Optical Fiber Splicing
ITU-T Recommendation L.400

Jun Carbonell, PECE

Inno Instruments, Inc.

ECM Networks

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Inno Instruments, Inc. - ECM Networks

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ITU-T recommendation Section L defines industry standards on Construction, installation and protection of cables and other Elements of outside plant

Section L.400

Fiber Optic Splicing

- Methodology
- Guidelines
- Testing

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Fiber Optic Applications in Communications

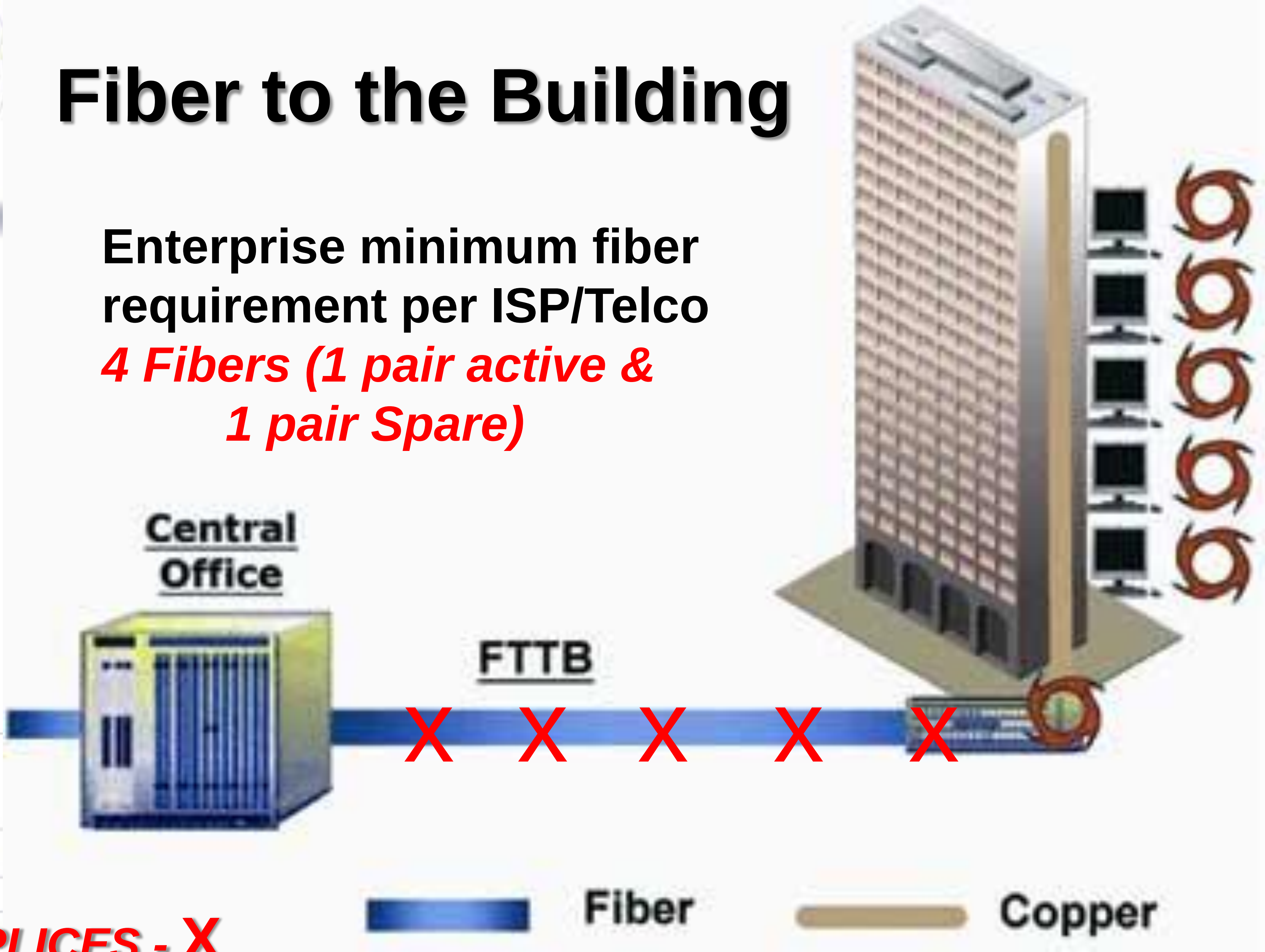
- International/ Domestic/ Regional Backbone Network
- Central Offices Interconnection
- Digital Loop Carrier Backhaul / DSLAM Backbone
- Mobile Phone Base Station Interconnection
- Fiber to the Home (GPON)

Single-mode Fibers have been developed for each application

- G.652 (Non-Dispersion Shift Fiber) - commonly used
- G.653 (Dispersion Shift Fiber) – Reduced Core Size for EDFA
- G.654 (Ultra Low Loss Optical Fiber) – Submarine Cables
- G.655 (Non-Zero Dispersion-Shifted Fiber) – Regional/DFON
- G.656 (Medium Dispersion Fiber) – Regional/DFON
- G.657 (Bend Insensitive Fiber) - FTTH

Fiber to the Building

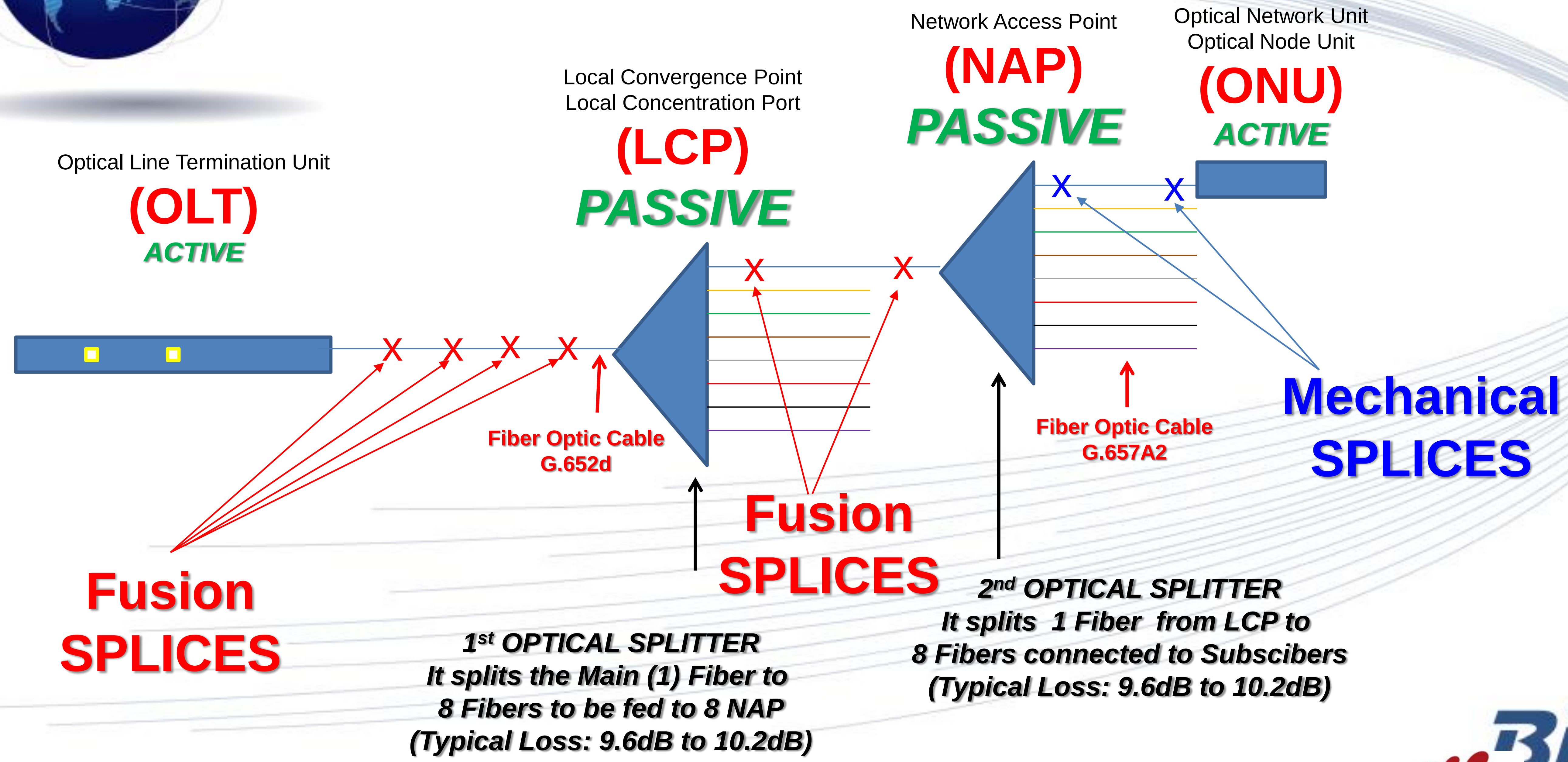
Enterprise minimum fiber requirement per ISP/Telco
4 Fibers (1 pair active & 1 pair Spare)



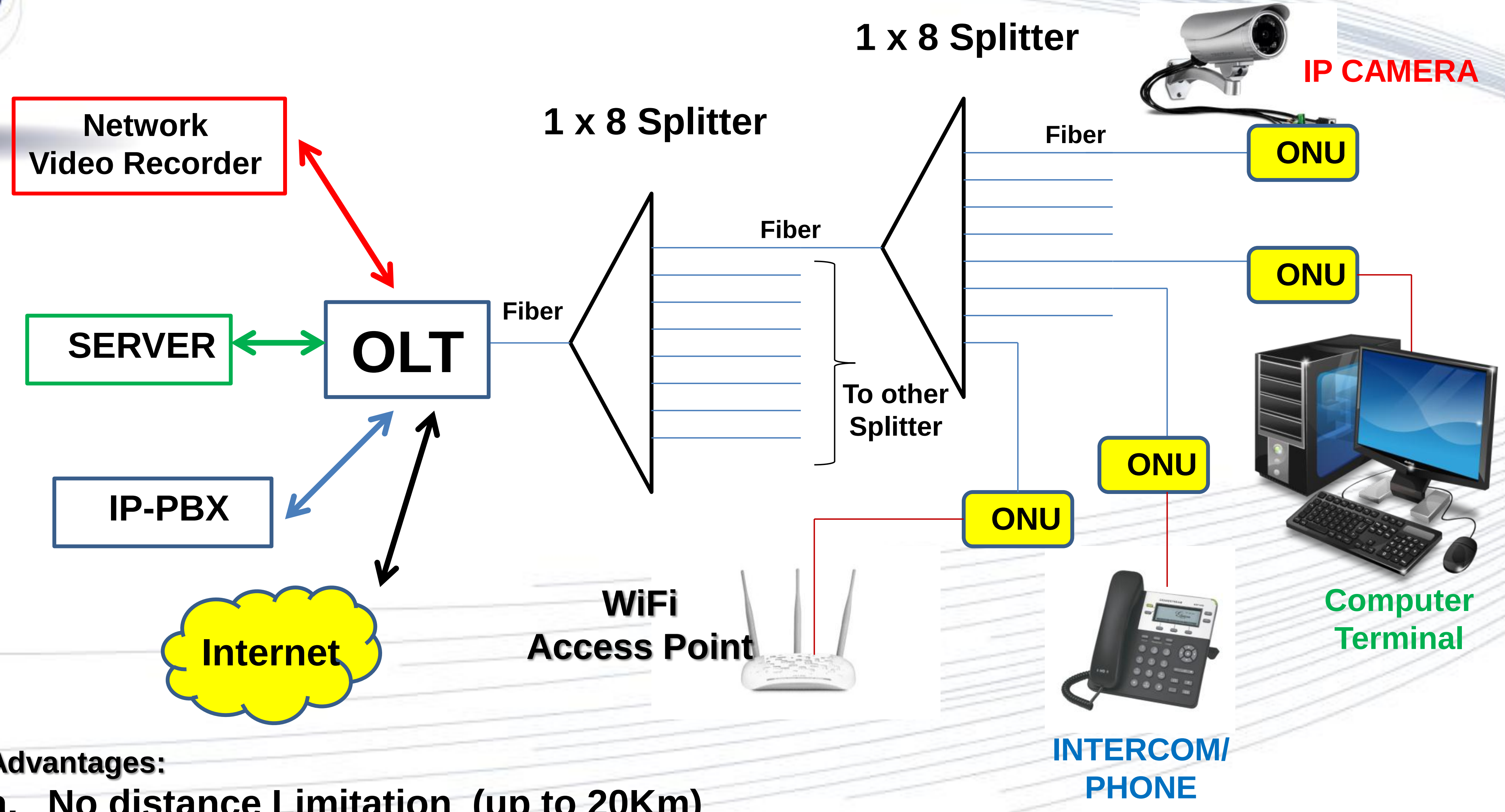
Fusion SPLICES - X

Fiber to the Home Network

Main Components (Active & Passive)



Other Passive Optic Network (PON) Technology application



Advantages:

a. No distance Limitation (up to 20Km)

b. Less Active Devices (Network Switches & Routers)

c. All IP applications in one fiber optic network

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Section 4.1 and 5.1 refers to Fusion Splices

Section 4.2 and 5.2 refers to Mechanical Splices

Objective is to obtain a <u>Low or Negligible splice loss</u>

90% of Fiber Optic Network are connected Using Fusion Splice

Fusion Splicing Methodology
ITU-T L.400 Section 4 and 5

a. Fiber cleaning and Preparation

b. Coating Stripping

c. Cleaning of bare fiber ends

d. Fiber cleaving

e. Splicing

5.5.1.2 Fusion Splicing

5.5.1.3 Proof Test

5.5.1.4 Splice Protection

5.6 Field Splice Loss Measurement

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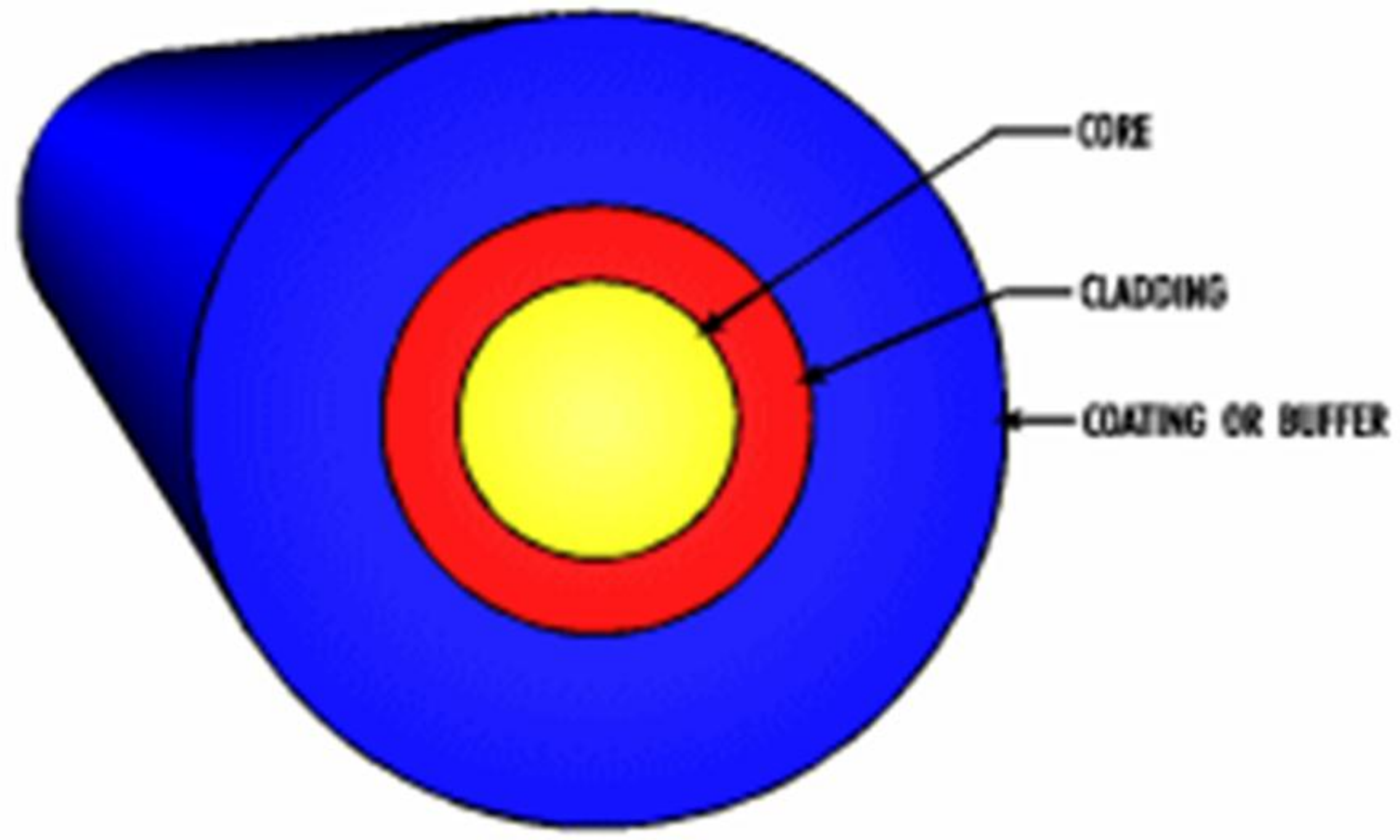
CROSS-SECTION OF AN OPTICAL FIBER



Fusion Splicing Methodology

Section 4 and 5

a. Fiber cleaning and Preparation

Removal of gel or any water-repellant chemical on the Fiber coating using fabric/paper tissue soaked with commercially available solvents or acrylic-friendly chemicals (Limonene Base)

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Fusion Splicing Methodology

Section 4 and 5

b. Coating Stripping

Removal of primary and secondary (if applicable) coating of bare fibers using Chemical, thermal or mechanical method. In case of chemical, manufacturer should supply safety information on chemical used. Mostly used method is mechanical.

For Ribbon Type Fibers, holders must be provided to strip, clean and splice to ensure good alignment.

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1. Removal of Coating

250 micron Coating

Exposing the Cladding & Core

Fiber Optic Strippers

125 & 900 micron Stripper (Mechanical)

125, 900 micron and 3mm Stripper (Mechanical)

125 & 900 micron Thermal Stripper

Ribbon Fiber Thermal Stripper

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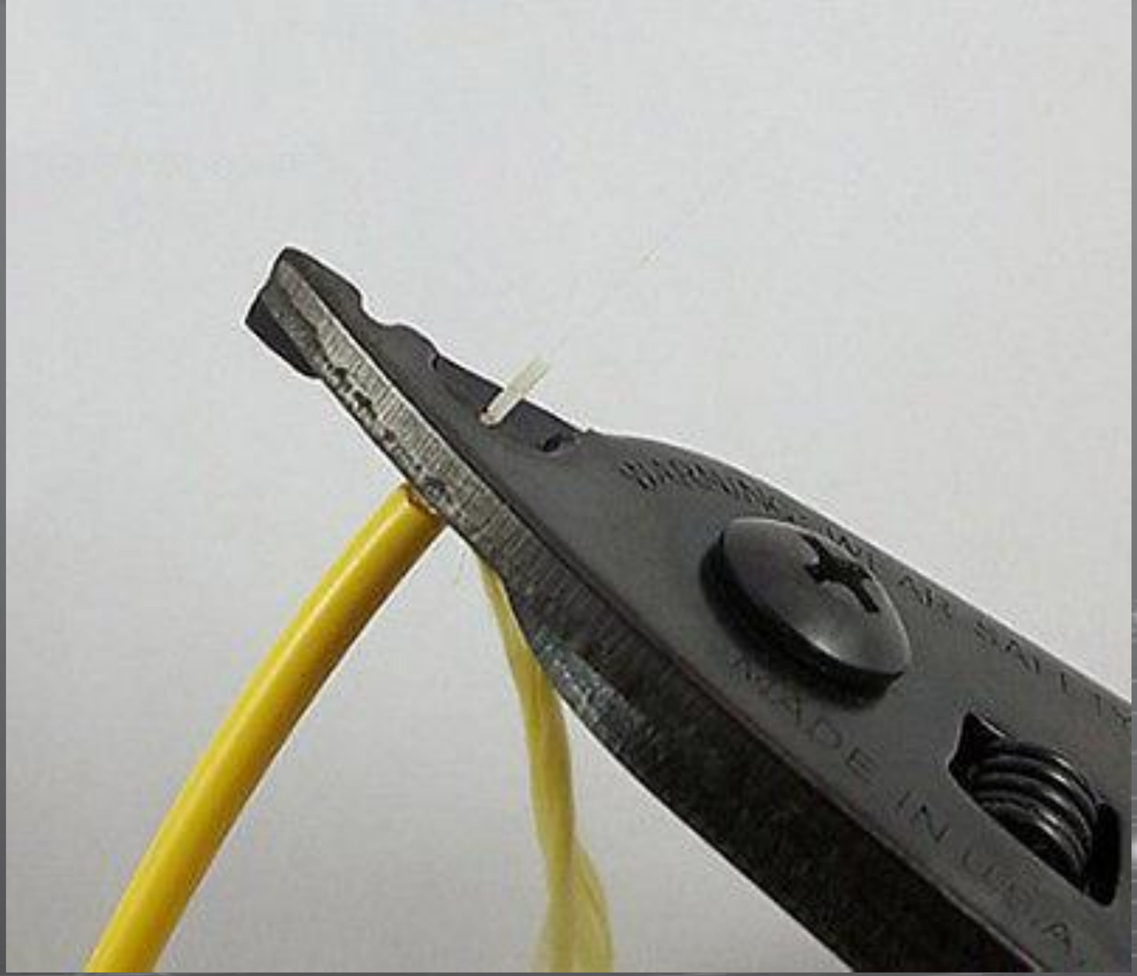
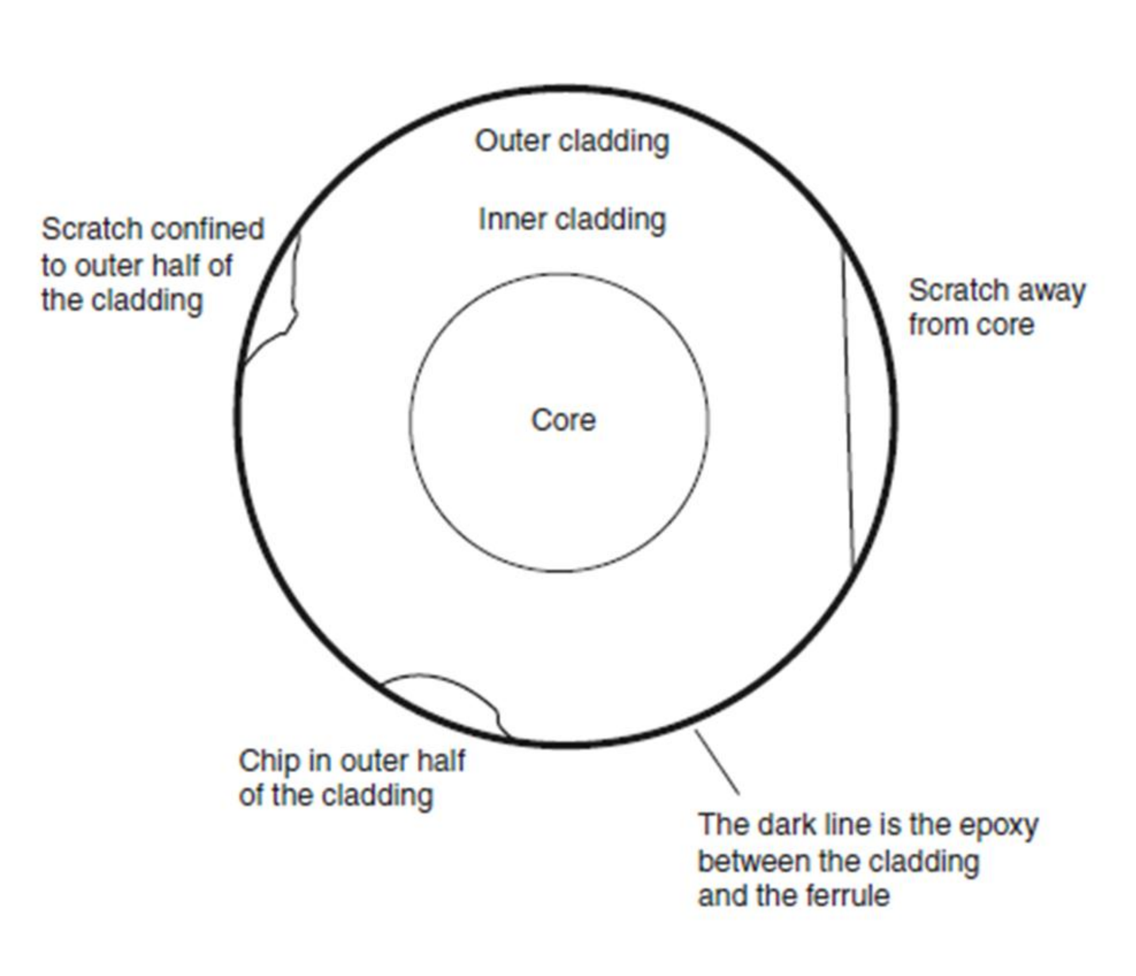
POORLY MAINTAINED STRIPPER CAN CREATE SCRATCHES ON CLADDING





Fusion Splicing Methodology

Section 4 and 5

c. Cleaning of bare fiber ends

Alcohol Dispenser

Lint free cloth/tissue

Fusion Splicing Methodology

Section 4 and 5

c. Cleaning of bare fiber ends

Isopropyl Alcohol
>95%

Isopropyl Alcohol
< 70%

Fusion Splicing Methodology

Section 4 and 5

d. Fiber cleaving

The bare fiber ends shall be cleaved perpendicularly to the longitudinal axis; the cut surface should be mirror-like without chip or hackle.

For Fusion splices, end angles should be <u>less than 1 degree</u>

For Mechanical splice, end angles <u>should be less than 4 degrees</u>

Cleaver should always be cleaned.

GOOD CLEAVER, GOOD SPLICE

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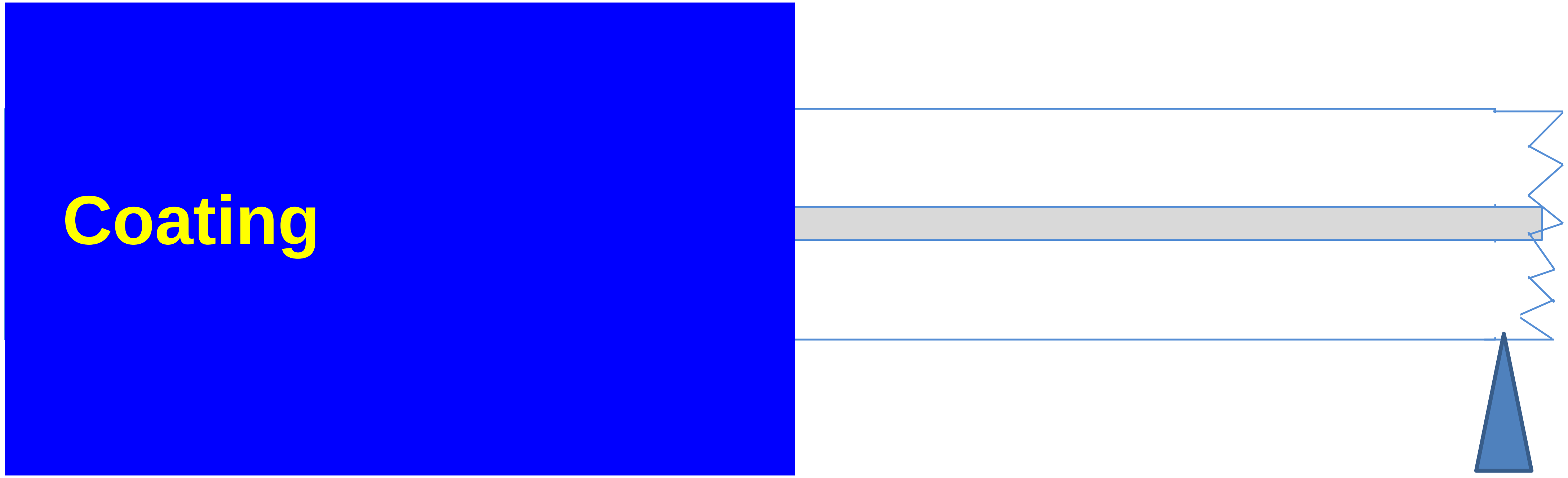
Coating



2. Cleaving the end of the fiber

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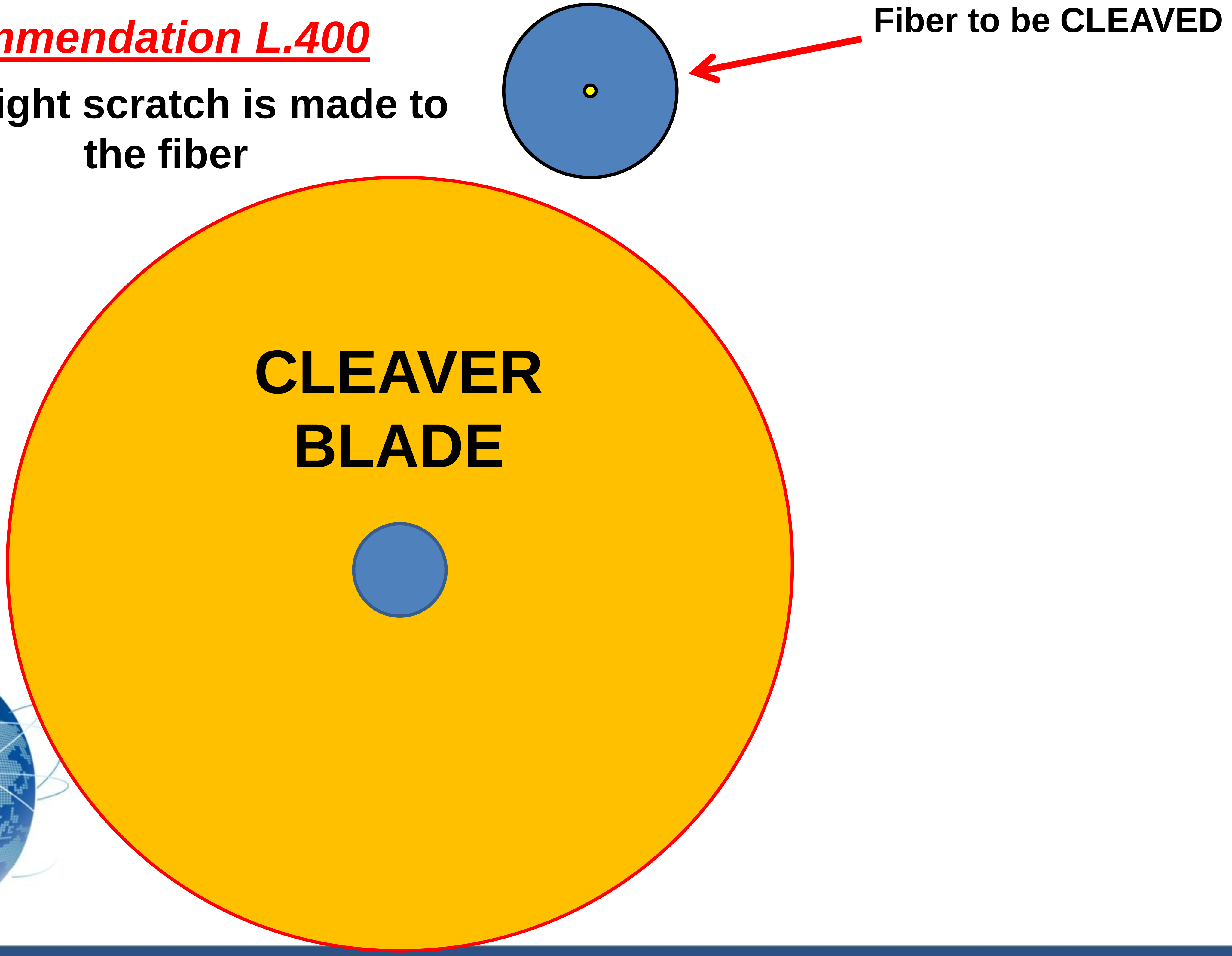
Very light scratch is made to the fiber



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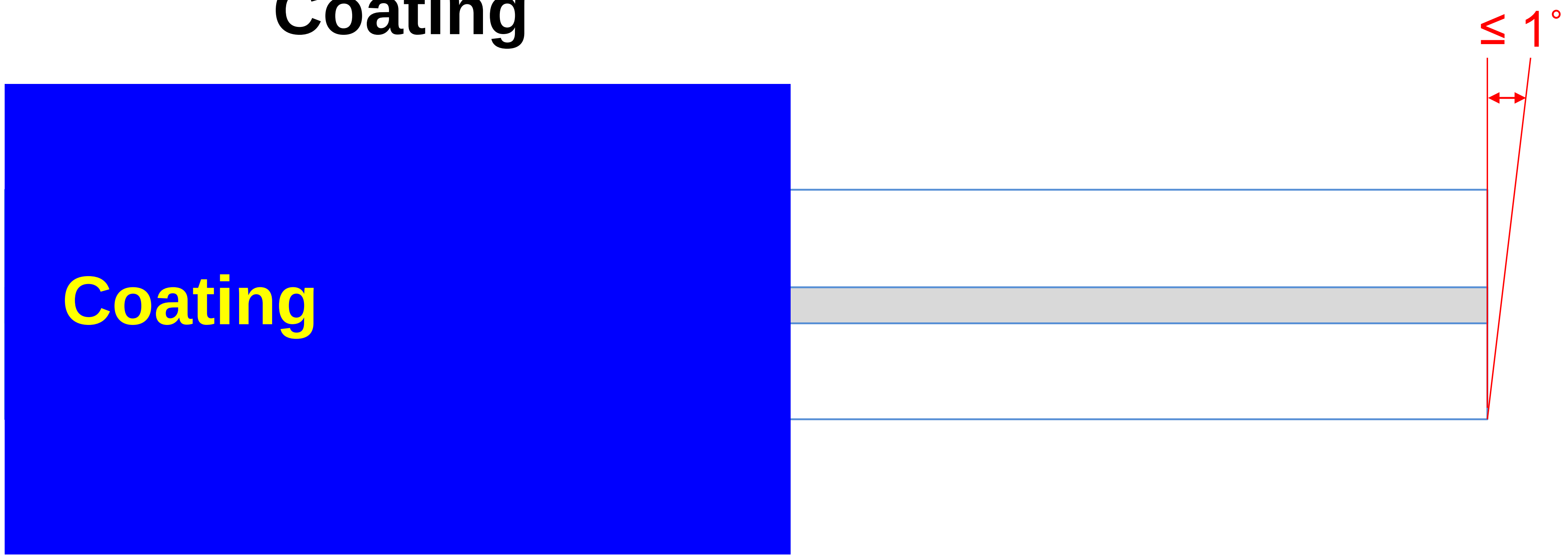
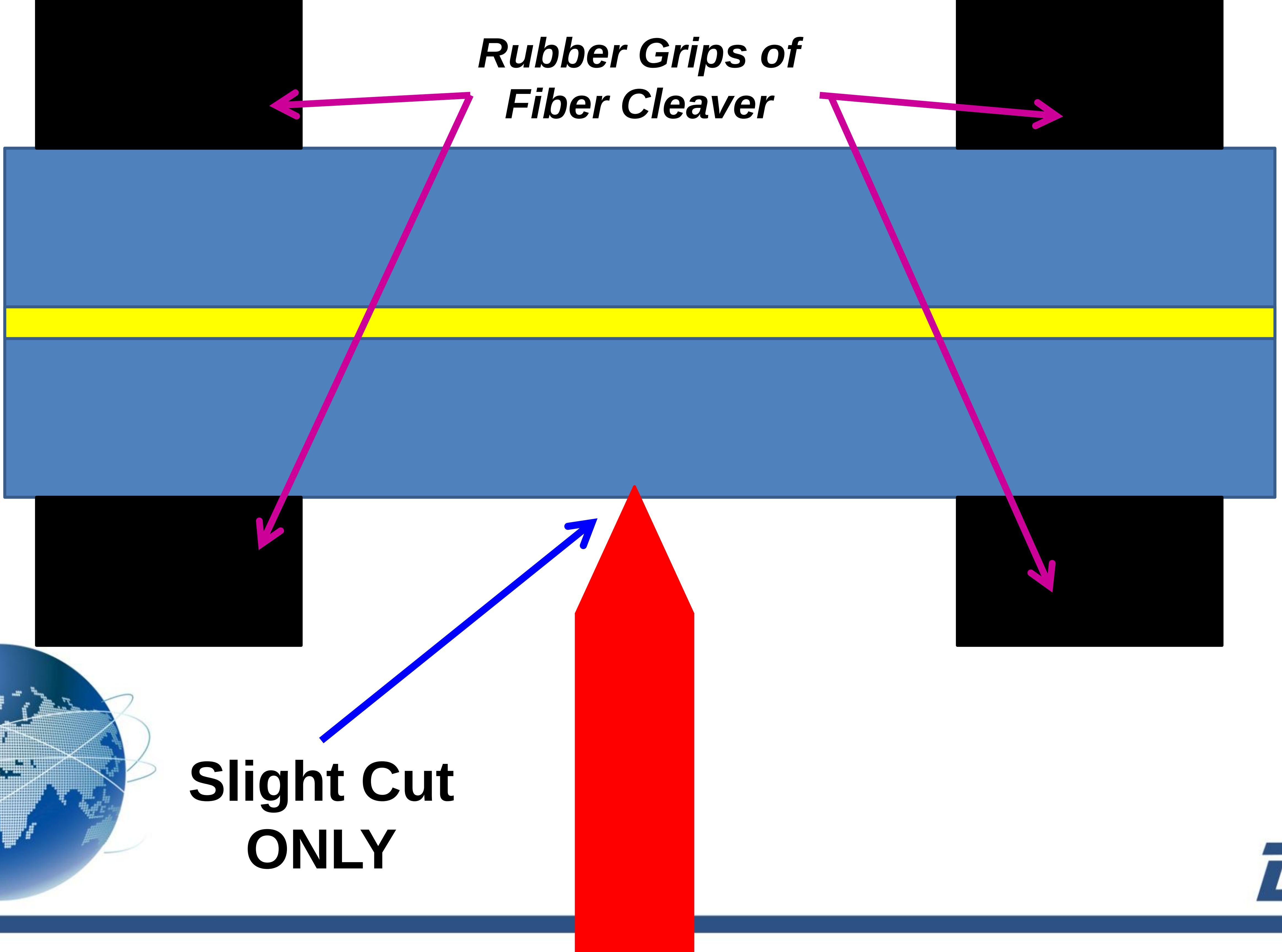
Angle should not be more than 1°
(fusion splicing)

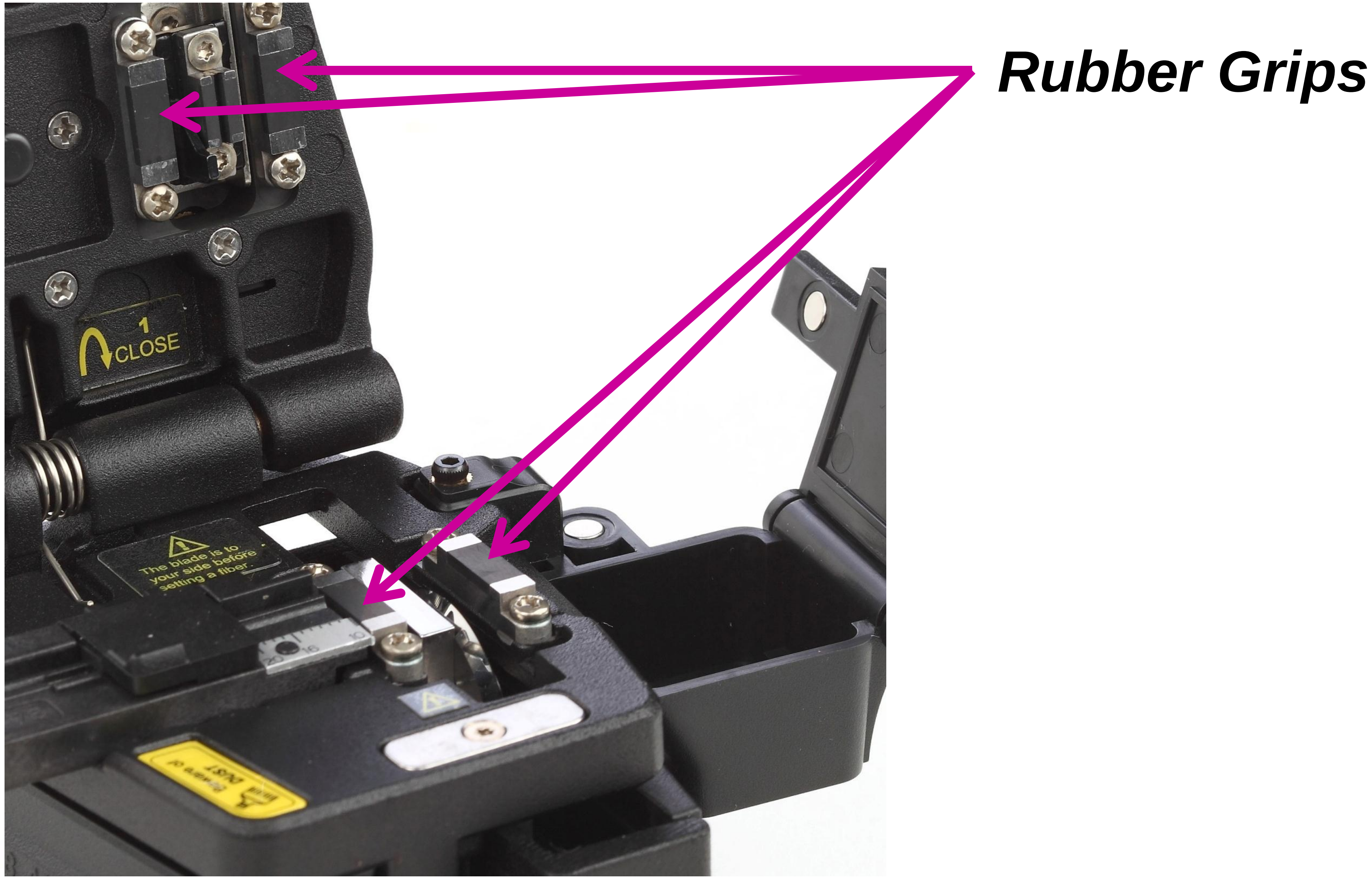
Coating



2. Cleaving the end of the fiber


Rubber Grips of
Fiber Cleaver
Slight Cut
ONLY

Fiber Optic Cleaver

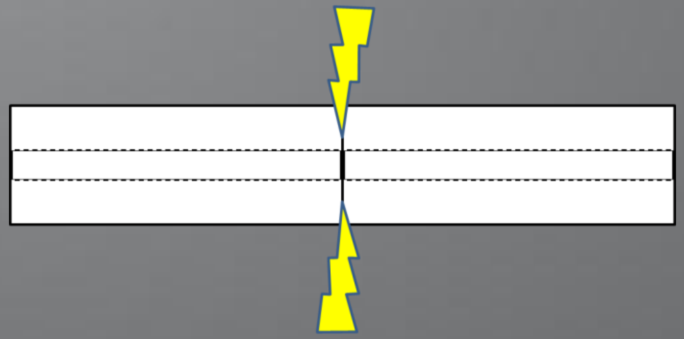


Fusion Splicing Methodology

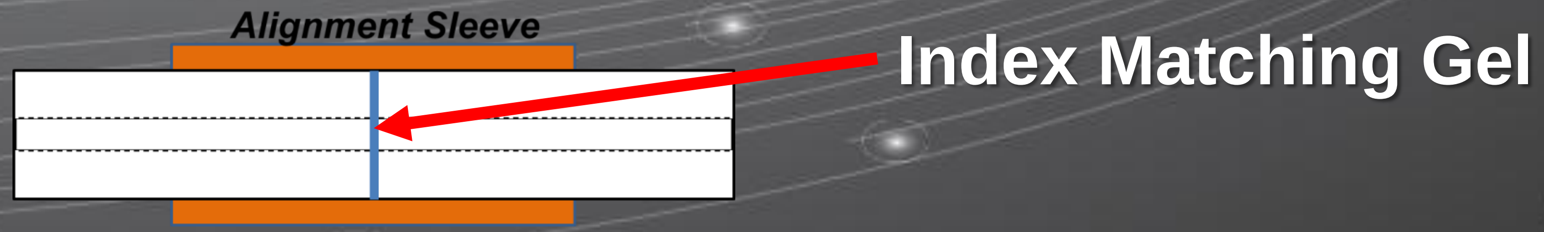
Section 4 and 5

e. Splicing

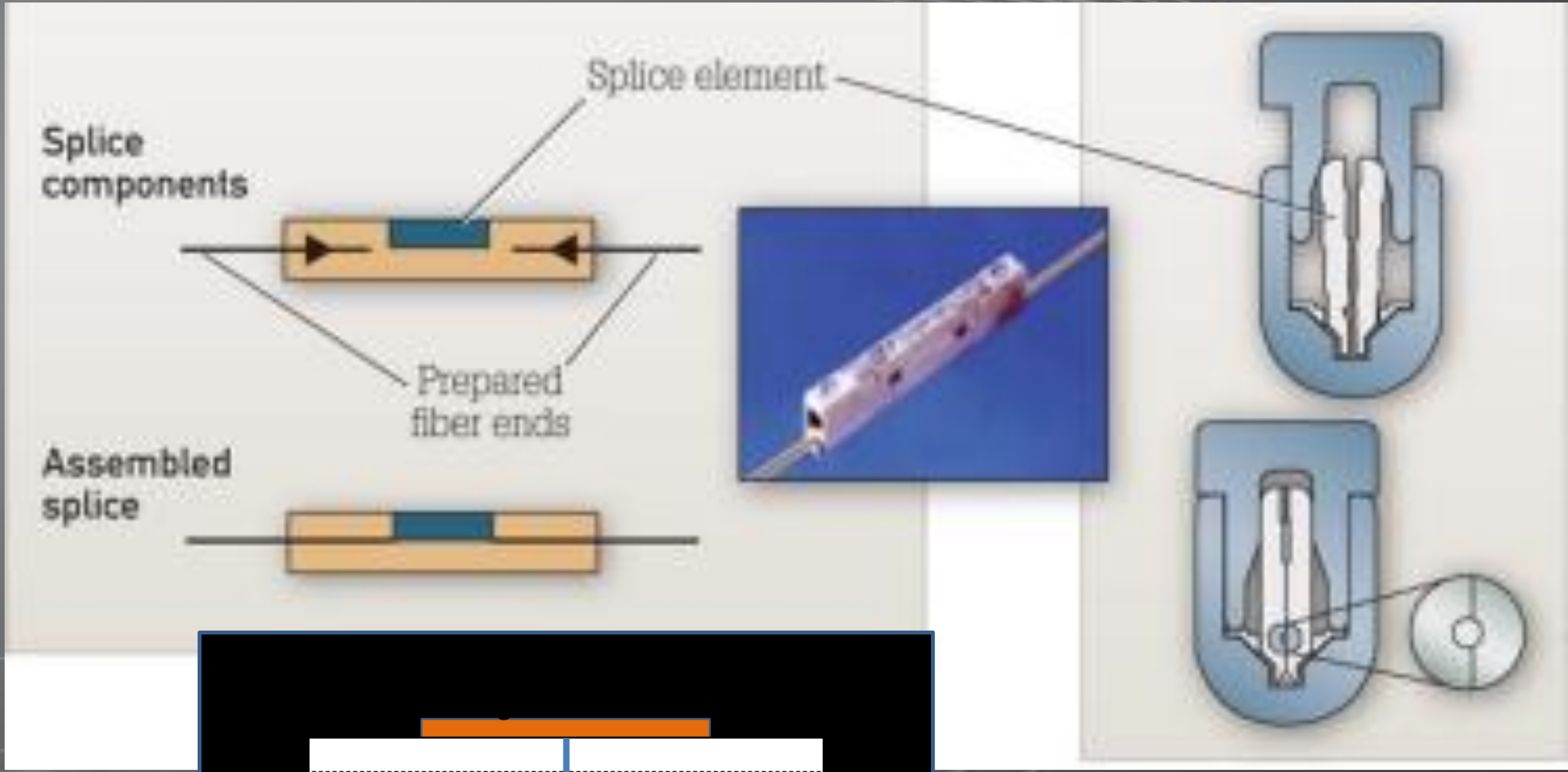
5.5.1 Fusion Splicing (Permanent)

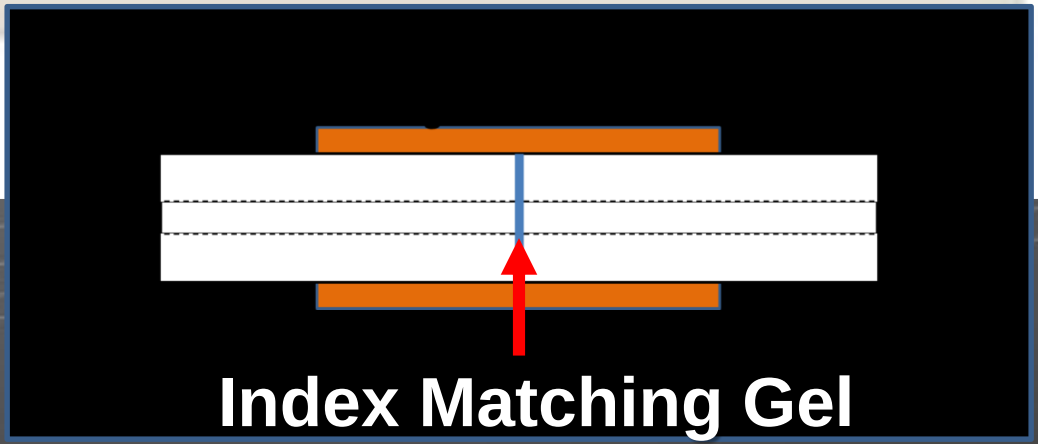


5.5.2 Mechanical Splicing (Semi-permanent)

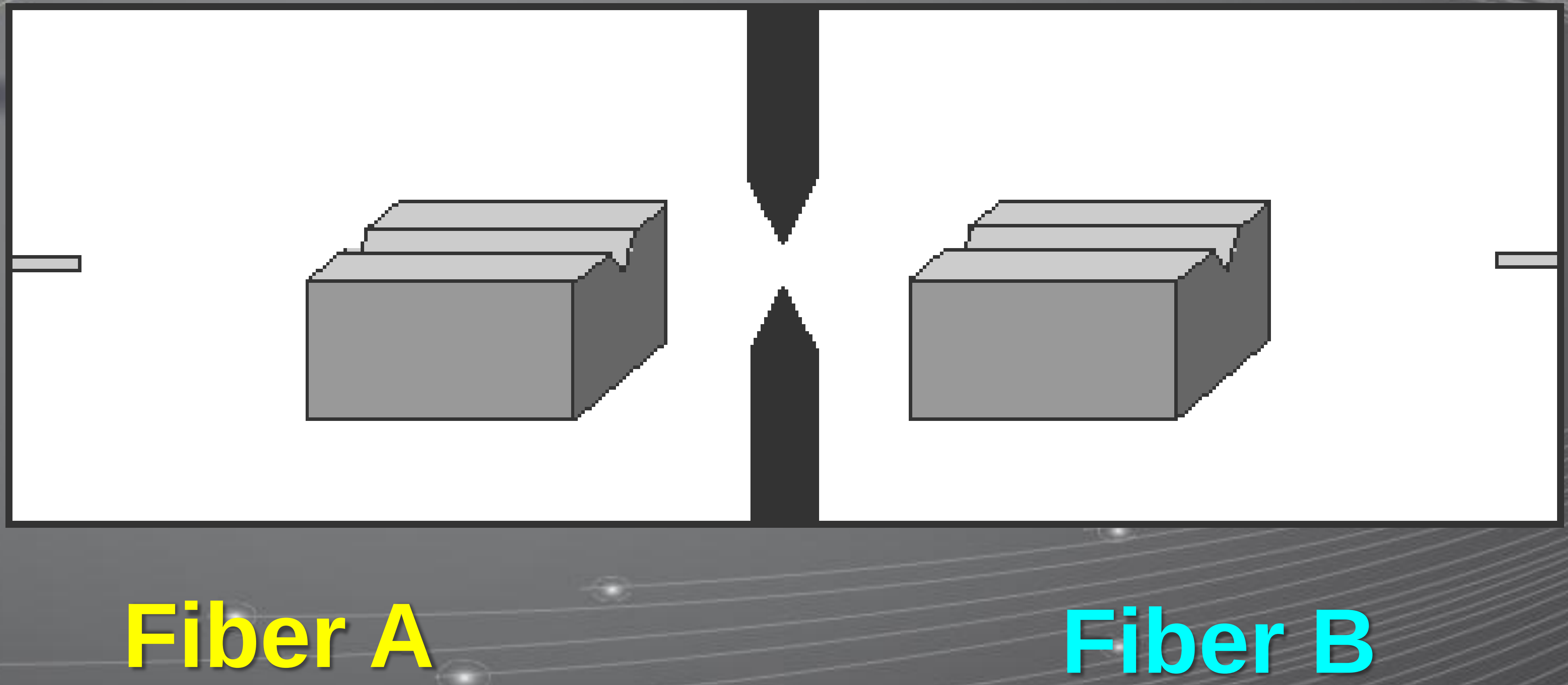


MECHANICAL (FIBER OPTIC) SPLICE





Fusion Splicing



Fusion Splicing Methodology

Section 4 and 5

5.5.1 Electric Arc Fusion Splicing

5.5.1.1 Control of the Splicing parameter and conditions

5.5.1.2 Fusion Splicing

5.5.1.3 Proof Test

5.5.1.4 Splice Protection

Fusion Splicing Methodology

Section 4 and 5

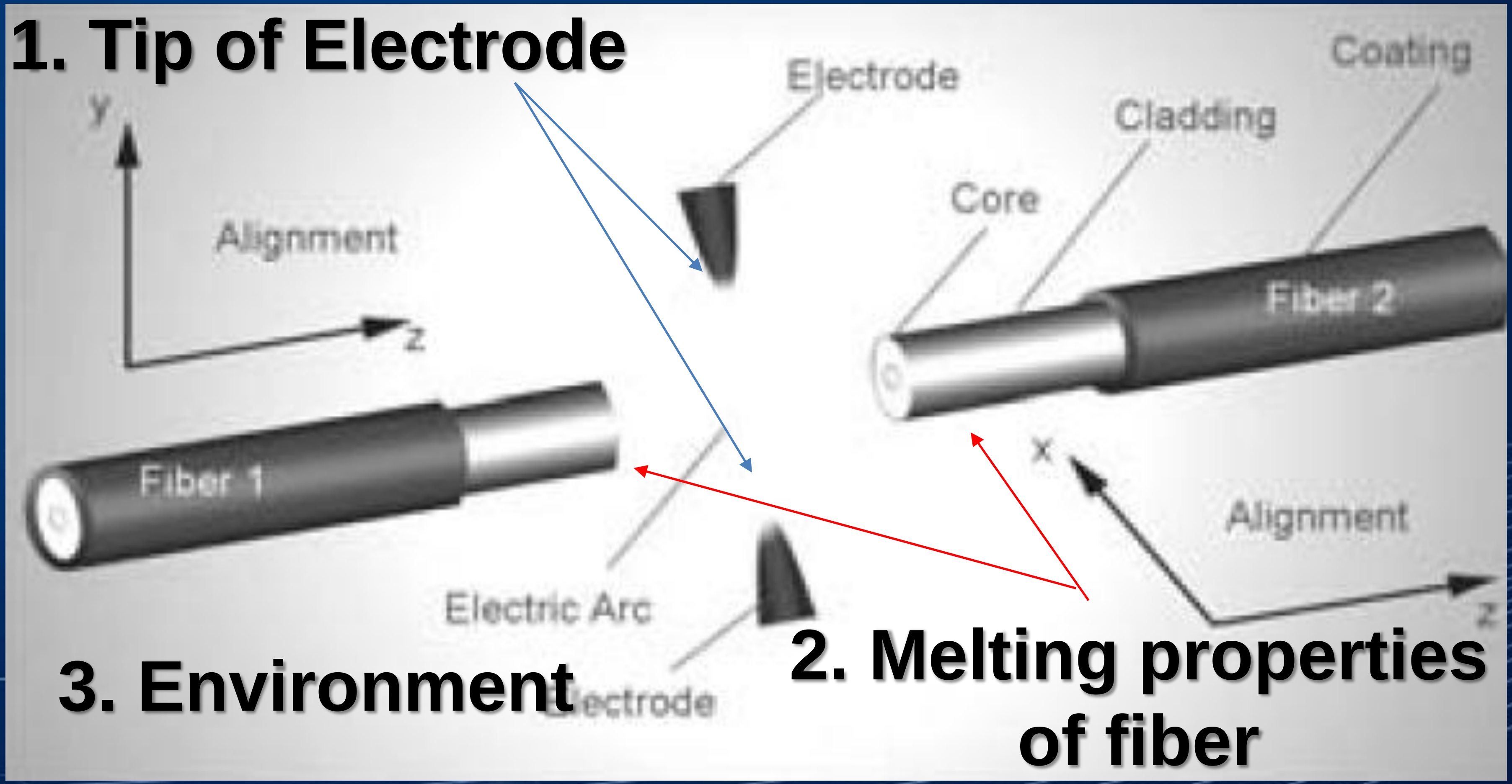
5.5.1 Electric Arc Fusion Splicing

5.5.1.1 Control of the Splicing parameter and conditions

Checking performance of Splicing Machine to adapt on the following:

- Condition of Electrode
- Type of Fiber
- Environmental conditions

Factors Affecting Fusion Splicing



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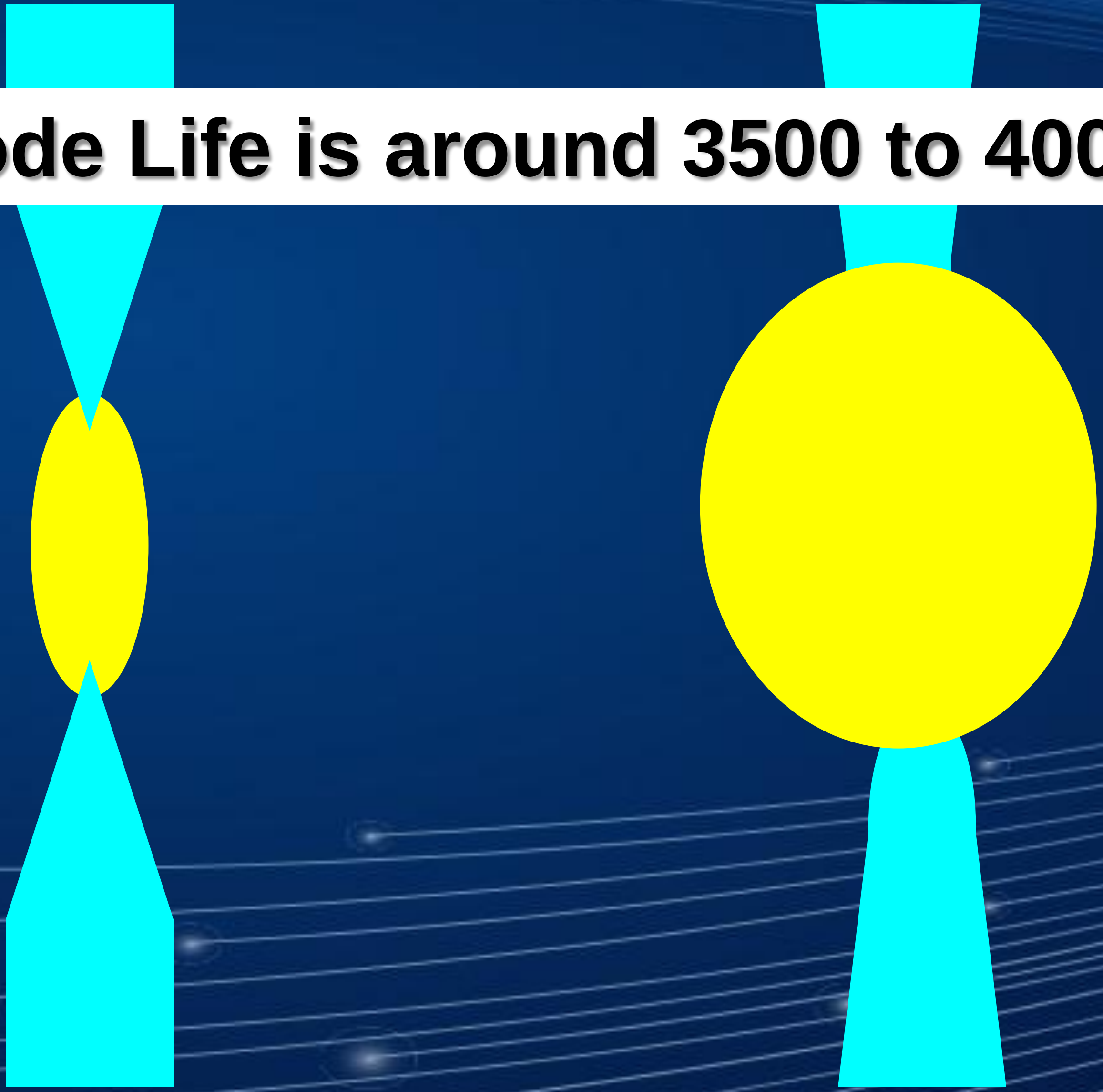
Condition of Electrode

Electrode Life is around 3500 to 4000 Splices

Brand New Electrode (Sharp Tip)



Old Electrode (Rounded Tip)

ELECTRODE TIP DISCHARGE

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Fiber Physical Dimensions And Material Properties

Table 4 – ITU-T G.652.D attributes

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1310 nm
	Range of nominal values	8.6-9.5 μm
	Tolerance	±0.6 μm
Cladding diameter	Nominal	125.0 μm
	Tolerance	±1 μm
Core concentricity error	Maximum	0.6 μm
Cladding noncircularity	Maximum	1.0%
Cable cut-off wavelength	Maximum	1260 nm
Macrobend loss	Radius	30 mm
	Number of turns	100
	Maximum at 1625 nm	0.1 dB
Proof stress	Minimum	0.69 GPa
Chromatic dispersion coefficient	λ_{0min}	1300 nm
	λ_{0max}	1324 nm
	S_{0max}	0.092 ps/nm^2 × km

Fiber manufacturer should comply with this specifications

Fusion Splicing Methodology

Section 4 and 5

5.5.1 Electric Arc Fusion Splicing

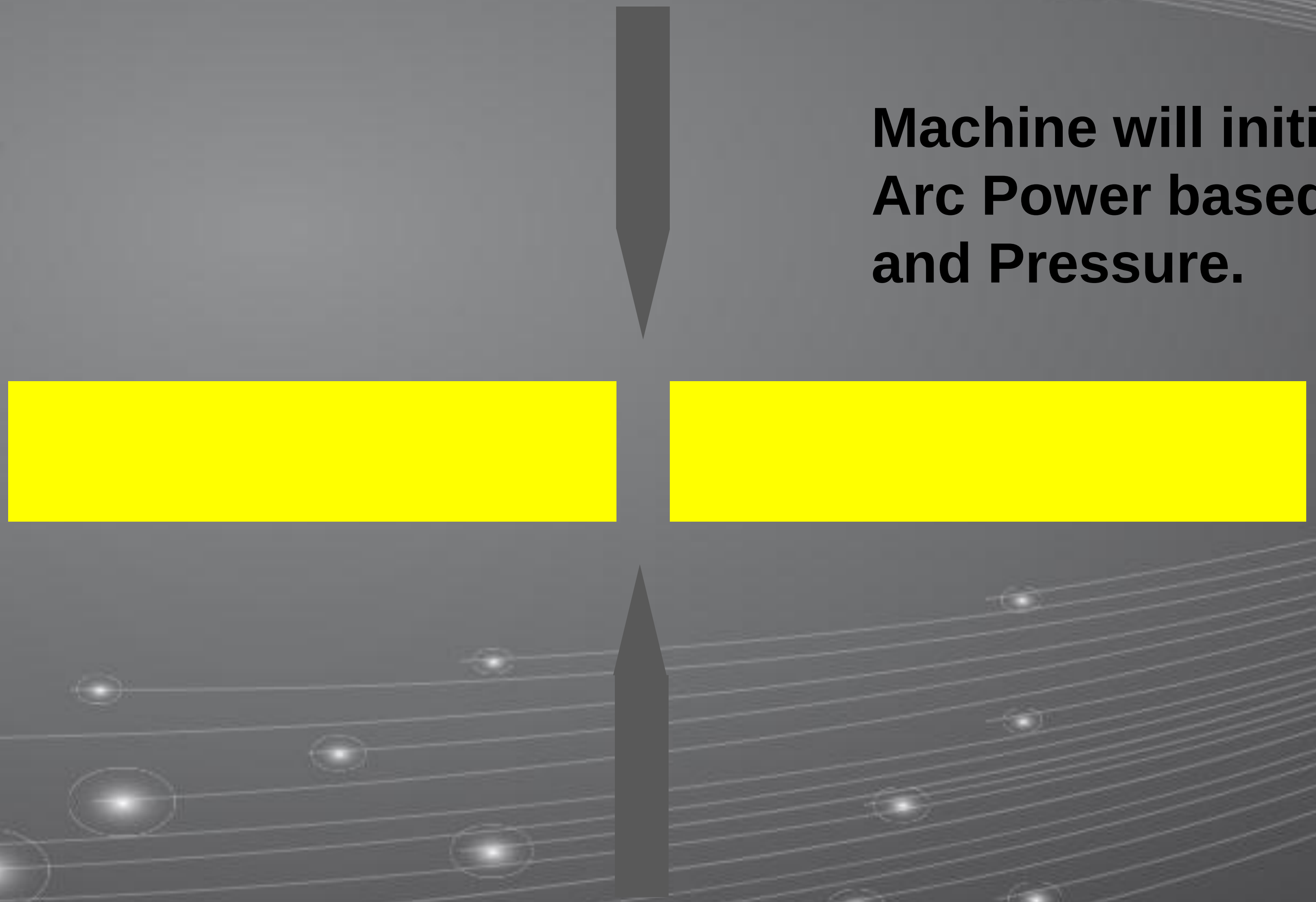
5.5.1.1 Control of the Splicing parameter and conditions

“ARC Calibration” or “ARC Test” Features

**This feature allow the fusion splicer to
Adjust the Electrode Power and position
Based on Temperature, Atmospheric Pressure
And Relative Humidity**

5.5.1.1 Control of the Splicing parameter and conditions

ARC CALIBRATION

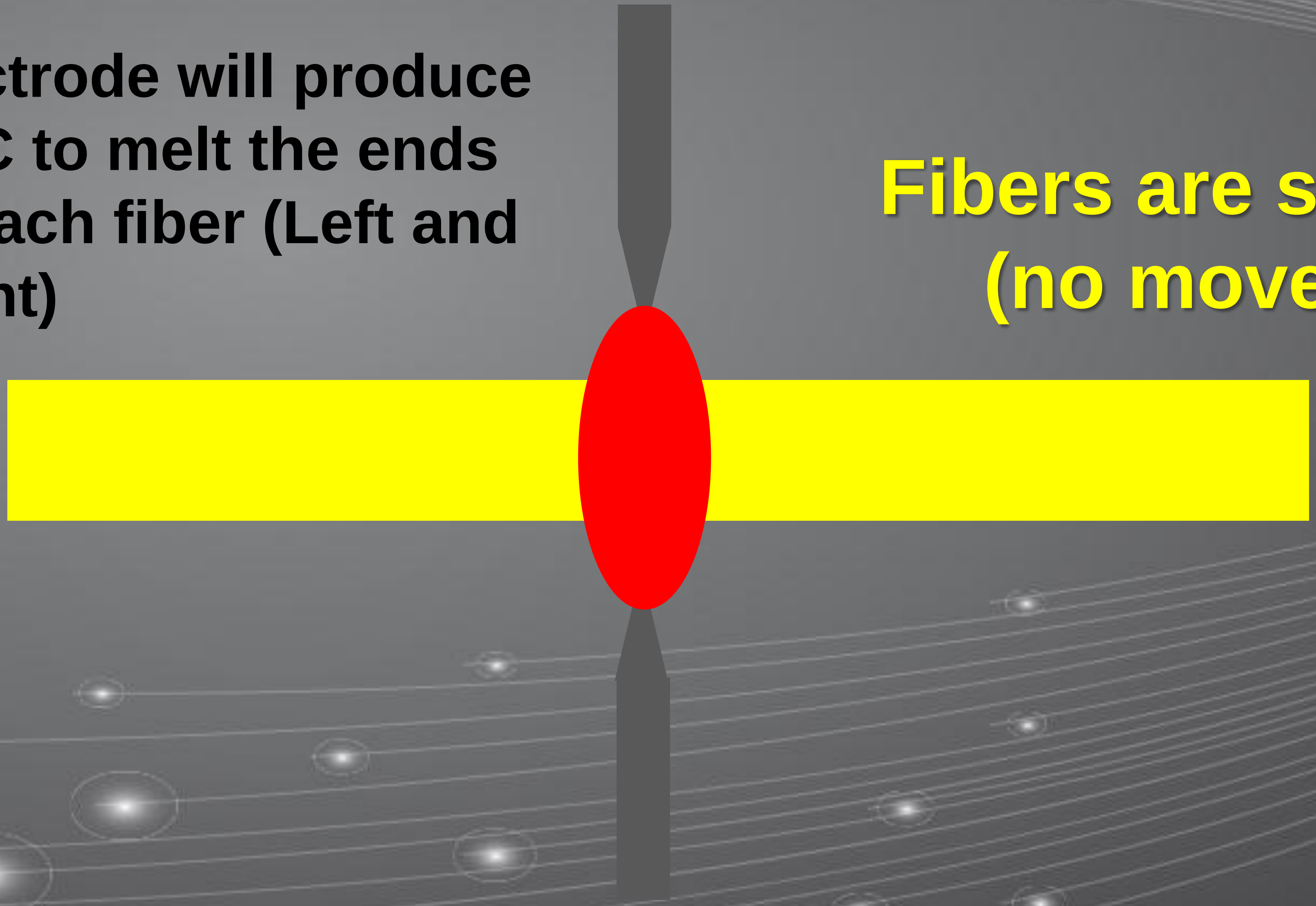


Machine will initially adjust the Arc Power based on Temp, RH and Pressure.

5.5.1.1 Control of the Splicing parameter and conditions

ARC CALIBRATION

Electrode will produce ARC to melt the ends of each fiber (Left and Right)

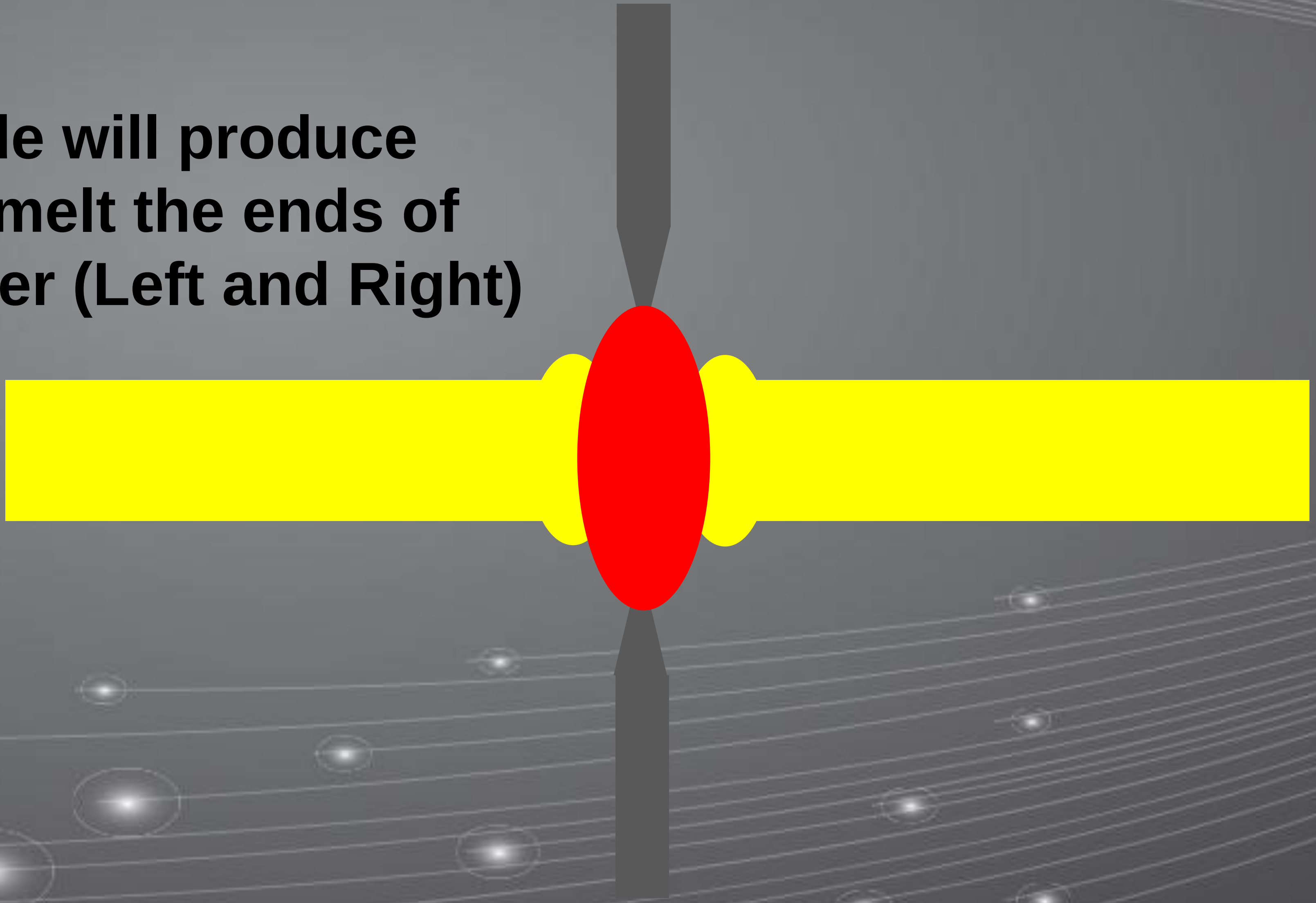


Fibers are stationary (no movement)

5.5.1.1 Control of the Splicing parameter and conditions

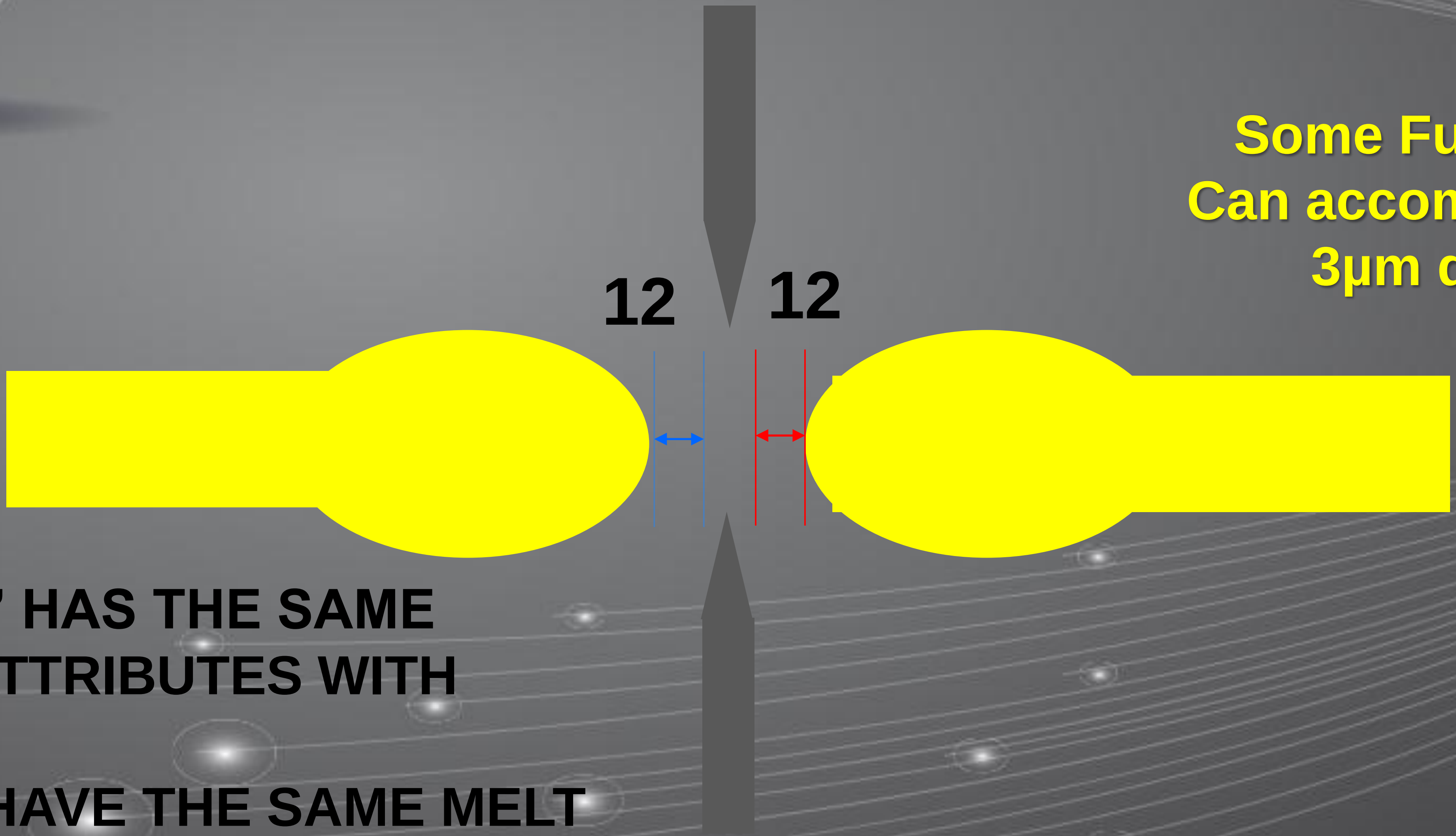
ARC CALIBRATION

Electrode will produce ARC to melt the ends of each fiber (Left and Right)



5.5.1.1 Control of the Splicing parameter and conditions

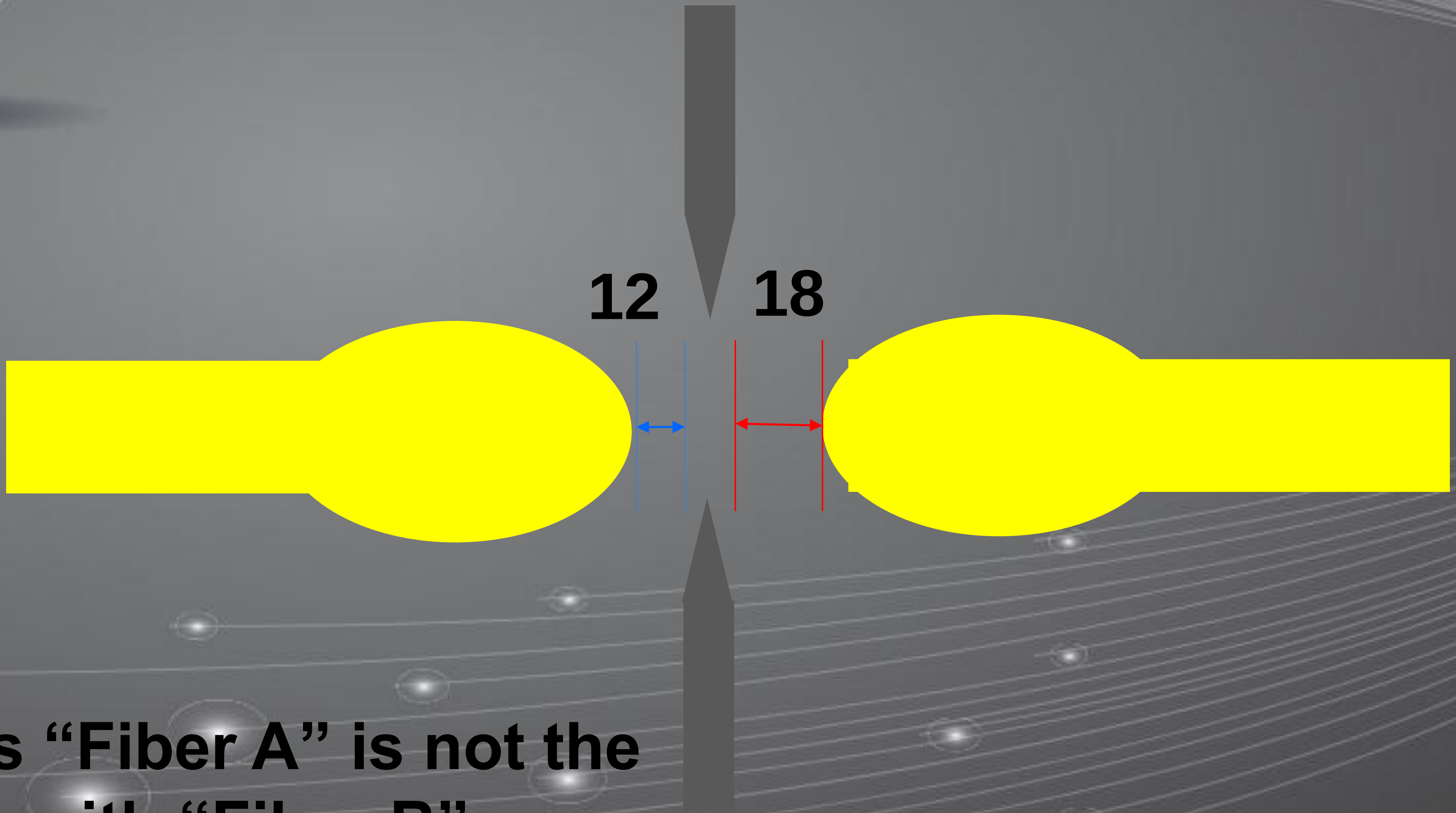
ARC CALIBRATION



Some Fusion Splicer Can accommodate up to 3µm difference

IF “FIBER A” HAS THE SAME PHYSICAL ATTRIBUTES WITH “FIBER B”
THEY WILL HAVE THE SAME MELT DISPLACEMENT

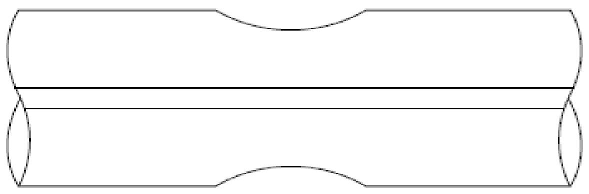
ARC CALIBRATION



This means "Fiber A" is not the Same with "Fiber B"

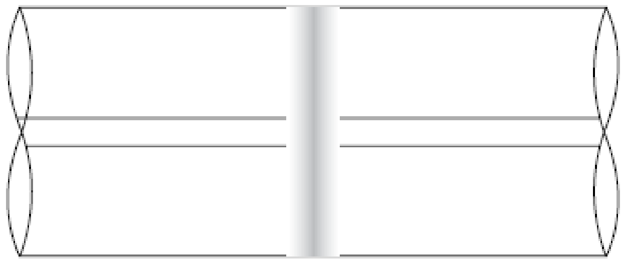
If ARC Calibration is not performed, it might yield to a defective splice

Defective Fusion Splice Images

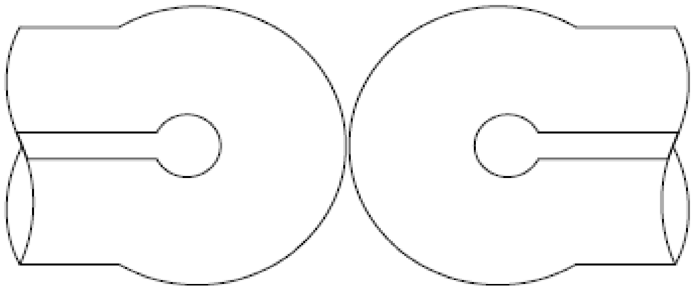


Thinning

Fat or Bulging

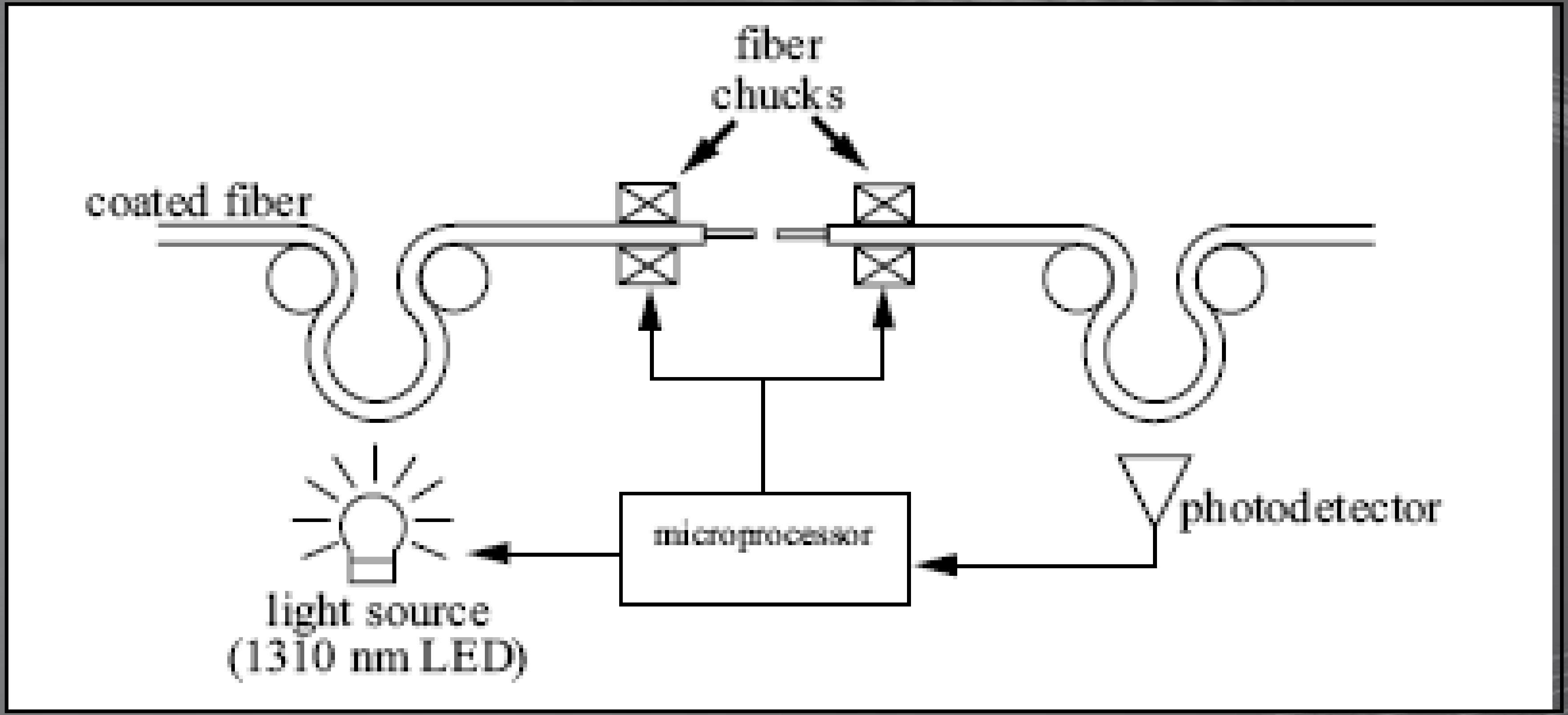


Line or Gap



Separation

Types of Fusion Splicing

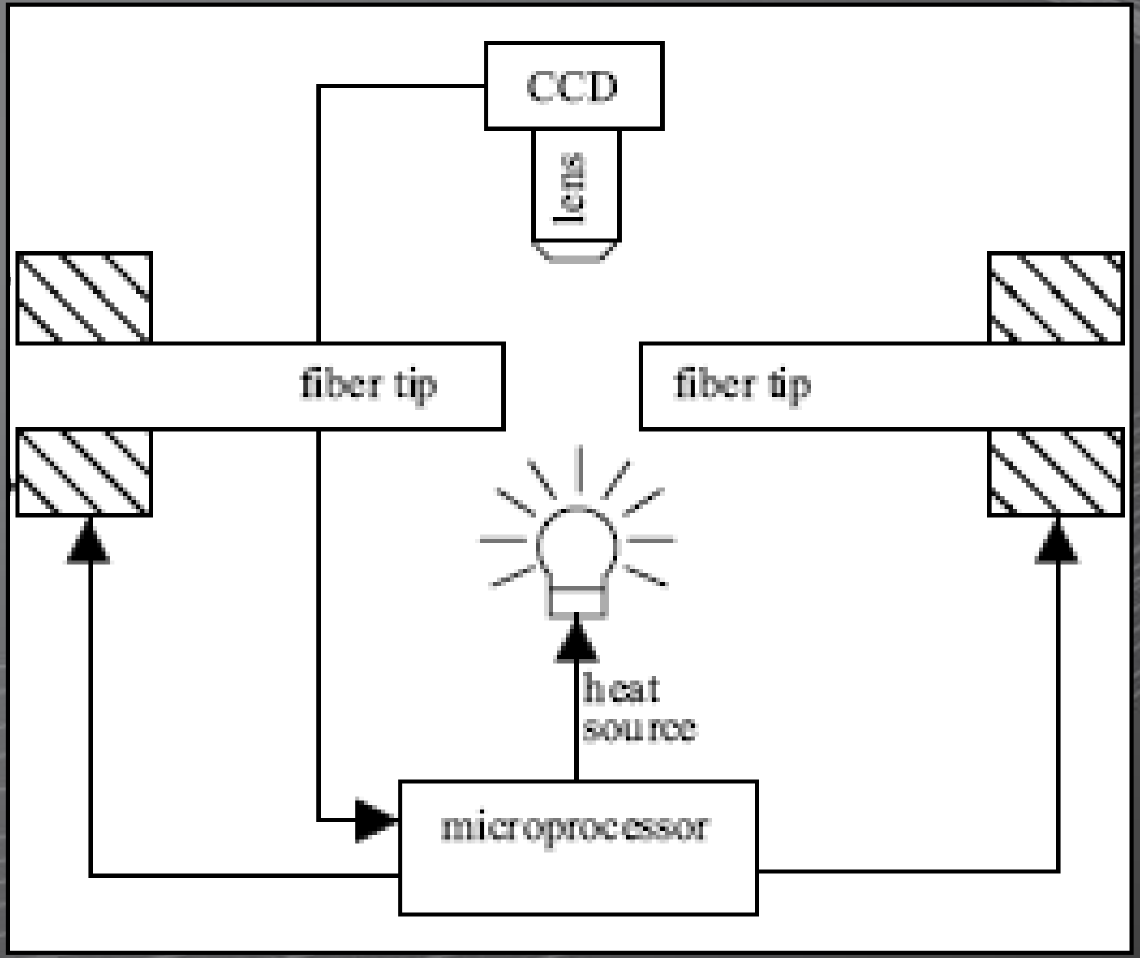


- **LID (Light Injection & Detection)**

The coated fiber is bent near the fiber tips to launch light and detect light. The arrows denote the flow of control to or from the microprocessor. Cannot splice if there if fiber is working or with signal.

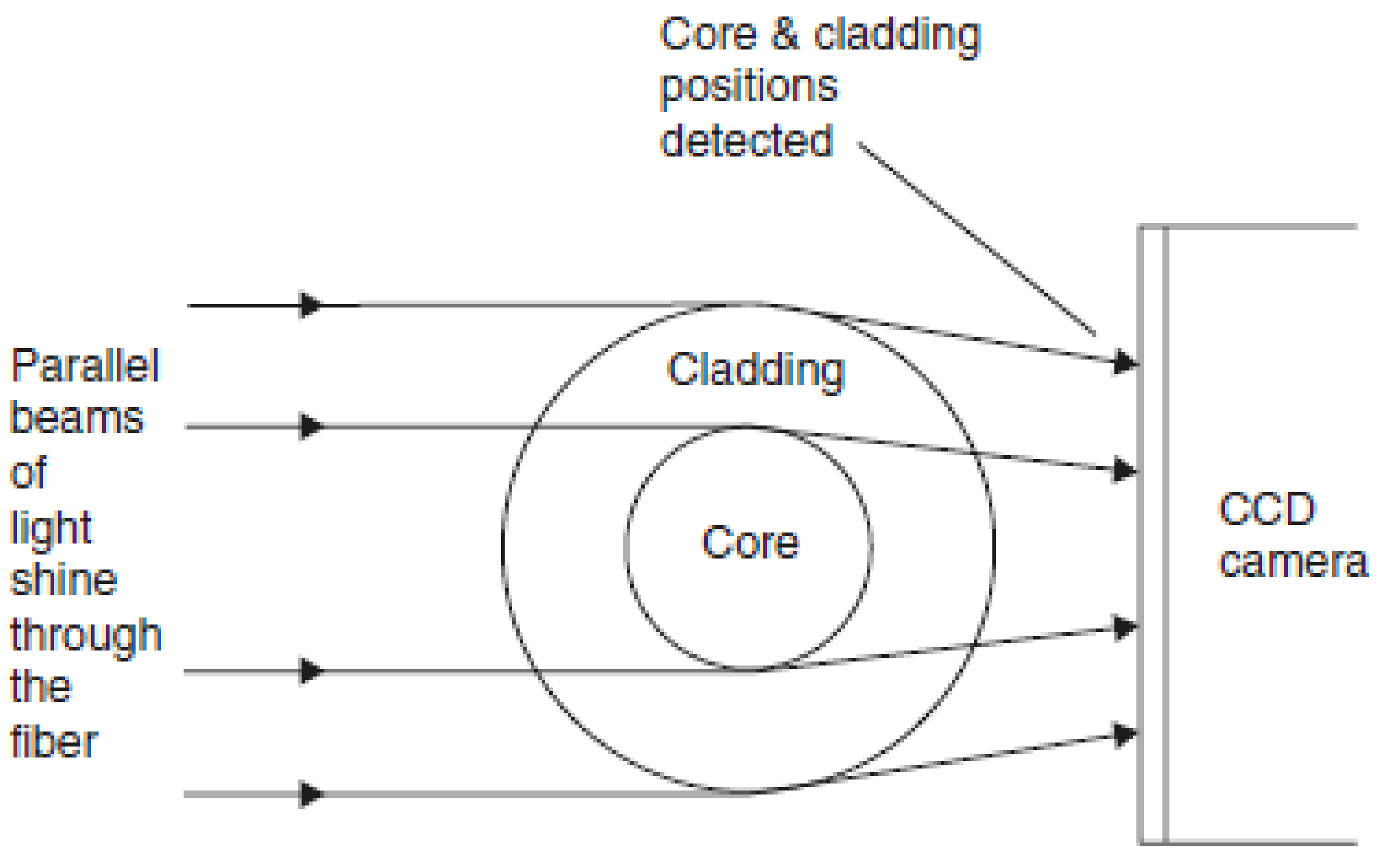
Types of Fusion Splicing

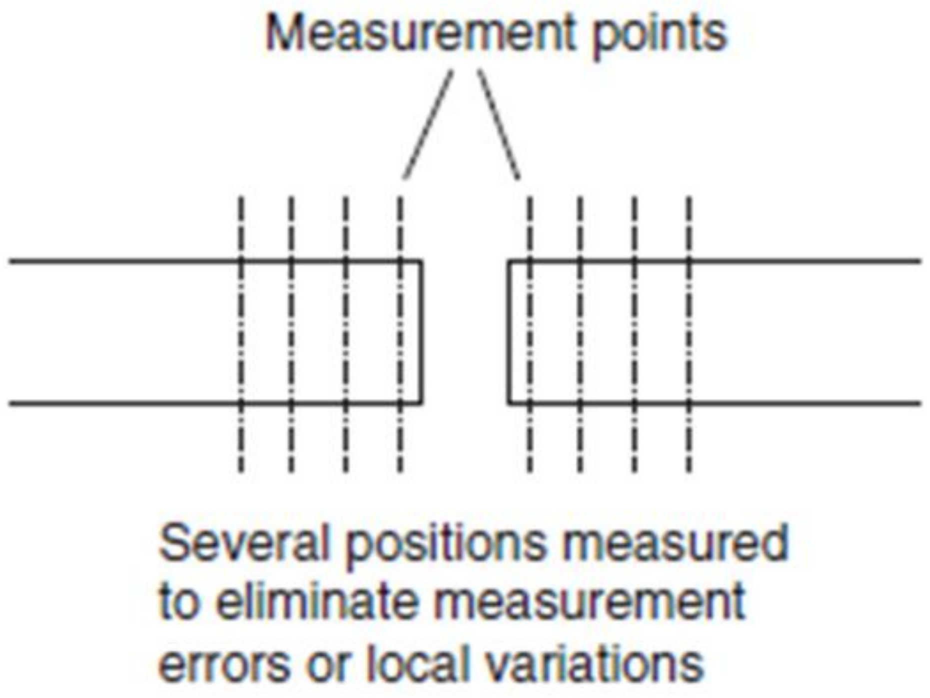
- **PAS (Profile Alignment System)**
- Components of a simplified fusion splicer including heat source, imaging lens, CCD, microprocessor, and chucks for positioning and aligning fiber tips. The thin arrows denote the flow of control to or from the microprocessor



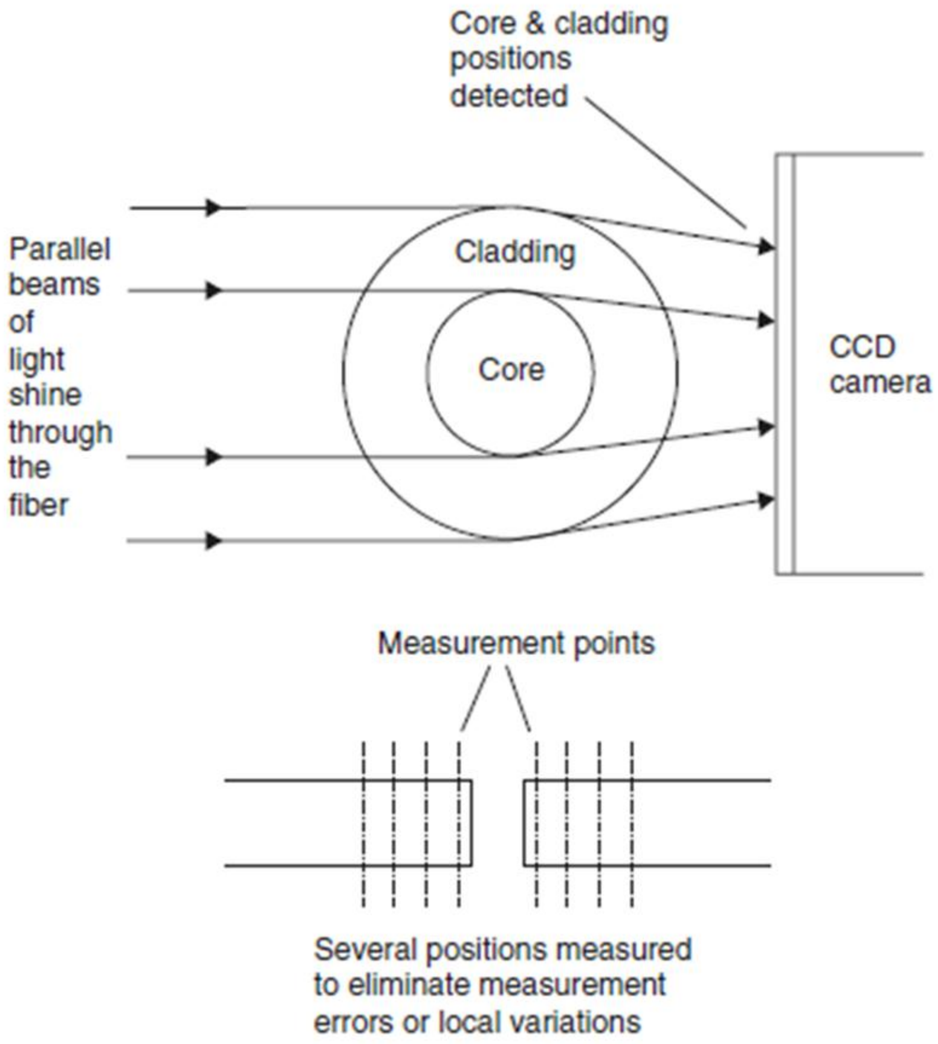
Fiber Splice Method

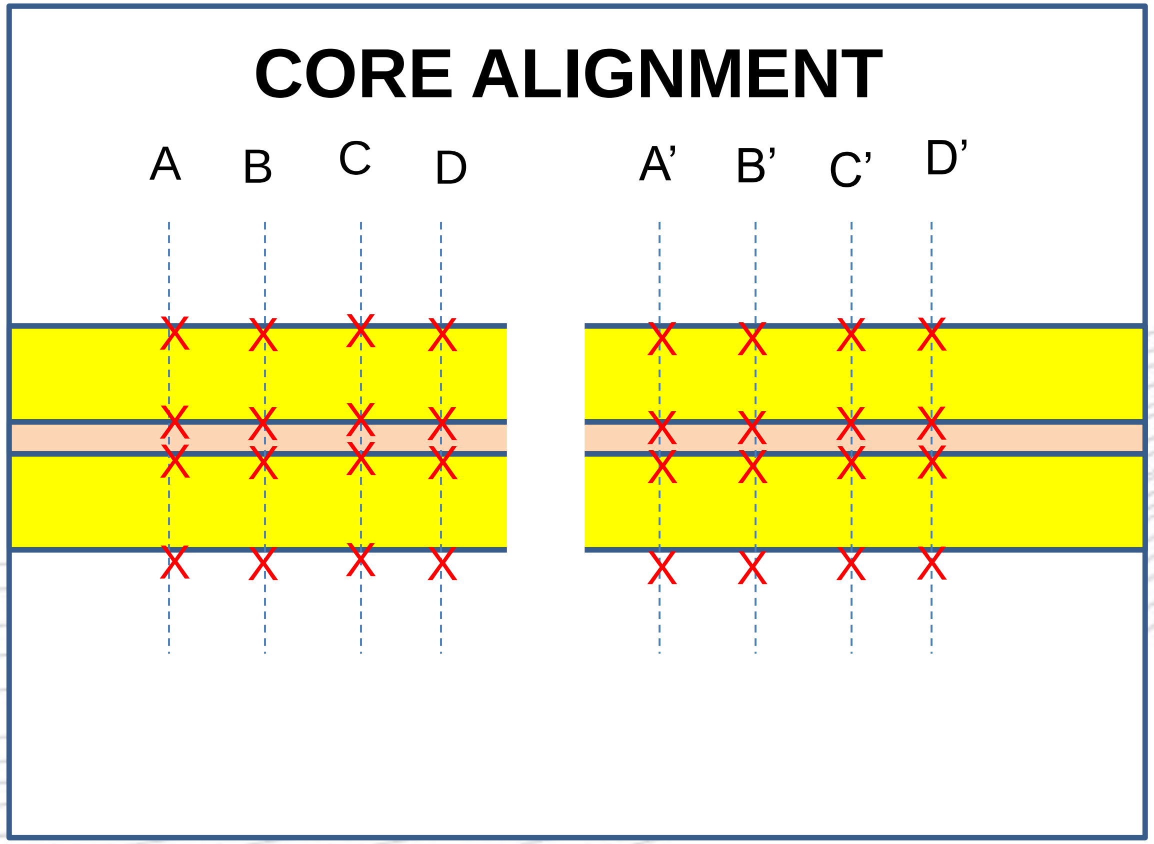
Profile Alignment System (PAS)



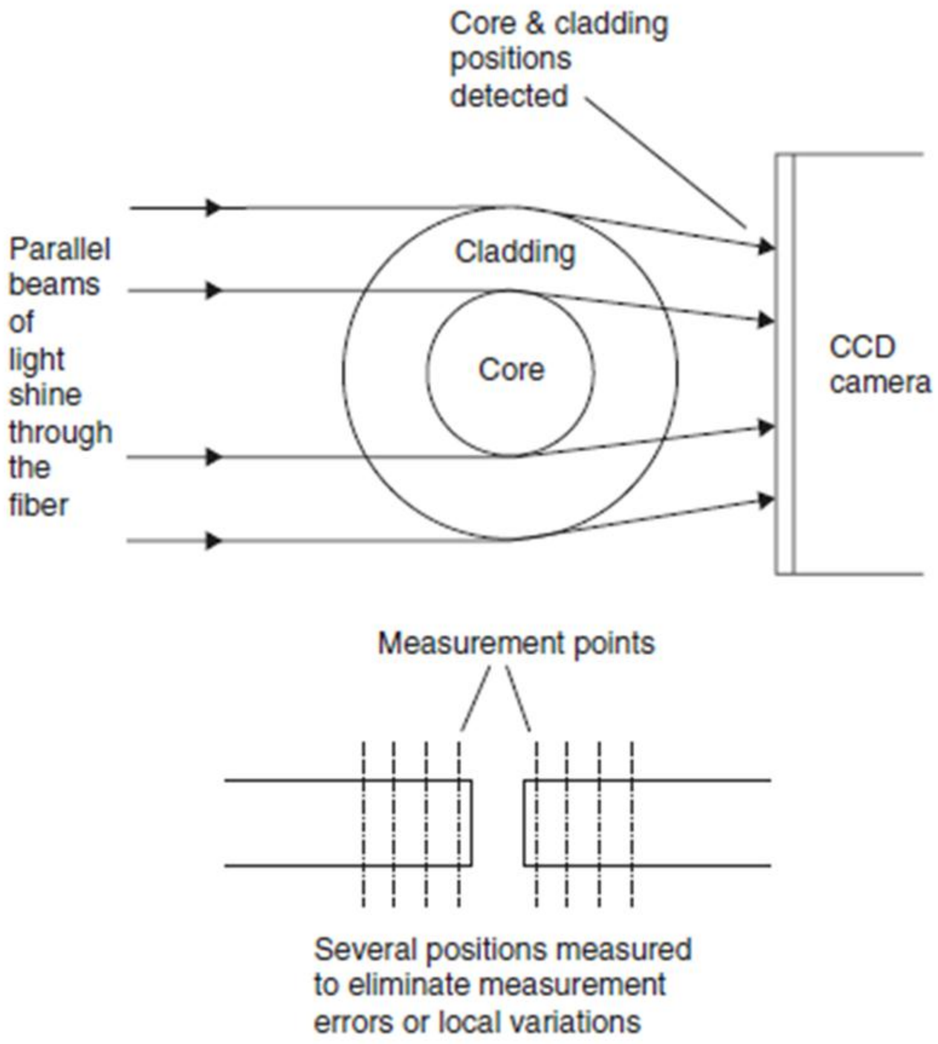


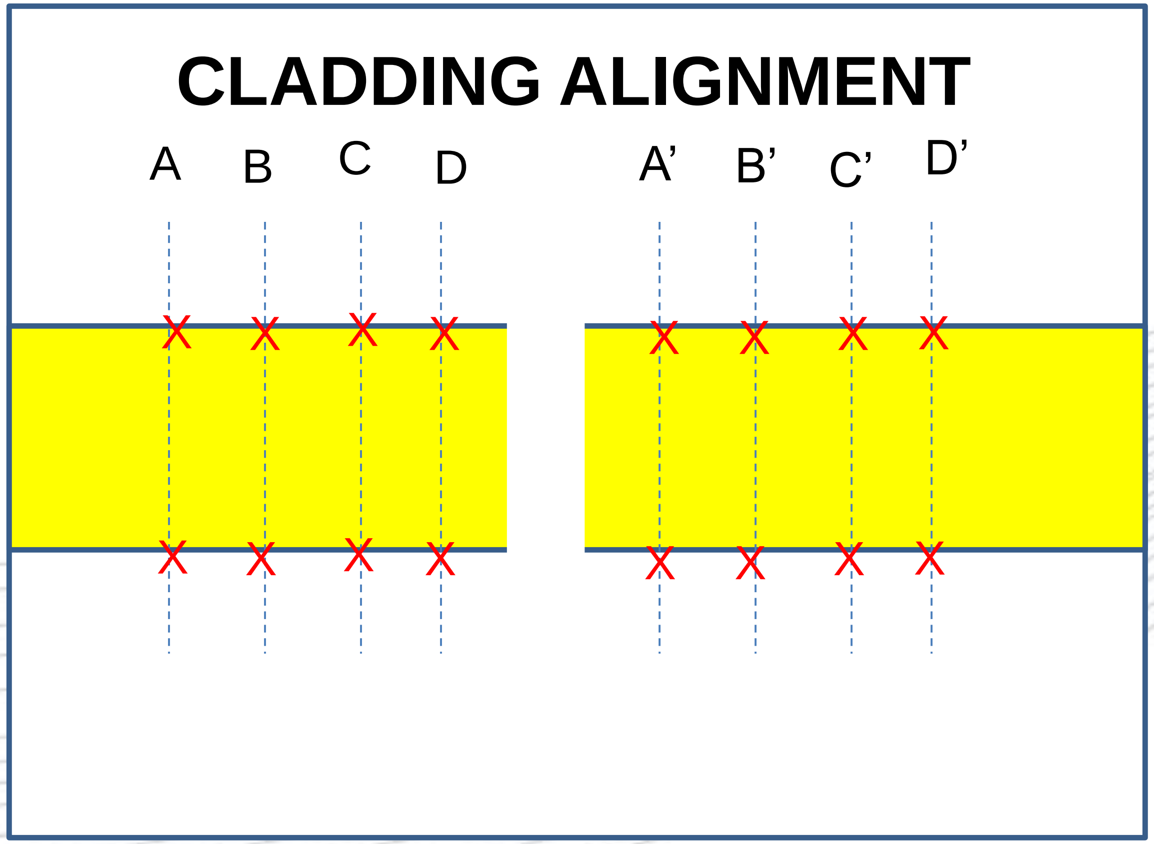
Estimated Splice Loss Measurement





Estimated Splice Loss Measurement





Core is not visible since it
Only concern is cladding

Fusion Splicing Methodology

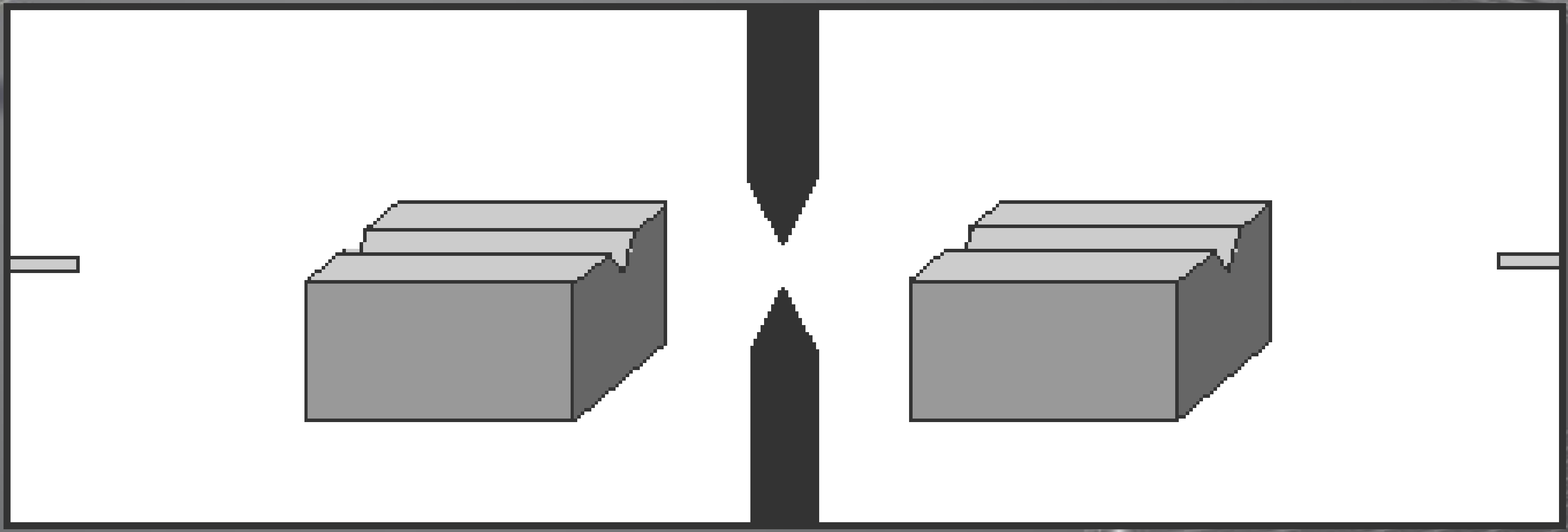
Section 4 and 5

5.5.1 Electric Arc Fusion Splicing

5.5.1.2 Fusion Splicing

Electric arcs heat the silica glass until it melts
in which fibers are longitudinally brought together
to obtain a geometrically continuous splice

Fusion Splicing



Fiber A

Fiber B

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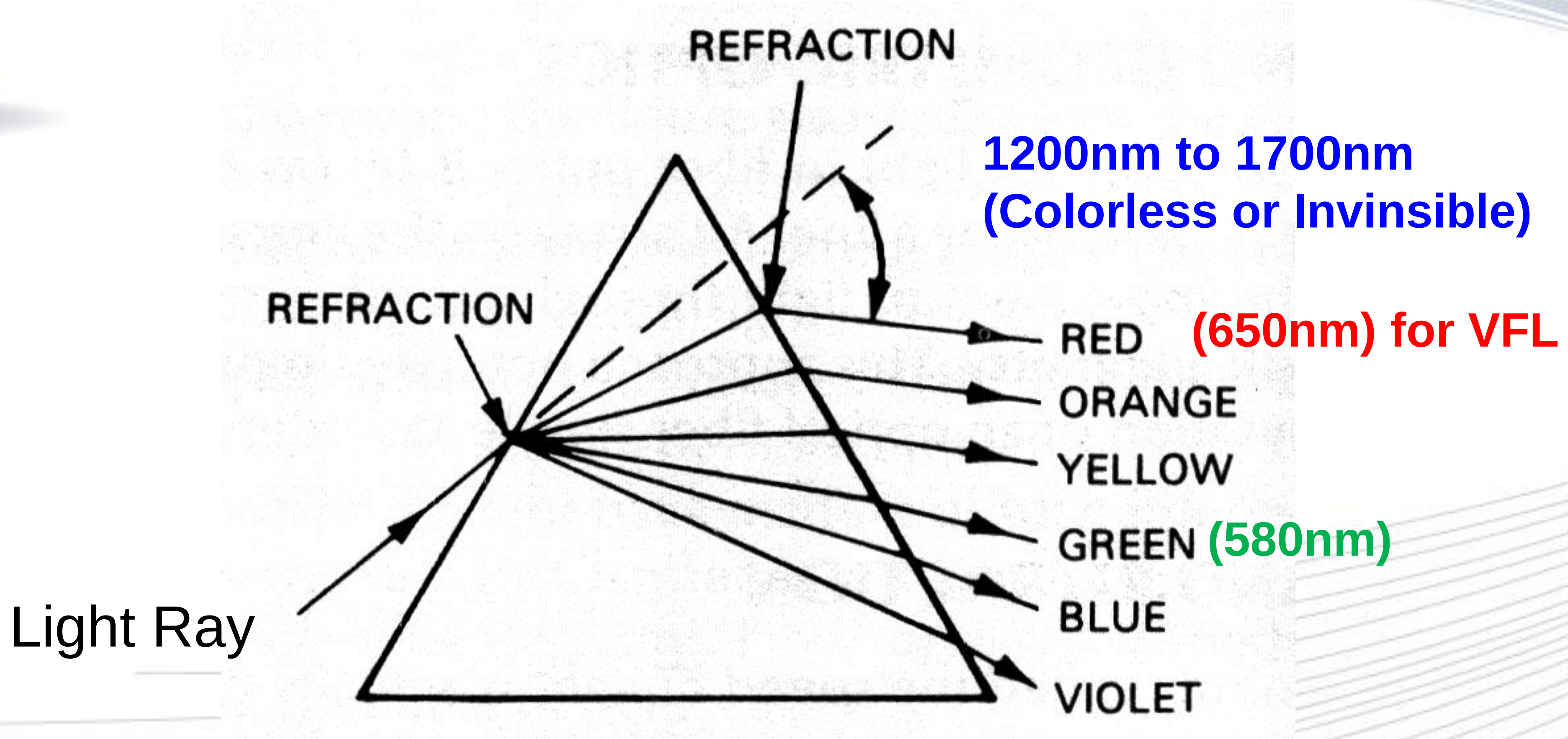
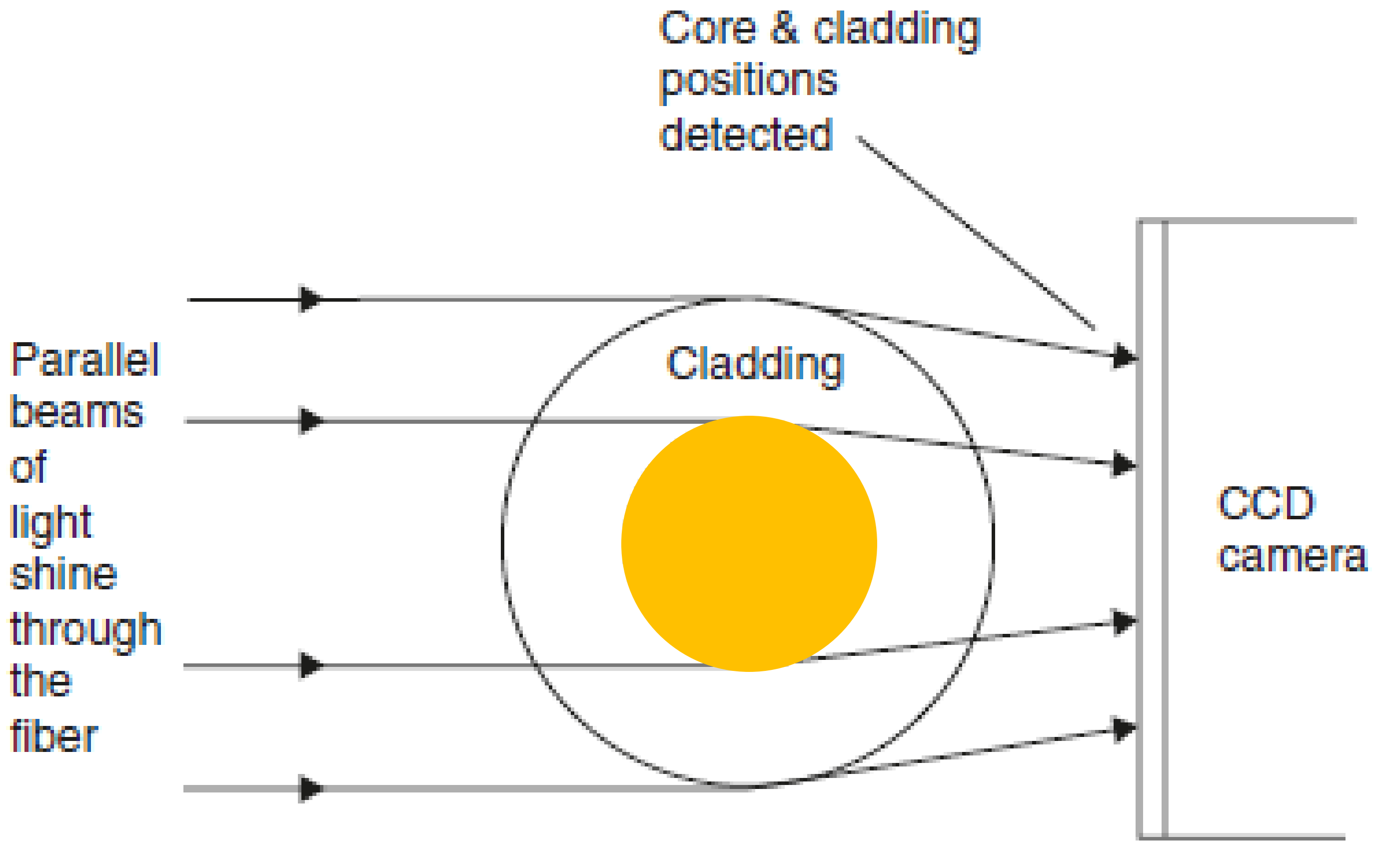
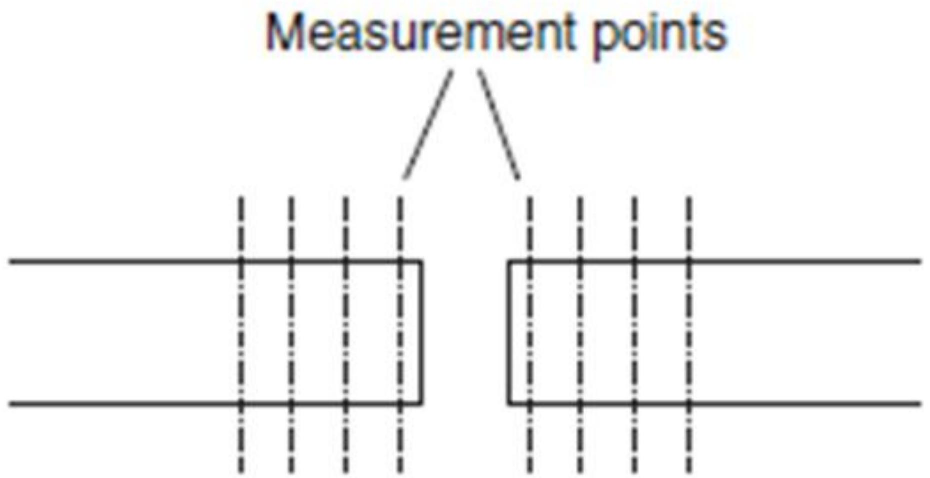
Wavelengths and their Colors



Fiber Splice Method

Profile Alignment System (PAS)





Light signal is not reflected on the CCD since 1310nm, 1490nm, 1550nm is not visible so it can perform alignment and splicing

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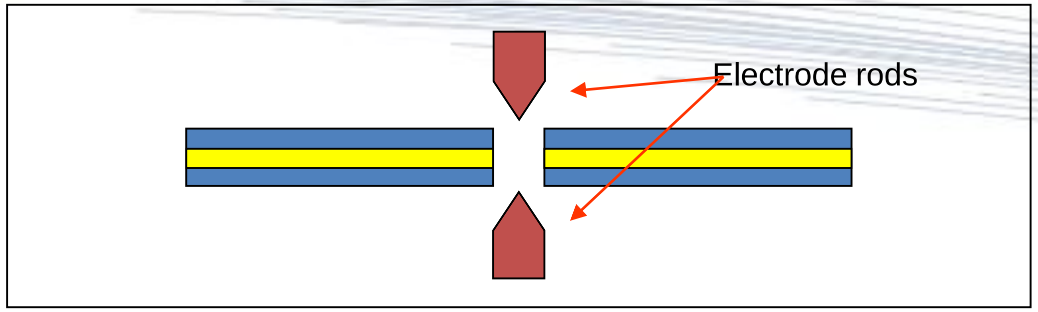
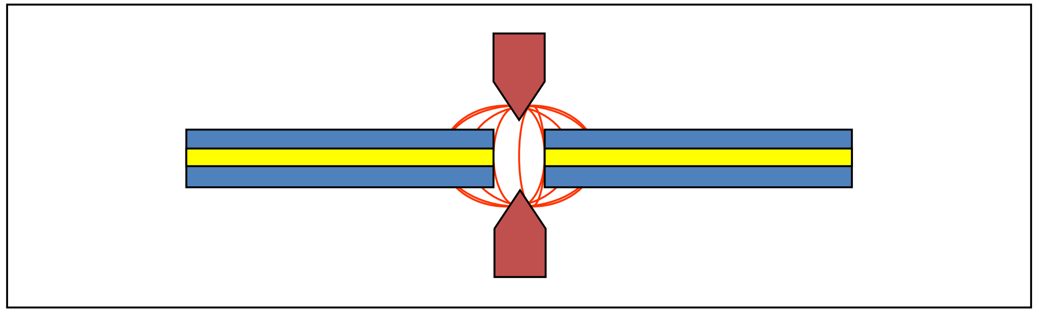
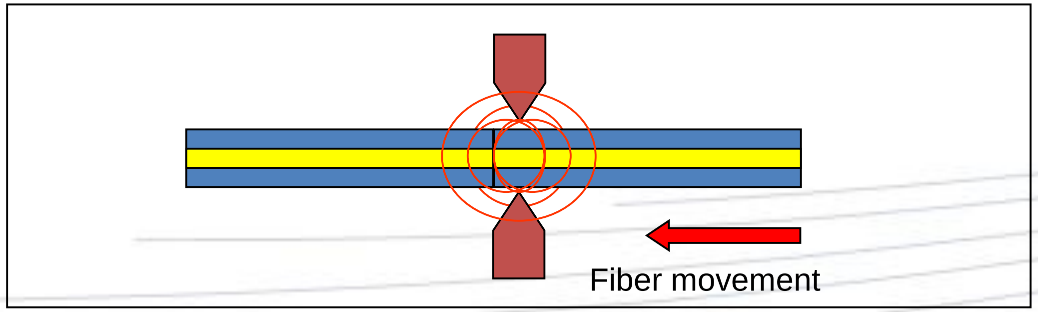
FUSION SPLICING PROCESS



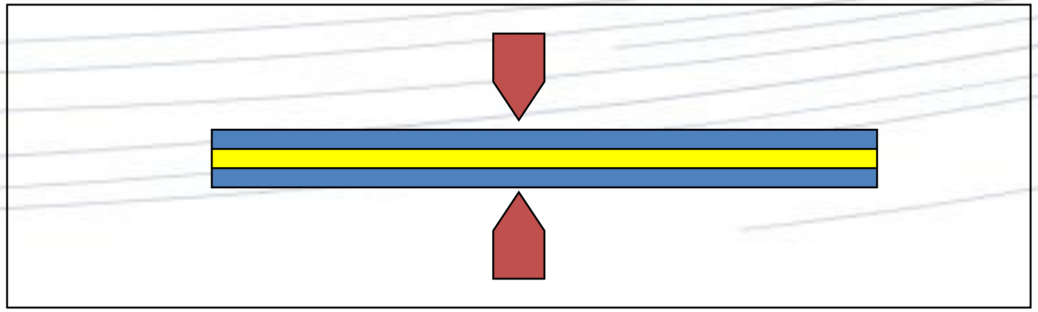
1) Determination of fiber position/ fiber alignment



2) Pre-fusion

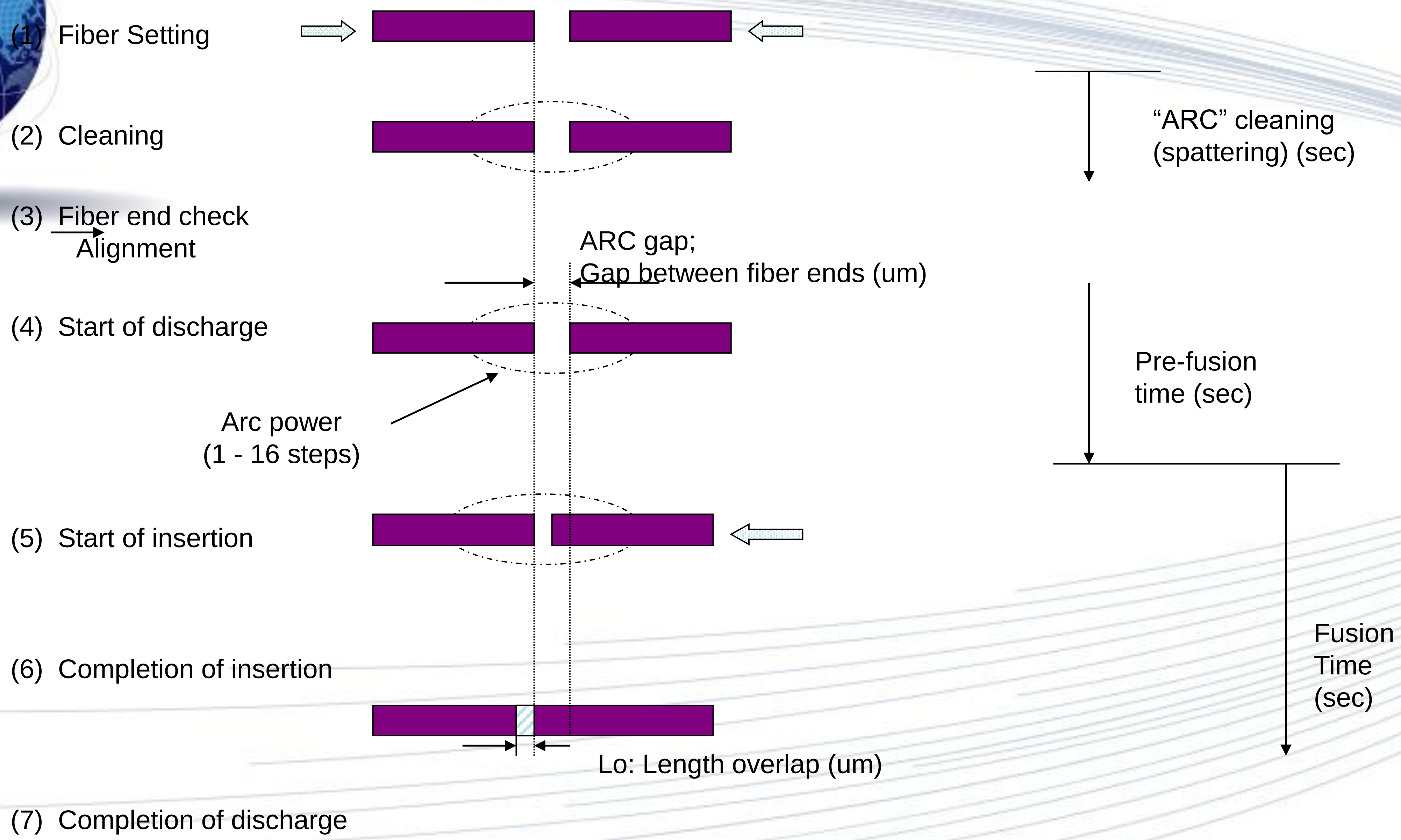


3) Stuffing and fusion

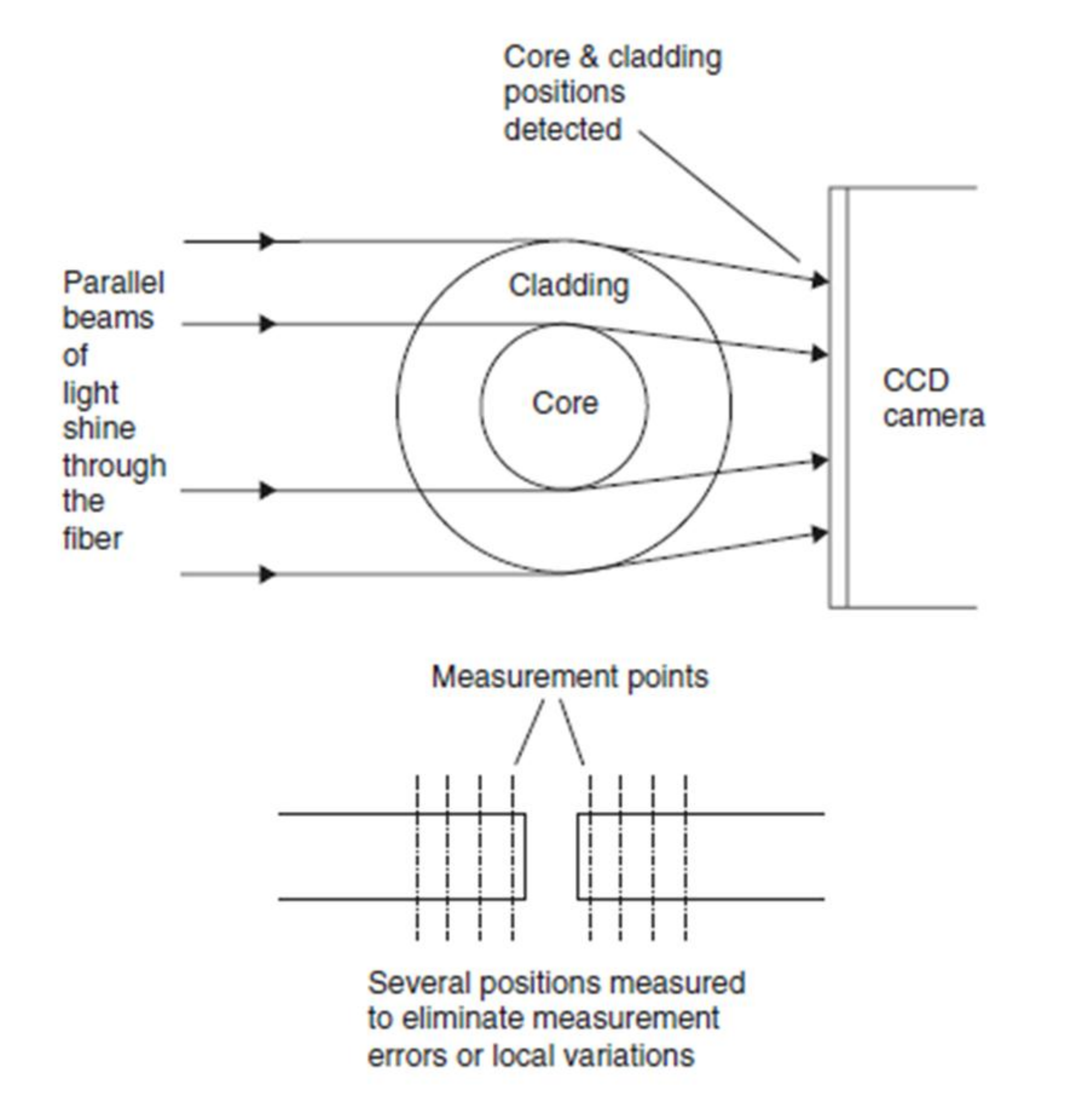


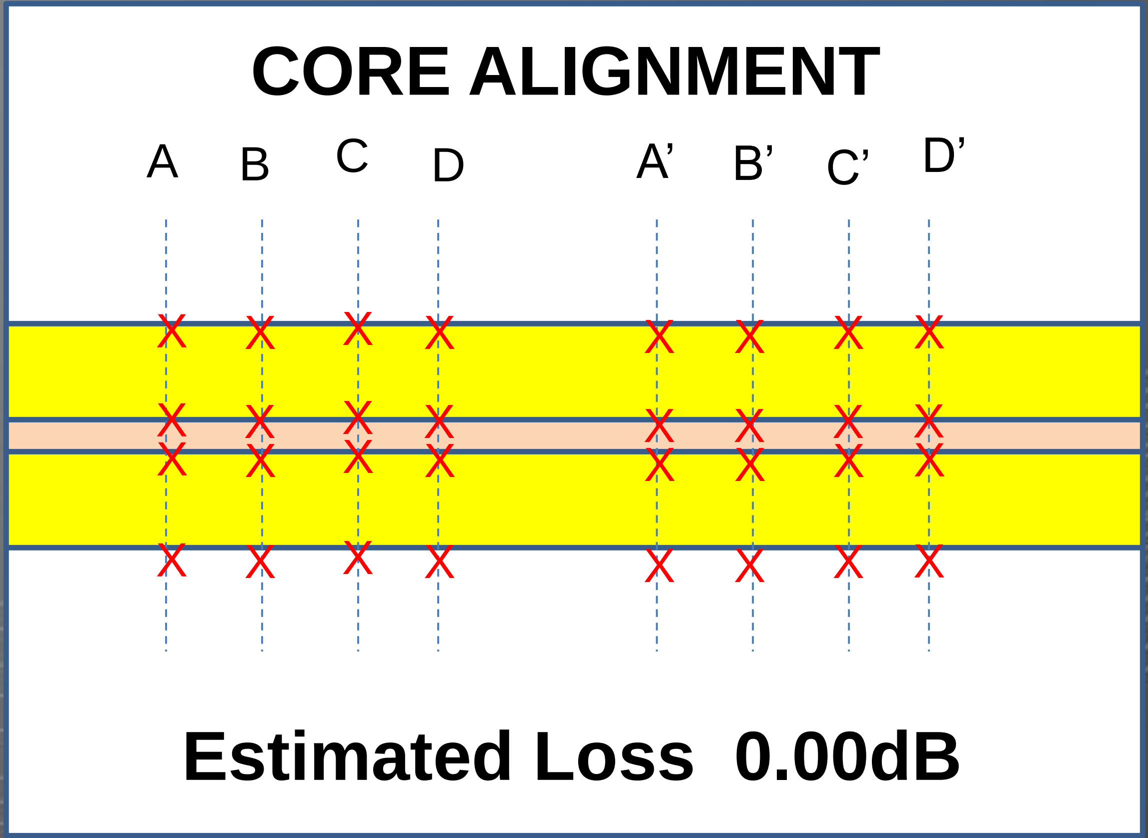
4) Loss measurement

FUSION SPLICING OPERATION TIMING

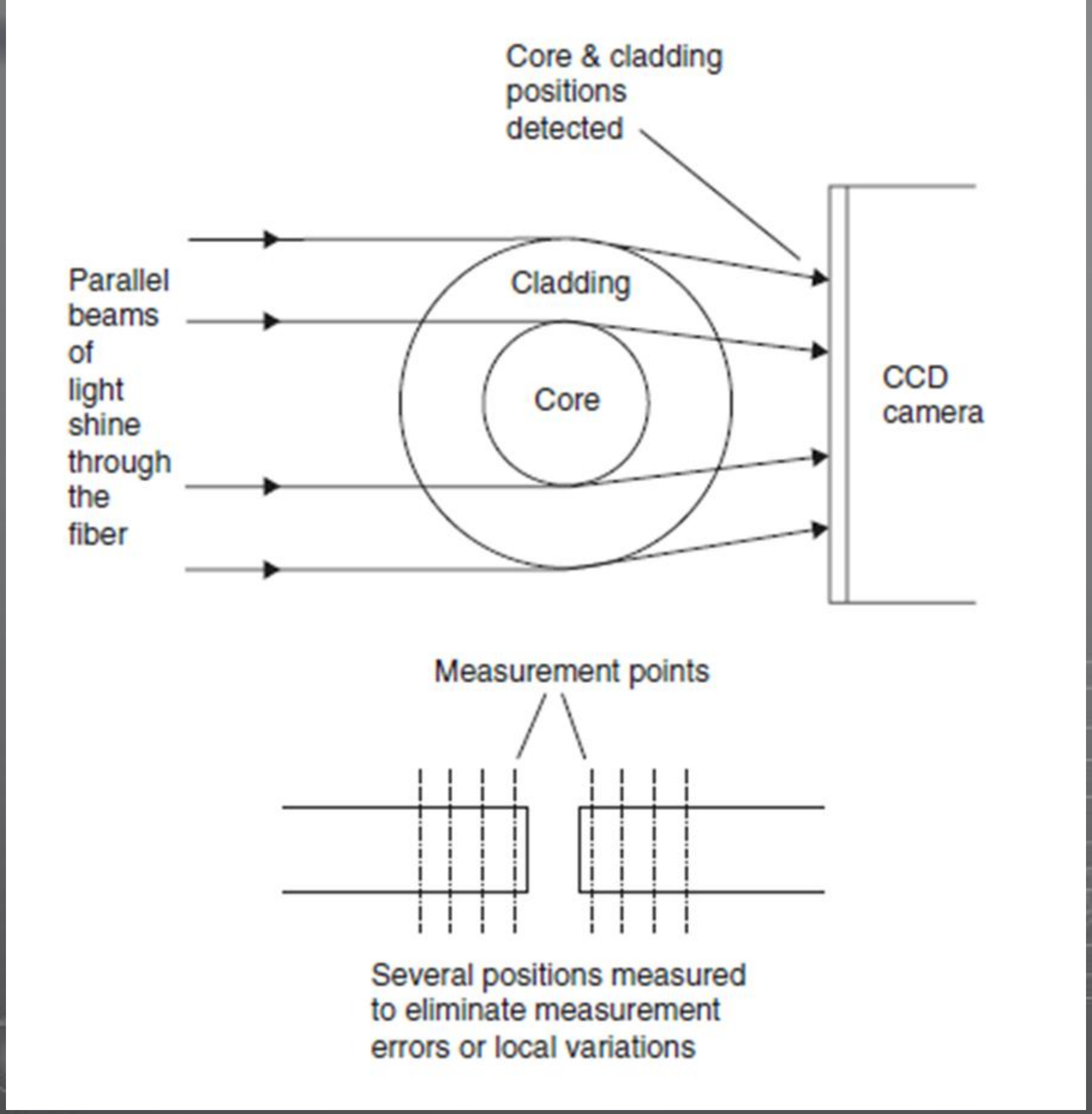


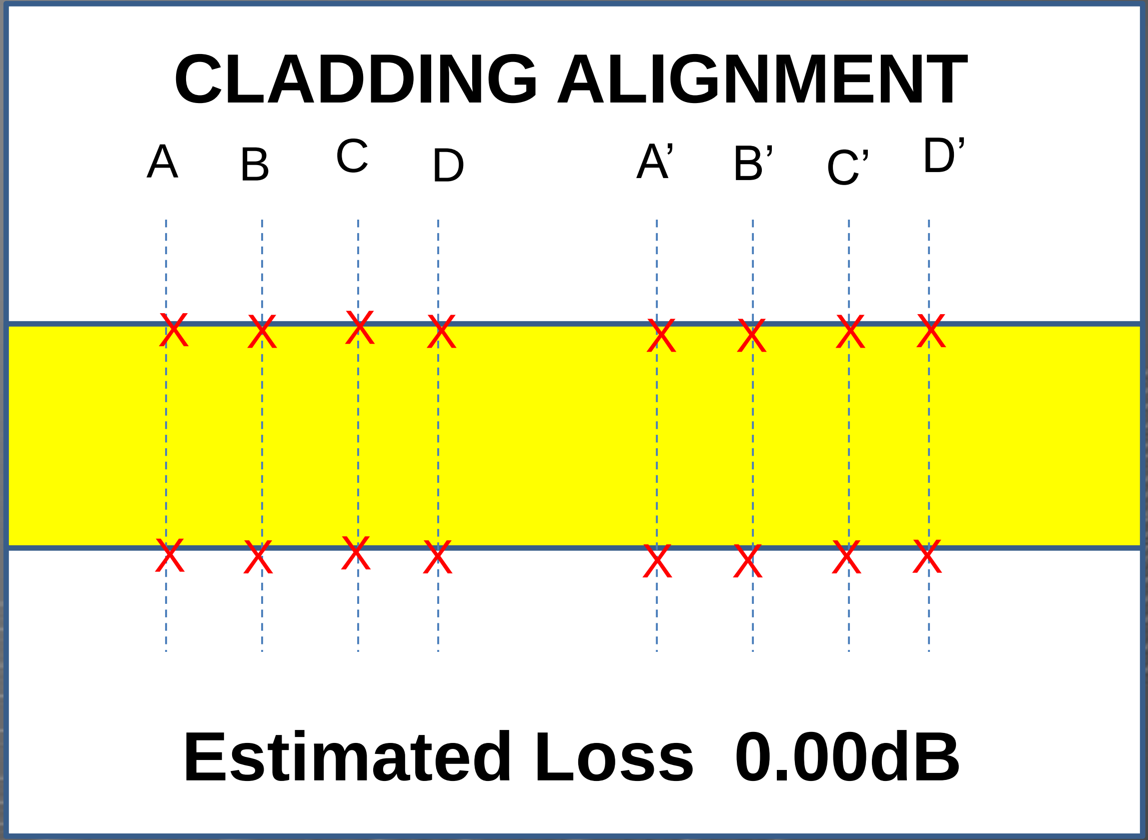
Estimated Splice Loss Measurement





Estimated Splice Loss Measurement

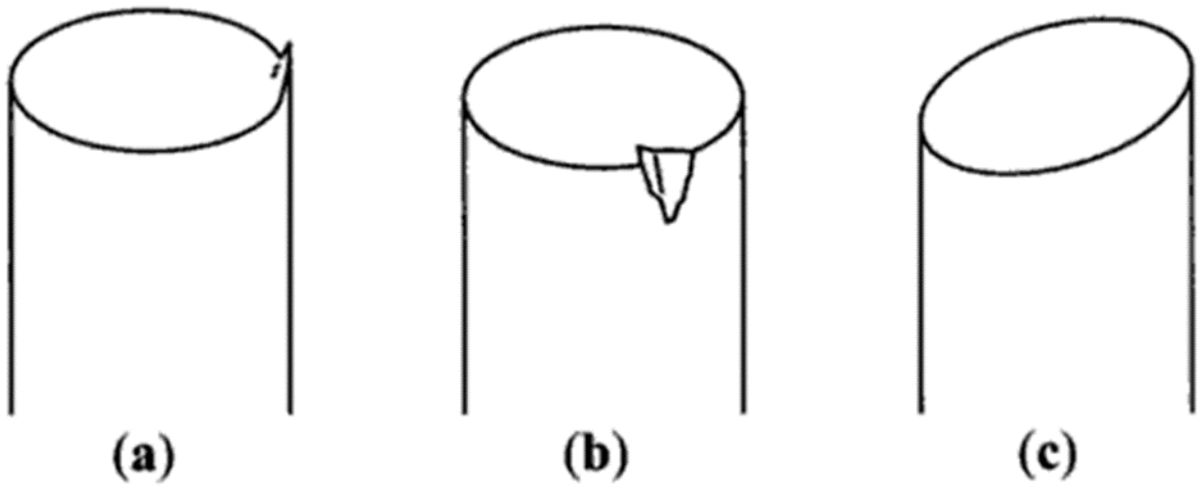




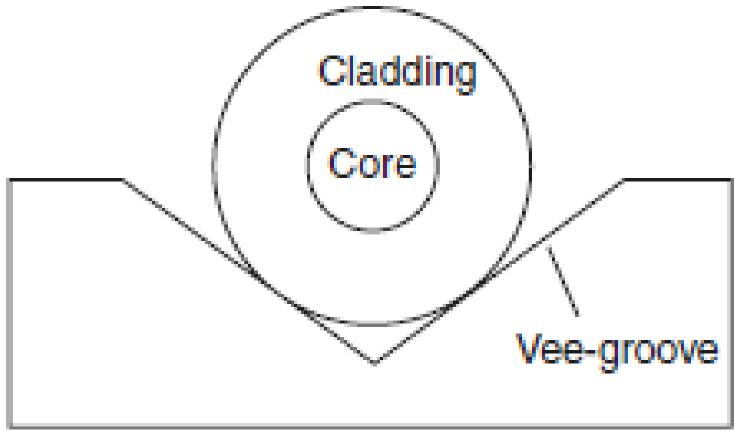
Core is not visible since it
Only concern is cladding

CAUSES OF EXTRINSIC SPLICE LOSS

Not Good Fiber end surface

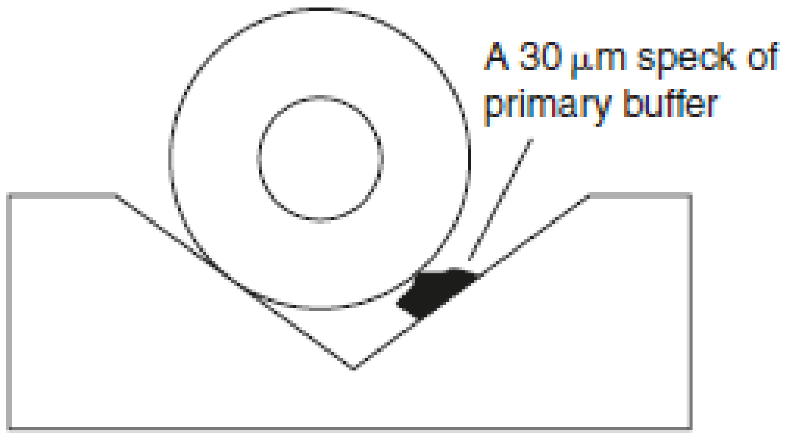


Lip Chip Angle



The vee-groove positions the fiber with precision

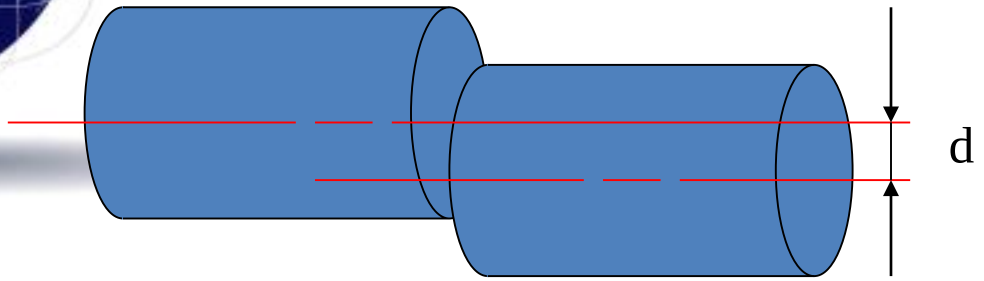
OK



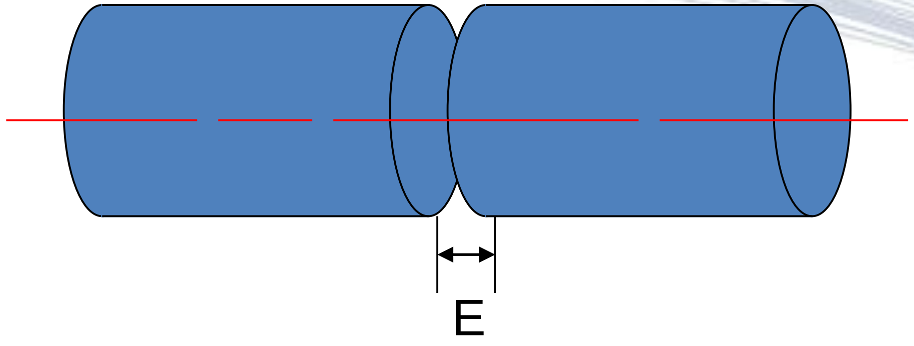
The slightest contamination can ruin the effect

NOT OK

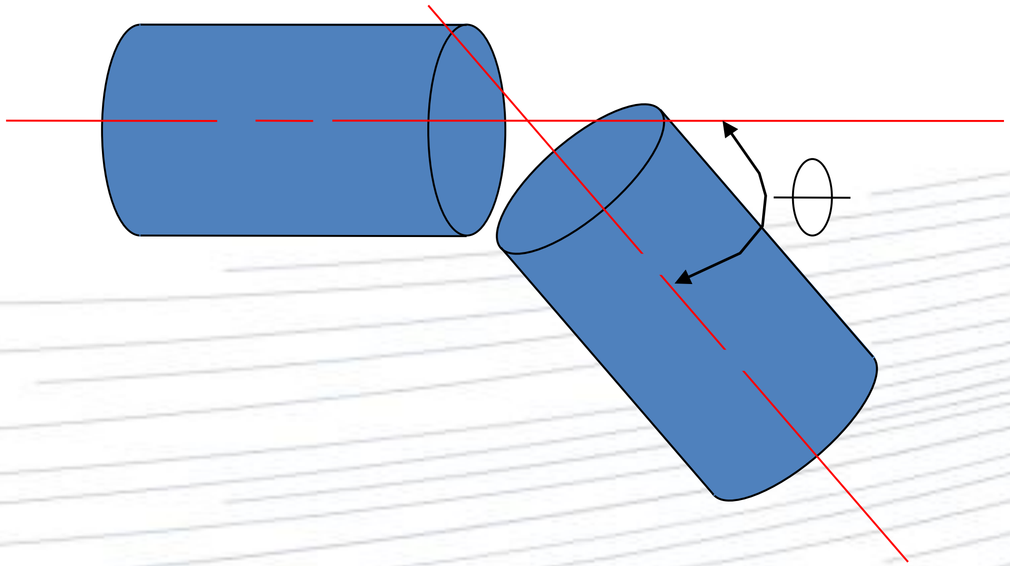
CAUSES OF EXTRINSIC SPLICE LOSS



Axial mis-alignment



End separation



Angular mis-alignment

Fusion Splicing Methodology
Section 4 and 5

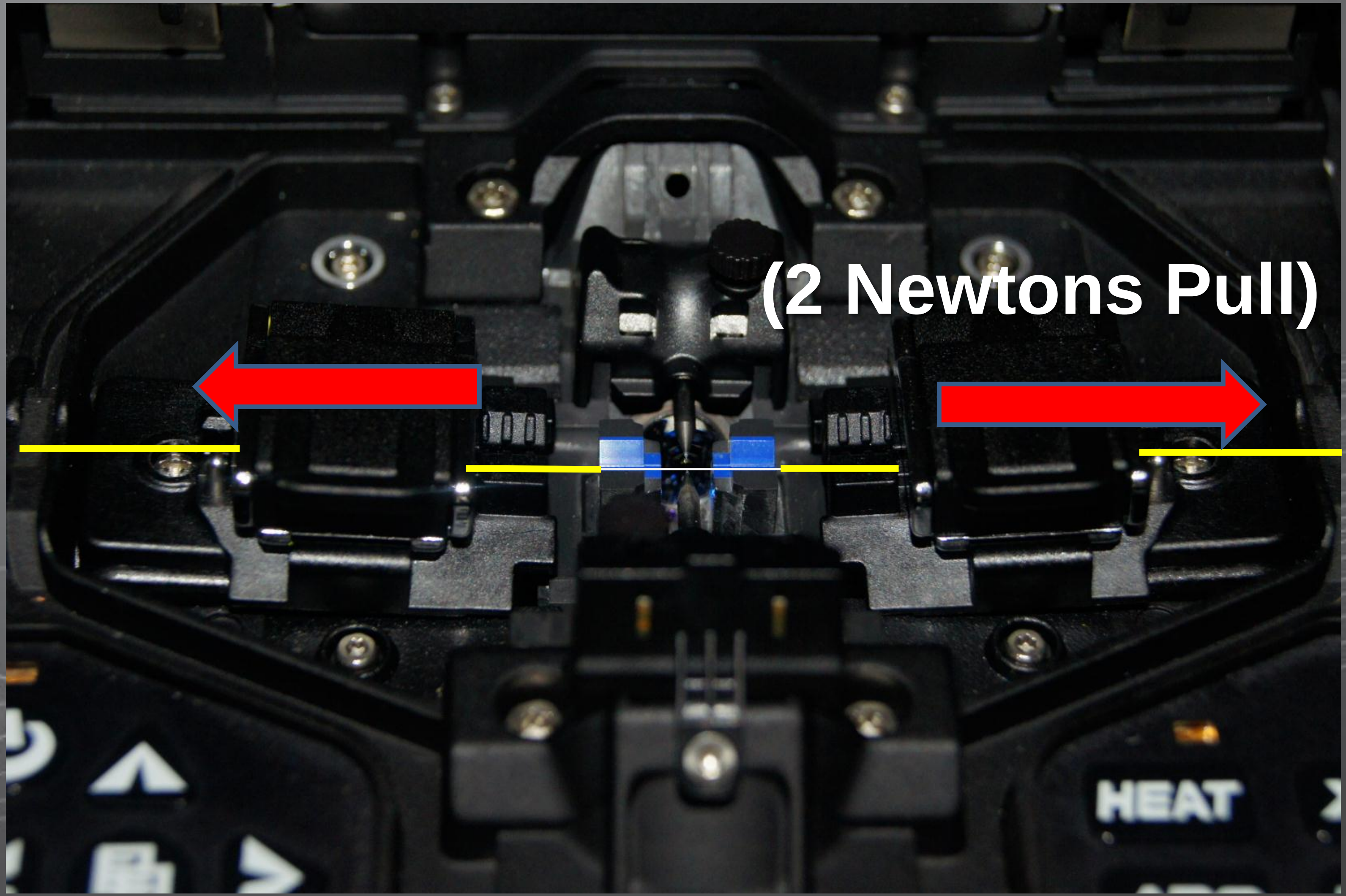
5.5.1 Electric Arc Fusion Splicing

5.5.1.3 Proof Test

Performing a tensile test on the completed
Splice by applying 2N on both ends
of the splice to ensure splice integrity

Fusion Splicing Methodology
Section 4 and 5

5.5.1.3 Proof Test



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Fusion Splicing Methodology

Section 4 and 5

5.5.1 Electric Arc Fusion Splicing

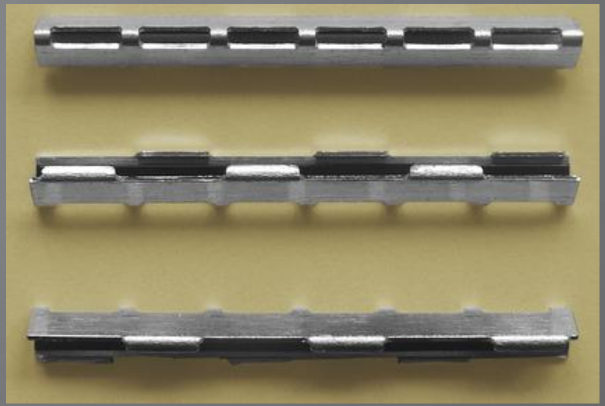
5.5.1.4 Splice Protection

Protector is a mechanical device or restored coating, that provides both mechanical and environmental protection to the single or multiple splices.
It shall never affect neither the attenuation of the splice nor its functional properties

Fusion Splicing Methodology

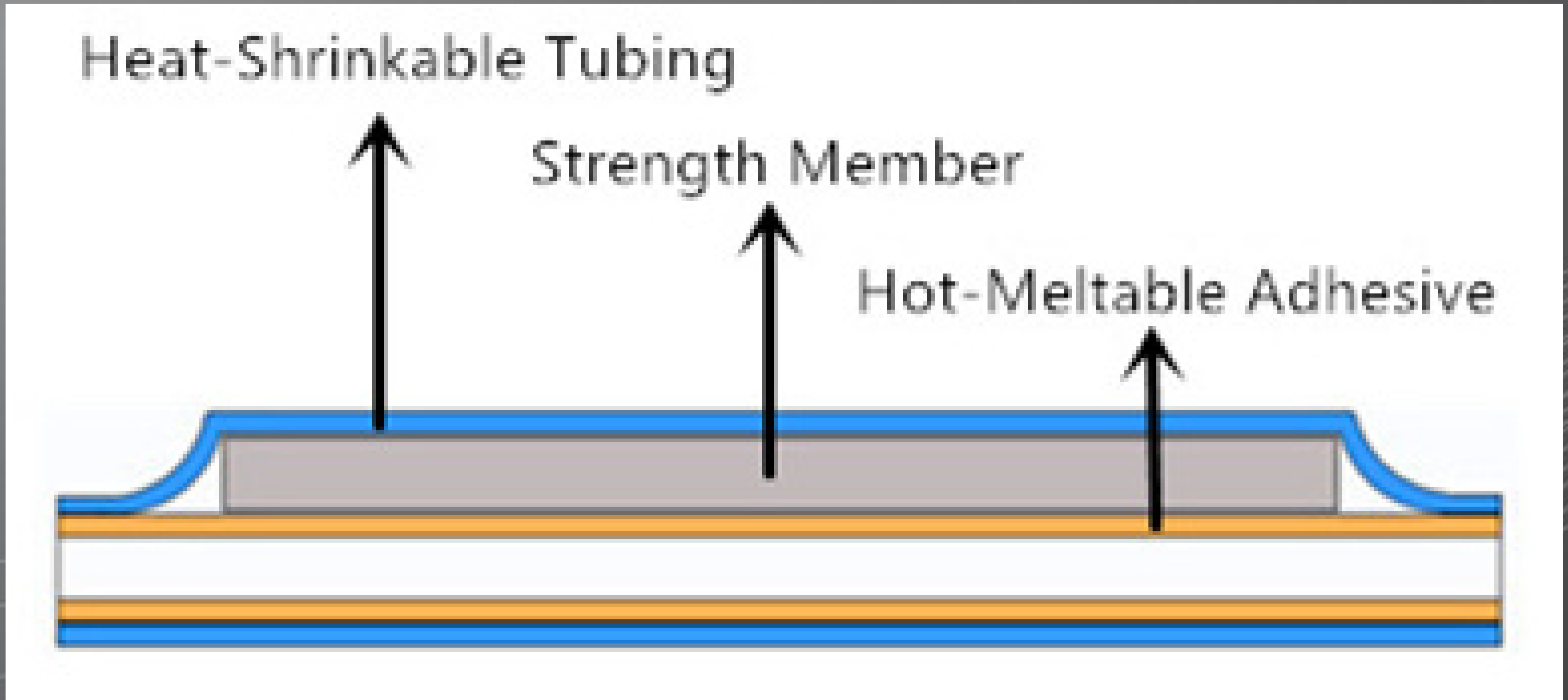
Section 4 and 5

Mechanical Splice Protector

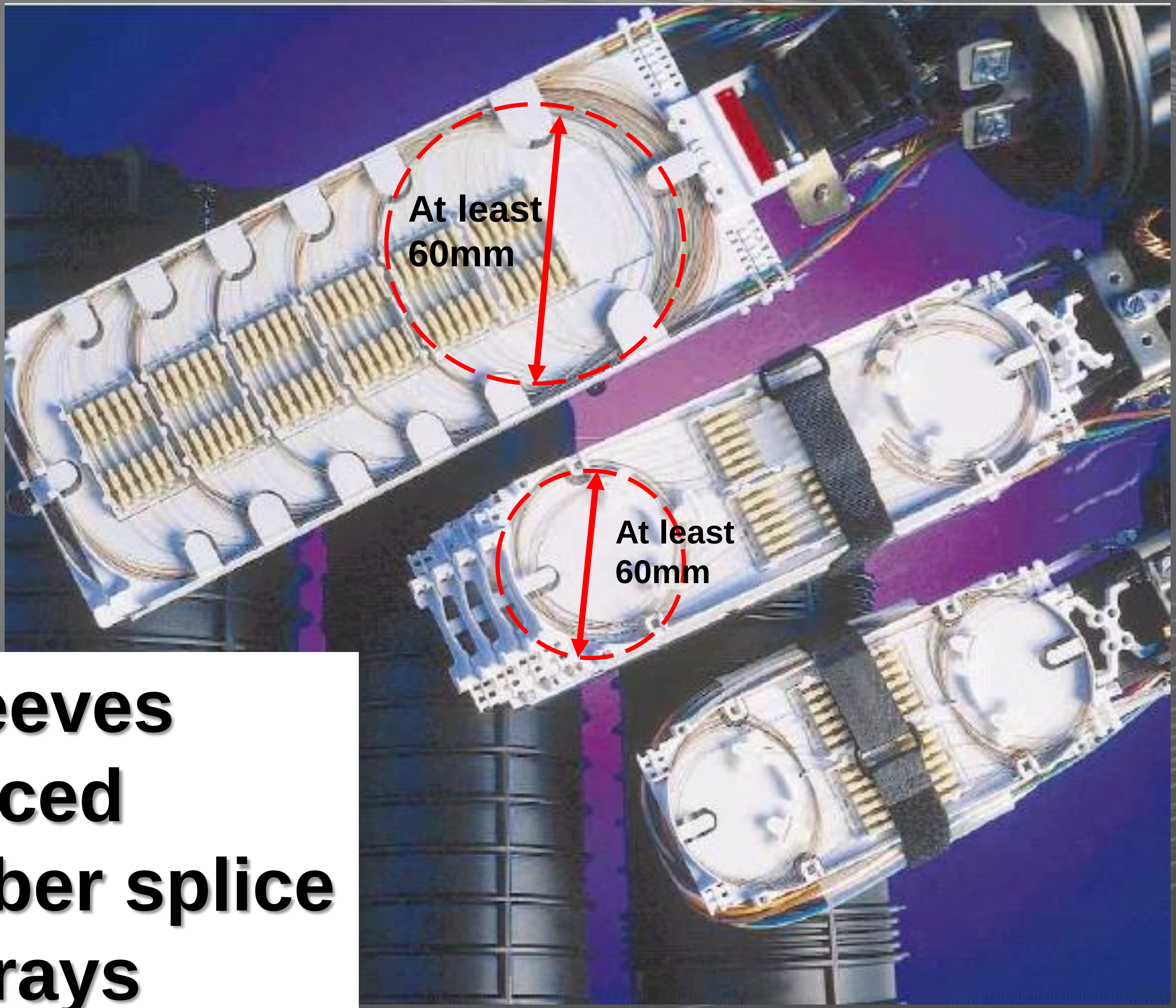


Heat Shrinkable Splice Protector

Heat Shrinkable Protection Sleeve

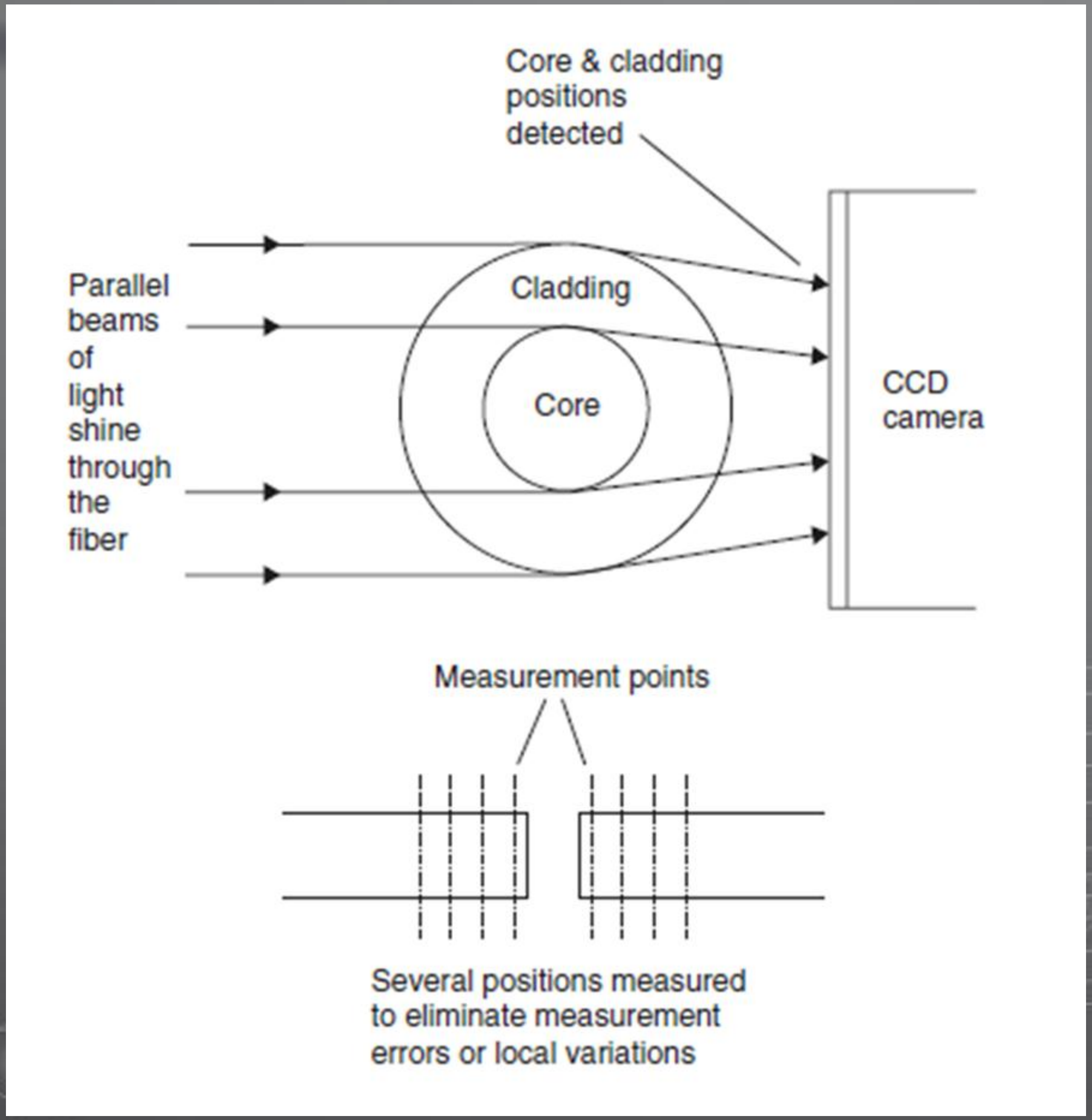


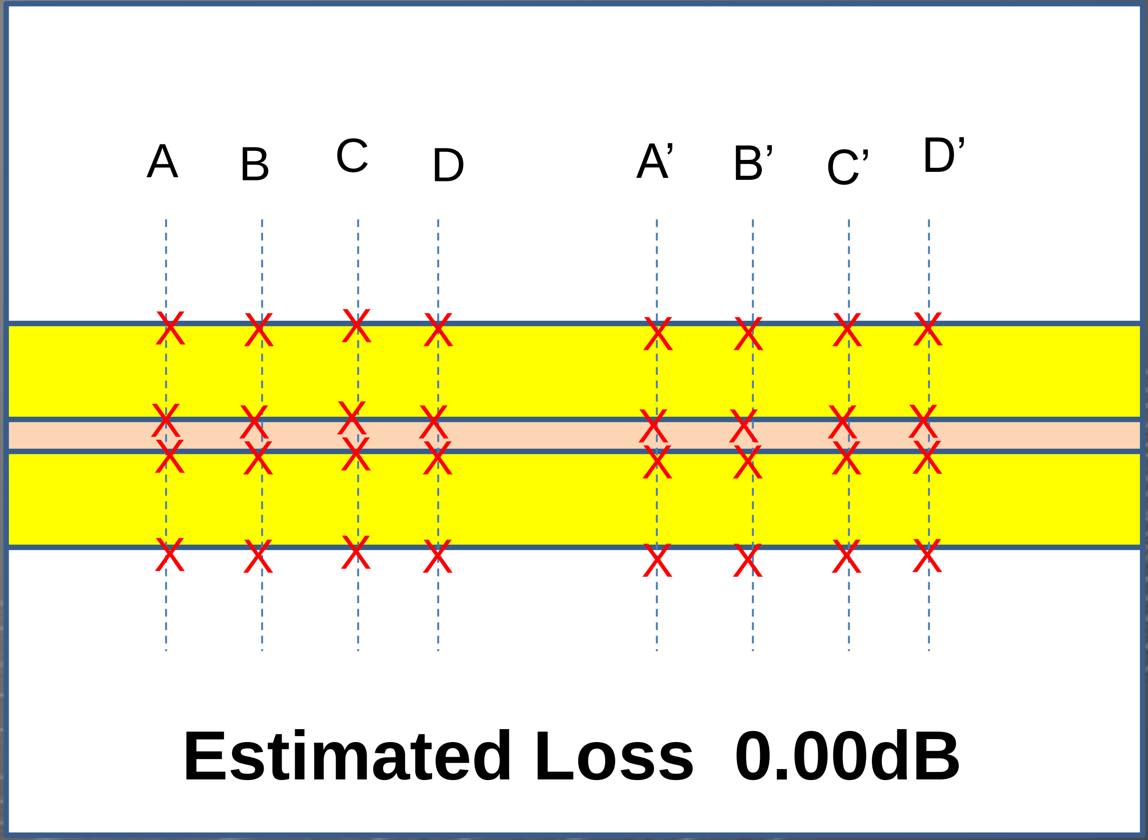
Fiber Optic Splice Closure & Splice Tray



Protection Sleeves Should be placed Properly on fiber splice Slot on fiber trays

5.6 Field Splice Loss Splice Measurement





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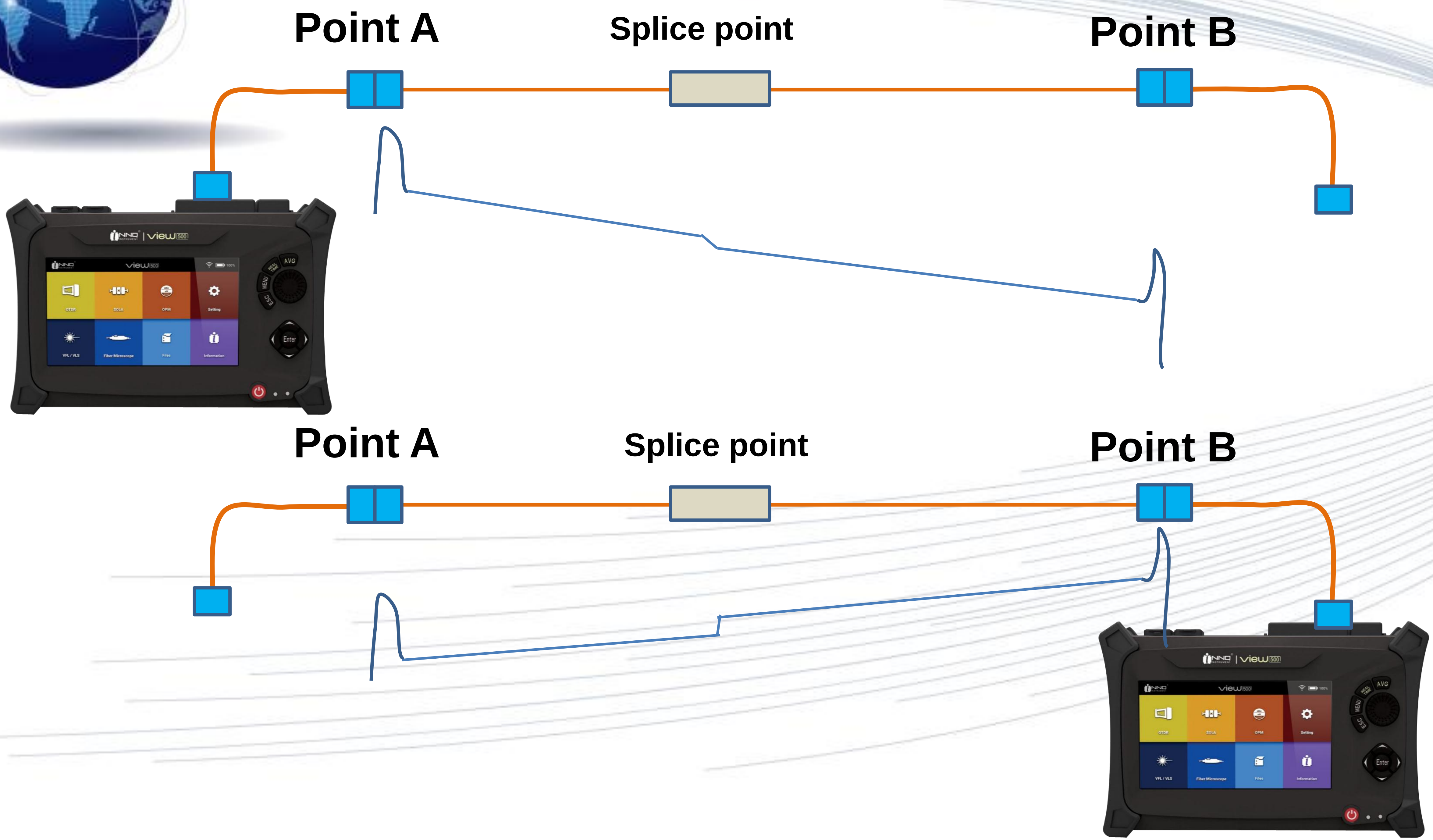
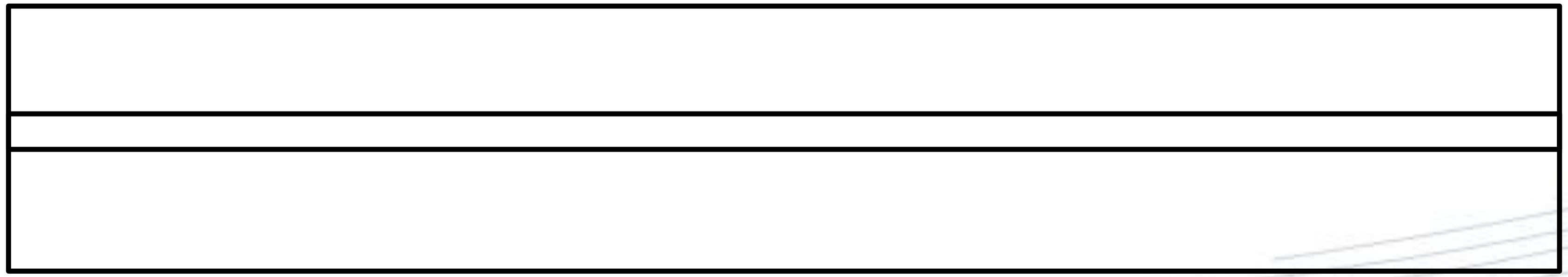
OTDR Two-direction Testing to determine Splice Loss



Fusion Splicing

Fiber A

Fiber B



A seamless or flawless splice is a good splice

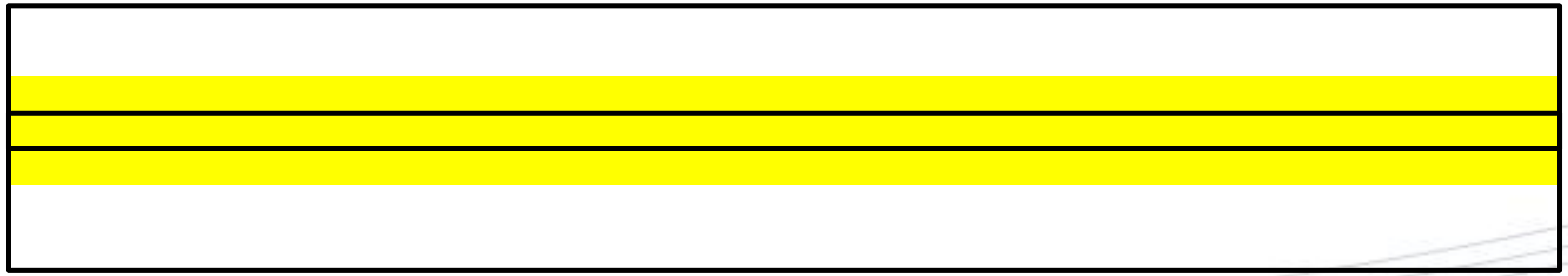
Estimated Loss 0.00 dB

Can we conclude that this is the actual splice loss?

Same Mode Field Diameter

Fiber A

Fiber B



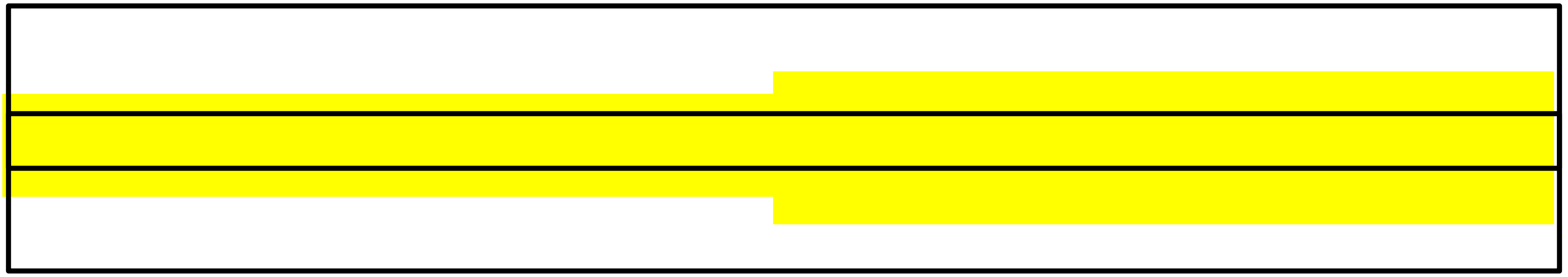
Seamless Visual Connectivity (Physical Appearance)
Seen by our naked eye

If MFD of Fiber A is EQUAL to MFD of Fiber B
Seen by the Light Signal (OTDR Signal)
travelling inside the core

Different Mode Field Diameter

MAJOR CAUSE OF INTRINSIC LOSS

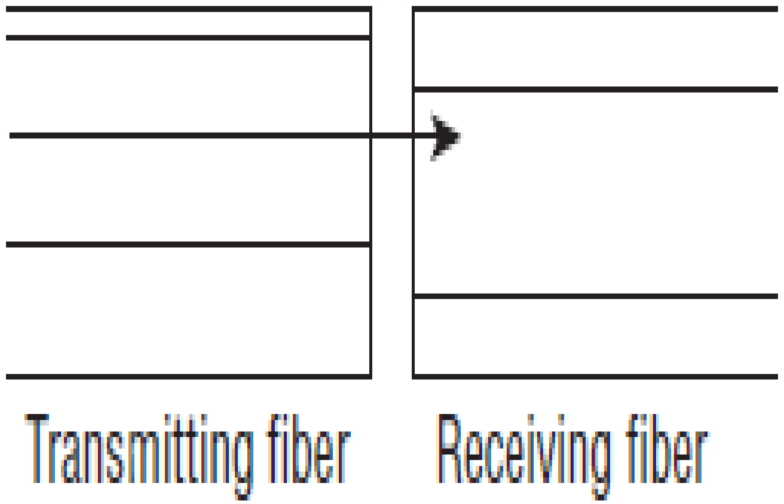
Fiber A **Fiber B**



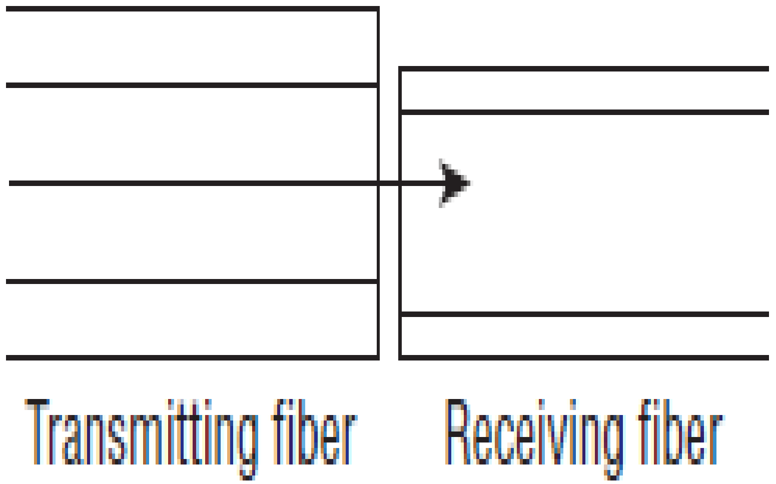
Seamless Visual Connectivity (Physical Appearance)
Seen by our naked eye

If MFD of Fiber A is NOT EQUAL to MFD of Fiber B
Seen by the Light Signal (OTDR Signal)
travelling inside the core

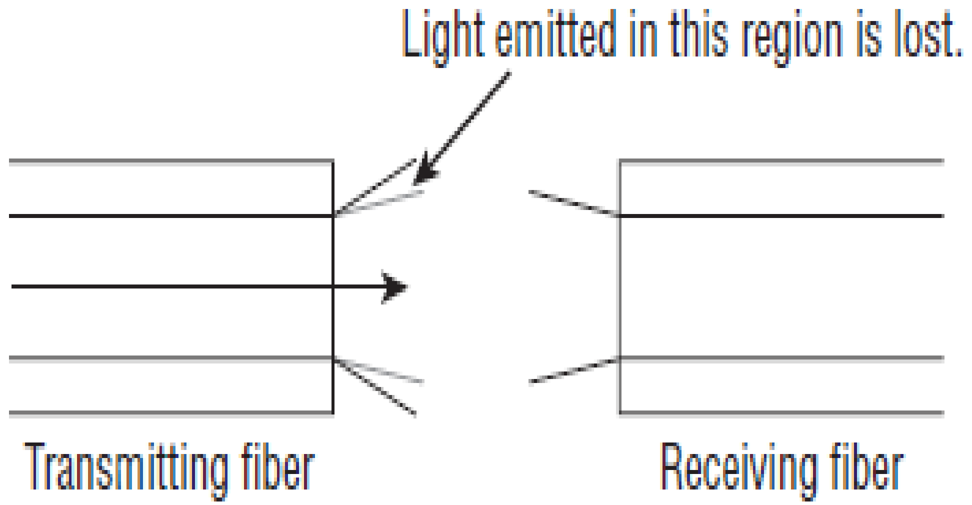
Other INTRINSIC LOSSES



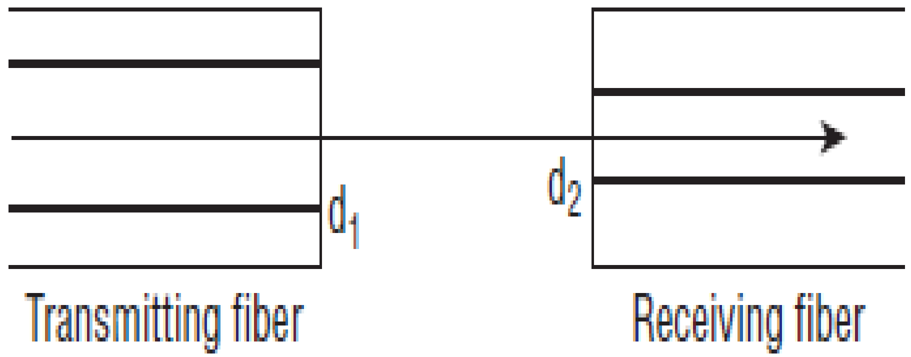
Off-center Fiber



Cladding Diameter Mismatch

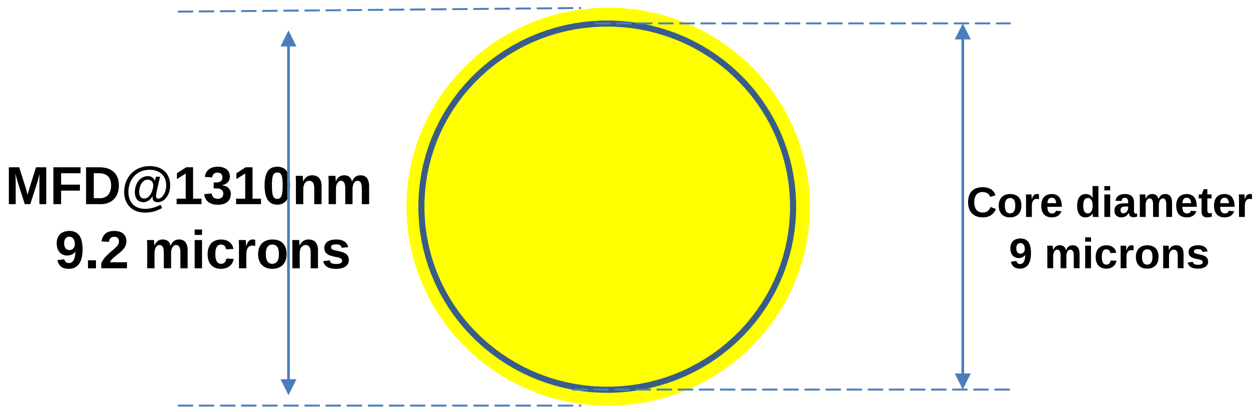


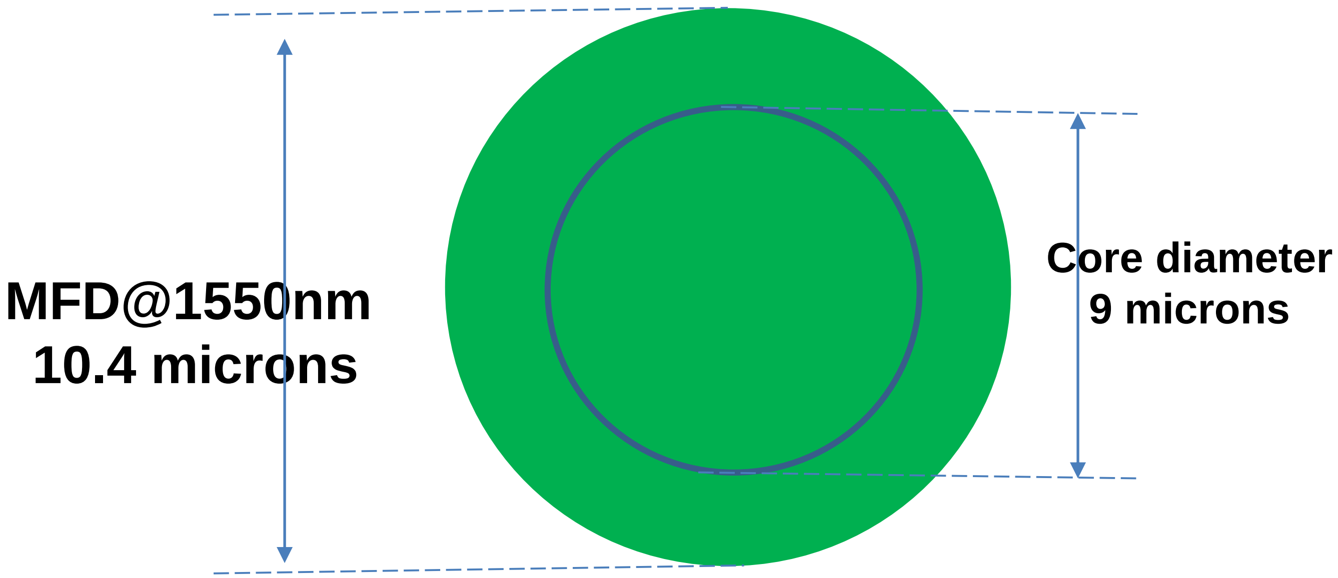
Numerical Aperture Mismatch (Multimode)



Core Diameter Mismatch

MODE FIELD DIAMETER





1310nm wavelength travels Slightly Outside the core

1550nm wavelength travels Beyond the core (part of the cladding)

In testing a splice loss, use 1310nm because it will give us the actual condition of the core joint

Sample of G.652D Specification sheet

Mode-Field Diameter

Wavelength (nm)	MFD (µm)
1310	9.2 ± 0.4
1550	10.4 ± 0.5

Fiber Manufacturer

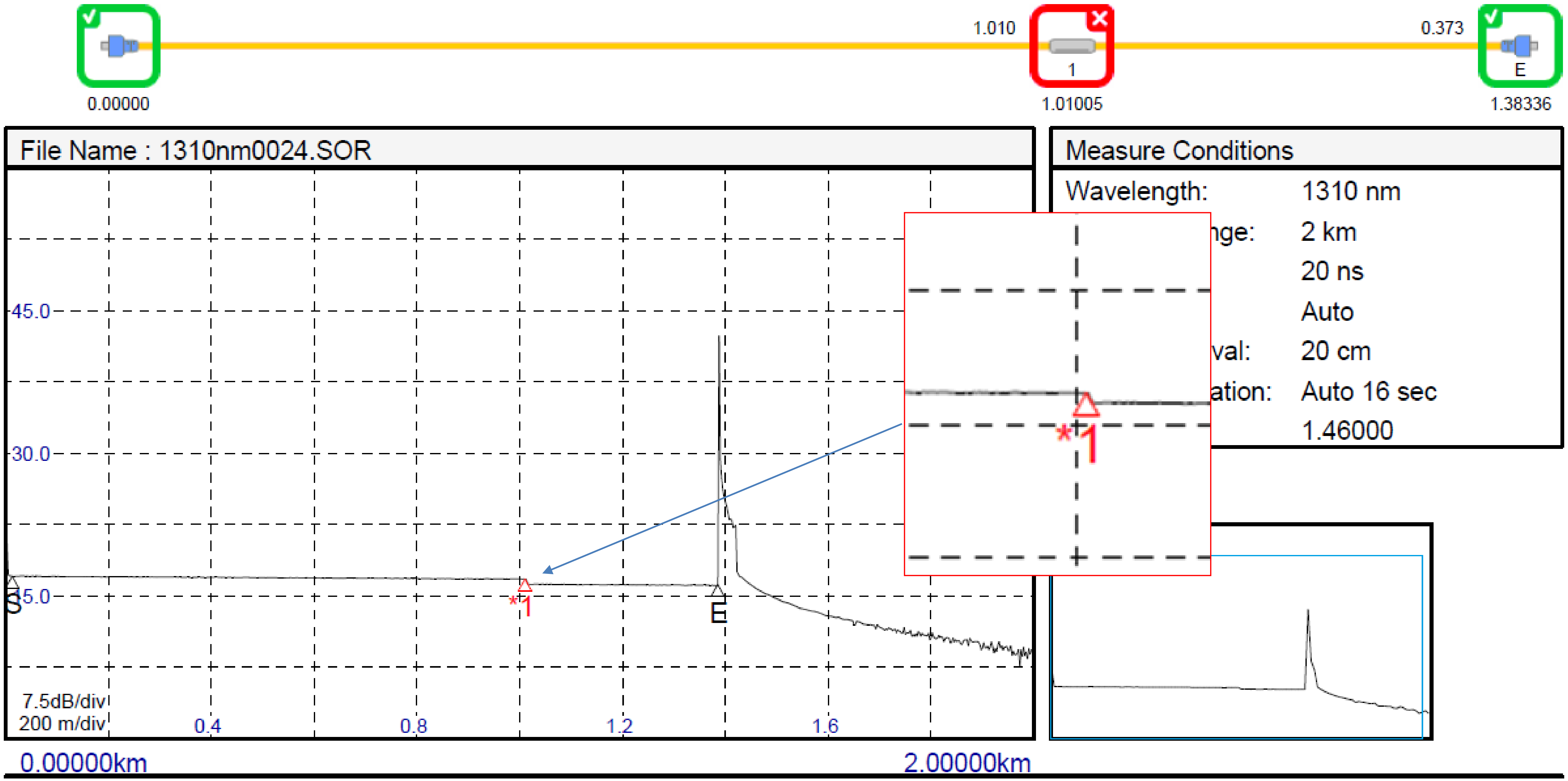
Group Refractive Index	
at 1310 nm	1.467
at 1550 nm	1.468
Mode Field Diameter	
at 1310 nm	9.2 ± 0.4 µm
at 1550 nm	10.4 ± 0.5 µm (typical)

Fiber Manufacturer

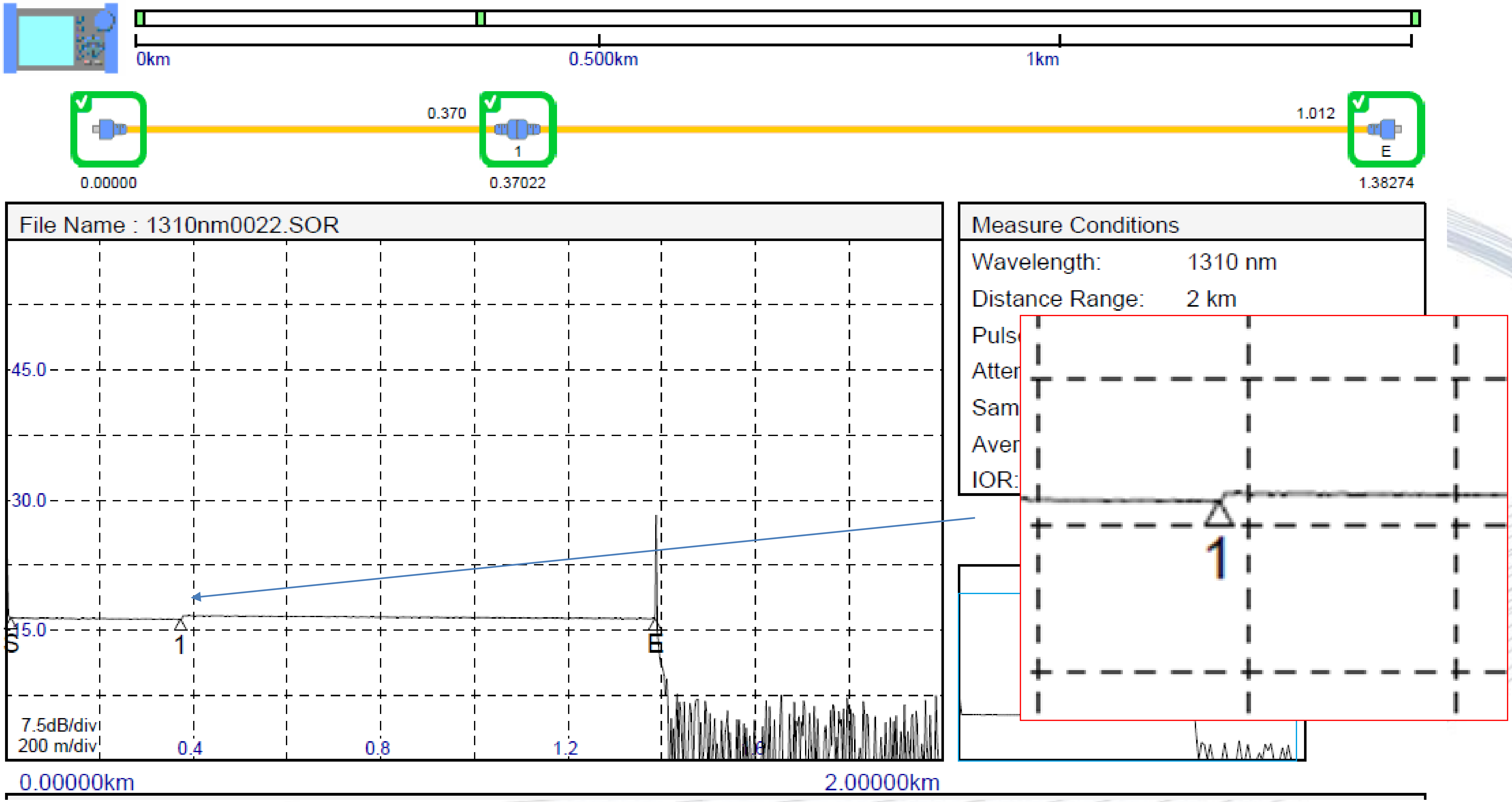
Cable Manufacturer

Mode field diameter (MFD)	1310 nm	8.7 ~ 9.5	[µm]
	1550 nm	9.9 ~ 10.9	[µm]

They source fibers from multiple vendors



Event No	Distance (km)	Section (km)	Splice Loss(dB)	Return Loss(dB)	Cumulate Loss(dB)	dB/km	Event Type	Section IOR
*1	1.01005		* 0.533		0.314	0.315		1.46000
E	1.38336	0.37331		14.569	0.955	0.289		1.46000



Event No	Distance (km)	Section (km)	Splice Loss(dB)	Return Loss(dB)	Cumulate Loss(dB)	dB/km	Event Type	Section IOR
1	0.37022		-0.406	73.890	0.134	0.370		1.46000
E	1.38274	1.01252		43.207	0.066	0.334		1.46000

A-B

Event No	Distance (km)	Section (km)	Splice Loss(dB)	Return Loss(dB)	Cumulate Loss(dB)	dB/km	Event Type	Section IOR
*1	1.01005		* 0.533		0.314	0.315		1.46000
E	1.38336	0.37331		14.569	0.955	0.289		1.46000

B-A

Event No	Distance (km)	Section (km)	Splice Loss(dB)	Return Loss(dB)	Cumulate Loss(dB)	dB/km	Event Type	Section IOR
1	0.37022		-0.406	73.890	0.134	0.370		1.46000
E	1.38274	1.01252		43.207	0.066	0.334		1.46000

SPLICE LOSS = [(LOSS A-B) + (LOSS B-A)] / 2

= [0.533 + (-.406)] / 2

= 0.0635

ITU-T G.671 Transmission Characteristics of Optical Components and Subsystems

Section 5.13 – Acceptable Optical Splice Loss

5.13 Optical splice

Clause	Parameter	Max	Min	Test method
	Insertion loss (dB) (Note 9)			[IEC 61300-3-4], [IEC 61300-3-7]
5.13.1	Mechanical splice	0.50	na	
5.13.2	Fusion splice (active alignment)	0.30	na	
5.13.3	Fusion splice (passive alignment)	0.50	na	
	Reflectance (dB)			[IEC 61300-3-6]
5.13.4	Mechanical splice	–40	na	
5.13.5	Fusion splice	–70	na	

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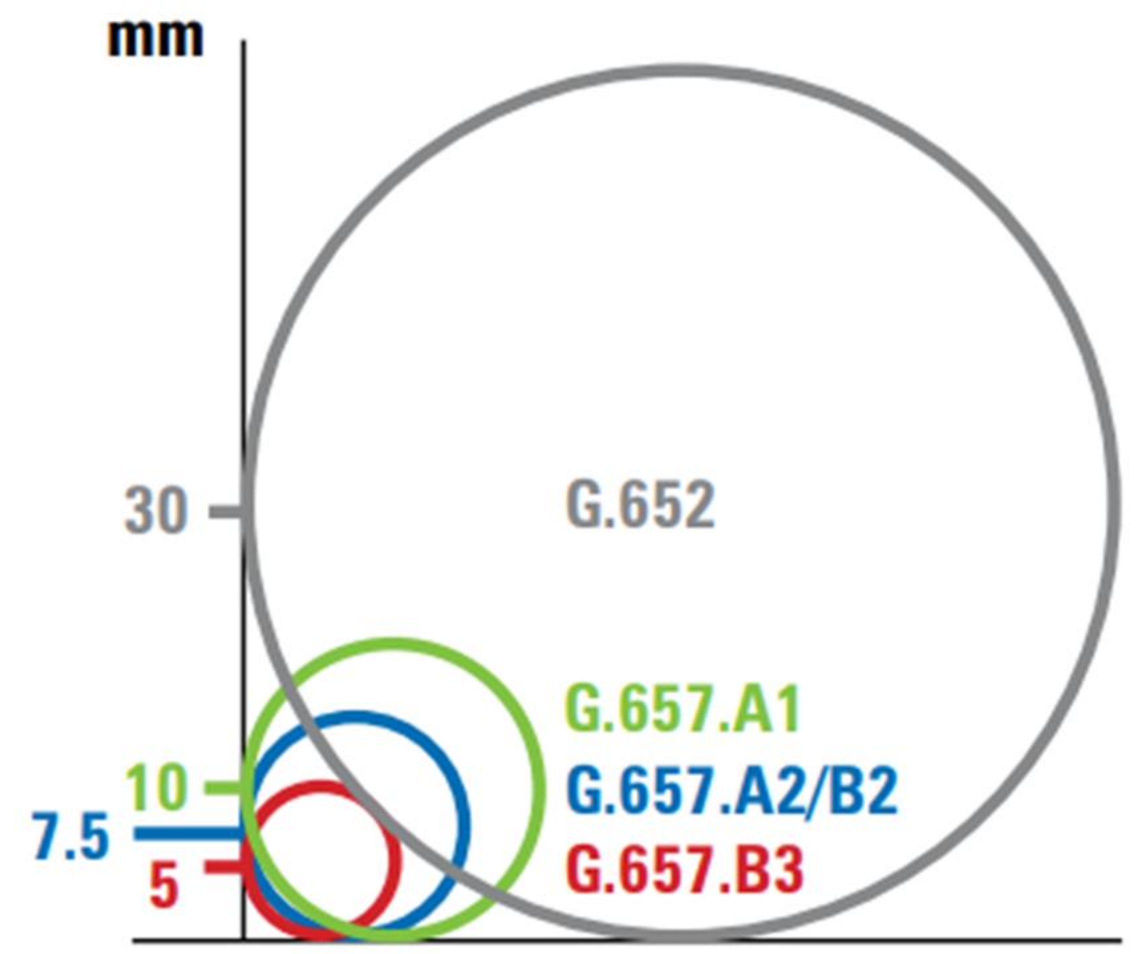
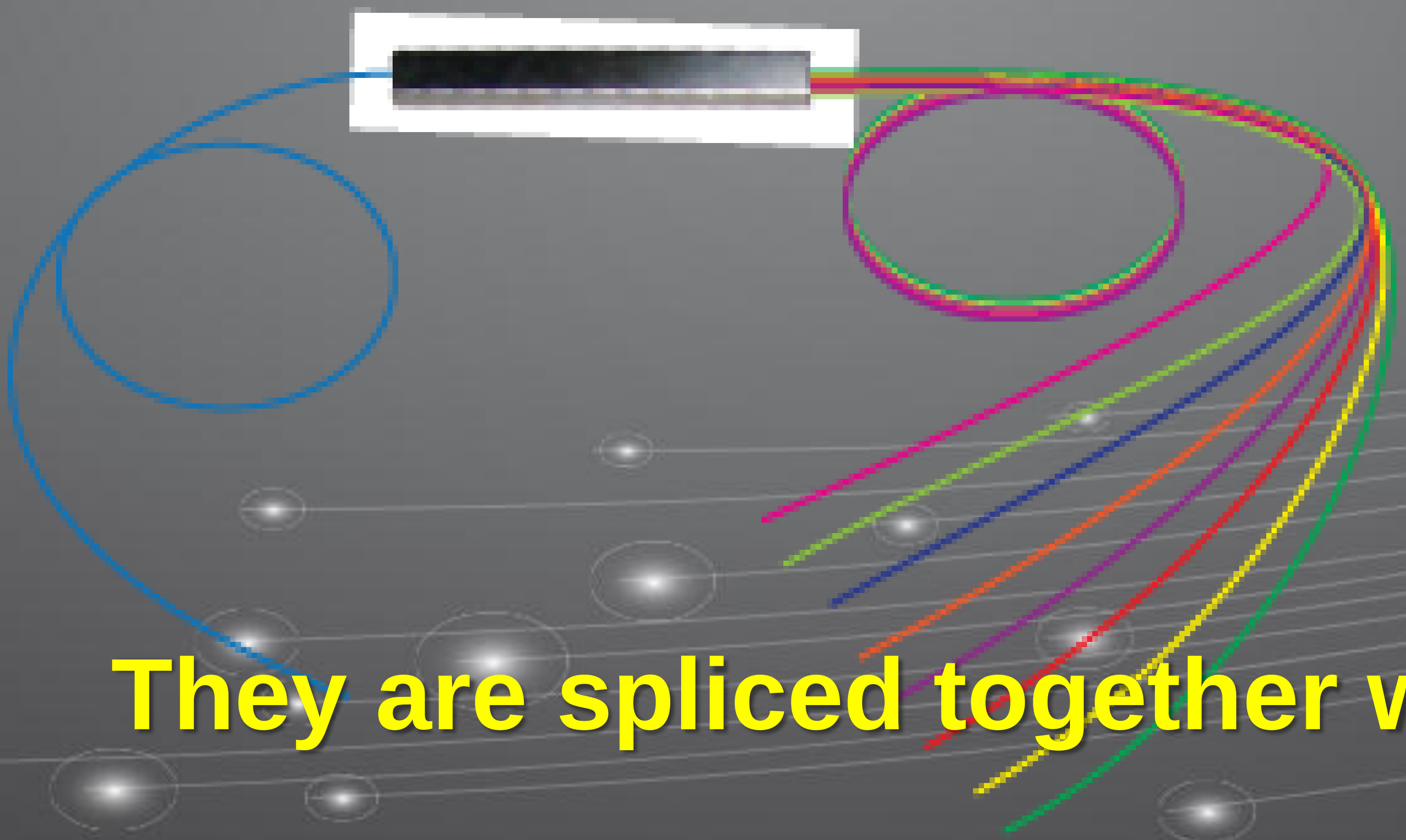
Fiber to the Home Implementation: G.657A

Figure 2 – Relevant specified bending radii for ITU-T G.652 and ITU-T G.657

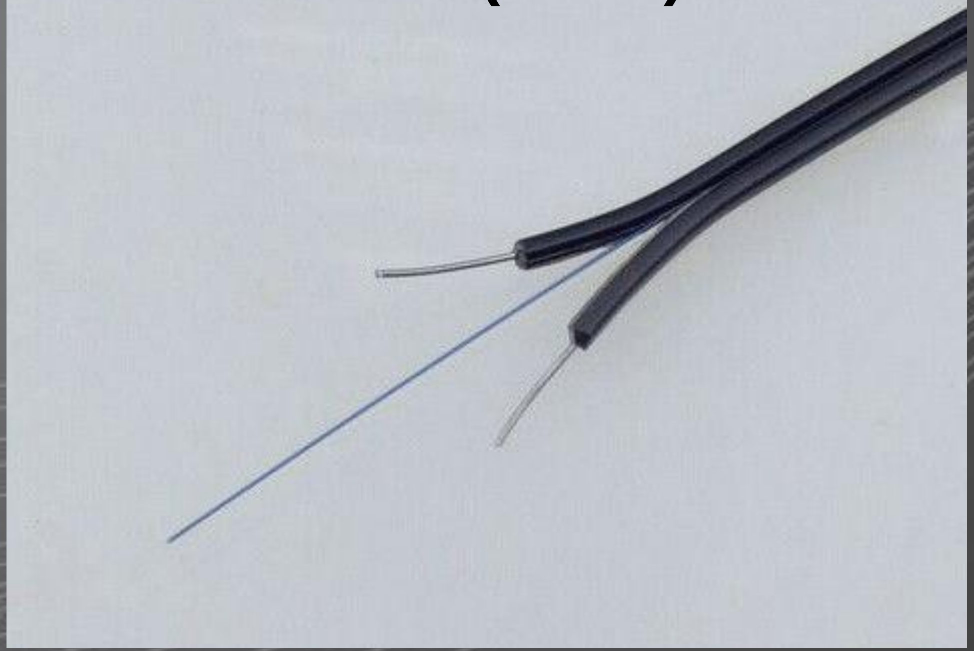


G.657A1 or A2 – used in FTTH application

1x8 Optical Splitters
used in LCP and NAP (FTTH)



Fiber Drop and Fiber Indoor Cable (FTTH)



They are spliced together with G.652D

As shown in Table 1, the mode field diameters of optical fibres meeting these specifications can differ substantially. The tolerances shown in Table 1 are wider than those typically stated by manufacturers.

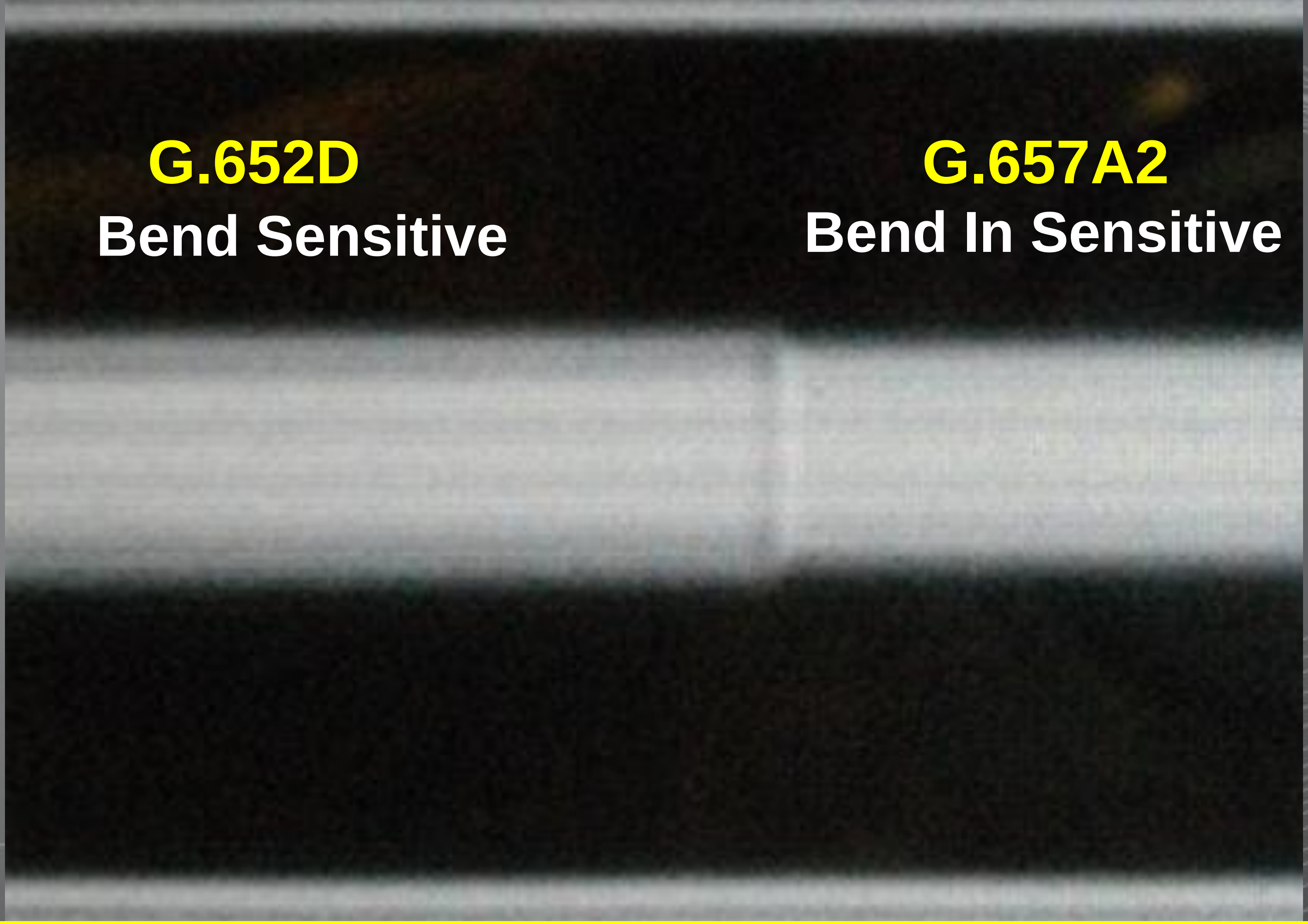
Proposed IEC 60793-2-50: 2008	ITU-T	Nominal MFD_{min} (µm)	Nominal MFD_{max} (µm)	MFD tolerance (µm)	Wavelength (nm)
Type B1.1	G652a, b	8.6	9.5	0.6	1310
-	G654a	9.5	10.5	0.7	1550
Type B1.2_b	G654b		13.00		
Type B1.2_c	G654c		10.5		
Type B1.3	G652c, d	8.6	9.5	0.6	1310
Type B2	G.653a, b	7.8	8.5	0.8	1550
-	G.655a	8.0	11.0	0.7	1550
-	G.655b				
Type B4_c	G.655c				
Type B4_d	G.655d				
Type B4_e	G.655e				
Type B5	G.656	7.0	11.0	0.7	1550
Type B6_a	G.657 Categories A1/2	8.6	9.5	0.4	1310
Type B6_b	G.657 Categories B2/3	6.3	9.5	0.4	1310

Table 1: Mode Field Diameter (MFD) specifications of singlemode optical fibre

MFD of G652D vs. G657A1&2 vs. G657B2&3

Proposed IEC 60793-2-50: 2008	ITU-T	Nominal MFD_{min} (μm)	Nominal MFD_{max} (μm)	MFD tolerance (μm)	Wavelength (nm)
Type B6_a	G.657 Categories A1/2	8.6	9.5	0.4	1310
Type B1.3	G652c, d	8.6	9.5	0.6	1310
Type B6_b	G.657 Categories B2/3	6.3	9.5	0.4	1310

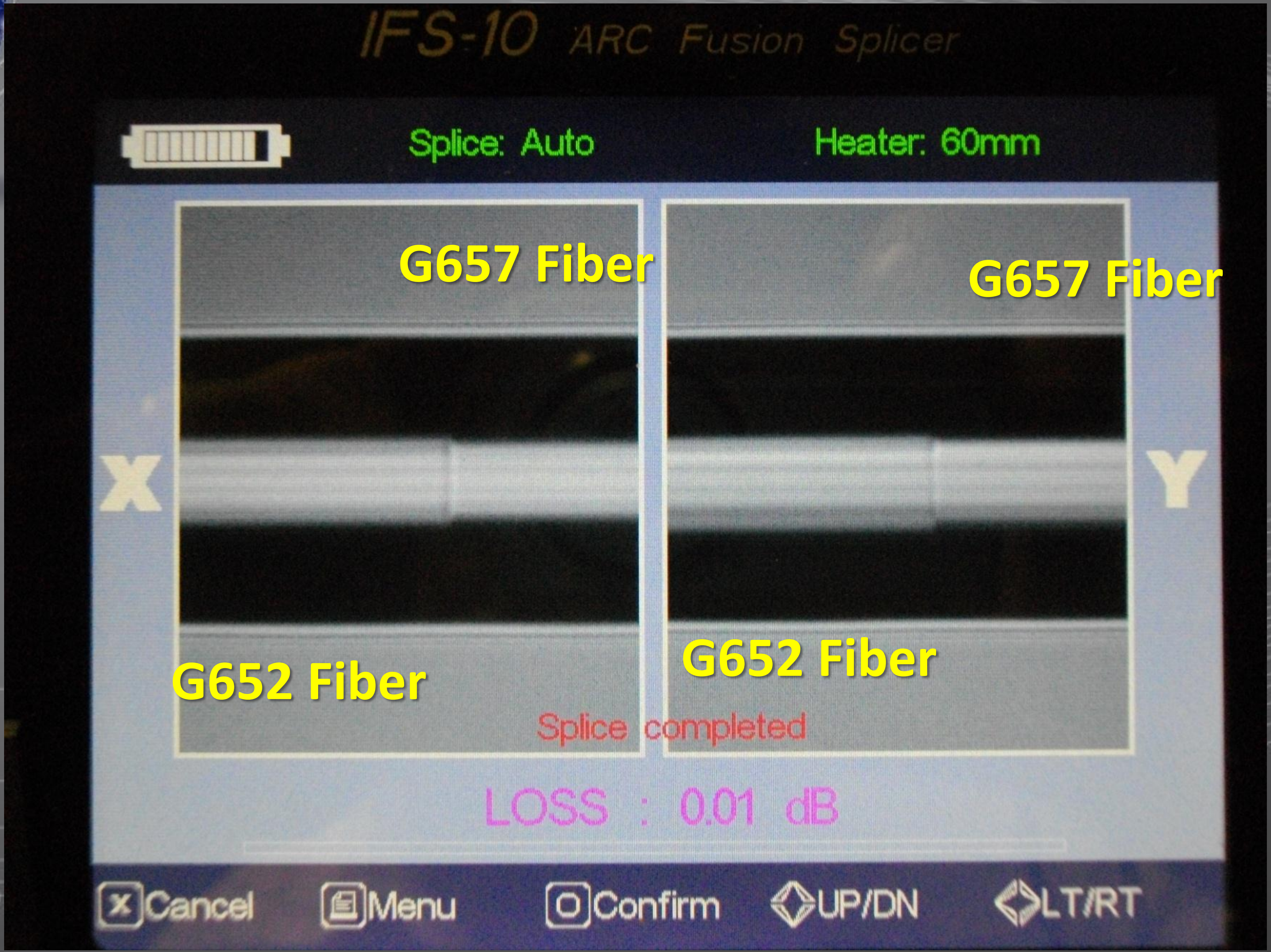
Magnified view of G.652D to G.657 Fusion Splice



The reason for the visible line in the splice is because of the slight difference in material Composition of the Bend Insensitive Fiber vs.G.652D fiber.

Magnified view of G.652D to G.657 Fusion Splice

G.652D and G.657 Splicing



SUMMARY

To maximize the power budget in your fiber network, reduce all sources of losses, especially the splice loss, by observing ITU-T recommendations.

1. ***Proper selection of Fiber Optic Cable***
2. ***Inform or train your technical personnel on proper fiber optic cable preparation prior to splicing***
3. ***Proper selection of Fusion Splicer***
4. ***Proper Splice Loss Testing***

THANK YOU

jun.carbonell@ecmnetworks.com

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