Optical Performance Evaluation of MT Connector Employing Solid Refractive Index Matching Material for High-Power Optical Transmission

Yukiko Sawano
Access Network Service Systems Laboratories,
NTT Corporation
1-7-1 Hanabatake, Tsukuba, Ibaraki, 305-0805, Japan
yukiko.sawano.bx@hco.ntt.co.jp

Chisato Fukai
Access Network Service Systems Laboratories,
NTT Corporation
1-7-1 Hanabatake, Tsukuba, Ibaraki, 305-0805, Japan
chisato.fukai.pv@hco.ntt.co.jp

Yoshiteru Abe
Access Network Service Systems Laboratories,
NTT Corporation
1-7-1 Hanabatake, Tsukuba, Ibaraki, 305-0805, Japan
yoshiteru.abe.gs@hco.ntt.co.jp

Ryo Koyama
Access Network Service Systems Laboratories,
NTT Corporation
1-7-1 Hanabatake, Tsukuba, Ibaraki, 305-0805, Japan
ryo.koyama.rh@hco.ntt.co.jp

Ikutaro Ogushi
Access Network Service Systems Laboratories,
NTT Corporation
1-7-1 Hanabatake, Tsukuba, Ibaraki, 305-0805, Japan
ikutaro.ogushi.df@hco.ntt.co.jp

Kazunori Katayama
Access Network Service Systems Laboratories,
NTT Corporation
1-7-1 Hanabatake, Tsukuba, Ibaraki, 305-0805, Japan
kazunori.katayama.xt@hco.ntt.co.jp

***Abstract*—We evaluate the high-power durability of multi-fiber optical connectors that use solid refractive index matching material designed to increase the number of fibers in multi-fiber connectors. We measured the temperature and return loss while passing high-power lights through optical fiber connections with gaps of several tens of microns filled with the refractive index matching material. We confirmed that the multi-fiber connector using the solid refractive index matching material did not deteriorate even at powers of 200 mW.**

Keywords*—*optical connector, solid refractive index matching material, MT connector, high-power transmission, return loss, insertion loss

I. Introduction

Optical transmission signal power is increasing to support the expansion of transmission capacity by wavelength division multiplexing, and the future introduction of space-division multiplexing transmission fibers may further increase this power. Fusion splicing or physical contact optical connectors are used at the connection points of optical fibers transmitting high power. It has been reported that physical contact optical connectors have high-power durability [1-3]. MPO connectors are used mainly in data centers and high return loss is provided by angled PC connection. MPO connectors achieve low insertion loss as their design anticipates that the ferrule will slide off axis due to spring pressure when the end faces of the MT ferrules, which are polished at an angle, contact each other. The pressing force of MPO connectors is proportional to the number of connected cores [4, 5]. This trend increases the difficulty of connector design and manufacturing and makes it difficult to control insertion losses. Due to the increase in the number of spliced cores, the total end surface area of the fibers to be spliced increases, making it difficult to ensure the return loss with the physical contact connection. Thus, we proposed a structure in which solid refractive index matching material is formed on the right-angle polished end face as a multi-fiber optical connector that can ensure the desired optical characteristics without the need to increase the pressing force on the ferrule even when the number of spliced cores increases [6]. The gel-type refractive index matching material used in conventional MT connectors makes it difficult to ensure that the end faces of all optical fibers are covered with the refractive index matching material, requiring end face cleaning and reapplication of the gel-type refractive index matching material at each connection and disconnection. Therefore, we decided to form solid refractive index matching material directly on the end face of the MT ferrule. Using the proposed structure, a prototype 84-fiber MT connector and a prototype 84-fiber MPO connector were fabricated. Tests showed that the proposed structure can realize a super multi-fiber optical connector that achieves high return loss with low pressing force of about 10 N [7]. Considering the future expansion of the application field of MPO connectors and the increasing number of cores to be spliced, connectors with solid refractive index matching material may be used for high-power transmission connections. The solid refractive index matching material itself has almost no absorption in the telecommunication wavelength band, however, some axis misalignment and gap between the optical fibers must be expected, and any light that leaks will heat the ferrule and thus the refractive index matching material. Raising the temperature of the refractive index matching material is expected to change its refractive index and thus the return loss value at the fiber connection point. There is reported a case of micron-level gaps between optical fibers filled with gel-type refractive index matching material developing high-power durability [8]. In this study, we formed solid refractive index matching material on the MT ferrules, and high power is transmitted while the MT ferrules were connected. For the first time we report ferrule temperature and return loss when high power is transmitted across the refractive index matching material between optical fibers several tens of microns apart. We also calculated the change in refractive index of the solid refractive index matching material with measured temperature. We obtained the calculated value of return loss variation by using the changed refractive index and the thickness of the solid refractive index matching material.

II. MULTI-FIBER CONNECTION USING SOLID REFRACTIVE INDEX MATCHING MATERIAL

Fig. 1 shows a schematic diagram of an MT ferrule with a layer of solid refractive index matching material formed on the end face of the connector. A layer of solid refractive index matching material is formed on the right-angle polished MT ferrule end face to cover the end faces of the optical fibers. When refractive index matching material is interposed between optical fiber splices, insertion loss and return loss depend mainly on the thickness of the solid refractive index matching material. Fig. 2 plots the calculated insertion loss and return loss versus the thickness of the refractive index matching material between the fiber cores to be spliced; these calculations used the splicing model and formulas presented in [9, 10]. The refractive index of the solid refractive index matching material was taken to be 1.448, the same as the solid refractive index matching material used in this experiment. As the solid refractive index matching material becomes thicker, the insertion loss increases. The minimum return loss is determined by the refractive index of the refractive index matching material and is sensitive to changes in thickness. Fig. 3 shows the procedure for forming the layer of solid refractive index matching material on an MT ferrule. First, the MT ferrule is fixed in a holding jig and a drop of liquid refractive index matching material is placed on the MT ferrule end face. Next, a spacer is placed so as to cover the guide holes of the MT ferrule. A glass plate is then pressed on top of the spacer and irradiated with UV light. When the refractive index matching material is cured, the thickness of the spacer becomes the thickness of the solid refractive index matching material. Finally, the spacer and glass plate are removed from the jig, leaving the MT ferrule with the solid refractive index matching material. Fig. 4 shows an external view of an MT ferrule with solid refractive index matching material so formed. Note that the two guide holes remain open. The film thickness is controlled by the thickness of the spacer. As shown in Fig. 2, thinner film thicknesses are desirable to reduce insertion loss. However, in order to obtain high return loss at all cores, uniformity of the layer thickness is important, and for 84-fiber level connectors, the film thickness should be about 50 µm [7]. Therefore, the layer thickness of the sample used in this high-power transmission experiment was set at about 50 µm. For comparison, three samples with a layer thickness of about 30 µm was also fabricated and evaluated.

III. EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 5. MT ferrules formed with solid refractive index matching material were assembled as the MT connector and high-power light was transmitted and return loss and temperature were measured. The OCWR (Optical Continuous Wave Reflectometer) measurement method of IEC 61300-3-6 was used to measure the return loss. In this method, the coupler branching ratio is set so that high-power light is input to the Device Under Test (DUT), while the optical power meter receives less than the allowable power to measure return loss. High-power light was generated by a Raman fiber laser (light source S_1) with a wavelength of 1.455 µm. The high-power light was input to the DUT via the coupler with a splitting ratio of about 99:1. The returned light was received by two optical power detectors (D_1, D_2). In this study, the output power of the laser was set to 200 mW, following the value of the signal optical power in a recent wavelength division multiplexing

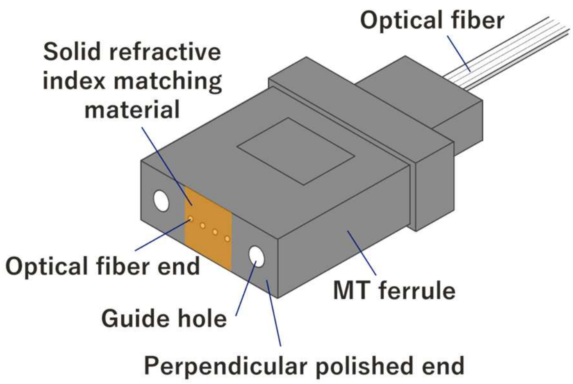

Fig. 1. MT connector structure with solid refractive index matching material

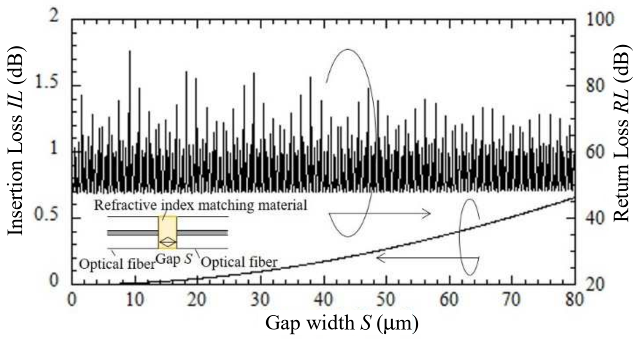

Fig. 2. Calculation results

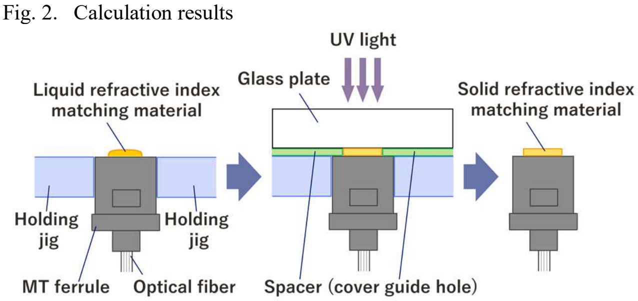

Fig. 3. Forming method

Fig. 4. Photograph of MT ferrule end Forming method

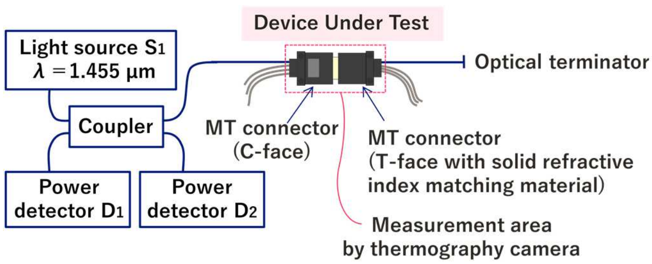

Fig. 5. Experimental setup

transmission experiment [11]. The DUT is a single-mode 4-fiber MT connector with solid refractive index matching material formed on the end face of the MT ferrule at the termination side (T-face) and not on the end face of the MT ferrule at the coupler side (C-face). When light is transmitted from the C-face to the T-face, the ferrule on the T-face side is considered to be more strongly affected by light leakage due to axial misalignment. The MT ferrule was used as an MT connector with guide pins and a clamp spring. High-power light was input and return loss was measured. Other than the MT connector all optical fibers were spliced by fusion splicing. In these measurements, high-power light was input to only one of the four fibers (Port 1) as the first step in high-power transmission experiments of solid refractive index matching material.

The area delineated by the red box in Fig. 5 was photographed with an infrared thermography camera, and the surface temperature of the MT connector was also measured.

Two layer thicknesses of the solid refractive matching material were tested: about 50 μm and about 30 μm. After measuring the return loss and temperature during high-power optical transmission using the 50 μm configuration, the 50 μm layer was removed and a 30 μm layer of solid refractive index matching material was formed on the same MT ferrule, and the return loss and temperature during high-power optical transmission were again measured. As the same ferrule was reused, any difference in the measured results is assumed to be due to the difference in the thickness of the layer.

IV. Result and Discussion

Three MT connector samples A, B, and C were evaluated. Table 1 shows the layer thickness, experimental and calculated results for each sample. Layer thickness was measured by laser microscopy. The results from sample A with layer thicknesses of about 50 μm and about 30 μm are identified by labels A-50, and A-30, respectively. The same is true for samples B and C. Insertion loss and return loss were measured for each connector sample; Table 1 lists them as "Initial_IL" and "Initial_RL" as the value before high-power optical transmission and "Last_IL" and "Last_RL" as the value after that respectively. Return loss before and after the experiment was measured by the OLCR (Optical Low Coherence Reflectometer) method. The insertion loss of the connector samples increased with layer thickness, which is consistent with the calculation results shown in Fig. 2. High-power injection experiments were performed after ensuring that high return loss was achieved for all samples. In Fig. 6 the maximum temperature (diamond markers, left axis) of the MT connector observed by thermography after turning on the Raman fiber laser and the time variation of return loss (square markers, right axis) measured by the OCWR method are shown. Fig. 6 plots the results of C-50. It can be seen that the return loss gradually decreases as the temperature increases. Return loss and temperature were measured until saturation was reached in both by judging from the amount of change in RL and reaching a steady state of heat distribution. The change value of temperature and RL shown in Fig. 6 were obtained for all samples, and the maximum change in temperature and return loss is summarized in Table 1 as a result. The change in temperature is shown as "Temp_change" and the change in the return loss as "RL_change".

Fig. 7 shows a typical thermal image of an MT connector during high-power light input from C-face to T-face and the maximum temperature point as the white dot. The temperature variation result ("Temp_change" in Table 1) indicates the amount of change from the temperature before light input to the maximum temperature during light input. We can confirm that the T-face MT ferrule became hotter than the C-face ferrule. It is thought that this is because the leakage light generated by the misalignment between the optical fibers irradiated the end face of the T-face ferrule, was absorbed by the ferrule material, and turned into heat. This may have heated the solid refractive index matching material, resulting in a change in its refractive index and consequently a change in return loss. The change in the refractive index of the solid refractive index matching material with respect to temperature is about −0.0004/°C. Similar to the calculations shown in Fig. 2, the return loss was calculated following the

TABLE I. Results

Sample	A-50	A-30	B-50	B-30	C-50	C-30
Thickness (μm)	46.973	24.748	45.997	25.723	41.761	26.090
RL_change (dB)	-3.981	-1.762	-3.160	-0.670	-1.761	-6.022
Temp_change (°C)	5.6	4.6	4.4	1.3	3.2	2.5
Calculated_ RL_ change (dB)	-4.4	-1.0	-3.4	-0.4	-1.0	-4.8
Initial_IL (dB)	0.57	0.28	0.64	0.38	0.74	0.27
Last_IL (dB)	0.59	0.31	0.55	0.56	0.62	0.18
Initical_RL (dB)	58.53	59.69	66.20	54.47	60.87	67.54
Last_RL (dB)	59.43	54.67	53.59	53.50	61.73	59.32

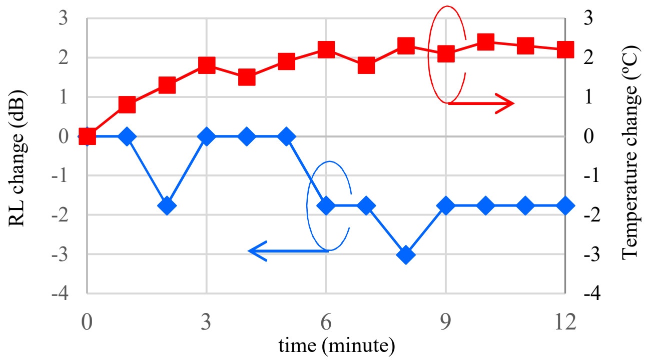

Fig. 6. Change in Temperature and RL of sample C-50

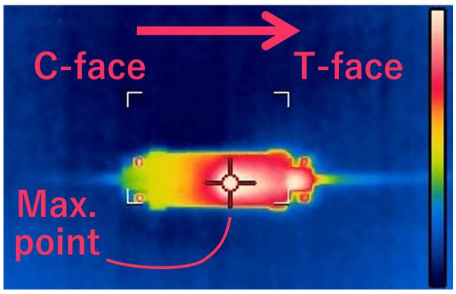

Fig. 7. Image of temperature distribution

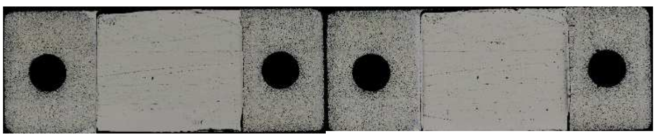

Fig. 8. Sample A-50 end face photograph (Left: before high-power light transmission, Right: After high-power light transmission)

splicing model in [9, 10] by using the observed temperature change in the refractive index of the solid refractive index matching material and the layer thickness of each sample. Table 1 shows the calculated change in return loss when the refractive index at room temperature was replaced by refractive index at high-power optical transmission. The calculated changes in return loss when the temperature changed are similar to the experimental values for both layer thickness (red area cells in Table 1), suggesting that the change in return loss in the experiment is due to the temperature response of the refractive index. All samples showed a decrease in return loss during high-power transmission, but the return loss remained sufficiently high during high-power transmission even if it was reduced by the change in the return loss measured before the high-power injection. The insertion loss and return loss measured after the power transmission experiment was completed are also shown in Table 1. In this case, a high power of 200 mW was injected, but there was no noticeable degradation in optical properties. Fig. 8 shows photographs of MT ferrule end faces with solid refractive index matching material, taken before and after the high-power transmission experiment. No physical changes such as peeling of the solid refractive index matching material due to the effects of the heat experienced during high-power transmission were observed.

V. Conclusion

In this study, we evaluated the temperature and return loss of an MT connector with solid refractive index matching material formed on the end face of the MT ferrule when carrying 200 mW high-power light. It was confirmed by measurements and calculations that axial misalignment of the connecting optical fibers allows light to leak which heats the MT ferrule. This temperature rise changes the refractive index of the solid refractive index matching material, which slightly decreases the return loss of the connection. The decrease is not a critical issue. There was no degradation in the optical characteristics between before and after high-power transmission. In the future, we plan to evaluate the characteristics when higher power is applied and to verify the characteristics when high power is applied to multiple fibers simultaneously.

References

[1] M. de Rosa, J. Carberry, V. Bhagavatula, K. Wagner and C. Saravanos, “High-power performance of single-mode fiber-optic connectors,” J. Lightw. Technol., vol. 20, no. 5, pp. 879 – 885, 2002.

[2] S. Yanagi, S. Asakawa, R. Nagase, “Characteristics of fibre-optic connector at high-power optical incidence,” Electron. Lett. vol. 38, no. 17, pp. 977 – 978, August 2002.

[3] C. Fukai, M. Kihara, R. Nagase, K. Saito, Y. Abe, T. Kurashima, K. Katayama, “Investigation Into the Influence of High-Power Optical Transmission on Fiber Withdrawal From Optical Connector,” J. Lightw. Technol., vol. 38, no. 18, pp. 5128–5135, 2020.

[4] IEC 61754-7-1: Fibre optic interconnecting devices and passive components – Fibre optic connector interfaces –Part 7-1: Type MPO connector family – One fibre row, 2014.

[5] IEC 61754-7-2: Fibre optic interconnecting devices and passive components – Fibre optic connector interfaces –Part 7-2: Type MPO connector family – Two fibre rows, 2017.

[6] Y. Abe, R. Koyama and K. Katayama, “Multi-fiber connection technique employing solid refractive index matching material,” in Proc. 26th Opto-Electron. Commun. Conf., 2021, pp. 1–3.

[7] Y. Abe, R. Koyama and K. Katayama, “84-fiber MPO connector employing solid refractive index matching material formed on perpendicular polished MT ferrule end,” in Proc. Optical Fiber Communications Conference and Exhibition, 2022, pp. 1–3.

[8] K. Hogari, K. Kurokawa and I. Sankawa, “Influence of High-Optical Power Light Launched Into Optical Fibers in MT Connector,” J. Lightw. Technol.. vol. 21, no. 12, pp. 3344–3348, 2003.

[9] M. Kihara, M. Uchino, M. Omachi and H. Watanabe, “Investigation into optical performance of fiber connections with imperfect physical contact,” J. Lightw. Technol., vol. 31, no. 6, pp. 967–974, 2013.

[10] M. Kihara and H. Watanabe, “Corrections to “Investigation into optical performance of fiber connections with imperfect physical contact,” J. Lightw. Technol., vol. 34, no. 15, pp. 3592–3595, 2016.

[11] A. Arnould, A. Ghazisaeidi, D. Le Gac, P. Brindel, M. Makhsiyan, K. Mekhazni, F. Blache, N. Fontaine, D. Neilson, R. Ryf, H. Chen, M. Achouche, and J. Renaudier, “103 nm ultra-wideband hybrid Raman/SOA transmission over 3 × 100 km SSMF,” J. Lightw. Technol., vol. 38, no. 2, pp. 504–508, 2020.