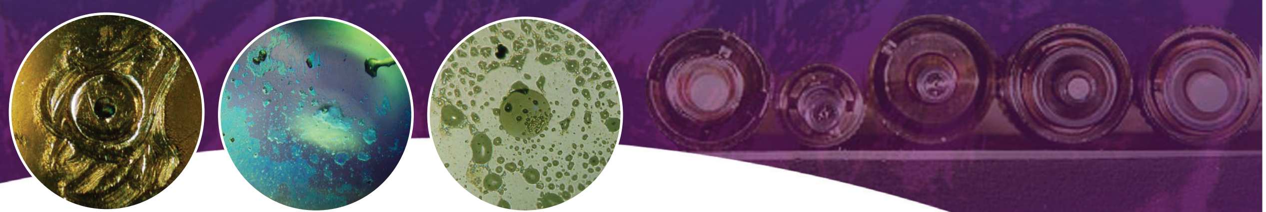
Qualitative Assessment on the Effects of Damaged Connectors and Optical Interfaces in Fiber Optic Measurements

White Paper



Presented by Peter Linowitz
Agilent Technologies
National Conference of Standards Laboratories (NCSL)

Abstract

In a world in which fiber optics becomes more a part of our lives, more people have become involved in its activities ranging from metrology through to production and installation. In much the same way that BNC and N-Type connectors are used on a daily basis without further thought, the dangers of fiber optic connectors being used in a similar fashion become more real. To quantify or predict the effects that a damaged fiber optic connector or optical interface can have on measurements can be difficult, but sometimes a qualitative assessment of the damage is all that is required in order to ensure that these connectors are kept in a condition of optimum performance. This paper in conjunction with the presentation will attempt to demonstrate and raise the level of awareness to these facts.

Background

In order to visualize the effects that damaged fiber optic connectors can have, it is necessary to have a basic understanding of the optical fiber and connector. The following will give a brief overview.

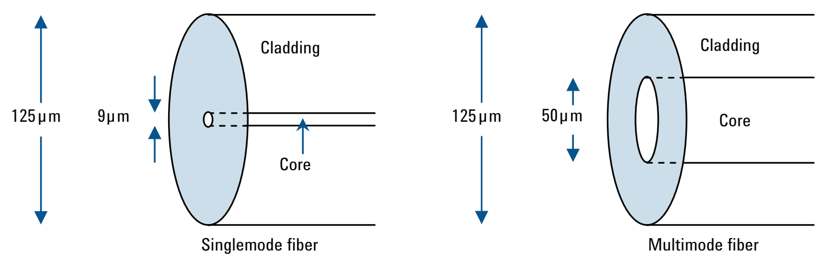


Figure 1. Optical fibers

Figure 1 shows the basic construction of two typical optical fibers. In common, they both consist of a glass fiber 125 microns (µm) in diameter. The central portion, referred to as the core, consists of glass with a refractive index slightly higher than that of the glass surrounding it (cladding). The diameter of the core determines whether the light within the fiber propagates in a singlemode or multimode fashion. Typical values for the core diameter are 9 µm for singlemode and 50 µm for multimode as shown in Figure 1. Light only propagates, or travels, within the core.

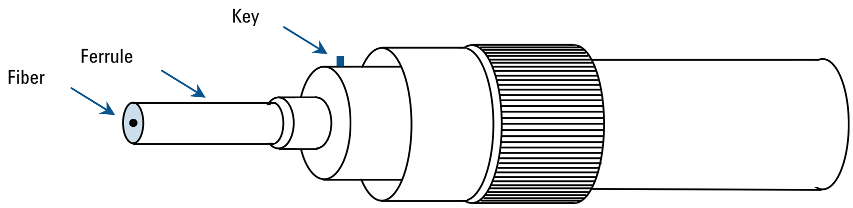


Figure 2. Optical Connector

Typical construction of a fiber optic connector is shown in Figure 2. The main component of the connector is the ferrule. This may be constructed from a metallic or ceramic material and for the more commonly used connectors such as FC/PC, ST, DIN and Diamond HMS-10 will have a diameter of 2.5 millimeters (mm). The optical fiber runs along the length of the ferrule and exits centrally at its end face. It is here that the fiber and ferrule end face is cut/polished to the connector's specification. Typical values of return loss for a connector can range from 14.6 dB for a straight connector end to even more than 60 dB for a slanted connector end.

Also shown in Figure 2 is the key. This is a protrusion that ensures that the connector always aligns in the correct orientation when connected to its female counterpart.

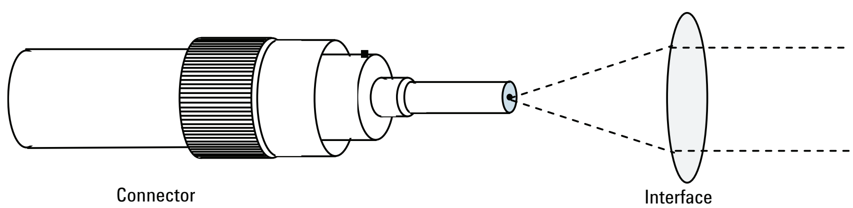


Figure 3. Optical connector interface

In its simplest form an interface may consist of two fiber optic connectors butted end to end using an alignment collar or tube such that the fibers within each ferrule are aligned in the same plane. The type of connectors used will determine whether the fibers are in physical or non-physical contact.

In the case where the light form an optical fiber is required to pass into or out of an optical component or system, it may be necessary to modify the divergent light that emits from the end of the fiber to match the characteristics of that component or system. Figure 3 shows such an interface in its simplest form. Here a lens is used as the interface. Its purpose is to collect the divergent beam of light that emits from the end of the optical fiber and convert it into a collimated or parallel beam. The converse is also true for this type of interface in that the lens can take a collimated beam of light and focus it into an optical fiber.

Conditions Affecting Performance

When light exits a glass fiber and enters air, a back reflection in the order of 3.5% of the incident is produced. This equates to a return loss of 14.5 dB and is known as a Fresnel Reflection. For some applications this is acceptable and an interface of the non-physical contact type is used. For other applications where maximum transmission and improved return loss are required, especially in systems using singlemode fibers, other techniques need to be employed. The simplest of these ensure that the two glass fiber ends are in physical contact with one another, thereby excluding the air that causes the Fresnel Reflection. This can be achieved by providing the glass fiber at the end of the ferrule with a highly polished flat or convex end face. This ensures a good physical contact between two mating fibers of the same type, provided they are clean and undamaged. Typical return losses that can be achieved using this technique are 30 - 40 dB. In order to achieve return losses up to 60 dB additional techniques need to be employed. This can include both flat and curved angled cuts and polishes to the ferrule/glass fiber end face in physical and non-physical contact forms.

In singlemode applications where core diameters of 9 µm need to be aligned to ensure maximum performance, quite clearly any degradation of ferrule or glass fiber end face can have significant effect on connector performance. This could be caused by dust or grit between two connectors in contact with one another, by damaged fiber ends, contamination and improper use and removal of index-matching compounds. This can lead to physical damage of the glass fiber end face itself. Where the damage is severe the damage can in turn be transferred to other good connectors that come into contact with it. Even dust or grid onto one connectors' end face can cause permanent damage to the fiber itself by burning into the glass. One has to remember in today's lightwave systems power densities of more than 30 kW/cm^2 can be achieved. To compare, a hotplate from a normal kitchen range achieves only a power density of 3 W/cm^2, more than 10.000 times smaller!

Presentation

The presentation is designed to complement the information within this paper and hence has a high pictorial content. The intent is to familiarize and raise the level of awareness to the following:

- The fiber optic connector
- The variety of connector types available
- The dimensions involved
- Damage sustained to connectors and the resultant effect on measurements
- Damage sustained to a lens type optical interface and the resultant effect on measurements

Conclusion

Although robust, fiber optic connectors are susceptible to microscopic damage that is not immediately obvious to the naked eye. This damage can have significant effects on measurements being made, whether in a laboratory, production or field environment. Although microscopic examination of connectors is not always practical, an awareness of these effects in conjunction with good practices can ensure that their performance is always optimized.

Literature

Senior, John M.: O*ptical Fiber Communications - Principles and Practice*, Prentice-Hall Int., London, 1985, ISBN 0-13-638248-7

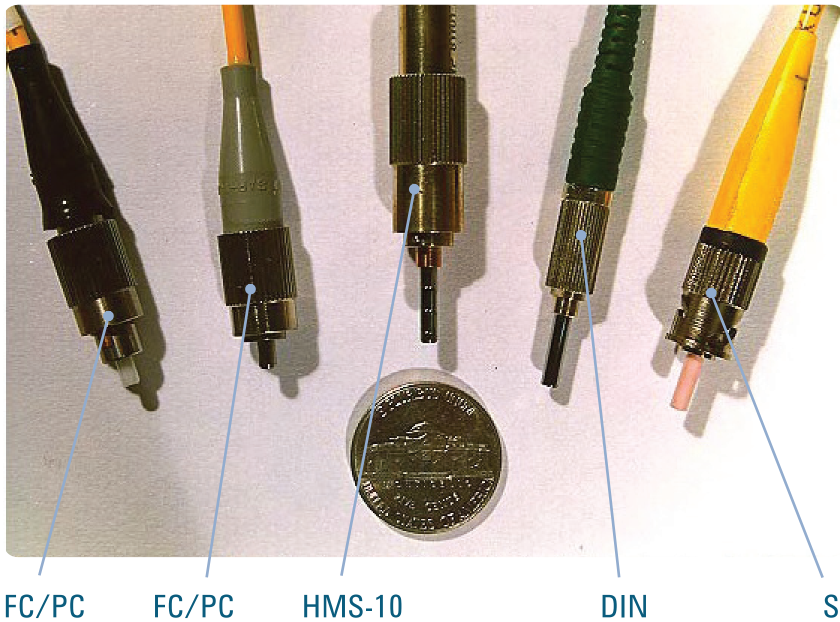
Hentschel, Christian: *Fiber Optic Handbook*, Hewlett-Packard, 1988, PN 5952-9654, ISBN 3-9801677-0-4

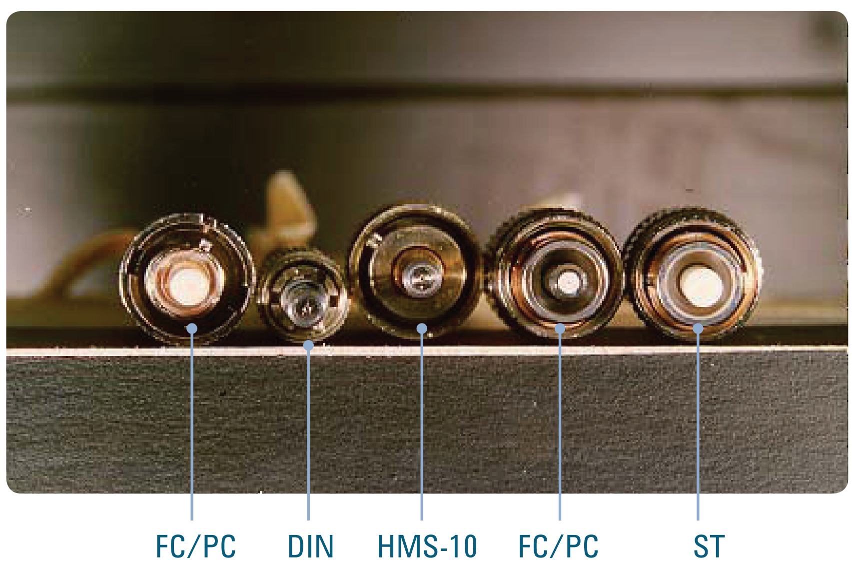
Rademacher, Wilhelm: *A High-Precision Optical Connector for Optical Test and Instrumentation*, Hewlett-Packard Journal, Vol. 38, No. 2, February 1987, p.28-30

Application Note 366-2: *How to Measure Return Loss of Optical Components*, Hewlett-Packard, 1988, PN 5952-9661

Handbook: L*ightwave Connection Techniques for Better Measurements*, Hewlett-Packard, 1991, PN 08703-90028

Connector Types



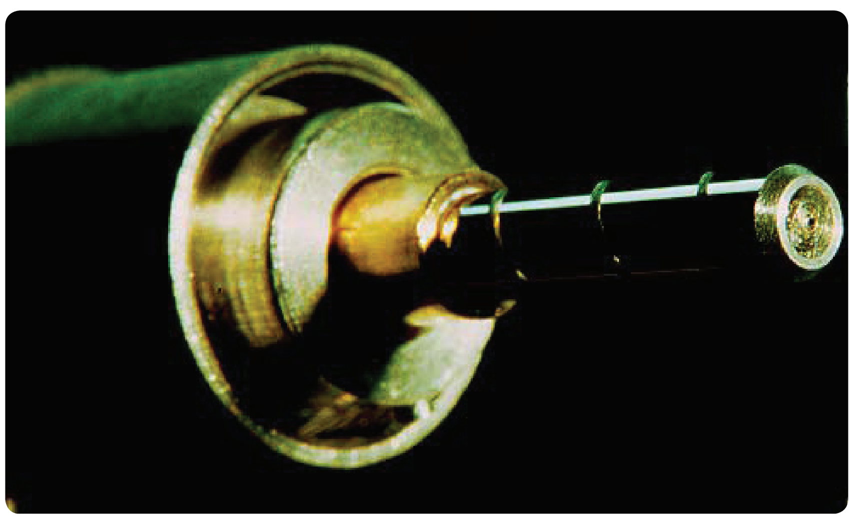


Connector types showing various constructions, e.g. metallic, ceramic, etc.

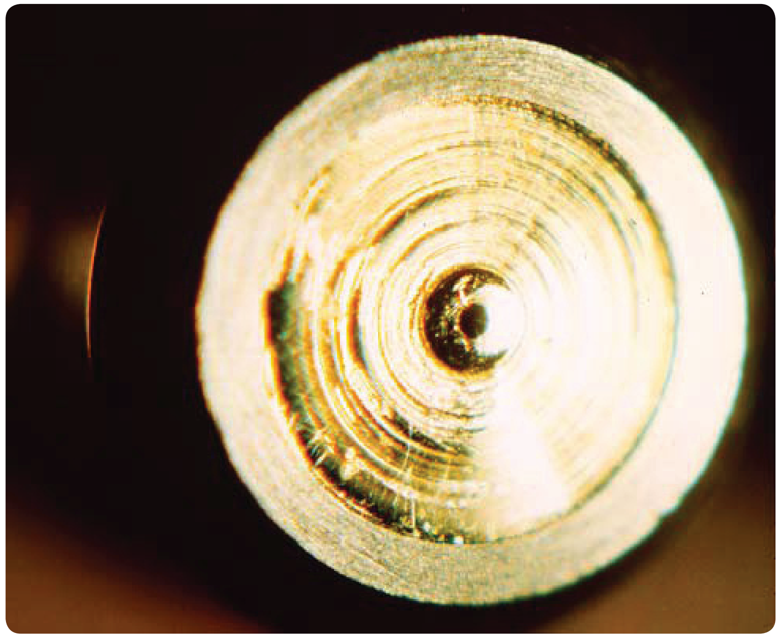
Feel of Dimensions ... (1)

Zooming in on HMS-10.

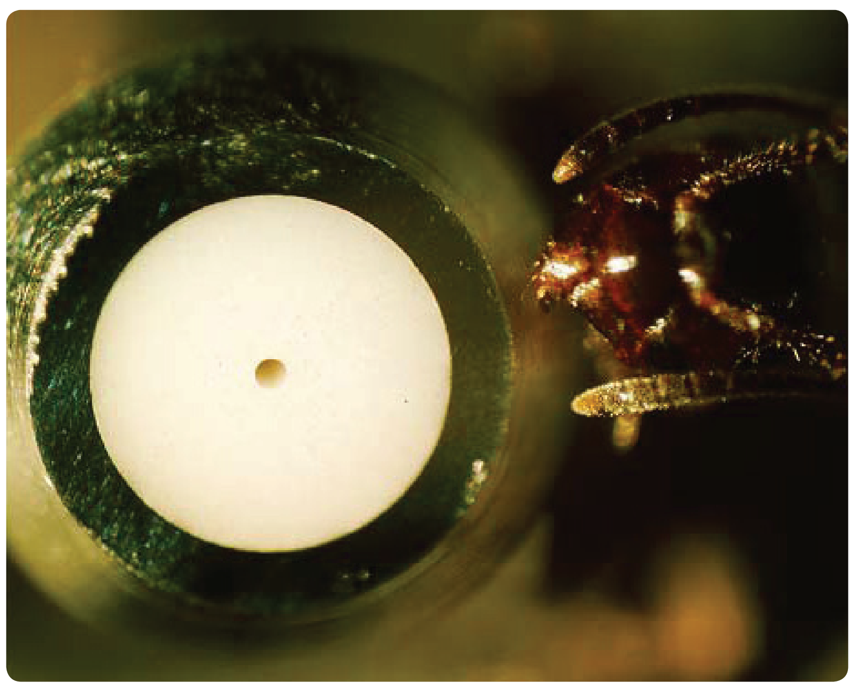
Feel of Dimensions ... (2)



Feel of Dimensions ... (3)

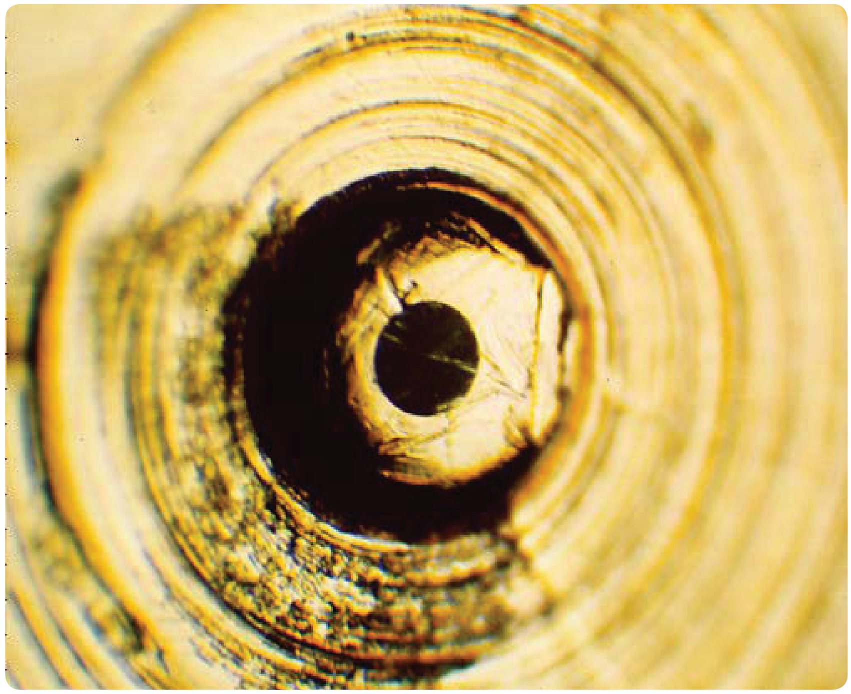


Feel of Dimensions ... (4)

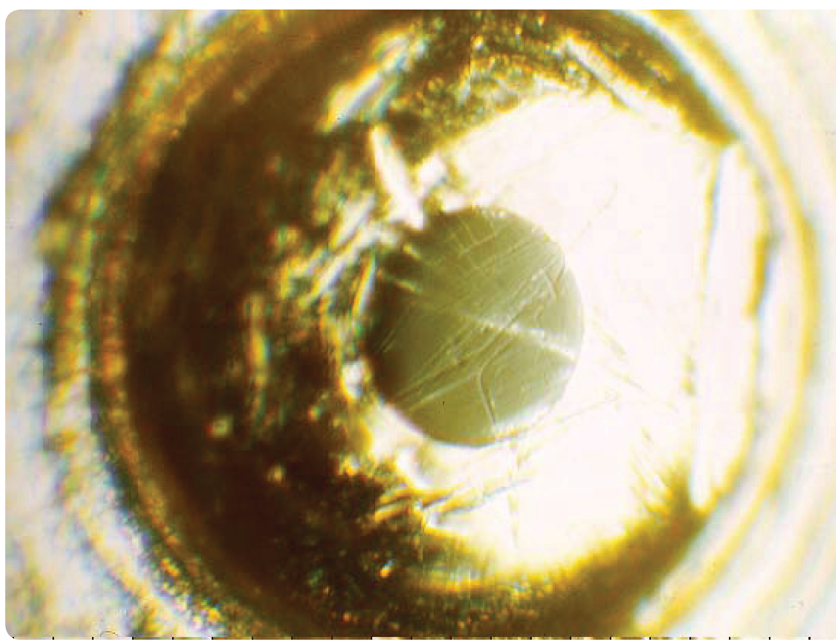


- Same scale as previous slide.
- This time FC/PC and head of an ant.
- The center circle inside the white area is 125 µm!
- The core itself is only a fraction of it, 9 µm. Seen as the red dot in the center

Feel of Dimensions ... (5)

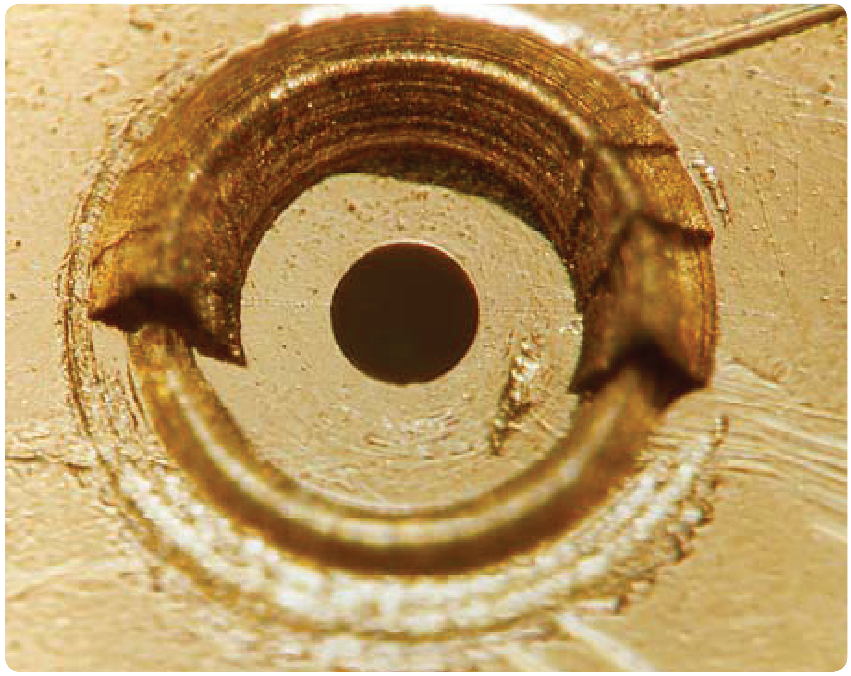


Feel of Dimensions ... (6)

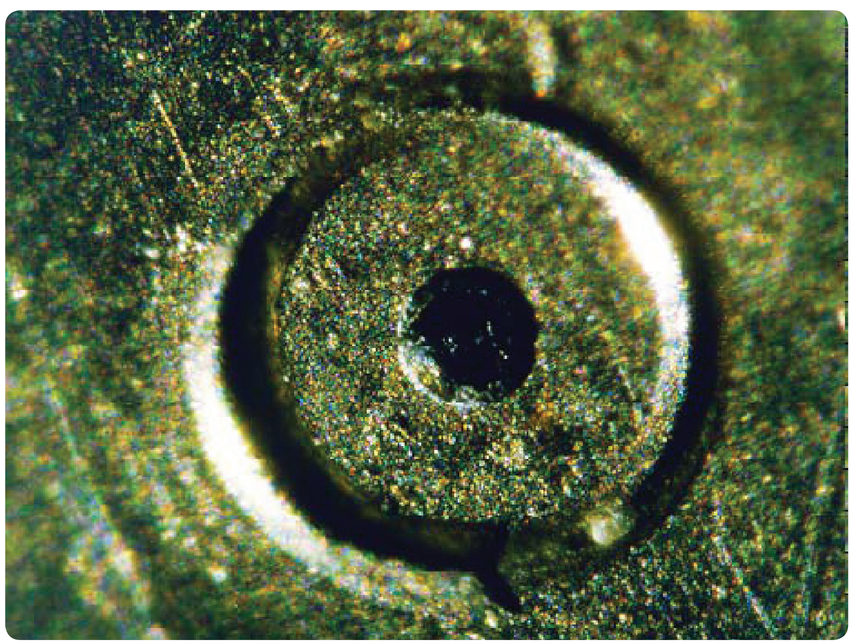


- 125 µm fiber and scratches;
- elbow scratch approx. 3 µm wide

HMS-10

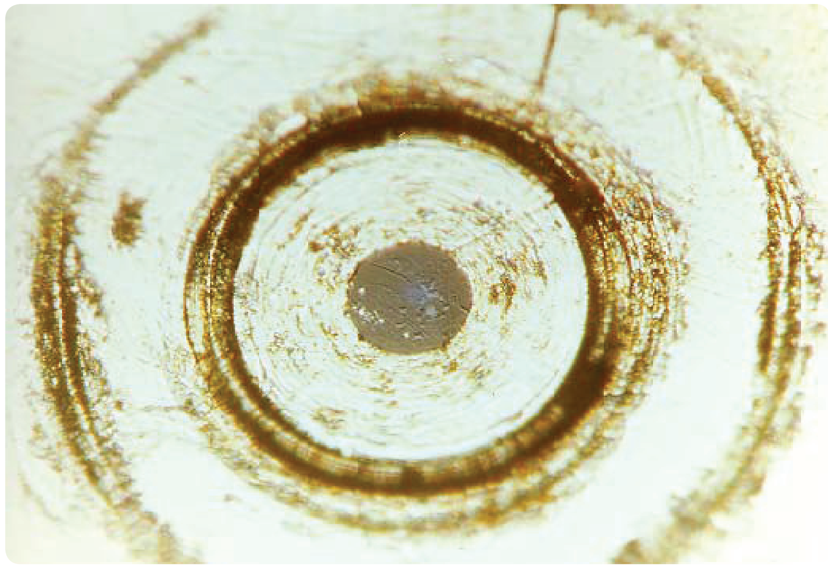


Good fiber in connector.



Extreme fiber damage on connector.

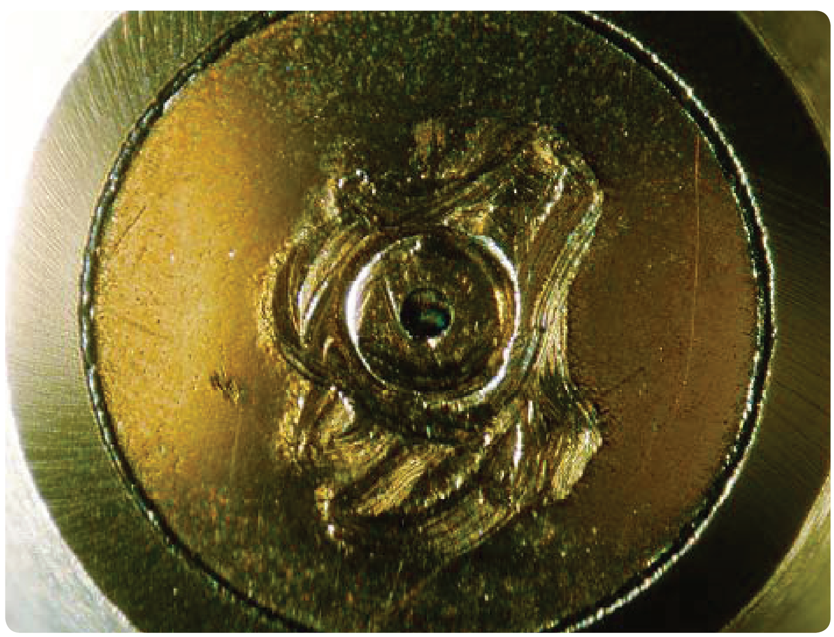
HMS-10



General example of damage:

- Scratches
- White objects are metallic particles embedded in fiber
- Pits are where metallic particles have fallen out

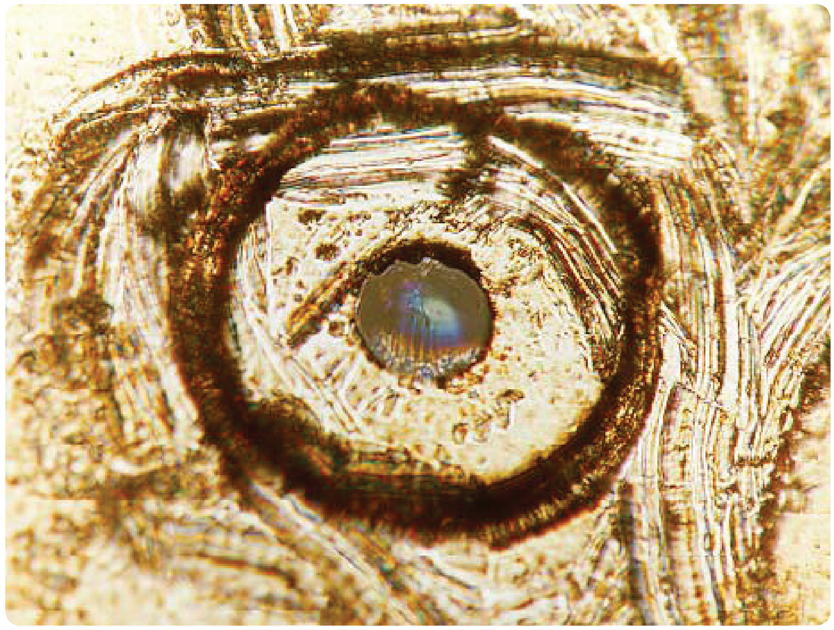
2.5 mm Ferrule



Assume that ferrule end was ‘cleaned’ by probing with pin.

Nickel/silver insert within Tungsten carbide ferrule easily scratched with pin. Insertion loss was approx. 8 dB.

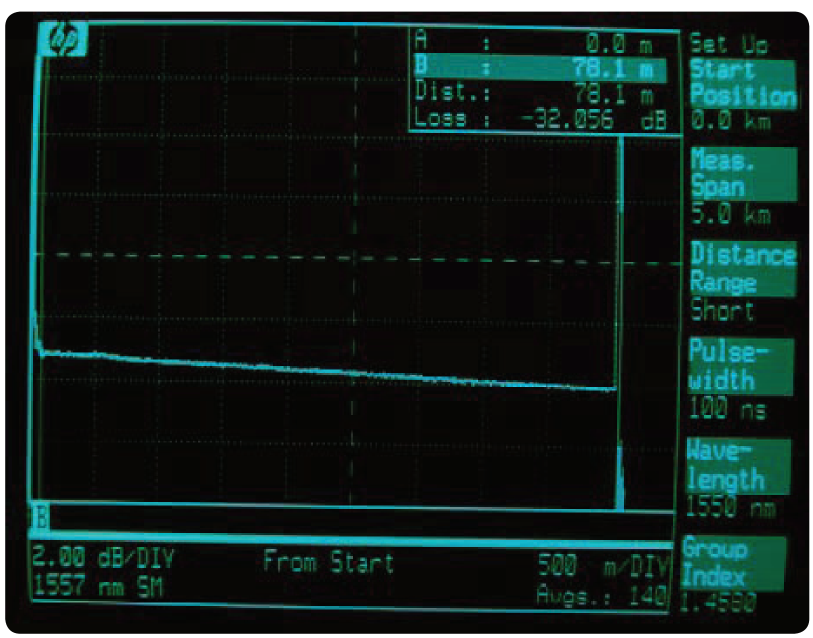
Fiber within 2.5 mm Ferrule



Previous slide magnified.

- Note where scratch leads to broken fiber edge
- Crescent mark across bottom of fiber is where metallic disposition has taken place when pin was drawn across surface of fiber

OTDR Trace



Good trace of 4.5 km delay line

Note good launch into a good fiber, i.e. minimum backreflection at connector interface

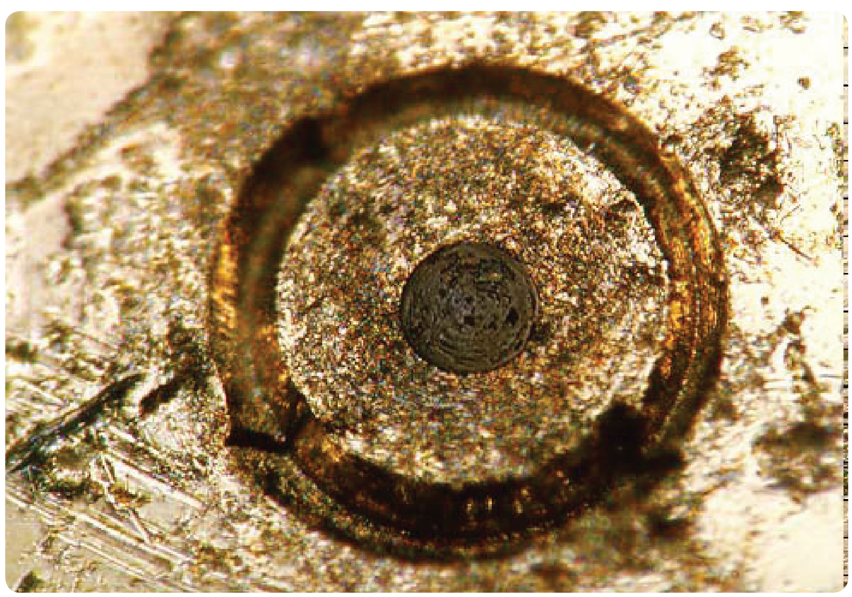
Fiber within 2.5 mm Ferrule

OTDR front panel connector/ferrule

Recessed ring effect either due to incorrect fiber inserted and rotated or missing key on correct connector. This caused extreme multiple reflections between this and the fiber .

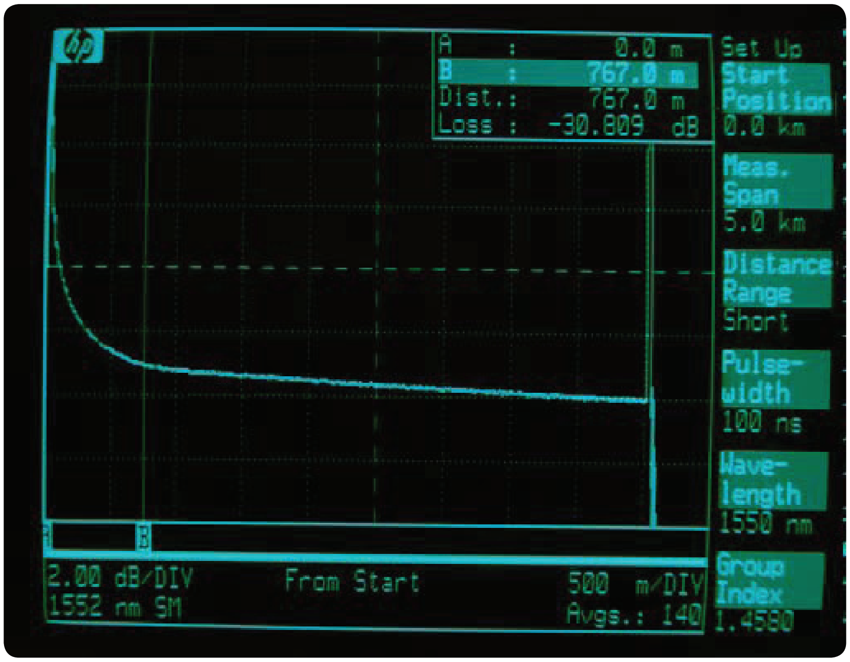
See page 13 for effects on OTDR measurement.

Fiber within 2.5 mm Ferrule



- After seeing this unit over a period of 1 year, the connector finally gave up.
- See page 13 for effects on OTDR measurement.

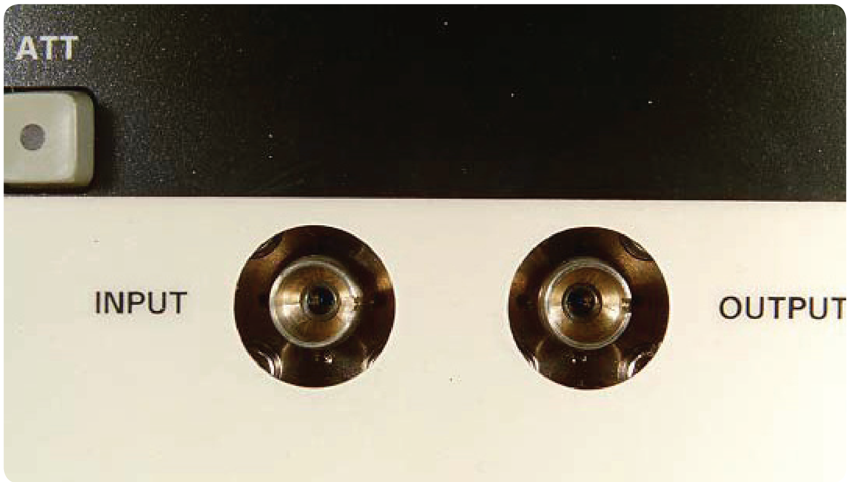
OTDR Trace



Typical result of damaged front panel connector

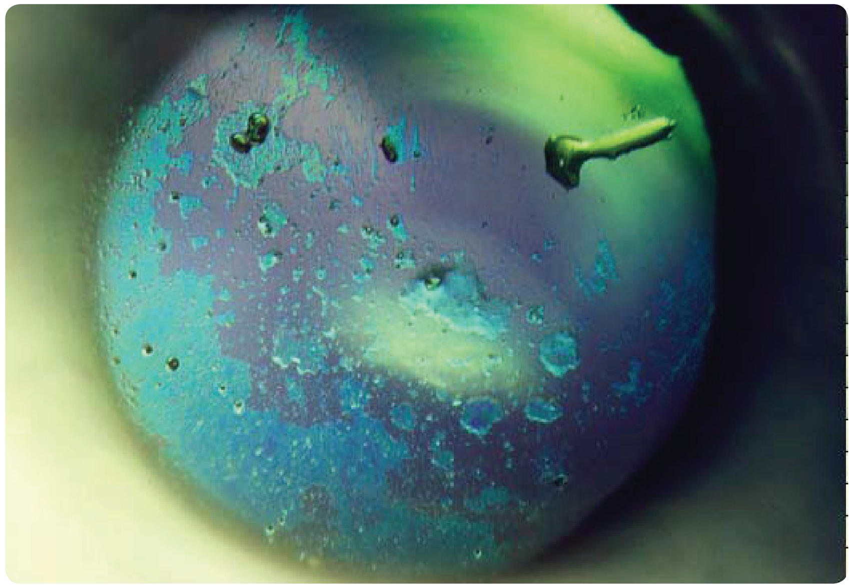
Note! Extreme back reflection at pulse launch and loss of 0.75 km before useable measurements can be made.

Optical Interfaces



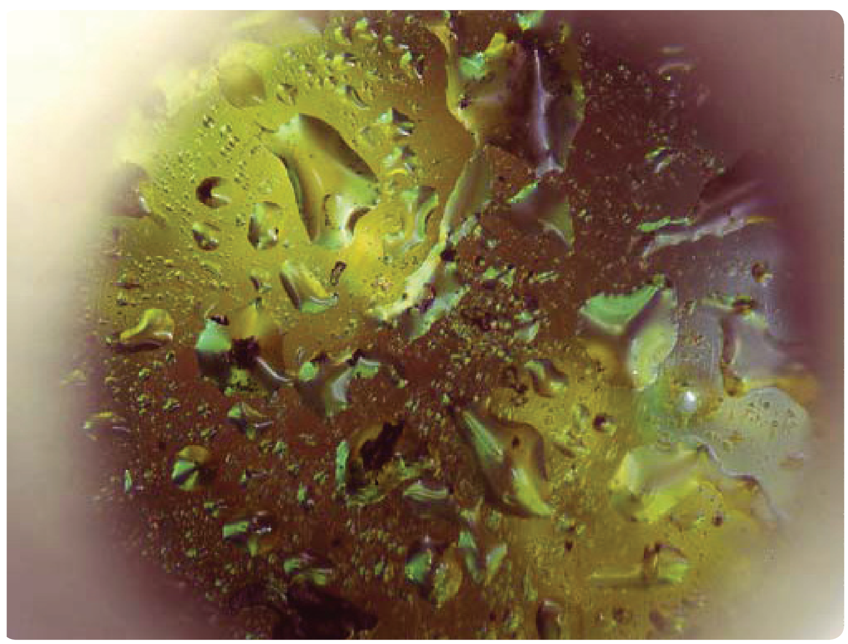
Front panel
Note collimating lenses (bluish color)

Optical Attenuator



Picture through front panel connector of collimating lens.

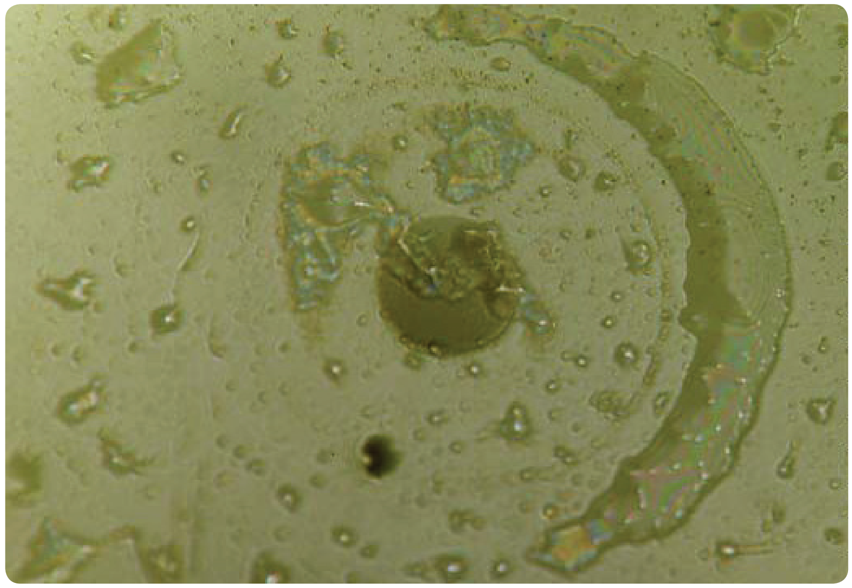
- Lens coated with Refractive Index matching (RI) liquid which has collected particles of dust and grit
- This unit showed approx. 10 dB insertion loss.



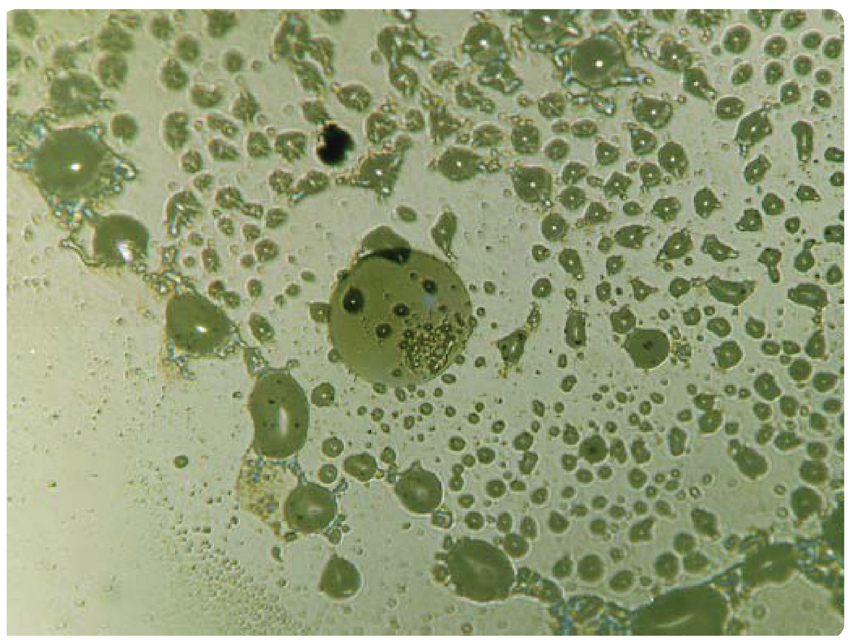
Picture through front panel connector of collimating lens.
User has attempted to remove RI liquid with solvent.

- Typical globular RI liquid pattern results when solvent has evaporated.
- This unit showed approx. 20 dB insertion loss.

FC/PC Connector



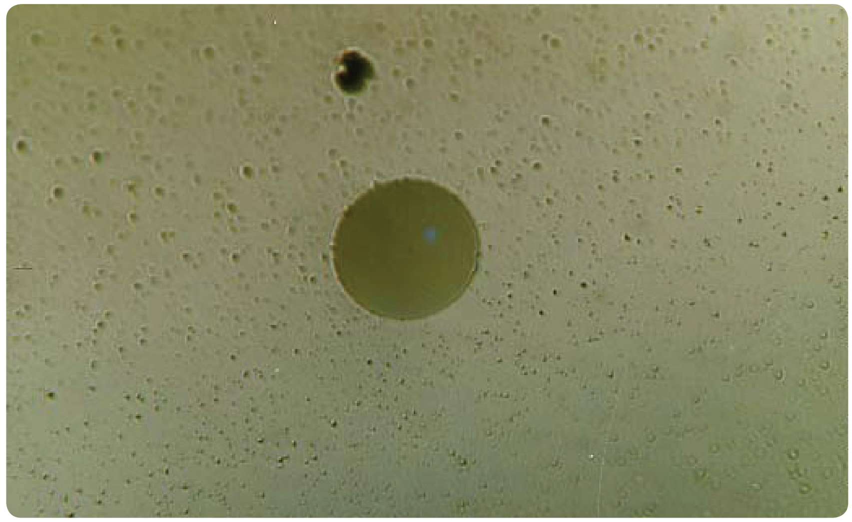
Ceramic ferrule showing RI liquid contamination



Isopropyl alcohol (IPA) applied with cotton bud and cleaned, waved in air to evaporate IPA.

Result: RI liquid reforms into globules.

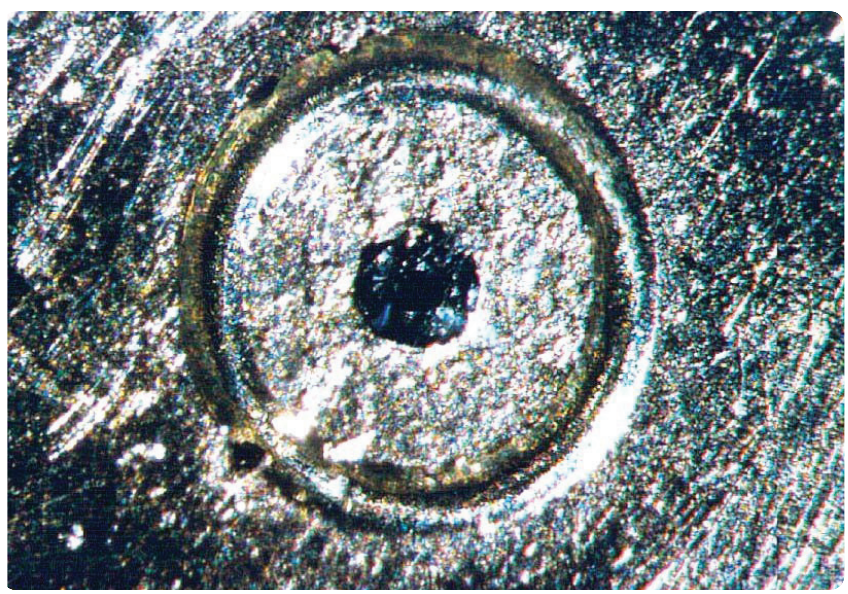
FC/PC Connector



Again cleaned with isopropyl alcohol in some way but compressed air blown over ferrule end.

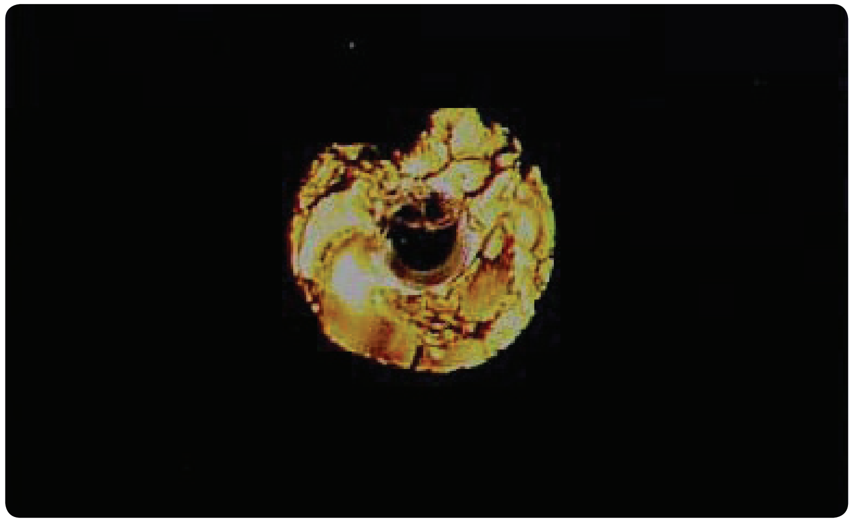
Result: clean connector/ferrule. Marks on ferrule end are part of the ceramic material.

OSA Input Connector



Multimode fiber with 62.5 µm core and 125 µm cladding diameter (black and dark blue, respectively).

OSA Input Connector

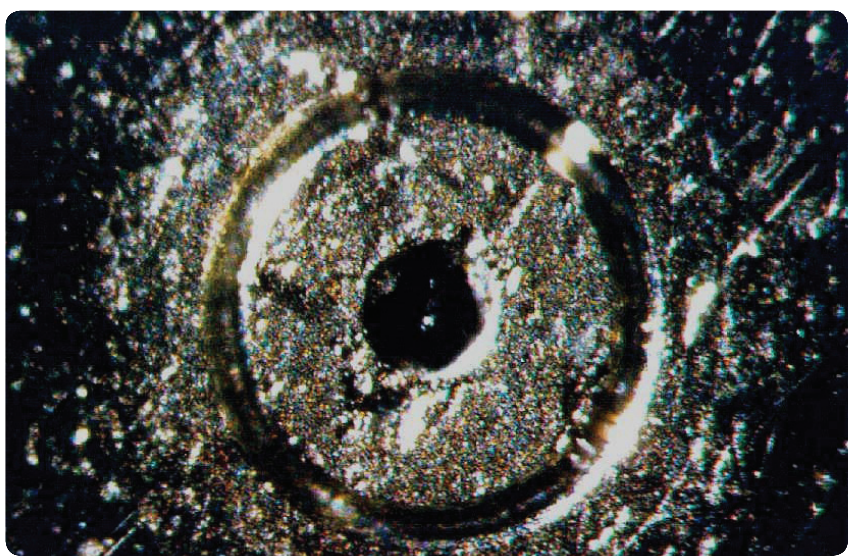


Multimode fiber from previous slide, back illuminated now.

Light is traveling through the cladding, where the center of the core is nearly without any light.

Note the scratches on the core and chipped effect across the entire surface of the fiber end face.

OSA Input Connector

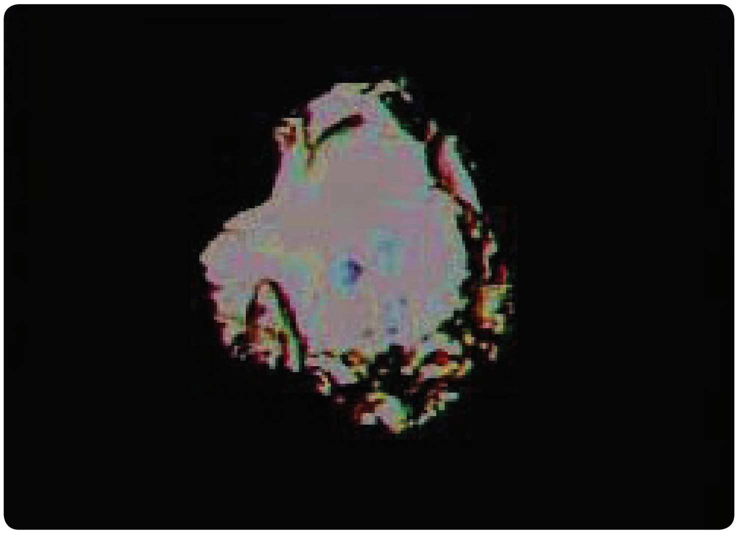


Multimode fiber

Front illumination.

Scratches on the core or cladding and chipped fiber end face are hard to see.

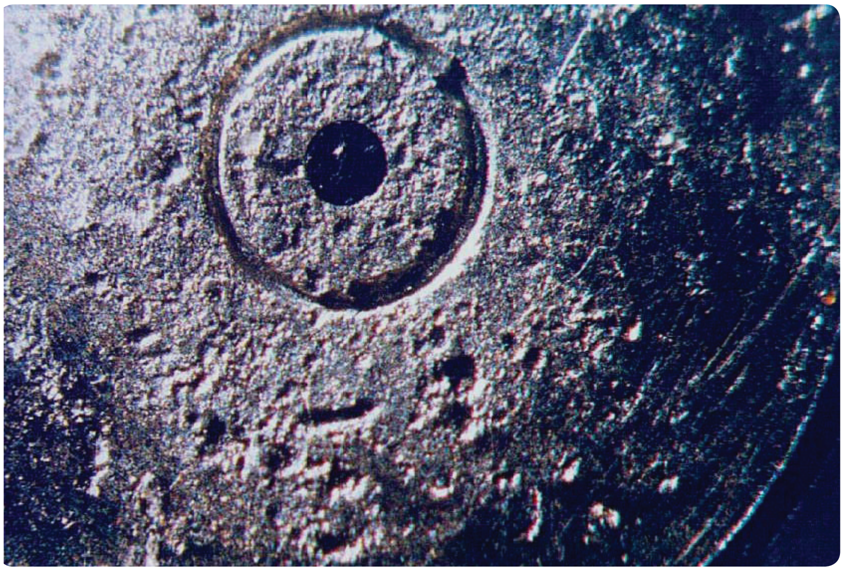
OSA Input Connector



Multimode fiber same connector as previous slide, back illuminated now.

Clearly recognizable are the deep scratches and chipped edges on the outer cladding.

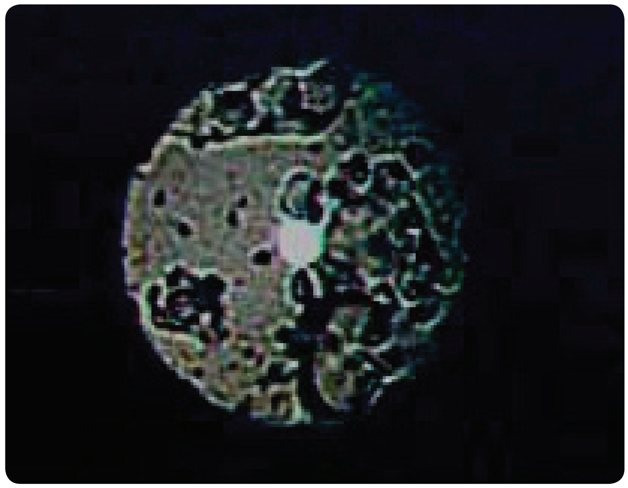
OTDR Input Connector



Singlemode fiber with even distributed dirt and dust.

- Note the fine scratches at the edge of the ferrule.
- They are generated by scrubbing the connector with other tools than lint-free cotton swaps or lens papers.

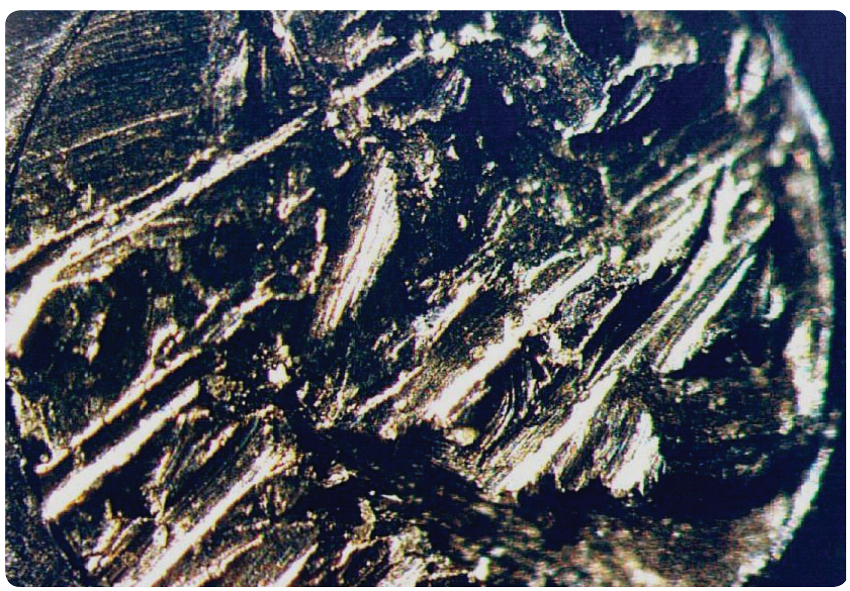
OTDR Input Connector



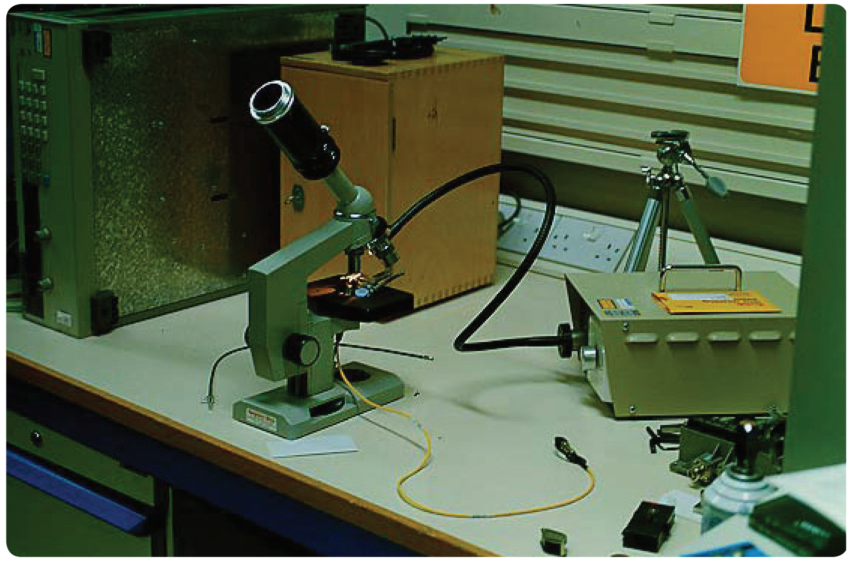
Singlemode fiber cladding and core of the previous slide (black) are now both visible (back illuminated).

- The core guides the most light.
- Damage is primarily on the cladding, but also on the edge of the core.

A completely damaged connector...



The Studio



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