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Fiber Lens Structure for Large Distance Measurement

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Abstract—We propose a new fiber lens structure for large distance measurement in which a polymer layer is added to a conventional fiber lens. The proposed fiber lens can adjust the working distance by properly choosing the refractive index and thickness of the polymer layer. In our numerical analysis for the fiber lens radius of 120 μm, the working distance of the proposed fiber lens is about 10 mm which is about 30 times larger than conventional fiber lens.

Keywords—fiber lens, distance measurement, collimation.

I. Introduction

Fiber lens has gotten lots of attention for optical free space interconnections, large distance coupling between an optical source and a fiber in a micro-electromechanical system, and optical measurements [1], [2], [3], [4]. Fiber lens of which diameter is typically less than 500 μm enables us to make small scale integrated optical systems without bulk optical devices. Applications of fiber lens are accurate distance measurement, area scanning, tomography, etc.

Fiber lens system consists of three parts: a single mode fiber, a coreless silica fiber to expand the beam from the single mode fiber, and a semi-spherical part at the tip of the coreless silica fiber acting as a lens. Requirements for a fiber lens, such as a working distance and a beam dimension, can be satisfied by properly choosing the process parameters involved with the fiber lens fabrication. There are several methods in making a fiber lens, such as attaching of graded-index grating fiber, chemical etching, and electric arc discharge methods [5], [6], [7]. The method of chemical etching or melting of a fiber tip is advantageous over others in making a small lens. Attaching method of a graded-index grating fiber gives well-defined working distance because process parameters for its grating can be precisely managed. One of the disadvantages for the graded-index grating fiber is the refractive index mismatch between the graded-index grating fiber and the optical single mode fiber, which reduces the optical power due to the reflection at the interface between them. The arc discharge method is advantageous in terms of optical loss and adjusting working distance, comparing with the previously mentioned chemically etched fiber lens and the graded-index fiber lens. For the arc discharge method, the fiber lens working distance can be manipulated by adjusting the length of the coreless silica fiber and the curvature of the coreless fiber tip, and the optical loss due to the reflective index difference is very small. However, if the largest radius of the semi-spherical lens is restricted to a certain size to take advantage of the small size of fiber lens, there is a limitation in extending the working distance for the arc discharge method.

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In this paper, we report a new optical fiber lens structure extending the working distance further, compared with other fiber lenses for large distance measurement. In the proposed fiber lens, we can adjust the working distance by changing the refractive index and thickness of the polymer layer. In the numerical analysis for our fiber lens structure in which the diameter of coreless fiber is 240 μm, we extend the working distance larger than 10 mm.

II. Proposed Fiber Lens Structure

Figure 1 shows the proposed fiber lens which consists of four parts: a single mode fiber, a coreless silica fiber (M_{12}), a semi-spherical lens (M_{23}), and a polymer layer (M_{34}). The

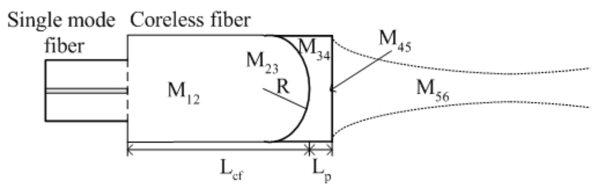

Fig. 1: The proposed fiber lens structure.

proposed fiber lens structure has the polymer layer at the tip of the fiber lens, M_{34} in Fig. 1, which conventional fiber lenses do not have. For the polymer layer, its refractive index is lower than the coreless silica fiber. The polymer layer with low refractive index acts as a concave lens extending the working distance of the fiber lens. By changing the refractive index and thickness of the polymer layer, we can adjust the working distance of the proposed fiber lens, while the working distances of conventional fiber lenses are dictated by the radius of the fiber lenses.

An ABCD matrix equation of the proposed structure can be described as in eq. (1).

$$M = M_{56}M_{45}M_{34}M_{23}M_{12} \tag{1}$$

$$M_{12} = \begin{bmatrix} 1 & L_{cf} \\ 0 & 1 \end{bmatrix} \quad M_{23} = \begin{bmatrix} 1 & 0 \\ \frac{n_2-n_1}{n_2R} & \frac{n_1}{n_2} \end{bmatrix}$$

$$M_{34} = \begin{bmatrix} 1 & L_p \\ 0 & 1 \end{bmatrix} \quad M_{45} = \begin{bmatrix} 1 & 0 \\ 0 & \frac{n_2}{n_3} \end{bmatrix}$$

$$M_{56} = \begin{bmatrix} 1 & L_w \\ 0 & 1 \end{bmatrix}$$

where n_1, n_2, and n_3 are refractive indexes of the core, the cladding of the single mode fiber, and the polymer layer (M_{34}), respectively, in Fig. 1. The working distance (L_w) can be found from the following eq. (2).

$$AC + a^2BD = 0 \quad (2)$$

with $a = \frac{\lambda}{\pi\omega_0^2 n_1}$.

III. Numerical Analysis

In our simulation, we use the eq. (3) to calculate the beam radius (ω_{f_0}).

$$\omega_{f_0} = c_0 \left[0.65 + \frac{1.619}{V^{3/2}} + \frac{2.879}{V^6}\right] \quad (3)$$

where $V = \frac{2\pi c_0}{\lambda_0}\left(n_1^2 - n_2^2\right)^{1/2}$.

where c_0 and λ_0 are core radius and wavelength, respectively. For $n_1 = 1.4675$ and $n_2 = 1.4622$ which are refractive indexes of the core and and the cladding of the single mode fiber in Fig. 1, respectively, the beam waist of ω_{f_0} is 4.448 μm in the single mode fiber. The laser beam with a wavelength of 1325 nm expands in the coreless silica fiber of which beam size can be described as in the eq. (4).

$$\omega_1 = \omega_0 \left[\left(\frac{n_1}{n_2}\right)\frac{A^2 + a^2B^2}{AD - BC}\right]^{1/2} \quad (4)$$

For a conventional fiber lens which does not have the polymer layer in the proposed structure, M_{34} in Fig. 1, we investigate the working distance in terms of fiber lens radius, (Fig. 2), with the coreless silica fiber length of 1.75 mm and the coreless silica fiber diameter of 240 μm. It shows that the working distance increases as the fiber lens radius increases. For the fiber lens without the polymer layer, the working distance of the fiber lens is about 340 μm for the fiber lens radius of 120 μm.

For our proposed fiber lens structure which has the polymer layer with a thickness of 30 μm and a refractive index of 1.348, we obtain the working distance of 10.4 mm, shown in Fig. 3, which is more than 30 times larger than the working distance of the fiber lens without the polymer layer,

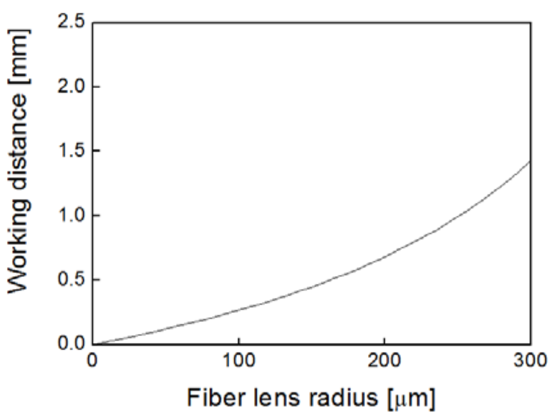

Fig. 2: Working distance vs. radius of fiber lens without polymer layer.

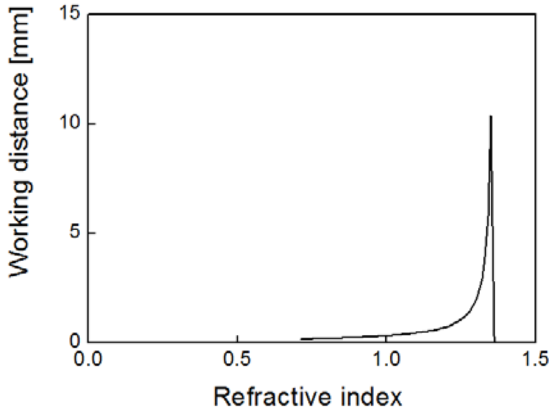

Fig. 3: Working distance vs. refractive index of the polymer layer with thickness of 30 μm in the proposed fiber lens structure.

for the same coreless silica fiber radius of 120 μm. Beyond the refractive index of 1.35, the working distance sharply decreases, because the polymer layer weakens the optical power of the fiber lens. For the coating layer thickness from 6 μm to 100 μm, the working distance of the fiber lens reduces from 10.37 mm to 10.30 mm. Figure 4 shows the working distance change in terms of the polymer layer thickness.

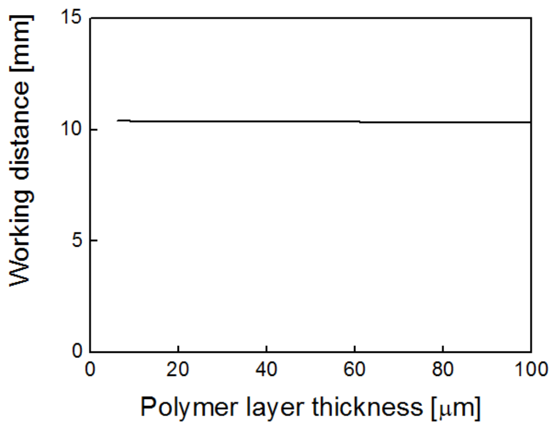

Fig. 4: Working distance vs. polymer layer thickness in the proposed fiber lens structure.

IV. Conclusion

We propose a new fiber lens structure which consists of four parts: a single mode fiber, a coreless silica fiber, a semi-spherical lens, and a polymer layer. In the proposed fiber lens, we can adjust the working distance by changing the refractive index and thickness of the polymer layer. Numerical analysis shows that low refractive index compared with that of the coreless silica fiber can extend the working distance. With a coreless silica fiber length of 1.75 mm, a fiber lens radius of 120 μm and the refractive index of 1.348, we obtain the working distance of 10.4 mm which is more than 30 times larger than the fiber lens without the polymer layer.

We believe the proposed fiber lens can be used for large distance measurements for small scale systems.

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