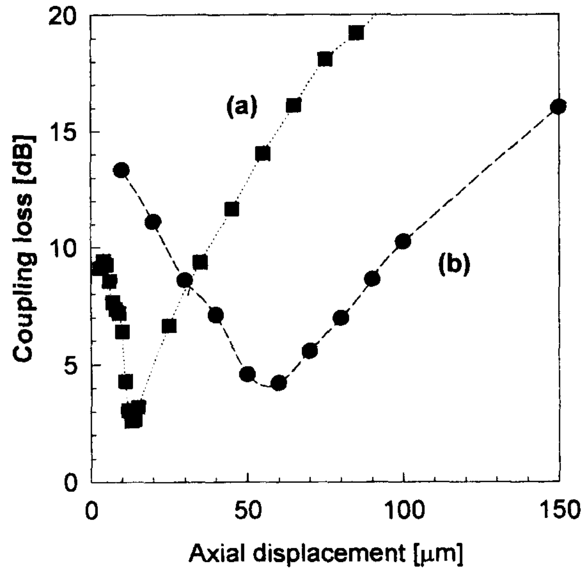

FIG. 3. The coupling loss between a 1.31 μm MQW-PBH FP-LD and two different types of fibers, namely (a) a standard single mode fiber with the tapered hemispherical fiber lens and (b) a TOEC fiber with the parabolic-like fiber lens as shown in Fig. 1(c).

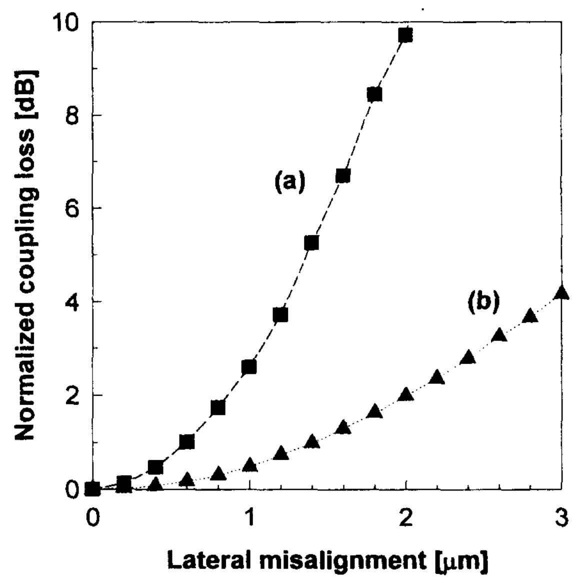

FIG. 4. Comparison of 1dB power loss of (a) standard single-mode and (b) TOEC fiber

grown by 3-step MOCVD epitaxies. A Corning SMF-28 fiber with beam spot size of 5.0 μm was heated using a Propane gas torch. The temperature of the flame is suspected to be 1,300°C $\sim$ 1,400°C under normal gas flux condition. The fiber was heat-treated for 24 hours in ambient N_2, and the near-field pattern was measured using infrared CCD. Once the thermally over-expanded core was made, the fiber was cleaved. The tapered hemispherical fiber lens was fabricated by arc discharge and slight pulling. Our theoretical work showed a coreless region length of about 1mm, a transition region length of the core dopants of 1 - 2 mm, and a parabolic shaped fiber lens are one of the most promising TOEC fiber structure to realize low coupling loss and long working distance simultaneously [8]. The length of the coreless region is defined as the length from the tip of the lens to the middle of the transition region.

The output power of the 1.31 μm MQW-PBH-LD was maintained at 2 mW. The coupling efficiencies between LD and fibers were measured by using an optical power meter with a large area PIN detector and XYZθ-translators with a accuracy of $\pm$ 0.1 μm.

Photographs (a) and (b) in figure 2 show the near-field pattern of the untreated single mode fiber and that of the heat treated fiber, respectively. The optical field of the TOEC fiber is spread over the whole fiber end face as expected. Figure 3 compares the coupling efficiencies between the 1.3 μm FP-LD and the two types of fibers. Curve (a) and (b) are the coupling efficiency for the normal fiber with the tapered hemispherical lens and that of TOEC fiber with the parabolic-like microlens as shown in Fig. 1(c), respectively. For the normal fiber, the minimum coupling loss, the optimum axial distance, and the axial tolerance for 1dB loss are 2.6 dB, 13 μm, and $\pm$ 1.2 μm, respectively. For the TOEC fiber, corresponding values are 4.2dB, 60 μm, and $\pm$11 μm. Fig. 4 shows the lateral tolerances of the two types of fibers. The lateral tolerance of the TOEC fiber is $\pm$1.5 μm which is 2.5 times larger than the $\pm$0.6 μm of the normal fiber. Although the coupling loss of the TOEC fiber is slightly larger than that of the normal fiber, its optimum axial distance and the misalignment tolerances are much better than those of the normal fiber. The larger coupling loss of the TOEC fiber results mainly from the difficulty of defining the coreless region length and from the deviation of the lens shape from the design. The coupling loss and the working distance of the TOEC fiber can be further improved by using the optimum structure of TOEC fiber [8].

III. CONCLUSIONS

We have proposed and demonstrated a new laser to fiber coupling scheme by using thermally over-expanded core(TOEC) fiber. Its improved coupling performances was verified in the coupling experiments between a 1.3 μm FP-LD and a TOEC fiber. The minimum coupling loss of 4.2 dB, the axial tolerance of ± 11 μm as well as the lateral tolerance of ± 1.5 μm for 1 dB loss were achieved at the working distance of 60 μm long.

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