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Recommendation

ITU-T L.312 (01/2024)

SERIES L: Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant

Maintenance and operation – Optical fibre cable maintenance

Optical fibre cable maintenance support, monitoring and testing system for optical fibre cable networks carrying high total optical power

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Recommendation ITU-T L.312

Optical fibre cable maintenance support, monitoring and testing system for optical fibre cable networks carrying high total optical power

Summary

Recommendation ITU-T L.312 describes the functional requirements for optical fibre cable maintenance systems for optical fibre cables carrying high total optical power. It also considers safety procedures and guidelines for the maintenance of outside optical fibre plants carrying high total optical power.

History[*]

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Keywords

Cable maintenance system, high total optical power, safety procedures and guidelines.

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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Recommendation ITU-T L.312

Optical fibre cable maintenance support, monitoring and testing system for optical fibre cable networks carrying high total optical power

1 Scope

This Recommendation describes the functional requirements of optical fibre cable maintenance systems for optical fibre cables carrying high total optical power. It applies to test equipment, optical switches for selecting fibre under test, test access modules for connecting test equipment to the communication line, testing optical fibre cords and optical connecting devices that are part of the maintenance system. It also considers safety procedures and guidelines for the maintenance of outside optical fibre plants carrying high total optical power.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.652] Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.664] Recommendation ITU-T G.664 (2012), *Optical safety procedures and requirements for optical transport systems*.

[ITU-T L.202] Recommendation ITU-T L.202/L.50 (2010), *Requirements for passive optical nodes: Optical distribution frames for central office environments*.

[ITU-T L.250] Recommendation ITU-T L.250 (2024), *Topologies for optical access network*.

[ITU-T L.300] Recommendation ITU-T L.300/L.25 (2015), *Optical fibre cable network maintenance*.

[ITU-T L.301] Recommendation ITU-T L.301/L.41 (2000), *Maintenance wavelength on fibres carrying signals*.

[ITU-T L.302] Recommendation ITU-T L.302/L.40 (2000), *Optical fibre outside plant maintenance support, monitoring and testing system*.

[ITU-T L.310] Recommendation ITU-T L.310 (2016), *Optical fibre maintenance depending on topologies of access networks.*

[IEC 60825-1] IEC 60825-1 (2014), *Safety of laser products – Part 1: Equipment classification and requirements*.

[IEC 60825-2] IEC 60825-2 (2021), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*.

3 Definitions

3.1 Terms defined elsewhere

For the purposes of this Recommendation, the definitions given in [ITU-T G.652], [ITU-T G.664], [ITU-T L.202], [ITU-T L.250], [ITU-T L.300], [ITU-T L.301], [ITU-T L.302], and [ITU-T L.310] are applied.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

APC	Angled Physical Contact
DRA	Distributed Raman Amplification
EDFA	Erbium-Doped Fibre Amplifier
FTTB	Fibre To The Building
FTTC	Fibre To The Curb
FTTH	Fibre To The Home
FTTx	Fibre to the x (where "x" indicates the final location on the user side of any one of a variety of optical fibre architectures, e.g., FTTH, FTTB, FTTC)
ODF	Optical Distribution Frame
OPM	Optical Power Meter
OTDR	Optical Time Domain Reflectometer
WDM	Wavelength Division Multiplexing

5 Conventions

None.

6 Fundamental requirements

This clause presents fundamental requirements for optical fibre cable maintenance systems for optical fibre cable carrying high total optical power. When high-power light is launched into an optical fibre cable maintenance system, the fibre-optic components in the system may be damaged in such a way that they no longer meet their specifications (e.g., optical loss). Generally, the term "high-power radiation" is used to refer to optical powers of several hundred milliwatts.

The fundamental requirements of an optical fibre cable maintenance system for optical fibre cable carrying a high total optical power are as follows:

– It must be safe for network operators when handling optical cables, cords and fibre-optic components given the possibility of high total optical power radiation. Network operator safety must be in accordance with [ITU-T G.664], [IEC 60825-1] and [IEC 60825-2].

– It should provide the functions of surveillance, testing and control listed in [ITU-T L.302] to meet the specifications for optical fibres or fibre-optic components in a high-power operating condition.

7 System requirements

This clause presents system requirements for optical fibre cable maintenance systems for optical fibre cable carrying high total optical power. There are two safety issues as regards optical fibre cable carrying high total optical power. One is human safety, and this problem relates to the exposure of eyes or skin to high-power radiation. The other is component safety. As there are several fibre-optic components in optical fibre cable maintenance systems, when the components have a larger optical loss than usual, this may pose an overheating and fire-hazard in a worst case scenario.

It is important for optical fibre cable maintenance systems to be able to detect faults in optical fibre cable networks, because this makes it possible for network operators of physical plant to avoid dangerous situations. There are several ways to implement maintenance functions such as for example optical time domain reflectometer (OTDR) testing of optical fibre cable, optical loss testing and the optical power monitoring of optical signal or pump power using an optical power meter (OPM). Therefore, optical fibre cable maintenance systems must have optical branching devices for test light insertion (e.g., optical couplers).

Table 7-1 shows the functions in optical fibre cable maintenance systems for optical fibre cable carrying high optical power. The table includes the system requirements for high-power light input and the methods employed to achieve them.

Table 7-1 – Functions in optical fibre cable maintenance systems

Functions	System requirements for high-power light input	Methods
Connection	No fibre fuse or intense temperature increase	Use of fusion splices instead of optical connectors which require polishing and cleaning of connector endfaces.
Termination	No tight optical fibre bends	Minimum bending radius $R \geq 30$ mm for testing optical fibre cords in optical distribution frame (ODF), however fibres with improved bending capability will allow more severe operating conditions.
Testing access for optical fibre line	No fibre fuse or intense temperature increase	Use of fusion splices. Use optical branching components with high tolerance to high optical power exposure.
Optical switch with butt-joint splice connection mechanism (e.g., fibre selector)	No intense temperature increase or optical loss increase	Attenuation of high-power light or gap between fibres at butt-joint splice $d < 10$ μm.

7.1 Connection for optical fibre cable carrying high total optical power

In terms of preventing a "fibre fuse", it is recommended not to use connectors especially near the output of a high-power optical source. Instead, fusion splices should be employed for the optical connection of an optical fibre line that carries a high total optical power. Materials that do not easily induce a temperature increase are recommended as the sleeves for fusion splices with a view to avoid overheating and fire hazards.

If connectors must be used for the optical connection of optical fibre cable carrying a high total optical power, the connector endfaces should be carefully cleaned and polished. Reflection and fibre endface inspection near the output of high-power source should be carried out, and special connectors may be needed, such as connectors with angled physical contact (APC) fibre endface.

7.2 Termination for optical fibre cable carrying high total optical power

7.2.1 Optical fibre cord for testing

The minimum bending radius of testing optical fibre cords in an optical distribution frame (ODF) in a central office should be 30 mm in accordance with [ITU-T L.202]. If a minimum bending radius of at least 30 mm is maintained for general single mode fibres, such as for example those defined in [ITU-T G.652], there will be no damage to the optical fibre cord of the maintenance system for optical fibre carrying a high total optical power. The susceptibility to damage depends on the coating and jacket material, the macro-bending loss, the energy conversion to local heating, the input power levels and the operating wavelengths. However, fibres with improved bending capability will allow the use of more severe operating conditions. The bend sensitivity of single mode fibres used in optical fibre cords to high-power damage can be evaluated by following the guidelines provided in [b-IEC TR 62547].

7.2.2 Optical fibre handling

Because network operators have to handle optical fibre cords when installing or performing maintenance on an optical fibre cable maintenance system, they must carefully handle optical fibre cable or cord that carries a high total optical power. Of course, the handling work should be carried out without tightly bending the optical fibre.

7.3 Testing access modules for optical fibre carrying high total optical power

Components that provide testing access have an optical connection point between optical fibre lines for test light insertion, so it is recommended to use a fusion splice for this connection point. It is desirable that the optical components for inserting test lights (e.g., optical coupler) have high tolerance to high optical powers.

7.4 Optical switch for optical fibre cable carrying high total optical power

An optical fibre cable maintenance system generally has optical switches for selecting the fibre under test. The conventional optical switch has a butt-joint splice connection mechanism with refractive index matching material, even if the maintenance systems accommodate an optical fibre line carrying a high total optical power. Regarding the optical switch with the butt-joint splice connection mechanism, any high-power light launched into the optical switch should be attenuated to a safe level. This is because the optical loss in the butt-joint splice connection, which has a large gap and refractive index matching material, increases greatly and the temperature also increases when a light of 200 mW or more is input. Therefore, it is desirable for the gap, d, between fibres at a butt-joint splice to be less than 10 μm if the butt-joint connection mechanism is used in the maintenance system. However, if switches based on some other connection technology are used, some higher optical powers might be allowed.

8 Testing and maintenance procedure

An auto-shutdown function is an effective way to prevent damage caused by accidents. The functions related to auto-shutdown should take account of [ITU-T G.664]. Optical fibre cable maintenance systems carrying a high total optical power or optical fibre communication systems should have an auto-shutdown function for the sake of safety. Testing and maintenance should be undertaken in optical fibre cable maintenance systems after the auto-shutdown function has operated.

The following fundamental procedures for testing and maintenance in optical fibre cable maintenance systems should be carried out.

- (1) power monitoring using low power test lights should be performed in central offices.
- (2) reflection test and fibre end inspection should be carried out to check the endface near the output of a high-power optical source.

- (3) after confirming that there are no large loss points in the optical fibre cable networks, low-power optical loss testing or OTDR testing should be carried out to detect fault locations.
- (4) optical loss testing or OTDR testing using a high optical power should be performed.

Appendix I

Catastrophic damage and destructive process induced in optical fibre cord by high-power pump light

(This appendix does not form an integral part of this Recommendation.)

I.1 Introduction

The demand for greater transmission capacity is growing rapidly as a result of the increase in the number of broadband multimedia services provided by the Internet. Wavelength division multiplexing (WDM) technology is a promising way of meeting this demand and is now being actively developed. Distributed Raman amplification (DRA) and remotely pumped erbium-doped fibre amplifier (EDFA) technologies have been applied to WDM systems as one way of extending the WDM channel wavelength range. When DRA is applied to WDM systems, high-power lights are launched into optical fibres and devices.

When the optical power increases, safety engineering needs to be undertaken to eliminate the potential hazards induced by high optical power in typical optical systems [b-Ogushi]. Account must also be taken of the fibre fuse phenomenon [b-Kashyap] and [b-Shuto], the high power performance of single-mode connectors [b-Rosa], and the reliability of optical fibre [b-Kurokawa] and [b-Percival]. Since the light with the highest optical power is transmitted into the optical fibre distribution system in a central office, which employs thin optical fibre cords [b-Hayano] and [b-Tachikura], the effect that this high optical power has on these cords must be clarified. Catastrophic damage has been reported in bent optical fibre [b-Percival].

This appendix describes investigations into the damage and destructive process induced in 1.1-mm and 1.7-mm optical fibre cords [b-Hayano] and [b-Tachikura] with a 33 dBm pump light in the 1480 nm band in WDM systems.

I.2 Experiments exposing optical fibre cords to high-power

Figure I.1 shows the experimental set-up used for exposing optical fibre cord to high power. The high-power optical sources were operated at a wavelength of 1480 nm, and the maximum power was 2 W. The diameters of the tested optical fibre cords, which were made of conventional single-mode fibre (SMF) and a tight buffer, were 1.1 mm and 1.7 mm, and the fibres were covered with 0.5 mm and 0.9 mm jackets, respectively. The damage caused to the optical fibre cords under high-power light input conditions was investigated. The powers launched into the fibre cords under test were 24, 27, 30, 31.7 and 33 dBm for 30 minutes. The diameters of the bent cords were 10 mm, and there were 10 bending loops. The temperature change and distribution of the test fibre cords were measured with infrared thermography.

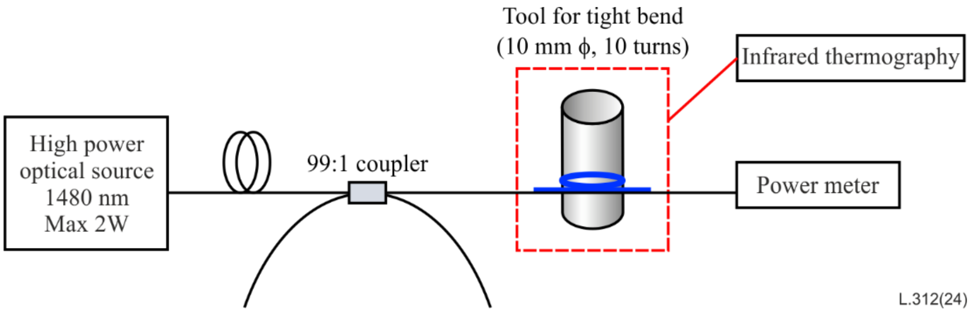


Figure I.1 – Experimental set-up

Figure I.2-a is a diagram of the bent optical fibre cord used for the test and the measured temperature distribution at an input power of 33 dBm measured by infrared thermography. Figure I.2-b shows that there was a clear temperature increase in the front turns caused by the leaked power of the 1480 nm light.

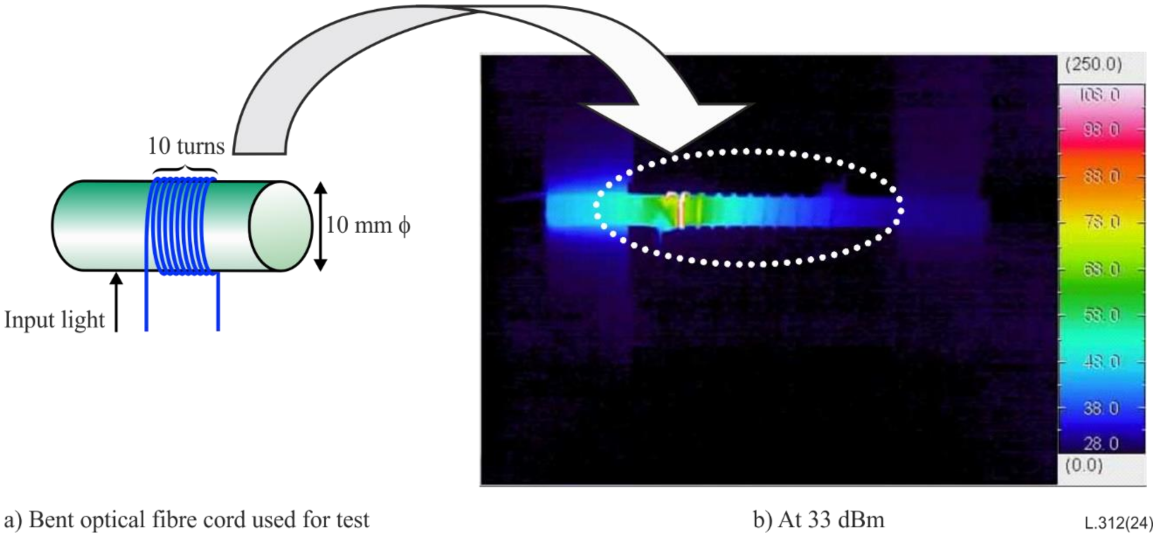


Figure I.2 – Temperature distribution induced by high-power light launched into optical fibre cord

Figure I.3 shows the measured temperature change induced in the 1.1 mm and 1.7 mm optical fibre cords with high-power light at a wavelength of 1480 nm. Figure I.3 shows the dependence of the characteristics on the input power. The temperature of the optical fibre cords increased simultaneously in accordance with the input power change. After this test at 33 dBm, the loss of the optical cords did not recover their initial loss. This is because the temperature increase caused catastrophic damage to the front few turns.

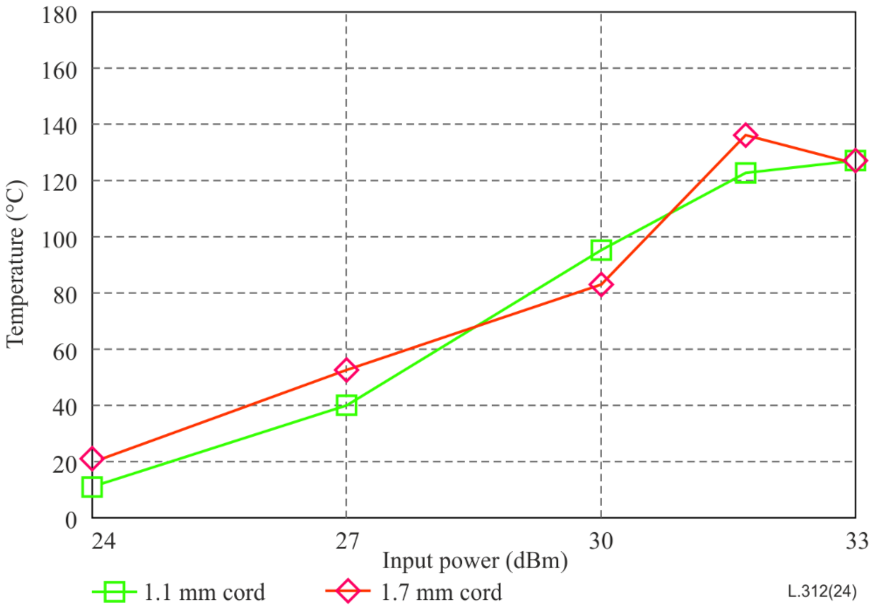
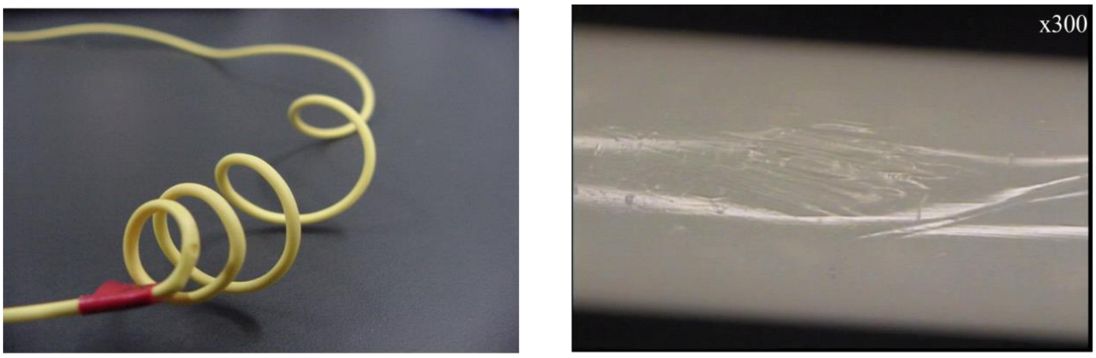


Figure I.3 – Measured temperature data of high-power light launched into optical fibre cord

I.3 Destructive process

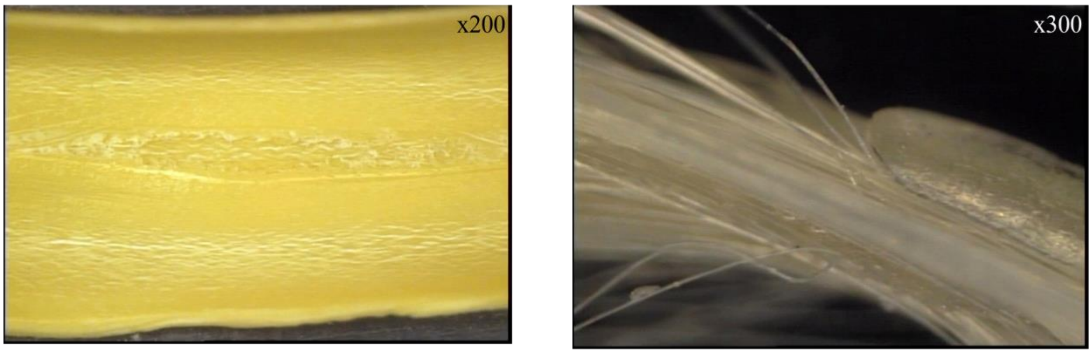
Figure I.4-a shows a photograph of a 1.7 mm diameter optical fibre cord damaged by a high-power light of 33 dBm. Figure I.4-b shows a typical damaged surface of the 0.9 mm primary fibre cording of a 1.7 mm cord and Figure I.4-c shows the inside surface of the fibre cord sheath. The catastrophic damage to the 1.7 mm cord was the melting of part of the 0.9 mm primary cording. A 1.1 mm diameter cord was also examined.

Figure I.4-d is a photograph of the damage to the 1.1 mm cord. The photograph shows that air bubbles exploded between the fibre and the primary cording as a result of the temperature increase.



a) Damaged optical fibre cord

b) Damaged 0.9 mm primary fibre cording



c) Inside surface of fibre cord sheath

d) Damaged 0.5 mm primary fibre cording

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Figure I.4 – Photographs of damaged optical fibre cord

I.4 Conclusion

The subject of this study was the damage and destructive process induced in optical fibre cord under high-power conditions in WDM systems. This work contributes to the design of optical cords for WDM systems that operate with high-power light.

The study in this appendix has found that tight bends can damage the fibre cord. This indicated that the condition when terminating the indoor cable and outside cable in the ODF must be considered. Since the typical optical fibre maintenance system is accommodated in the ODF, the condition of the test access module which connects to the indoor cable and the outside cable should also be considered.

Appendix II

Ignition induced by a high-power light input at a butt-joint splice with refractive index matching material

(This appendix does not form an integral part of this Recommendation.)

II.1 Introduction

Recently, the optical power in optical communication systems has been increasing rapidly through the use of wavelength division multiplexing (WDM) or distributed Raman amplification (DRA) technologies. When DRA technology is applied to WDM systems, a high-power light is launched into optical fibres and devices. The intensity of that optical power reaches several watts, and so it is important to know how optical fibres and devices behave under such high-power light input conditions.

In high-power systems, safety engineering must be undertaken to eliminate the potential hazards that the optical power may induce. Account must also be taken of the various problems caused by high-power light. These problems include the fibre fuse phenomenon [b-Kashyap], the high-power performance of single-mode connectors [b-Rosa], the influence of a high-power light launched into optical fibres in an MT connector [b-Hogari], the reliability of optical fibre [b-Kurokawa] and [b-Percival] and the destruction process of optical fibre cords [b-Ogushi]. Since the light with the highest optical power is launched into the optical fibre distribution systems in a central office, the effect that it has on the optical fibre devices in these systems must be clarified. The devices are fibre selectors, which are installed in fibre line testing systems, or MT connectors, which are employed in connection splices. These devices have a butt-joint splice connection mechanism, which often has a function for reducing Fresnel reflection and suppressing optical connection loss by using refractive index matching material [b-Melliar-Smith] and [b-Kihara], for example, silicone oil, silicone resin, or glycerine. However, there have been no reports on the influence of a high-power light launched into a butt-joint splice with refractive index matching material.

This appendix describes how a high-power light was launched into a butt-joint splice with refractive index matching material and evaluated the robustness of the splice. In addition, we observed some form of ignition induced by the high-power light input.

II.2 Experiments on high-power light at a butt-joint splice

Figure II.1 shows our experimental set-up for exposing a butt-joint splice connection to high-power light.

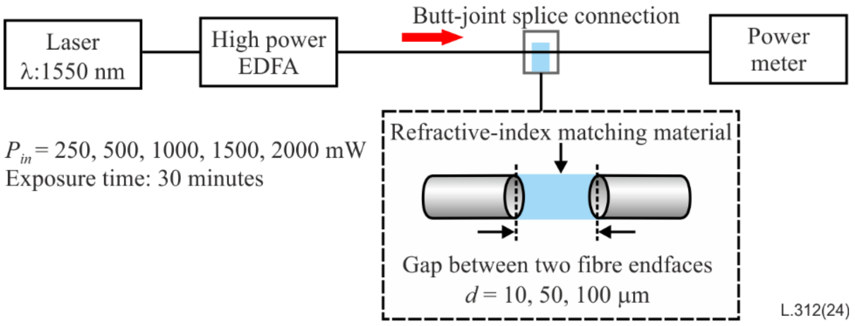
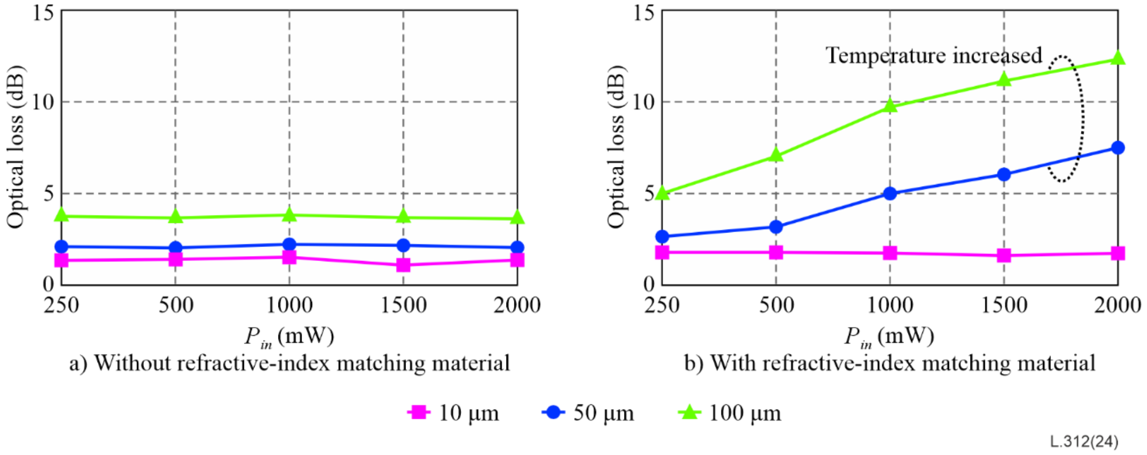


Figure II.1 – Experimental set-up

A laser was used operating at a wavelength of 1.55 µm and in the CW mode and an EDFA as the high-power optical source. A V-groove was used to connect the fibres. The gaps (*d*) between the two fibre endfaces on the V-groove were 10, 50 and 100 µm. With the exception of the butt-joint splice connection, fusion splices were employed for all the splice connections to avoid a fibre fuse and to reduce connection loss. The optical powers launched into the butt-joint splice connections under test (P_{in}) were 250, 500, 1000, 1500 and 2000 mW. The exposure time was 30 minutes. The optical loss changes were measured with and without refractive index matching material. A refractive index matching material that is commonly used in fibre selectors and MT connectors was employed.

Figure II.2 shows the measured loss induced in the butt-joint splice a) with and b) without refractive index matching material. In Figure II.2-a, it is found that the optical losses depend on d, and are independent of the input power P_{in}. Figure II.2-b shows that the optical losses at the butt-joint splice with refractive index matching material increase as a function of input power P_{in} at $d = 50$ and 100 µm. The optical loss values were larger than those calculated using the conventional formula for optical connection loss [b-Marcuse]. The temperature of the refractive index matching material rose as the optical loss increased. It was found that the optical loss and temperature change at $d = 10$ µm were negligible and independent of the input power P_{in}.

The refractive index of the refractive index matching material depends on temperature because its molar refractivity is temperature-dependent and the thermal coefficient of its refractive index ($\Delta n/\Delta T$) is negative [b-Kihara]. It is thought that the distribution profile of the refractive index of the refractive index matching material changes in addition to $\Delta n/\Delta T$. As a result of this change in the distribution profile of the refractive index, the mode-field diameter of the light propagating in the refractive index matching material changes, and the optical loss increases when the gap between the two fibre endfaces is large and with a high-power light input.



a) Without refractive-index matching material

b) With refractive-index matching material

Figure II.2 – Measured optical loss of high-power light launched into butt-joint splice

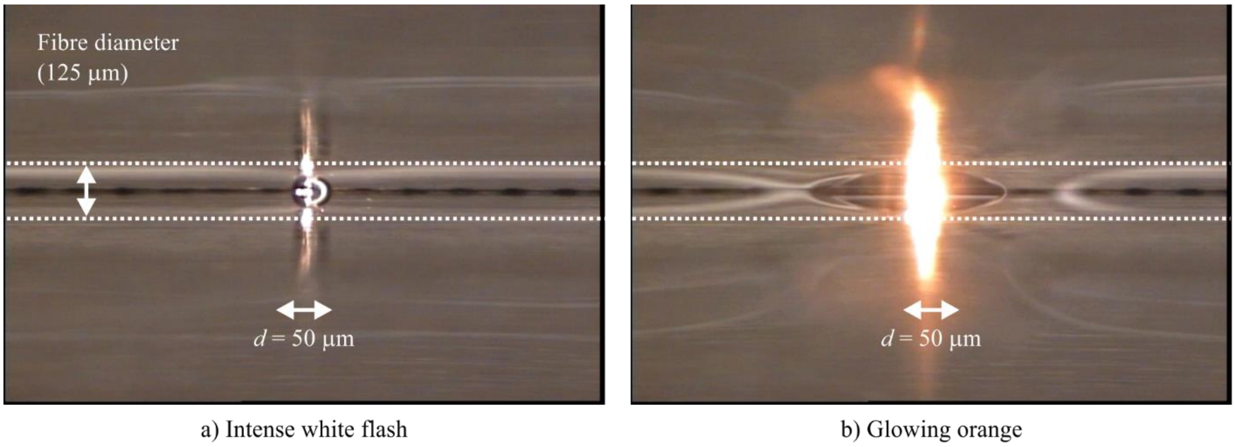
II.3 Observation of ignition caused by high-power light input

In these experiments, a phenomenon that induced catastrophic damage at the butt-joint splice connection part was observed. A tiny air bubble accidentally appeared between the fibres in the refractive index matching material when a high-power light exposure test was performed. This phenomenon immediately induced an extremely large increase in optical loss. Therefore, this phenomenon was investigated by deliberately generating air bubbles between fibres in refractive index matching material, and testing them at $d = 50$ µm and $P_{in} = 2000$ mW. A CCD microscope was prepared to record a video image when a high-power light was launched into the splice. It was observed that an ignition occurred at the butt-joint splice after a few minutes.

Figure II.3 shows photographs of the ignition taken from our video. First, there were several flashes in the refractive index matching material that included the air bubble. After a few seconds, an intense white flash was seen near the fibre core, as shown in Figure II.3-a, and the luminescence changed from white to orange. The orange flashing continued stably for about 70 seconds. It subsequently glowed bright orange as seen in Figure II.3-b, and the orange flashing continued stably until the optical input was stopped. As soon as the optical input was turned off, the flashing ceased.

It was found found that a black residue was attached to the fibre after the ignition had occurred, and that the silica glass of the tested fibre was not fused in this experiment. A componential analysis of this residue was carried out, and Si, O and C were detected. The refractive index matching material used was silicone oil [b-Ito], which contained these elements. It was considered that the quality of the silicone oil changed, and that it generated the black residue.

A high-power light exposure test was performed at the butt-joint splice with refractive index matching material and without either an air bubble or refractive index matching material at P_{in} = 1000, 1500 and 2000 mW, and d = 10, 50, 100 µm. No ignition was observed.



a) Intense white flash

b) Glowing orange

Figure II.3 – Photographs of the video of ignition at the butt-joint splice with refractive index matching material

The silicone oils are poly dimethylsiloxane, with the general formula $[-(CH_3)_2SiO-]_n$. These silicone oils are generally highly resistant to thermal oxidation because the bond energy of a siloxane bond [-Si-O-] is very large. In these experiments, methylphenyl silicone oil was employed as the refractive index matching material. Phenyl groups $[C_6H_5-]$ are introduced into some of the side chains of polysiloxane, and methylphenyl silicone oil has greater resistance to thermal oxidation resulting in the introduction of phenyl groups [b-Ito] and [b-Bannister]. Therefore, the flash point of the methylphenyl silicone oil used in the experiments was very high at over 300ºC. Nevertheless, the ignition in these experiments occurred in the presence of air bubbles. This observation indicated that the temperature at the butt-joint splice connection reached at least 300ºC. This phenomenon was not observed when there was no air bubble in the refractive index matching material because of the lack of oxygen. In such cases, the phenomenon would be not thermal oxidation but a thermal decomposition reaction in the higher temperature environment.

II.4 Conclusion

This appendix indicates that studies found that the optical loss and temperature increased at a butt-joint splice with refractive index matching material when there was a large gap $d \geq 50$ µm between the two fibre endfaces and with a high-power light input. It was found that ignition occurred at the butt-joint splice with refractive index matching material and oxygen induced by a high-power light input, and this caused catastrophic damage to the butt-joint splice connection.

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