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A New Scheme of Hyperbolic-end Microlens Using Fusion Technology

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Abstract

We proposes a new scheme of the tapered hyperbolic-end fiber (THEF) by etching the fiber end in a hydrofloride (HF) solution with a thin layer of oil floating on top of the HF. The tapered hyperbolic-end fiber microlens results in a more than 2 dB improvement in coupling efficiency when compared to the currently hemispherical microlenses.

1. Introduction

The coupling efficiency is improved by using a microlens on the end of the fiber to match both the spot sizes and the wavefront of the laser beam with those of the fiber [1-3]. The hemispherical microlenses with taper asymmetry and larger Fresnel's reflection loss have demonstrated imperfect coupling with a typical coupling efficiency of 50% [4, 5].

Recently, hyperbolic microlenses fabricated directly on the end of the fiber by CO_2 laser micromachining have demonstrated up to 90% coupling efficiency [6].

The THEFs have demonstrated up to 86% coupling efficiency for a laser with an aspect ratio of 1:1.5. This study makes it possible to fabricate the hyperbolic microlenses using etching and fusion techniques that result in a more than 2 dB improvement in coupling efficiency when compared to the currently available hemispherical microlenses.

2. Manufacturing Process

The fibers used in this study were Corning step-index single-mode fibers. The glass composition was SiO_2-GeO_2-P_2O_5 for the core and pure SiO_2 for the cladding with low impurity content. The fiber core diameter, the beam spot size, and the refractive index difference were 8 µm, 5 µm, and 0.3%, respectively, at a wavelength of 1.55 µm. In this study, the THEF was designed with a longer taper length and a smaller taper angle with a small radius of curvature. The THEFs were fabricated by etching the fiber end in a 55% HF solution placed in a teflon beaker, with a thin layer of oil floating on top. Different density of oil floating on the HF solution were investigated. The oil density was defined by weight per volume (g/cm^3). Figure 1 shows the taper angle as a function of oil density. This result shows that the taper angle is dependent on the oil density. The oil floating on the HF with oil solution with lower density and much etching effect caused by HF deposition due to vaporization exhibits a smaller taper angle. After the fiber was etched to the desired tapered shape, a hyperbolic microlens for the THEF was formed by heating the fiber tip in a fusion splicer.

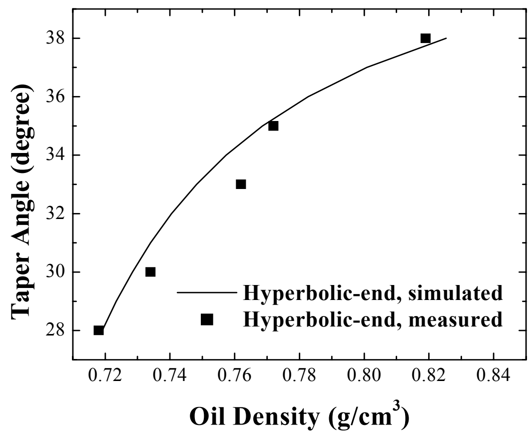


Fig. 1. The taper angle as a function of oil density.

3. Measurements and Results

I. A Comparison of Coupling Efficiency Between Hyperbolic-end and Hemispheric-end Microlenses

The feature of the hyperpolic-end microlens have a smaller taper angle, i.e. $2\theta_{hp1} < 2\theta_{hs}$, and $2\theta_{hp2}$ larger than $2\theta_{hp1}$ is necessary. In Fig. 2, both microlenses have a radius of curvature of 9.5 µm.

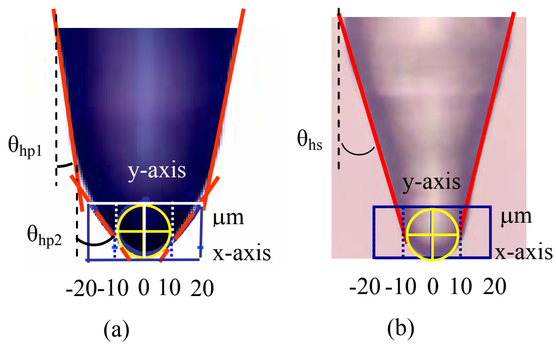


Fig. 2. Both microlenses have a radius of curvature of 9.5 µm.

Figure 3 shows the coupling efficiency as a function of the lens's radius of curvature both the hemispherical-end microlens and hyperpolic-end microlens. A maximum coupling efficiency of 86.8% of hyperbolic-end microlens was obtained between a fiber lens with a radius of 9.5 µm and a laser diode with aspect ratio of 1:1.5. But the hemispheric-end microlens was 64.5% only with a radius of 12.5 µm.

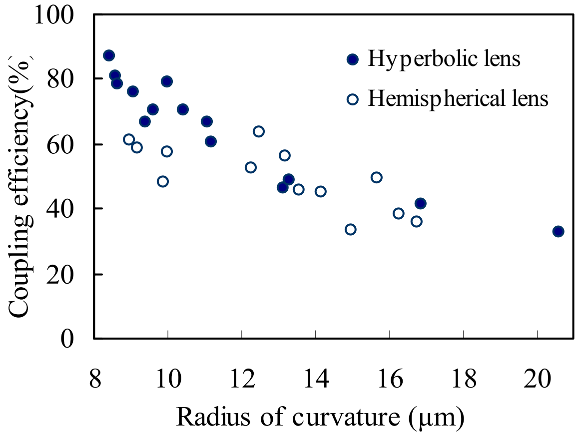
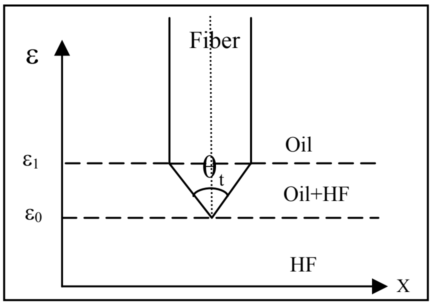


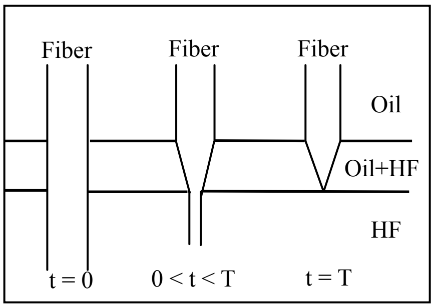
Fig. 3. The coupling efficiency as a function of the lens's radius of curvature both the hemispherical-end microlens and hyperpolic-end microlens.

II. An Emperical Model for Taper Length Depending on Oil Density

The HF with oil solution can be divided three layers: the bottom layer of uncontaminated HF solution, the interface layer of HF with oil solution, and the most top layer of oil, as shown in Fig. 4(a). Figure 4(b) is the etching process of tapered fiber. The local oil density, γ(z), is assumed to vary in the z-direction. The fiber in layer I can be etched to a long round stick, while the fiber in layer II can be etched to form a longer taper length and smaller taper angle.



(a)



(b)

Fig. 4. (a)The HF with oil solution can be divided three layers (b) etching process of tapered fiber.

The local oil density, γ(ε) in three different layers can be expressed by

$$\gamma(\varepsilon) = \begin{cases} \text{constant} & \varepsilon_1 < \varepsilon \\ \left[p + q\,\gamma(\varepsilon)\right]\left(\varepsilon - \varepsilon_0\right) & \varepsilon_0 < \varepsilon < \varepsilon_1 \\ 0 & \varepsilon < \varepsilon_0 \end{cases} \qquad (1)$$

where the p and q are constants. Based on Fig. 6, the taper angle, θ_t, is given by

$$\theta_t = 0.5 \tan^{-1}\left(d_f / 2\varepsilon\right) \qquad (2)$$

where the d_f is the fiber diameter of 125 μm. From Eqs.1 and 2 yields

$$\theta_t = 0.5 \tan^{-1}\left\{d_f\left[p + q\gamma(\varepsilon)\right] / 2\gamma(\varepsilon)\right\}$$

where the constants p and q are −0.113 and 0.169, respectively. The constants p and q are from the experimental values of the taper angle related the oil density.

4. Conclusion

The high-coupling performance of microlenses with a hyperbolic profile was due to the improved mode matching between laser and fiber when compared to currently available hemispherical microlenses, which showed a maximum coupling efficiency of 65% [4,5]. Hyperbolically shaped microlenses fabricated through the optimization of etching and fusion processes have demonstrated up to 86% coupling efficiency for a laser with an aspect ratio of 1:1.5.

5. Acknowledgements

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