Side-view Rotational Alignment Method for Trench-assisted 4-core Fibers

Masaki Ohzeki, Yusuke Sasaki, Katsuhiro Takenaga, Kentaro Ichii and Kazuhiko Aikawa
Optical Technologies R&D Center, Fujikura Ltd., 1440, Mutsuzaki, Sakura, Chiba, 285-8550, Japan
E-mail: masaki.ozeki@jp.fujikura.com

Abstract: A trench-assisted 4-core fiber has been successfully aligned in fusion splicing by determining an optimal focus position of a fusion splicer and matching the two fibers at the marker using a side-view rotational alignment method. © 2022 The Author(s)

1. Introduction

Global internet traffic has been increasing year by year with the rapid spread of web conferences and video streaming services. To meet the demand for higher capacity in communication, space division multiplexing (SDM) technologies have been proposed [1]. Among various SDM fibers for high-capacity communication, uncoupled single-mode multicore fibers (MCFs) draw attention because uncoupled MCFs do not require complex multiple-input multiple-output processing.

Recently, uncoupled 4-core fibers with standard 125-μm-cladding (4CFs) have been actively developed toward the standardization. The cladding diameter of 4CFs is the same as standard single-mode fibers (SSMFs) and is compliant with ITU-T Recommendation G.657.A1 [2]. In general, 4CFs have a marker for identifying each core, and thus requires the rotational alignment of the marker as well as cores. A typical rotational alignment method for MCFs, the side-view method, is well-suited to conventional splicers, but recognizing the marker was difficult before [3, 4]. However, a new side-view alignment method, Interrelation Profile Analysis 2 (IPA2), has recently been developed [5]. This method has demonstrated the ability to align step-index 4CFs (SI-4CFs) through the identification of the marker [6]. Moreover, the productivity of SI-4CFs is high because their index profile is simple For these reasons, SI-4CFs have been considered as one of the most promising MCFs for actual use.

On the other hand, inter-core crosstalk of SI-4CFs is relatively high. That increases noise in communication, thus suppressing crosstalk is important especially for long-haul transmission. Trench-assisted 4CFs (TA-4CFs) have been proposed as an MCF that suppresses the crosstalk and has compatibility with existing SSMFs [7]. TA-4CFs have a trench layer around the cores with a refractive index lower than that of the cladding. Although the trench-assisted structure has the great advantage of suppressing crosstalk, it has the disadvantage of making side-view alignment more difficult. TA-4CFs also need to be aligned using the side-view method, through the identification of the marker.

In this paper, it is demonstrated that the use of the IPA2 method allows matching TA-4CFs at the markers and also the side-view alignment by optimizing the focus position of the fusion splicer. This alignment method is practical because it is easy to perform and limits splice loss. It was revealed that the appearance of the markers in the side-view images depends on the focus position by ray tracing simulation. To the best of our knowledge, this is the first report on succeeding in the rotational alignment through the identification of marker of TA-4CFs.

2. IPA profiles of the TA-4CF

To confirm the rotational alignment ability of the IPA2 method for TA-4CFs, IPA profiles were obtained using the method. Figure 1 shows obtained IPA profiles of the left and right TA-4CFs after alignment. An IPA profile is a waveform plotted using the features obtained from the side-view images while fibers make one rotation. Figure 2 shows the cross-sectional image of the TA-4CF we used. The core pitch of the fiber is 40 μm, and the details of the fiber design are given in Refs [7]. A fusion splicer, FSM-100P+, was used in this measurement. As shown in Fig.1, there are two types of peaks that appear alternatively four times during one rotation. The number of the peaks

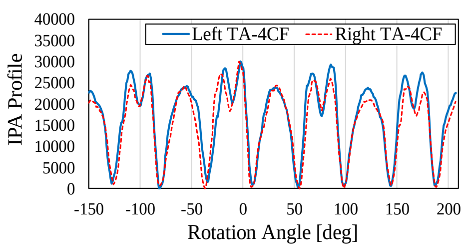

Fig. 1. IPA profiles of TA-4CF after alignment.

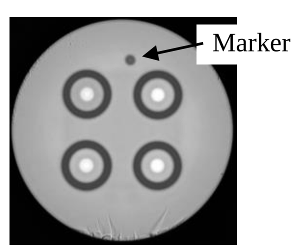

Fig. 2. Cross-sectional image of TA-4CF.

corresponds to the number of the cores of the TA-4CF, so these profiles reflect a periodic structure originating from the cores. However, there are no characteristics originating from the marker. Moreover, all four sets of the peaks are indistinguishable because their shapes are very similar. Therefore, it is difficult to identify the marker and also to distinguish each core of the TA-4CF using a default-set IPA2.

3. Optimal focus position

As can be seen from Fig.2, the marker of the TA-4CF which we used is arranged outer than cores from the cladding center. It indicates that changing the focus position causes changing the irradiance pattern of the marker and trench structures in side-view images, and may result in an asymmetrical IPA profile. Since the marker breaks the symmetry of the TA-4CF, we can assume that obtained IPA profiles include marker information when asymmetric IPA profiles are obtained. Therefore, we evaluated the degree of asymmetry of IPA profiles by changing the focus position and searched for the optimal focus position where the degree of asymmetry is the highest. The higher the degree of asymmetry is, the easier identifying the marker is.

As an indicator of degree of asymmetry, we used the ratio of height of the largest peak to that of the second largest peak (RHLS) gained using the cross-correlation function of the IPA profiles in the left and right fibers. The cross-correlation function takes the maximum value at the angle where the IPA profiles of the left and right fibers best match. Since the TA-4CF has four-fold symmetry, the cross-correlation function has four peaks. The peaks have almost the same height in the highly symmetric IPA profiles, while these peaks have different height in the asymmetric IPA profiles. Hence, if the RHLS is large, the degree of asymmetry of the IPA profiles is large.

Figure 3 shows a plot of the acquired RHLS while the focus position is changed. The default focus position is 1.00, and the IPA profiles obtained at this focus position are highly symmetric because the RHLS is almost 1. This result corresponds to the symmetricity of the profiles in Fig. 1. Figure 3 also shows that the degree of asymmetry of the IPA profiles is maximum at a focus position of 0.56. This means that the optimal focus position is 0.56. The IPA profiles gained at the optimal focus position is shown in Fig. 4.

Figure 4 shows no clear features resulting from the marker in the profiles, and there is only one angle where the profiles of the left and right fibers match because the profiles are asymmetry. In addition, we verified that the marker position of the left and the right fibers after alignment matched using the end-view function of the splicer. Taking that into account, aligning the TA-4CFs seems to be possible by matching the marker at a focus position of 0.56.

Next, we measured splice loss to check whether the TA-4CFs are correctly aligned, with marker being matched, using the IPA2 method at this focus position. Figure 5 shows a histogram of measured splice loss only when the alignment was implemented successfully. The measurement was carried out 12 times for all four cores each at a wavelength of 1310 nm, and the average splice loss was 0.20 dB. We also proved that the markers matched after splicing by checking light continuity between a pair of ports of a fan-in fan-out device. The success rate of alignment was about 80% but still inadequate. Since the peak shape of the gained RHLS shown in Fig. 3 is too steep, RHLS drops if the focus position is slightly off the best one. Thus, more accurate focusing is needed for increasing the success rate. As described above, the rotational alignment of the TA-4CFs with the marker being identified has been achieved by optimizing the focus position.

4. Side-view simulation using ray tracing method

We performed ray tracing simulation to consider the reason why we can align the TA-4CFs with the markers matching when the focus position was set at 0.56. Figures 6 (a) and (b) show the angular dependence of irradiance computed from that of side-view images at focus positions 1.00 and 0.56, respectively, at the center of the TA-4CF. In Figs. 6 (a) and (b), the blue solid lines represent the normalized irradiance computed from entire rays that passed through the fiber, and the red dashed lines show the normalized irradiance computed only from the irradiance of rays that passed through the marker. It means that, the blue solid lines are related to the IPA profiles, and the red dashed ones indicate the degree of inclusion of information derived from the marker.

As shown in Fig. 6 (a), four nearly symmetrical peaks appeared as the solid blue line. On the other hand, the blue

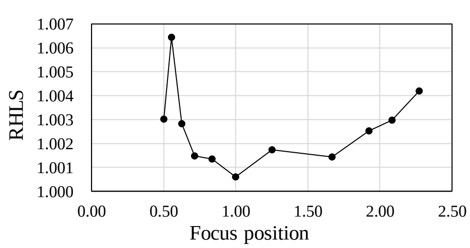

Fig. 3. Focus position dependence of the RHLS.

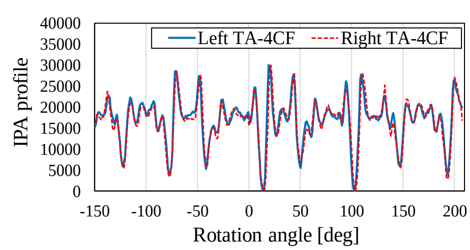

Fig. 4. IPA profiles of the TA-4CF after alignment at focus positon 0.56.

solid line in Fig. 6 (b) is asymmetry and shows a peak between 300 and 330 degrees of the rotation angle which is different in shape from the other three peaks. These results are consistent with the IPA profiles shown in Fig. 1 and Fig. 4. In both focus positions, there are two peaks at rotation angles of 125 and 305 degrees, as shown in Figs. 6 (a) and (b) indicated as the red dashed lines. The peak height at around 125 degrees is larger than that at around 305 degrees in both figures, but the latter peak is more important. The peak between 300 and 330 degrees of the blue solid line in Fig. 6 (b) shows a difference from the other three peaks around 305 degrees, which should contain information about the marker. Consequently, it is expected that side-views at a rotation angle of 305 degrees show difference in marker appearance at focus positions of 1.00 and 0.56.

Figures 7 (a) and (b) show the simulated side-view images excluding the rays that passed through the marker at a rotation angle of 305 degrees at focus positions of 1.00 and 0.56, respectively. Since this simulation used the rays excluding those passed through the marker, a shadow of the marker appeared as a dark line in the side-view images. In Fig. 7 (b), a characteristic dark line appearing near the center, but it does not in Fig. 7 (a). This result indicates that the marker-derived brightness pattern clearly appears in the shadow position of the marker in Fig. 7 (b), but there is no such position in Fig. 7 (a). This is the reason why the marker can be recognized using the IPA2 method by changing the focus position.

5. Conclusion

We conclude that the focus position is a key parameter for side-view alignment with marker recognition of the TA-4CF using the IPA2 method. There was an optimal focus position where the marker was most easily recognized, because changing the focus position changes the appearance of the marker in side-view images. The asymmetrical IPA profiles were obtained at the optimal focus position, and there was a unique alignment angle where the profiles of the left and right fibers match. Finally, rotational alignment with marker matching at that angle is feasible. We believe this method should provide a practical rotational alignment for TA-4CFs. Perhaps this method can be used for other trench-assisted fibers as well.

6. References

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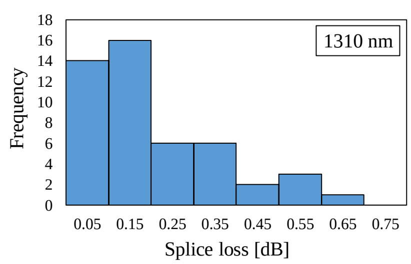

Fig. 5. Splice loss distribution of the TA-4CF using IPA2 method.

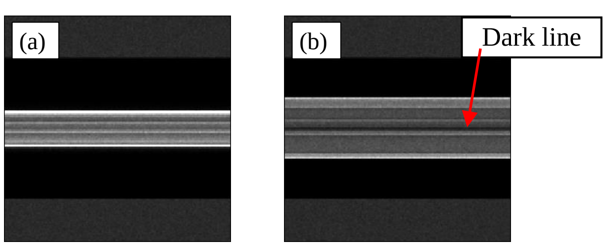

Fig. 7. Simulated side-view images of the TA-4CF using the rays excluding those passed through the marker at
(a) focus position 1.00 and (b) focus position 0.56.

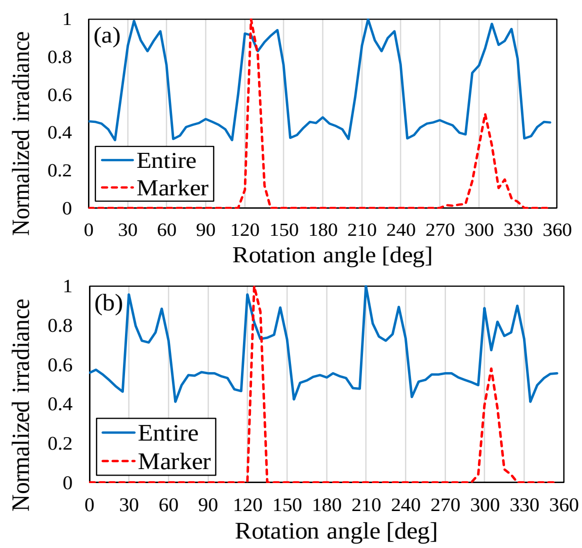

Fig. 6. Simulated irradiance profiles of the TA-4CF at
(a) focus position 1.00 and (b) focus position 0.56.