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SERIES L: CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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

ITU-T Recommendation L.68

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

Summary

ITU-T Recommendation L.68 describes the functional requirements for optical fibre cable maintenance systems for optical fibre cable carrying a high total optical power. It also considers safety procedures and guidelines for the maintenance of outside optical fibre plant carrying a high total optical power.

Source

ITU-T Recommendation L.68 was approved on 22 October 2007 by ITU-T Study Group 6 (2005-2008) under the ITU-T Recommendation A.8 procedure.

FOREWORD

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CONTENTS

Introduction

Broadband optical access services are now commercially available. The number of FTTx subscribers is increasing rapidly. Trunk line communication traffic is also growing quickly due to the expansion of FTTx services. To meet the demand for increased transmission capacity, wavelength division multiplexing (WDM) and distributed Raman amplifier (DRA) technologies have been employed in trunk line transmission systems, and consequently high power communication signals and high pump powers have been introduced into optical fibre cables. If we are to maintain the optical cable networks reliably, we must study optical fibre cable maintenance systems that can be applied to optical fibre cable carrying a high total optical power.

Recently, the optical power in optical communication systems has been increasing rapidly through the use of WDM or distributed Raman amplification technologies. When DRA technology is applied to WDM systems, a high power light is launched into optical fibres and fibre-optic components. The intensity of that optical power reaches several watts, and such a high power light may induce damage in optical fibres or fibre-optic components.

During maintenance work, network operators must handle optical fibres or fibre-optic components carefully in central offices that employ high power systems with a view to preventing accidental eye or fire hazards. Since the light with the highest optical power is launched into the optical fibre distribution systems and the maintenance systems in a central office, we must clarify the effect that it has on the fibre-optic components in these systems.

ITU-T Recommendation L.68

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 cable carrying a high total optical power. It applies to test equipment, optical switches for selecting a test fibre, test access modules for connecting test equipment to the communication line, testing optical fibre cords and optical connecting devices that are contained in the maintenance system. It also considers safety procedures and guidelines for the maintenance of outside optical fibre plant carrying a 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] ITU-T Recommendation G.652 (2005), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.664] ITU-T Recommendation G.664 (2006), *Optical safety procedures and requirements for optical transport systems*.

[ITU-T L.25] ITU-T Recommendation L.25 (1996), *Optical fibre cable network maintenance*.

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

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

[ITU-T L.42] ITU-T Recommendation L.42 (2003), *Extending optical fibre solutions into the access network*.

[ITU-T L.50] ITU-T Recommendation L.50 (2003), *Requirements for passive optical nodes: Optical distribution frames for central office environments*.

[ITU-T L.53] ITU-T Recommendation L.53 (2003), *Optical fibre maintenance criteria for access networks*.

[IEC 60825-1] IEC 60825-1 (2007), *Safety of laser products – Part 1: Equipment classification and requirements*.

[IEC 60825-2] IEC 60825-2 (2007), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*.

[IEC 61292-4] IEC/TR 61292-4 (2004), *Optical amplifiers – Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers.*

3 Definitions

For the purpose of this Recommendation, the definitions given in [ITU-T G.652], [ITU-T G.664], [ITU-T L.25], [ITU-T L.40], [ITU-T L.41], [ITU-T L.42], [ITU-T L.50] and [ITU-T L.53] apply.

4 Abbreviations

This Recommendation uses the following abbreviations:

DRA Distributed Raman Amplification

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 Fundamental requirements for optical fibre cable maintenance systems for optical fibre cable carrying high total optical power

"High power light" for optical fibre cable maintenance systems is defined as follows. When high power light is launched into maintenance systems, the fibre-optic components in the systems may be damaged in such a way that they do not meet their specifications (e.g., optical loss). Generally, the term high power light is used to refer to light that has an optical power of several hundred milliwatts. The fundamental requirements for optical fibre cable maintenance systems for optical fibre cable carrying a high total optical power are as follows:

– It must be safe for network operators to handle the optical fibre cables, cords and fibre-optic components when they are carrying a high total optical power light. Network operator safety must be in accordance with [ITU-T G.664], [IEC 60825-1] and [IEC 60825-2].

– An optical fibre cable maintenance system should provide the functions of surveillance, testing and control listed in [ITU-T L.40] to meet the specifications for optical fibres or fibre-optic components even if they are carrying a high power light.

6 System requirements for optical fibre cable maintenance systems for optical fibre cable carrying high total optical power

There are two kinds of safety issue as regards optical fibre cable carrying a high total optical power. One is human safety, and this problem relates to the exposure of eyes or skin to high power light. The other is component safety when there is a high power light input. There are several fibre-optic components in optical fibre cable maintenance systems for optical fibre cable carrying a high total optical power. When the components have a larger optical loss than usual, this may pose a fire-hazard in the worst case.

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 or physical plant to avoid dangerous situations. There are several ways to implement maintenance functions: OTDR testing for optical fibre cable, optical loss testing and the optical power monitoring of optical signal or pump power using OPM. Therefore, optical fibre cable maintenance systems must have optical branching devices for test light insertion (e.g., an optical coupler).

Table 6-1 shows the functions in optical fibre cable maintenance systems for optical fibre cable carrying high optical power. The list below includes the system requirements for high power light input and the methods employed to achieve them.

Table 6-1 – 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. No need for optical connectors or polishing and cleaning of connector endfaces.
Termination	No tight bending of optical fibre	Minimum bending radius R ≥ 30 mm for testing optical fibre cords in ODF, but fibres with improved bending capability will allow more severe conditions.
Testing access for optical fibre line	No fibre fuse or intense temperature increase	Use of fusion splices. Optical branching component with high tolerance to high power light 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.

6.1 Connection for optical fibre cable carrying high total optical power

In terms of preventing a "fibre fuse", connectors should not be used for optical fibre connection 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 should be recommended as the sleeves for fusion splices with a view to avoiding fire hazards.

If connectors must be used for the optical connection of optical fibre cable carrying a high total optical power, the connector endfaces must be carefully cleaned and polished.

6.2 Termination for optical fibre cable carrying high total optical power

6.2.1 Optical fibre cord for testing

The minimum bending radius of testing optical fibre cords in an ODF in a central office should be 30 mm in accordance with [ITU-T L.50]. If a minimum bending radius of at least 30 mm is maintained for general single mode fibres (e.g., that 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 wavelengths. However, fibres with improved bending capability will allow the use of more severe conditions.

6.2.2 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 any tight bending of the optical fibre.

6.3 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 a fusion splice should be employed for this connection point. It is desirable that the optical components for inserting test lights (e.g., optical coupler) have a high tolerance when exposed to high power light.

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

An optical fibre cable maintenance system generally has optical switches for selecting a test fibre. The optical switch conventionally 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 powers might be allowed.

7 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 of testing and maintenance in optical fibre cable maintenance systems should be carried out.

– First, power monitoring using low power test lights should be performed in central offices.

– Second, 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.

– Finally, optical loss testing or OTDR testing using a high power light should be performed in optical fibre cable networks that carry a high total optical power.

Appendix I

Japanese experience: 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 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, a high power light is launched into optical fibres and devices.

When the optical power increases, we have to undertake safety engineering to eliminate the potential hazards induced by high optical power in typical optical systems [b-Ogushi]. We must take account 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], we must clarify the effect that this high optical power has on these cords. Catastrophic damage has been reported for 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 we 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. We investigated the damage caused to the optical fibre cords under high power light input conditions. 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.

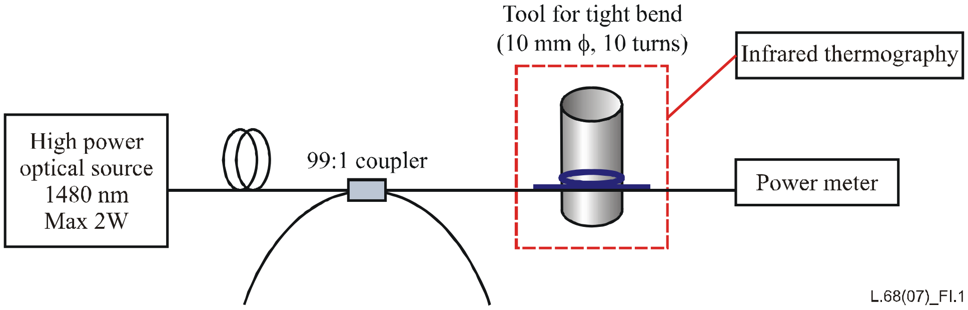

Figure I.1 – Experimental setup

Figure I.2-a is a diagram of the bent optical fibre cord we 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.

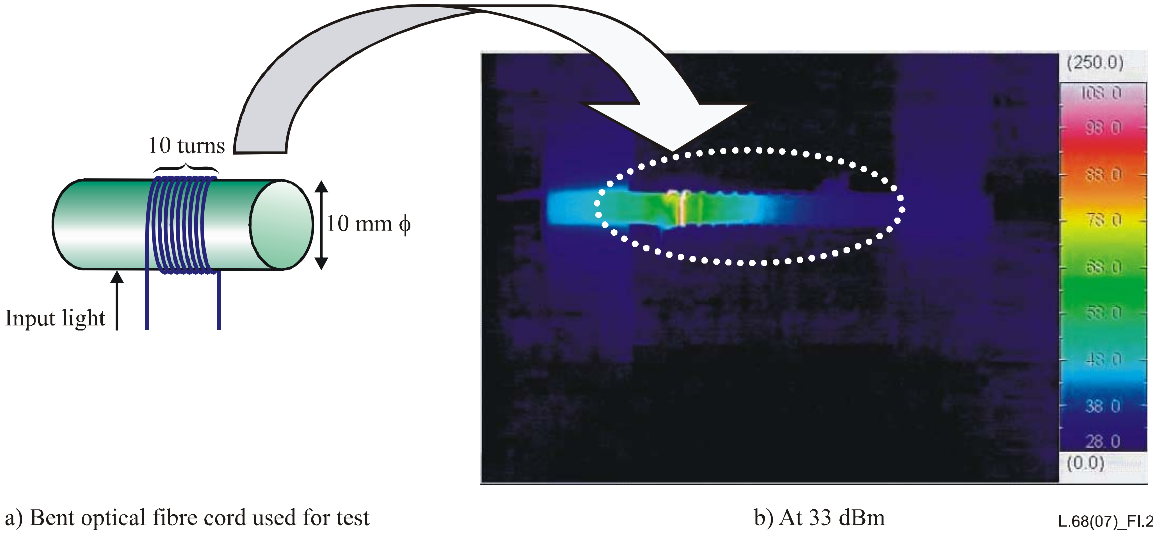

Figure I.2 – Temperature distribution induced by high power light launched into optical fibre cord

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 high power light input. 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.

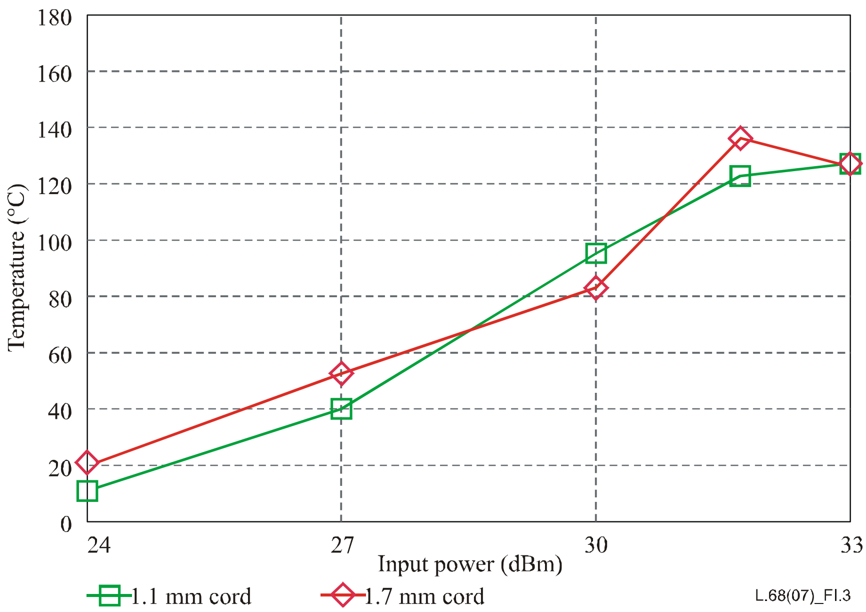

Figure I.3 – Measured temperature data of high power light launched into optical fibre cord

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 caused by the melting of part of the 0.9 mm primary cording. We also examined 1.1 mm diameter cord.

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.

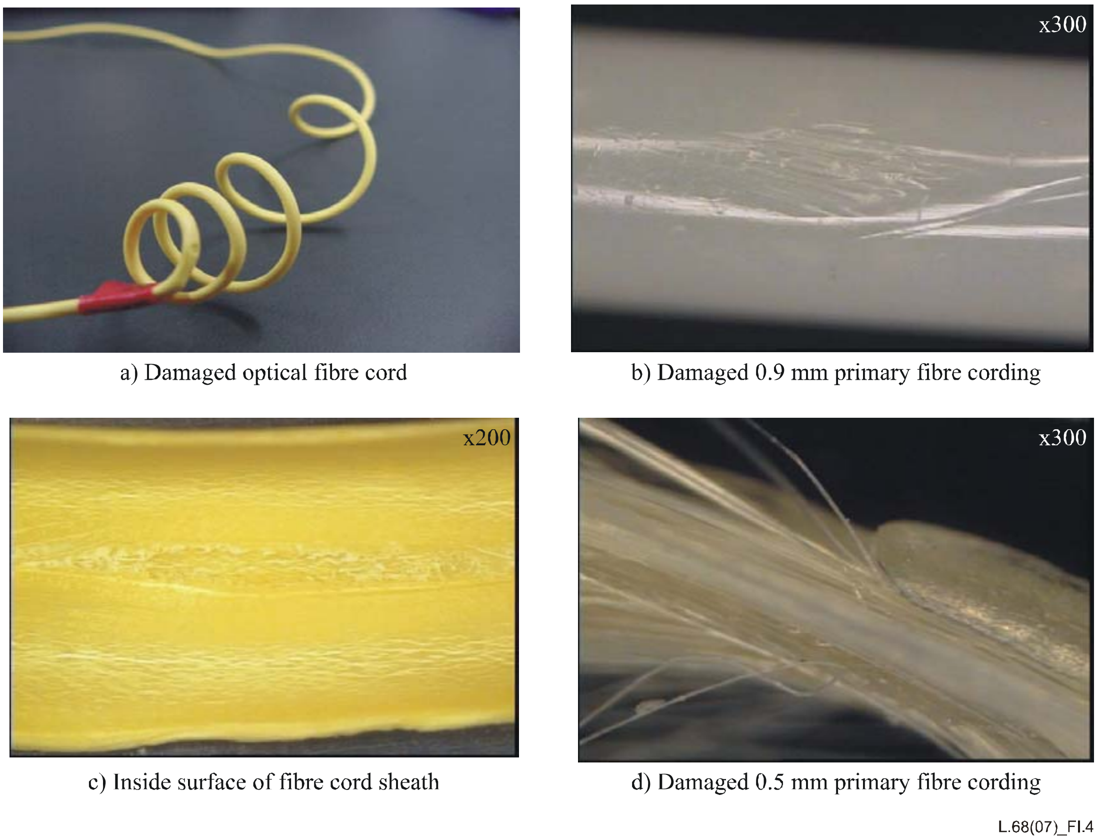

Figure I.4 – Photographs of damaged optical fibre cord

I.4 Conclusion

We have investigated 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 the tight bend causes some damage of 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, one should also consider the condition of the test access module which connects to the indoor cable and the outside cable.

Appendix II

Japanese experience: 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, we have to undertake safety engineering to eliminate the potential hazards that the optical power may induce. We must also take account 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, we must clarify the effect that it has on the optical fibre devices in these systems. 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 we launched a high power light 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 setup for exposing a butt-joint splice connection to high power light.

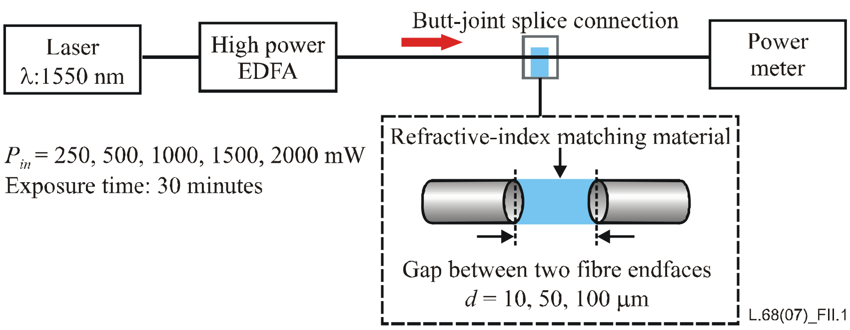

Figure II.1 – Experimental setup

We used a laser operating at a wavelength of 1.55 µm and in the CW mode and an EDFA as the high power optical source. We used a V-groove 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, we employed fusion splices 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. We measured the optical loss changes with and without refractive index matching material. We employed a refractive index matching material that is commonly used in fibre selectors and MT connectors.

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, we find 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. We 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]. We believe 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.

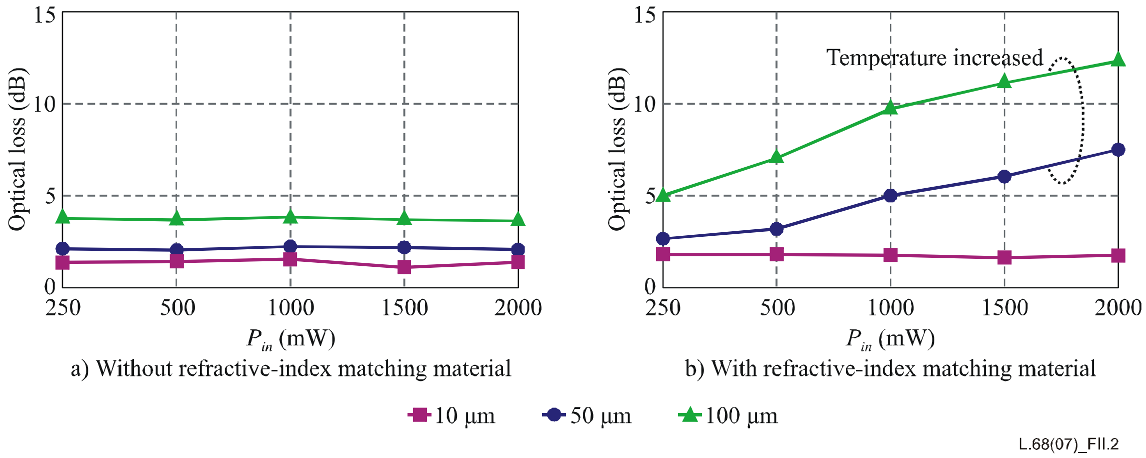

Figure II.2 – Measured optical loss of high power light launched into butt-joint splice

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

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

We 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 after this experiment. We undertook a componential analysis of this residue, and detected Si, O and C. The refractive index matching material we used was silicone oil [b-Ito], which contained these elements. We considered that the quality of the silicone oil changed, and that it generated the black residue.

We performed a high power light exposure test 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. We observed no ignition.

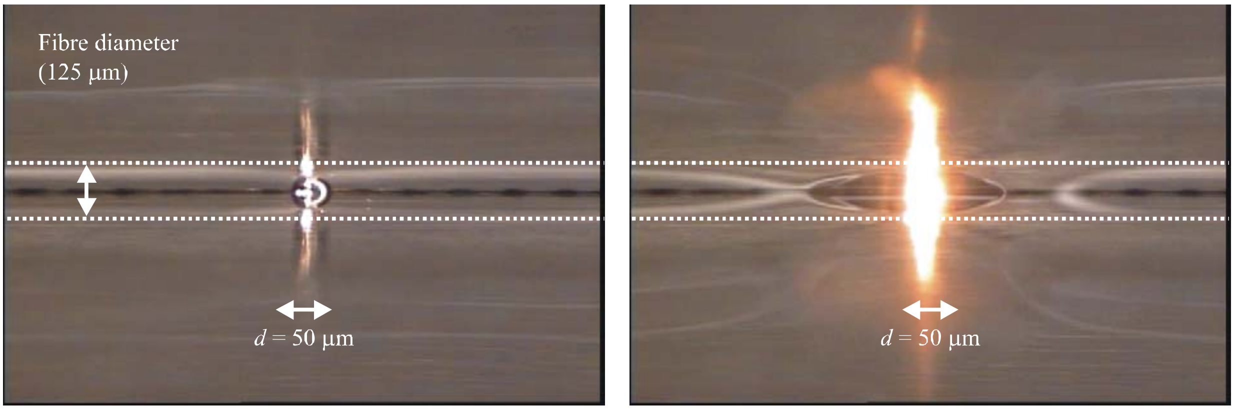

Figure II.3 – Photographs of the video of ignition at the butt-joint splice with refractive index matching material

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 our experiments, we employed methylphenyl silicone oil 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 our experiments was very high at over 300ºC. Nevertheless, the ignition in our 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 in the butt-joint splice connection.

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