A WAVELENGTH INSENSITIVE, NON-CONTACT AND HIGHLY EFFICIENT FIBER OPTIC CONNECTOR USING UP-TAPERED MULTIMODE OPTICAL FIBERS

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Abstract: *A wavelength independent, non-contact and highly efficient fiber optic connector has been demonstrated. The connector consists of a pair of up-tapered multimode optical fibers. The insertion loss was measured to be 0.9 dB in the wavelength range from 410 to 790 nm. This novel fiber optic connector will find applications in multi-color illumination systems, where frequent plugging and unplugging of the connector are necessary.*

1. Introduction

Recently, multi-wavelength laser illumination systems have been developed. For example, an endoscope system for medical diagnoses, which uses both near infrared laser (1300 nm) for optical coherence tomography (OCT) and ultraviolet laser (405 nm) for laser induced fluorescence (LIF), has been reported [1]. In such a system, a broad bandwidth and highly efficient fiber optic connectors are required.

A PC (physical contact) connector might satisfy the requests, but a non-contact optical connector should be required in the real field use. Because of frequent plugging and unplugging of the connector for exchanging illumination heads may increase opportunity to pollute the end face of the optical fiber, leading to surface damages. Such frequently reconnection is performed to, for example, sterilize of the illumination heads, assure portability, etc.

Typical ways for non-contact optical connect are lens collimator or butt coupling, but each method has some demerits. With lens collimator, it should avoid the chromatic aberration, and with butt coupling, the coupling efficiency should be too low when the ends of fiber are placed with a certain distance.

To address these issues, we propose and demonstrate a fiber optic connector consisting of a pair of up-tapered multimode fibers. A multimode fiber has an advantage to guide illumination of a few hundreds of watts. Although an up-tapered single mode optical fiber connector has been proposed as a non-contact connector [2,3], a multimode counterpart should be capable of delivering intense illumination.

2. Principle of up-tapered optical fiber connector

Fig. 1 shows the up-tapered optical fiber connector consisting of a pair of up-tapered multimode fibers. The pair of up-tapered multimode fibers is placed with air-gap to perform non-contact optical connection. The fiber taper expands the beam diameter and simultaneously reduces the beam divergence angle. Within the limit of geometrical optics, propagating light follows:

$$r_{\mathrm{in}}\mathrm{NA}_{\mathrm{in}} = r_{\mathrm{out}}\mathrm{NA}_{\mathrm{out}}$$

where r_{in} / NA_{in} is core radius / numerical aperture of the incident surface and r_{out} / NA_{out} is that of the outgoing surface. For example, NA_{out} reduces to half of NA_{in} when r_{out} is twice bigger than r_{in}.

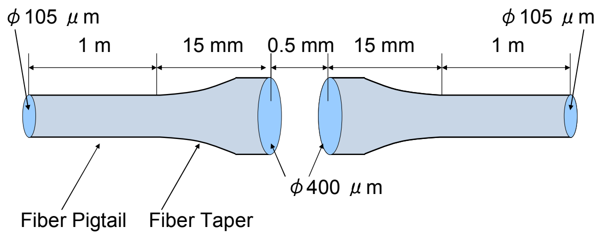

Fig. 1. Optical fiber connector using up-tapered multi-mode optical fiber

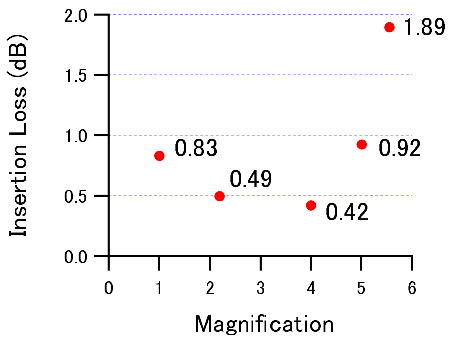

Fig. 2. Calculated insertion loss of the up-tapered fiber-optic connector by ray tracing. Note that reflections on the end faces are ignored in this calculation.

This reduction of the beam divergence angle suppresses the insertion loss when the fibers are separated with an air gap of around 0.5 mm.

Since the reduction of beam divergence is due to total internal reflection in taper transition region, chromatic dispersion of beam divergence angle is minimal. This enables wavelength-insensitive connection in our connector.

3. Experiments

A ray tracing calculation of insertion loss of up-tapered multimode optic connector was performed to find out the best magnification in this case. In the calculation, up-tapered multimode fibers were placed with an air gap of 0.5 mm as shown in Fig. 1. The up-tapered multimode fibers had taper transition regions of 15-mm long and were followed by fiber pigtails, whose quartz core diameter was 105µm, clad diameter was 125 µm and N.A. was 0.22. We employed ZEMAX (Radiant ZEMAX, LLC.) for the calculation. Fig. 2. shows the calculated insertion loss for several magnifications. Here, reflection on the end faces was ignored to evaluate the limit of insertion loss caused by the up-taper transition region.

According to the ray tracing, the magnification of 4 would minimize the insertion loss and the loss would to be 0.42 dB. If concerned the fresnel reflection on the end faces, the insertion loss is assumed to be increased by 0.3dB.

The up-tapered multimode fiber whose magnification was 4 was fabricated. A taper transition region was formed by heating and drawing a multimode fiber whose core diameter was 400 µm, clad diameter was 500µm and N.A. was 0.22. A couple of up-tapered multimode fiber was placed with air-gap of 0.5 mm.

4. Results and discussion

The far-field radiation patterns of the up-tapered multimode fiber and a non-tapered multimode fiber are shown in Fig. 3. The radiation patterns are measured with a laser source at λ = 790 nm. The beam divergence angle of up-tapered multimode fiber is 2.6° which is defined as the angle including 63% of total propagated power. In contrast, the beam divergence angle of non-tapered multimode fiber is 10.2°. Ratio of beam divergence between up-tapered fiber and non-tapered fiber is measured to be 1:3.9, which shows excellent agreement with theoretical value (1:4).

Fig. 4. shows the measured and the calculated insertion losses with ray tracing simulation for gap of 0.5 mm with laser sources at λ = 410, 450 and 790 nm. The insertion loss is measured to be 0.9 dB and does not depend on the operating wavelengths.

Because anti-reflective coatings were not applied to the fabricated optical connector, the insertion loss should be increased by 0.3 dB, which arises from reflection on the end faces. Hence, with anti-reflective coating on the end faces, we expect that the insertion loss will fall down to 0.6 dB.

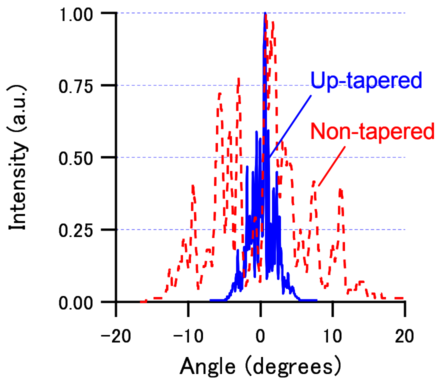

Fig. 3. Far-field radiation pattern of the up-tapered multimode fiber (solid line) and the non-tapered multimode fiber (dashed line) is seen in section.

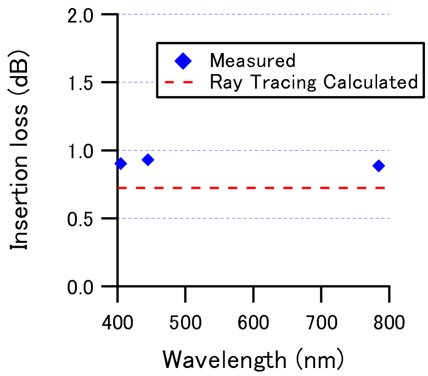

Fig. 4. Comparison of insertion loss for gap of 0.5 mm between measured and calculated by ray tracing.

5. Conclusions

A wavelength insensitive, non-contact and highly efficient fiber optic connector with an insertion loss of 0.9 dB in the range of 410 to 790 nm has been demonstrated.

This fiber optic connector is suitable for laser illumination systems which employ multi-wavelength light sources and require frequent replacement, such as endoscopes that use multi-color laser illumination and optical sensing fiber devices could use this fiber optic connector.

References

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