B-13D0091B

Introduction of PANDA fibers

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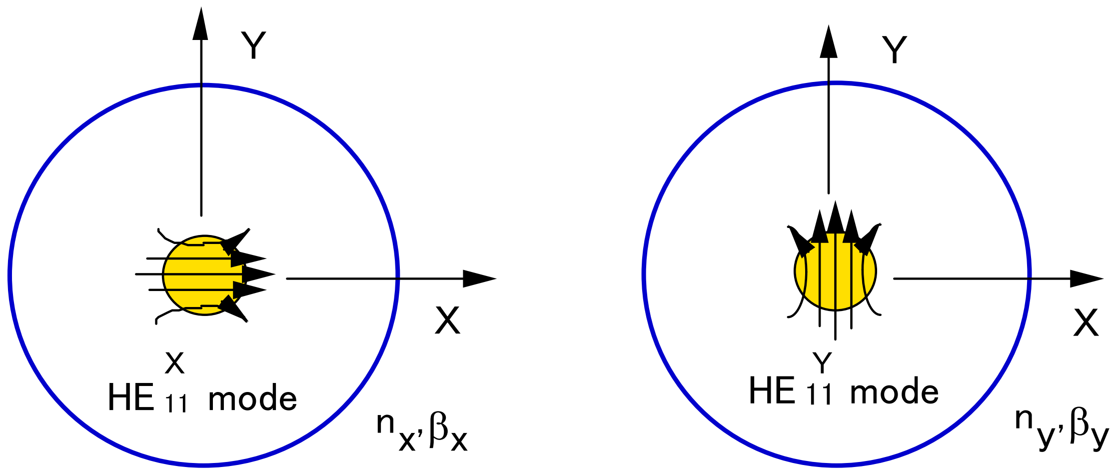
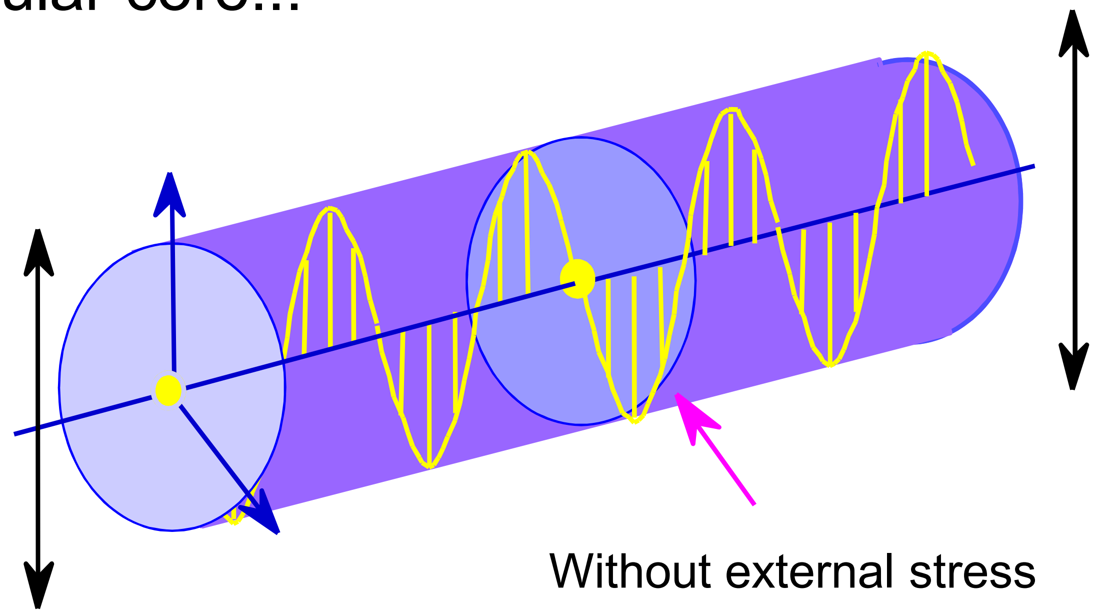
Polarization modes in ideal SM fiber

- Single-mode (SM) fiber have two degenerated orthogonal polarization modes, which have the identical propagation constant: $n_x=n_y$, $b_x=b_y$
- Rotational asymmetries such as core ellipse or lateral stress induce birefringence and resolve the degeneracy.



Polarization in ideal SM fiber

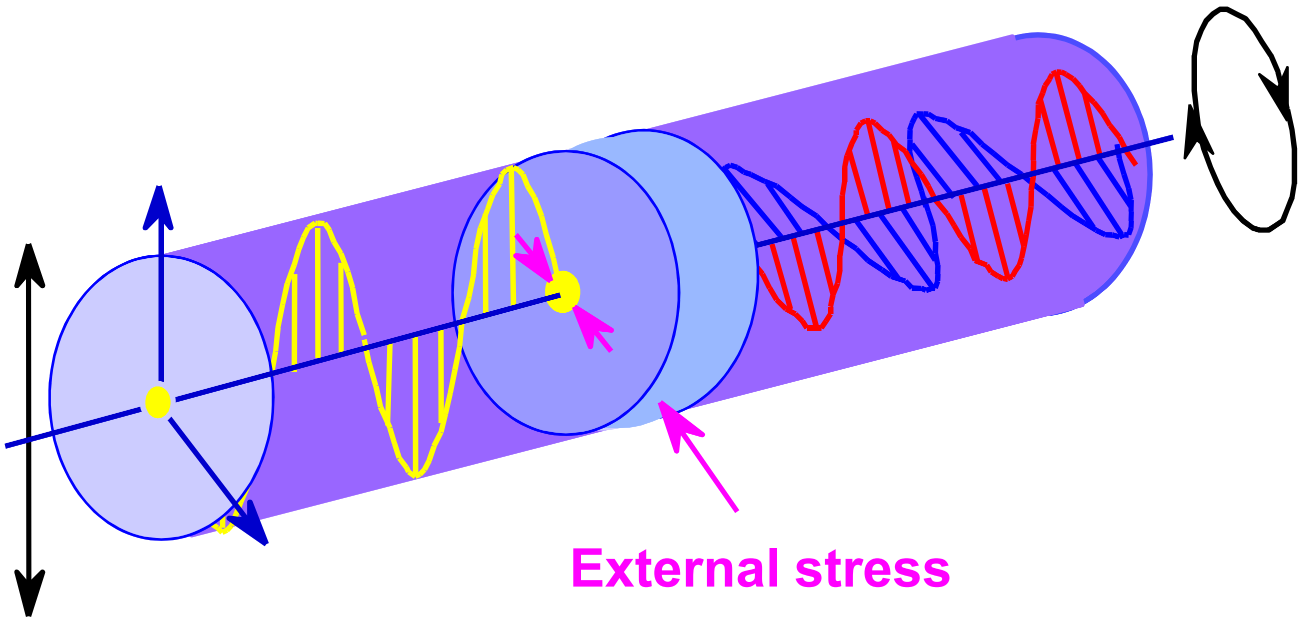
- An ideal SM fiber with perfect rotational symmetry is able to maintain any state of polarization.
- If any stress is induced on the fiber or a fiber has an non-circular core...



Without external stress

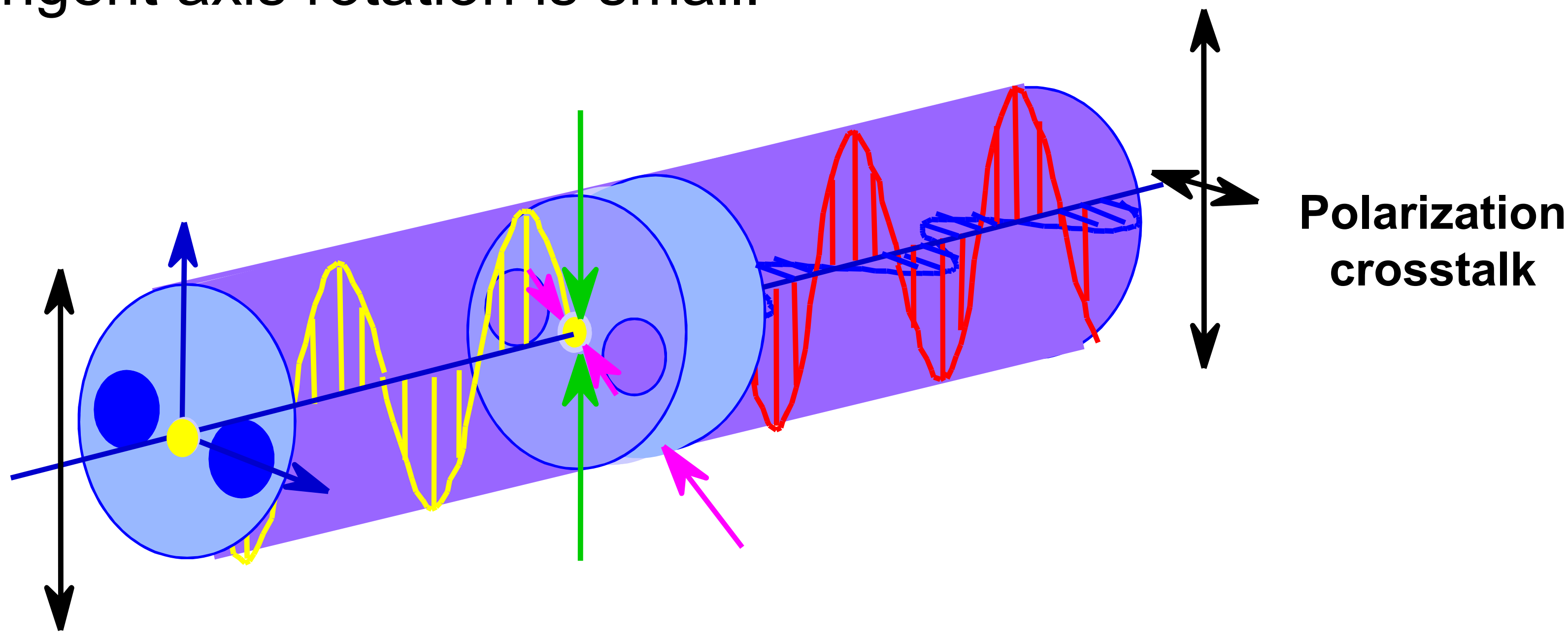
Polarization in actual SM fiber

- Stress-induced phase difference causes polarization change.
- State of polarization at output is unstable.



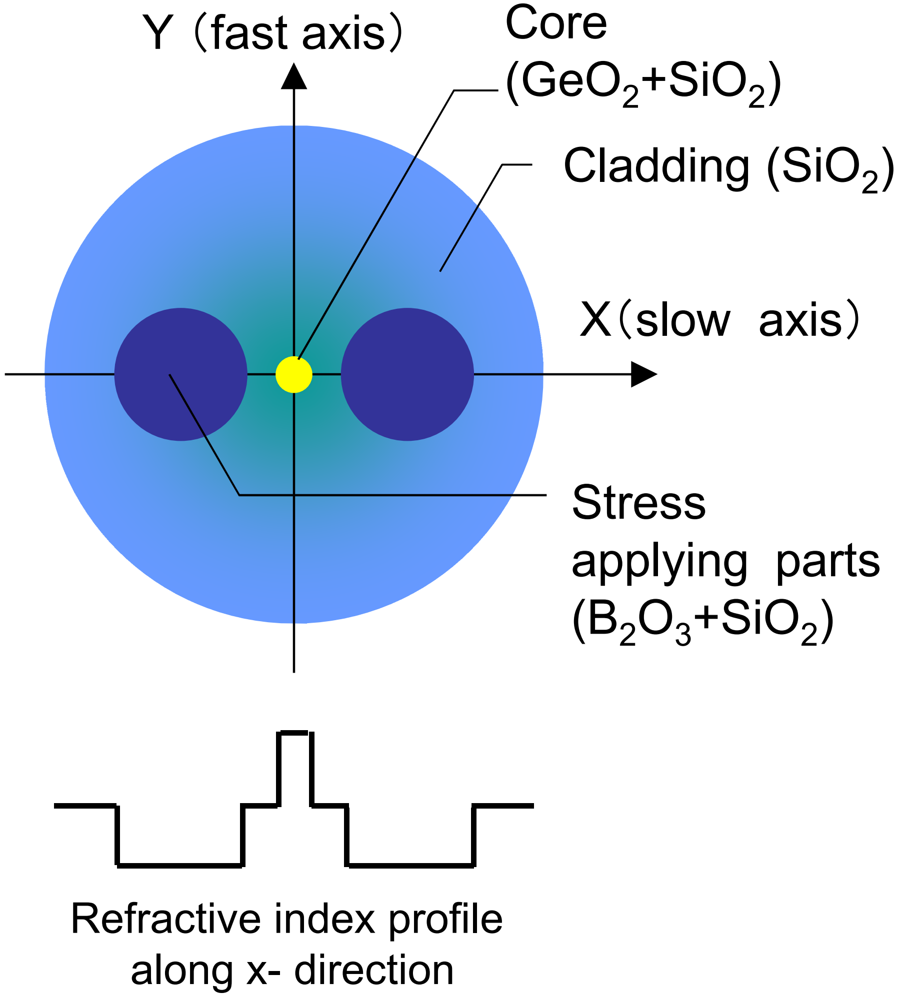
How to maintain polarization

A fiber with high internal birefringence is able to maintain linear polarization against external perturbations since its birefringent axis rotation is small.

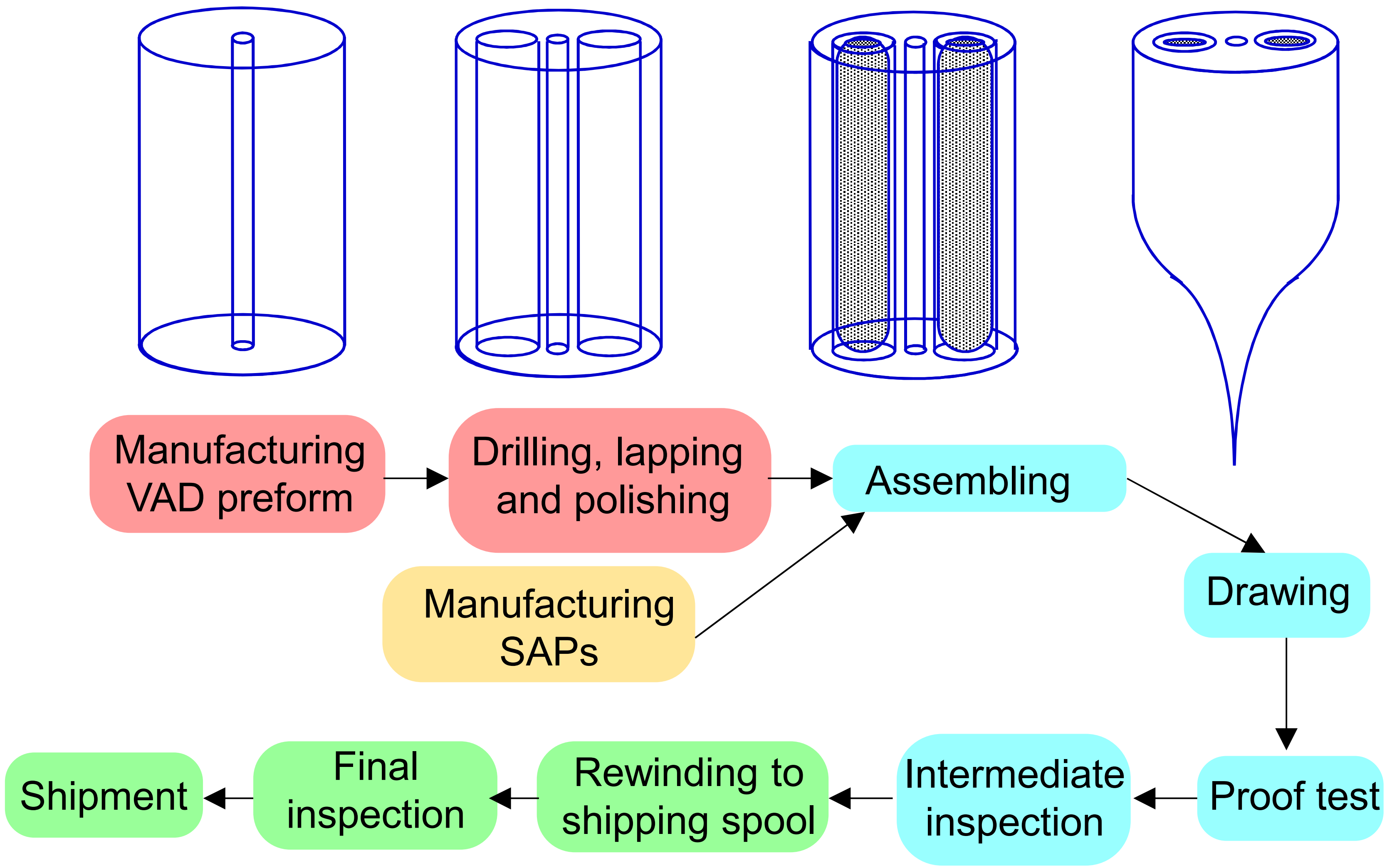


Structure of PANDA fiber

- Boron-doped SAP (Stress applying parts) has higher thermal coefficient of expansion than the cladding (SiO_2).
- The SAP shrinks more than the cladding during cooling process of fiber drawing process.
- Tensile stress between SAPs applied to the core induces large birefringence.



Production process of Fujikura PANDA



Inspection items and methods on PANDA fiber

	Application	Method or technique	Reference
Fiber diameter	O / I / F	Gray scale	ITU-T G.650
Core offset	I / F	Gray scale	ITU-T G.650
Coating diameter	O / I	Microscope	---
Mode field diameter	I	Far-field pattern / Variable aperture	ITU-T G.650
Cutoff wavelength	I	Bend reference	ITU-T G.650
Attenuation	I	OTDR / Spectral loss (cutback)	ITU-T G.650
Group beat length	I	JME / Wavelength scan	ITU-T G.650
Crosstalk	F	Direct	FOTP-193

O: Process measurement
I : Intermediate inspection
F: Final inspection

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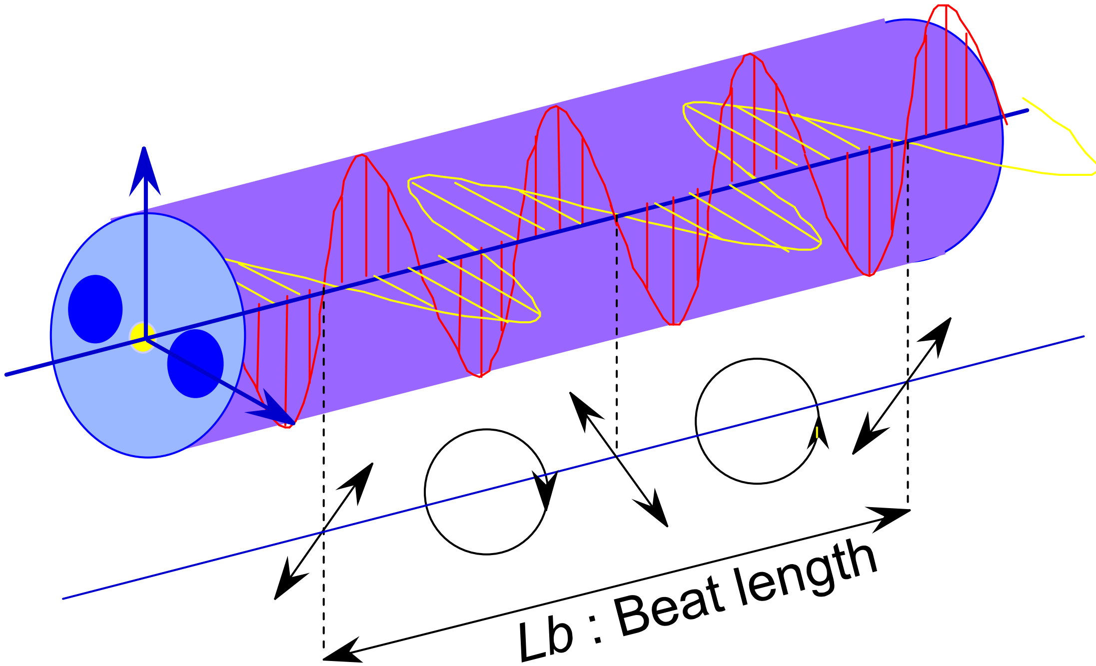
Beat length

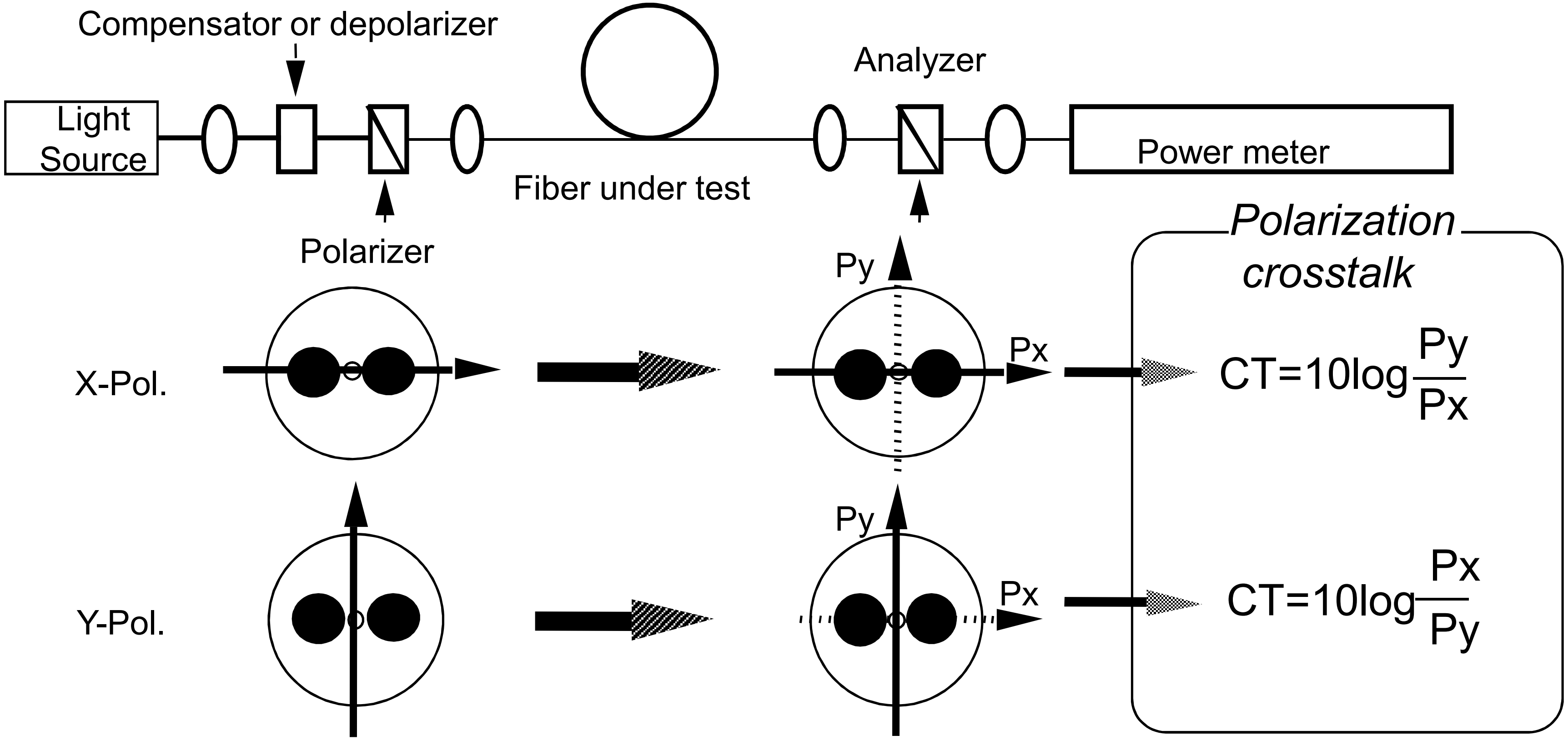
- Beat length *Lb* is the length which phase difference between X and Y polarization modes equals 2π along a PM fiber.
- Relation between beat length(*Lb*), birefringence(*B*), and wavelength(*λ*) is expressed by the following equation:

$$Lb = \frac{\lambda}{B}$$



Measurement of polarization crosstalk

Fujikura measures the extinction ratio of output light while linearly polarized input light is launched into fiber.



Unit: dB

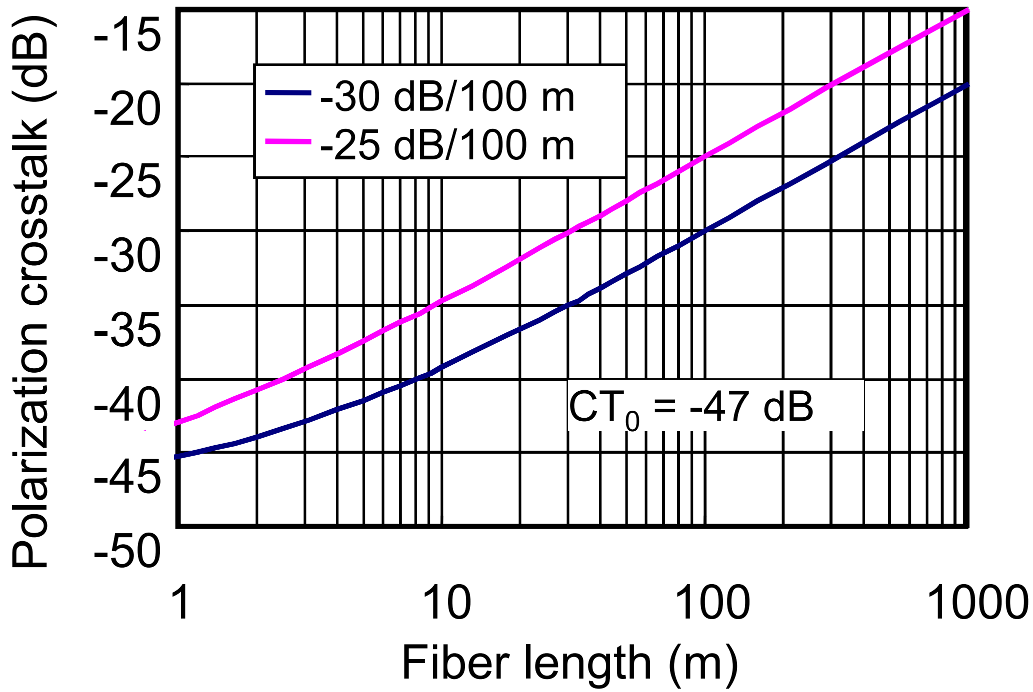
Power coupling coefficient

- Polarization crosstalk in linear expression is proportional to fiber length through random mode-coupling.
- Power coupling coefficient, h-parameter, is defined as a power coupled to the orthogonal mode in unit length.

$$h = \frac{\tan^{-1}(\eta)}{L} \approx \frac{\eta}{L}$$

$$\eta = \frac{P_y}{P_x} = 10^{CT/10}$$

L: Fiber Length



Reliability performance

	Test item	Reference	Condition	Results
1	Observation of Coating	---	Origin, Temperature-humidity aging, Water soak, Hot water soak	Passed
2	Strippability	IEC,GR-20	Origin(45,23,0degC), Temperature-humidity aging, Water soak, Hot water soak	Passed
3	Attenuation	---	Aging(-40,85degC), Temperature cycling Temperature-humidity aging, Hot water soak	Passed
4	Polarization Crosstalk	---	Aging(-40,85degC), Temperature cycling Temperature-humidity aging, Hot water soak	Passed
5	Tensile strength	IEC,GR-20	Origin, Aging(-40,85degC),Temperature cycling, Temperature-humidity aging	Passed
6	Fatigue value	IEC,GR-20	Origin, Temperature-humidity aging	Passed
7	Other	UL1581 VW-1	For reference, Flame retardant type only	Passed

Fiber strength certification by Mitsunaga theory

Below failure probability equation is commonly used for telecom networking.

$$F = 1 - exp\left[-N_p L \frac{m}{n-2} \frac{\varepsilon_s^n t_s}{\varepsilon_p^n t_p} \right]$$

Griffith flaw model shows micro defects on the fiber. Flaws are grown to break by external stress to the fiber. If no external stress, then no break.

Fiber break is caused by below conditions

Frequency of low strength portion : Initial distribution of low strength

Growing speed of flaws : Ambient condition such as temperature / moisture

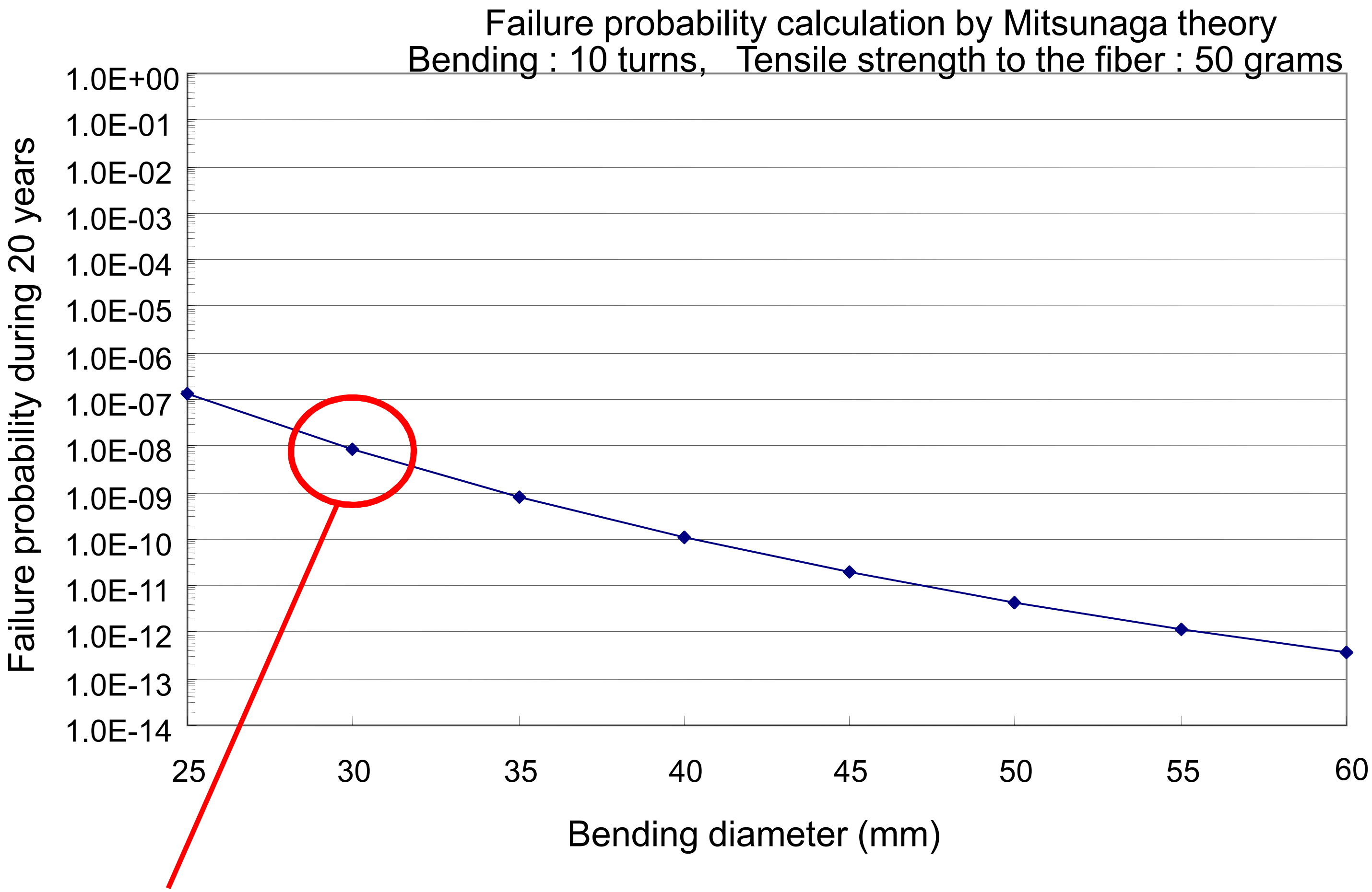
Stress : Tensile stress, Twisting stress

Macro bending stress, Micro bending

The equation covers only for tensile stress and macro bending, but not for twisting stress and micro bending to the fiber.

Mitsunaga, et al. : “Failure prediction for long length optical fiber based on proof testing”, J.Appl. Phys. 53(7), July 1982

PANDA fiber failure probabilities after 2% proof test



Radius 15mm failure probability is around 1.0E-08 after 20 years.

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PANDA fiber lineup

(2) Product type:
SM: Single Mode fiber
SRSM: Small Radius Single Mode fiber
(Minimum bending radius 15 mm)
BISM : Bend Insensitive Single Mode fiber
(Minimum bending radius 7.5 mm)
DS: Dispersion Shifted single mode fiber
ED: Erbium Doped single mode fiber
SC: Pure Silica Core single mode fiber
HA: High NA single mode fiber

(5) Coating structure:
U: UV/UV coated fiber
Y: Polyimide coated fiber
H: UV/UV/Polyester-elastomer coated fiber
J: UV/UV/Polyester-elastomer/Polyolefin cord

RC SM 15 - PS- U 17 D (-H)

(1) (2) (3) (4) (5) (6) (7) (8)

(1) Cladding diameter:
Blank: 125 μm
RC : 80 μm

(3) Operating wavelength:
15: 1550 nm
14: 1400-1500 nm
13: 1300 nm
98: 980 nm
85: 850 nm
63: 630 nm
53: 530 nm
48: 480 nm
40: 400 nm

(6)Coating diameter:
17: 165 μm
25: 250 μm
40: 400 μm
50: 500 μm
90: 900 μm
20: 2.0 mm

(8)Proof level:
Blank : 1%
-H : 2%

(7) UV curable resin type:
D: UV/UV resin type D
C: UV/UV resin type C

(4)Polarization maintaining ability:
PS : Standard,
PX : Extra,
PR : Reduced polarization

Lineup of coating type

- UV coating (Coating diameter 250 μm, 400 μm)

- UV/Polyester-elastomer coating
  (Coating diameter 500 μm, 900 μm)

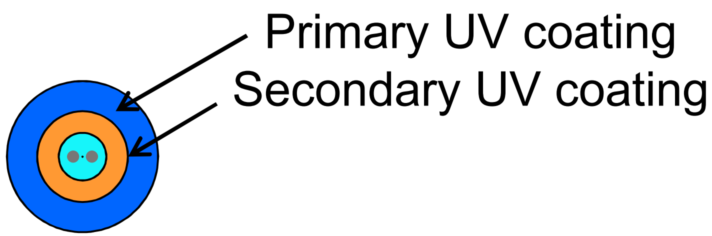
  Coated by UL94-V-0 compliant flame-resistant polyester-elastomer

  UL1581-VW1 Equivalent

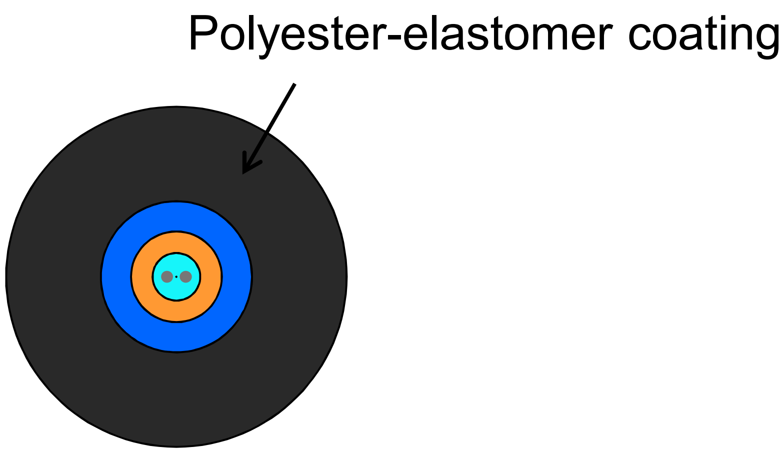
- UV/Polyester-elastomer/Polyolefin coating
  (Coating diameter 2 mm)

  Equivalent of IEC60332-3 Category C

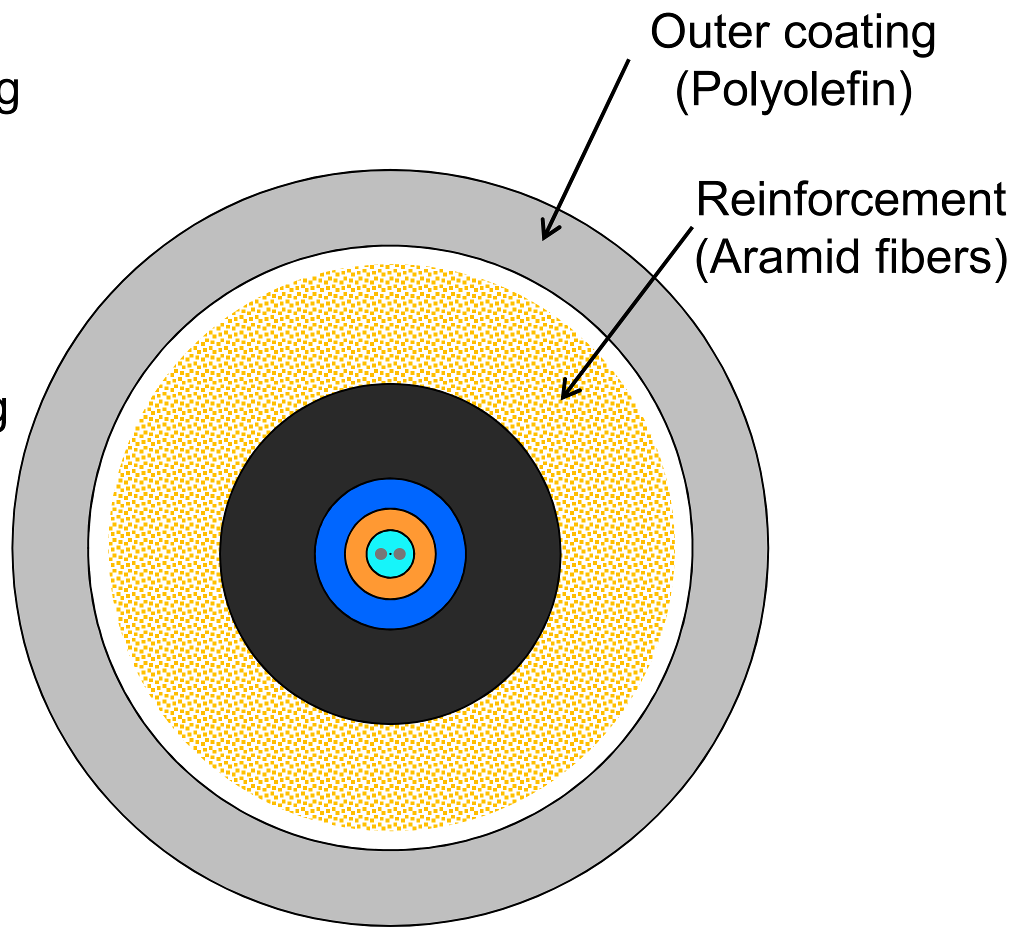
Cross section drawing for each coating



UV coating fiber



UV/Polyester-elastomer coating



UV/Polyester-elastomer/Polyolefin coating

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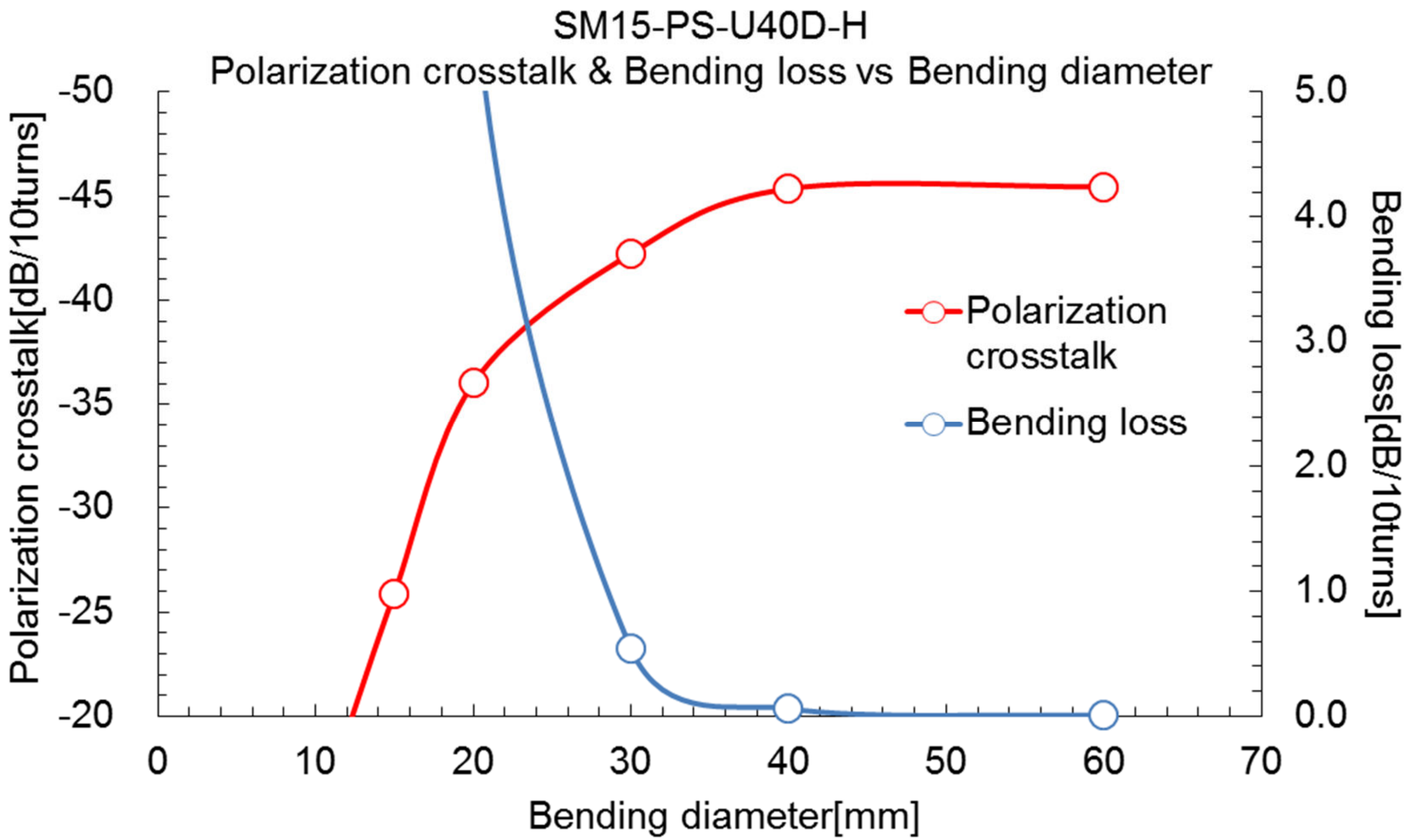
Bend performance of 125 μm cladding PANDA

- No significant performance degradation in a bend diameter ≥40 mm of 2% proof test PANDA fibers.
- 1% proof should be bent ≥ D60mm due to life time.



Specifications for UV/UV PANDA fibers

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	µm	+/-0.5 µm	Max. dB/km	mm	Max. dB/100m	µm	-	µm
SM85-PS-U40D	0.85	5.5	3.0	1.0 - 2.0	-30	0.65 - 0.80	UV/UV	400±15
SM85-PS-U25D								245±15
SM98-PS-U40D	0.98	6.6	2.5	1.5 - 2.7		0.87 - 0.95		400±15
SM98-PS-U25D								245±15
SM13-PS-U40D	1.3	9.0	1.0	2.5 - 4.0		1.13 -1.27		400±15
SM13-PS-U25D								245±15
SM14-PS-U40D	1.40 - 1.49	9.8	1.0	2.8 - 4.7		1.26 - 1.38		400±15
SM14-PS-U25D								245±15
SM15-PS-U40D	1.55	10.5	0.5	3.0 - 5.0		1.30 - 1.44		400±15
SM15-PS-U25D								245±15

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Specifications for 900 μm PANDA fibers

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	μm	+/-0.5 μm	Max. dB/km	mm	Max. dB/100m	μm		μm
SM85-PS-H90D	0.85	5.5	3.0	1.0 - 2.0	-30	0.65 - 0.80	UV/Polyester-elastomer(Black)	900 ± 100
SM98-PS-H90D	0.98	6.6	2.5	1.5 - 2.7		0.87 - 0.95	UV/Polyester-elastomer(Green)	
SM13-PS-H90D	1.3	9.0	1.0	2.5 - 4.0		1.13 - 1.27	UV/Polyester-elastomer(Black)	
SM14-PS-H90D	1.40 -1.49	9.8	1.0	2.8 - 4.7		1.26 - 1.38	UV/Polyester-elastomer(Black)	
SM15-PS-H90D	1.55	10.5	0.5	3.0 - 5.0		1.30 - 1.44	UV/Polyester-elastomer(Black)	

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Specifications of 2mm PANDA fibers

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	µm	+/-0.5 µm	Max. dB/km	Max. mm	Max. dB/100m	µm		mm
SM85-PS-J20D	0.85	6.5	3.0	1.0 - 2.0	-30	0.65 - 0.77	UV/ Polyester-elastomer(Black)/ Polyolefin(Gray)	2.0 ± 0.2
SM98-PS-J20D	0.98	6.0	2.5	1.5 - 2.7		0.87 - 0.95	UV/ Polyester-elastomer(Green)/ Polyolefin(Gray)	
SM13-PS-J20D	1.3	9.0	1.0	2.5 - 4.0		1.13 - 1.27	UV/ Polyester-elastomer(Black)/ Polyolefin(Gray)	
SM14-PS-J20D	1.40 -1.49	9.8	1.0	2.8 - 4.7		1.26 - 1.38		
SM15-PS-J20D	1.55	10.5	0.5	3.0 - 5.0		1.30 - 1.44		

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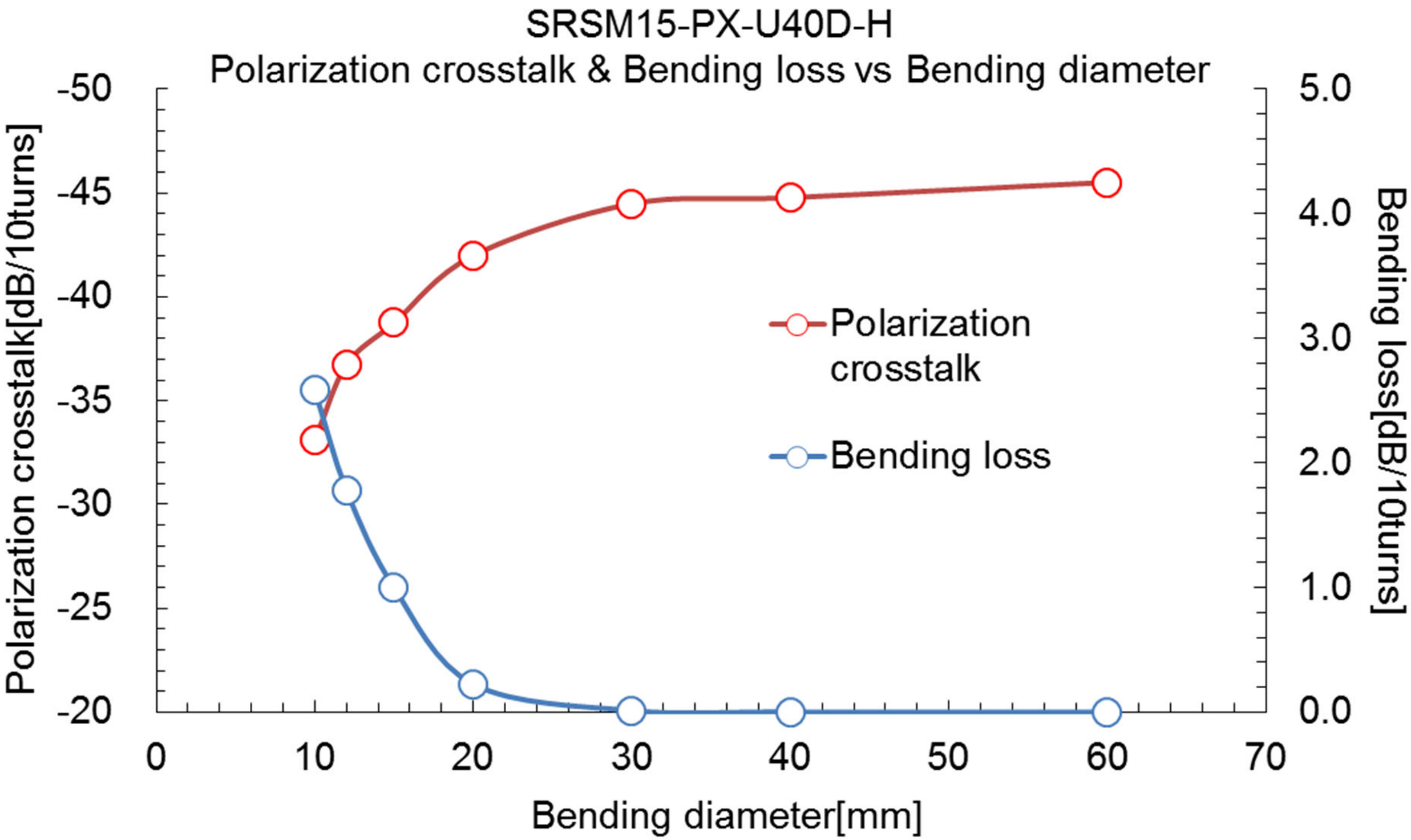
PANDA fiber lineup for small bending diameter

SR15 type PANDA fibers

- SR15 series SM fibers have been widely released and spread as standard telecommunication cable.
- Fujikura has SR15 type PANDA fibers.
- Widely spread 125 μm parts and accessories are usable.
- Splice properties to SR15 series are very good.

SRSM15-PX-H bending properties



Specifications of SRSM15 type

Items	Unit	Specification
MFD at 1550 nm	μm	9.5 +/- 0.4
Attenuation at 1550 nm	dB/km	Less than 0.50
Bending loss (Bending diameter = 30 mm, 10 turns at 1550 nm)	dB	Less than 0.50
Fiber cutoff wavelength	nm	Less than 1440
Beat length at 1550 nm	mm	2.0 - 5.0
Polarization crosstalk at 1550 nm	dB/100m	Less than -30
Bending Polarization crosstalk at 1550 nm	dB	Less than -30 Bending diameter = 30 mm, 10 turns
Coating diameter SRSM15-PX-U40D-H SRSM15-PX-H90D-H	-	 400 μm UV/UV 900 μm UV/Polyester-elastomer
Proof level	%	More than 2

New! Specifications of 500 μm coating SR15 type PANDA fibers

Items	Unit	Specification
MFD at 1550 nm	μm	9.5 +/- 0.4
Attenuation at 1550 nm	dB/km	Less than 0.50
Bending loss (Bending diameter = 30 mm, 10 turns at 1550 nm)	dB	Less than 0.50
Fiber cutoff wavelength	nm	Less than 1440
Beat length at 1550 nm	mm	2.0 - 5.0
Polarization crosstalk at 1550 nm	dB/100m	Less than -25
Bending Polarization crosstalk at 1550 nm	dB	Less than -25 (Bending diameter = 30 mm, 10 turns at 1550 nm)
Coating diameter SRSM15-PX-H50D-H	-	500 μm UV/Polyester-elastomer
Proof level	%	More than 2

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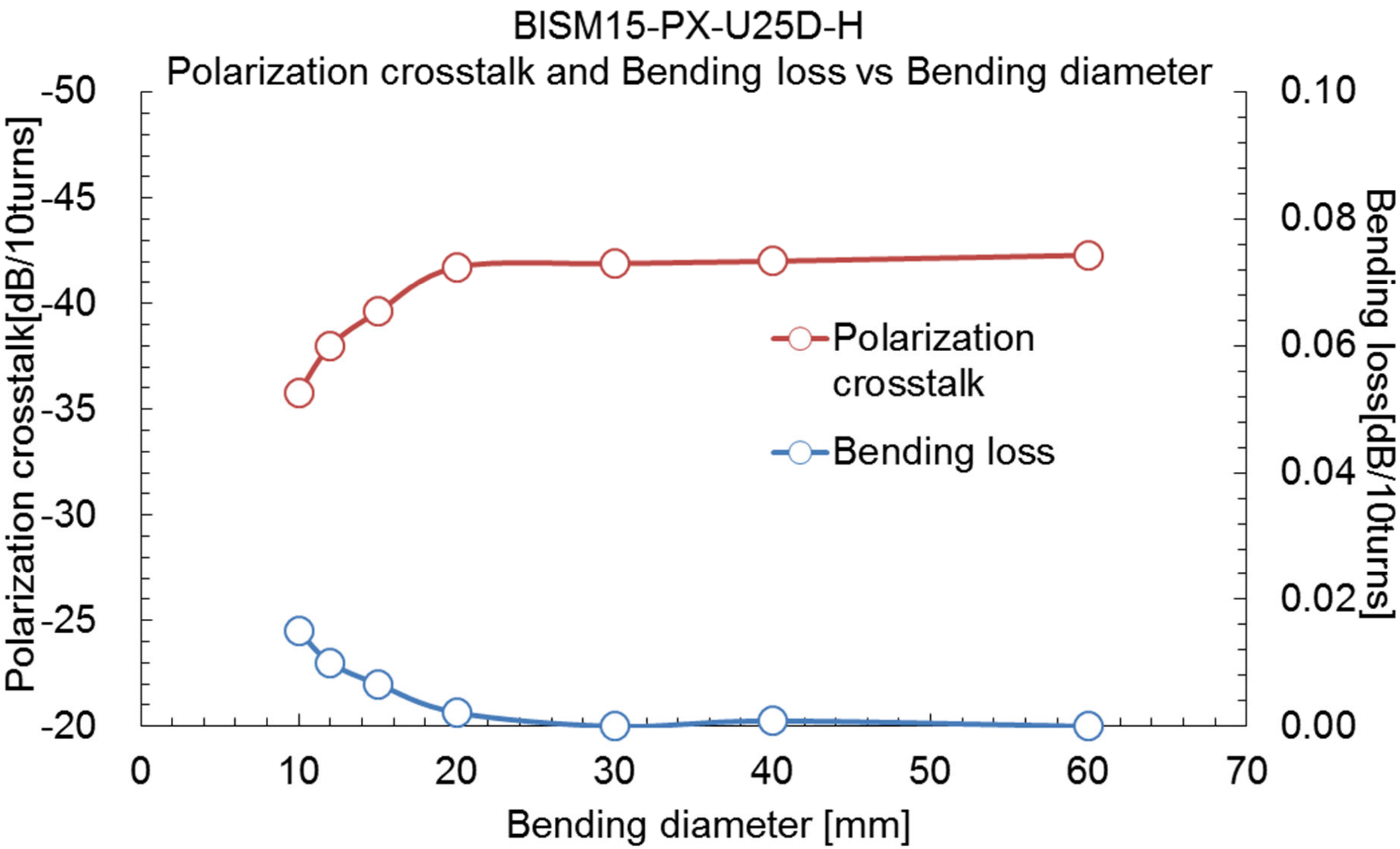
New ! Ultra bend insensitive type (BISM)

In response to the request of our customers who use PANDA fibers in condition of the further small bend radius , Fujikura has released BISM15-PX-U25D-H and H50D-H with allowable smallest bend radius .

New ! Bend performance of BISM type



New ! Specification of BISM type

Wavelength : 1550 nm

Item	Unit	Specification	
		BISM15	SRSM15
MFD	μm	9.0 +/- 0.4	9.5 +/- 0.4
Attenuation	dB/km	≦3.0	≦0.50
Bending loss	dB	≦1.0 Bending diameter =15 mm, 10 turns	≦0.50 Bending diameter ＝30 mm, 10 turns
Cutoff wavelength	nm	≦1440	≦1440
Beat length	mm	≦ 3.0	2.0 - 5.0
Polarization cross-talk	dB/100m	≦-30	≦-25 (500 μm type), ≦-30 (Other types)
Bending Polarization cross-talk	dB	≦-30, Bending diameter =15 mm, 10 turns	≦-30 Bending diameter ＝30 mm, 10 turns
Coating	-	250 μm UV 500 μm polyester-elastomer	250 μm, 400 μm UV, 500 μm, 900 μm polyester-elastomer
Proof level	%	≧ 2	≧ 2

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Low birefringence PANDA fiber

Suitable for manufacturing of optical fiber couplers

- High controllability of cladding mode suppression and lowering excess loss at the manufacturing of fusion type couplers

- SAPs (Stress applying parts) interval is widely located

- Lower birefringence than standard PANDA fibers

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Specifications for low birefringence PANDA fibers

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	μm	+/-0.5 μm	Max. dB/km	mm	Max. dB/100m	μm	-	μm
SM63-PR-U25D-H	0.63	4.5	12	1.5 - 3.5	-25	0.50 -0.62	UV/UV	245 +/-15
SM98-PR-U25D-H	0.98	6.6	3.0	2.8 - 4.9		0.80 -0.95		
SM13-PR-U25D-H	1.3	9.0	1.0	3.8 - 5.6		1.11 -1.27		
SM14-PR-U25D-H	1.40 -1.49	9.8	1.0	4.1 - 7.3		1.26 -1.38		
SM15-PR-U25D-H	1.55	10.5	0.5	4.4 - 7.8		1.30 -1.44		

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Specifications for Dispersion Shifted PANDA fibers

Spec. of chromatic dispersion :less than +/- 3 ps/nm/km @ 1550 nm

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	μm	+/-1.0 μm	Max. dB/km	mm	Max. dB/100m	Max. μm		μm
DS15-PS-U40A	1.55	8.0	0.5	3.0 - 5.0	-30	1.53	UV/UV	400 ± 15
DS15-PS-N90A					-25		UV/ Polyamide(Blue)	900 ± 100
DS15-PS-G20A							UV/ Polyamide(Blue)/ Polyolefin(Gray)	2000 ± 200

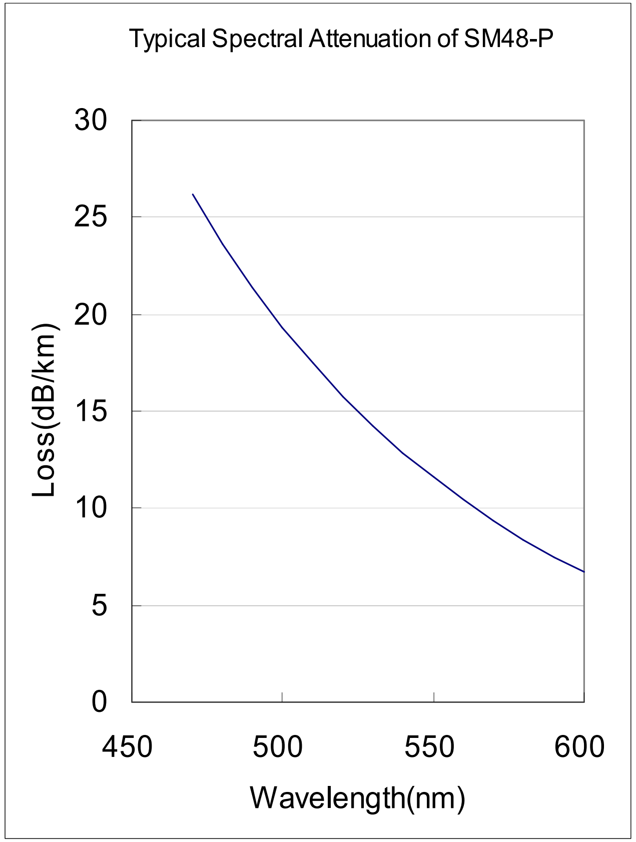
Contents

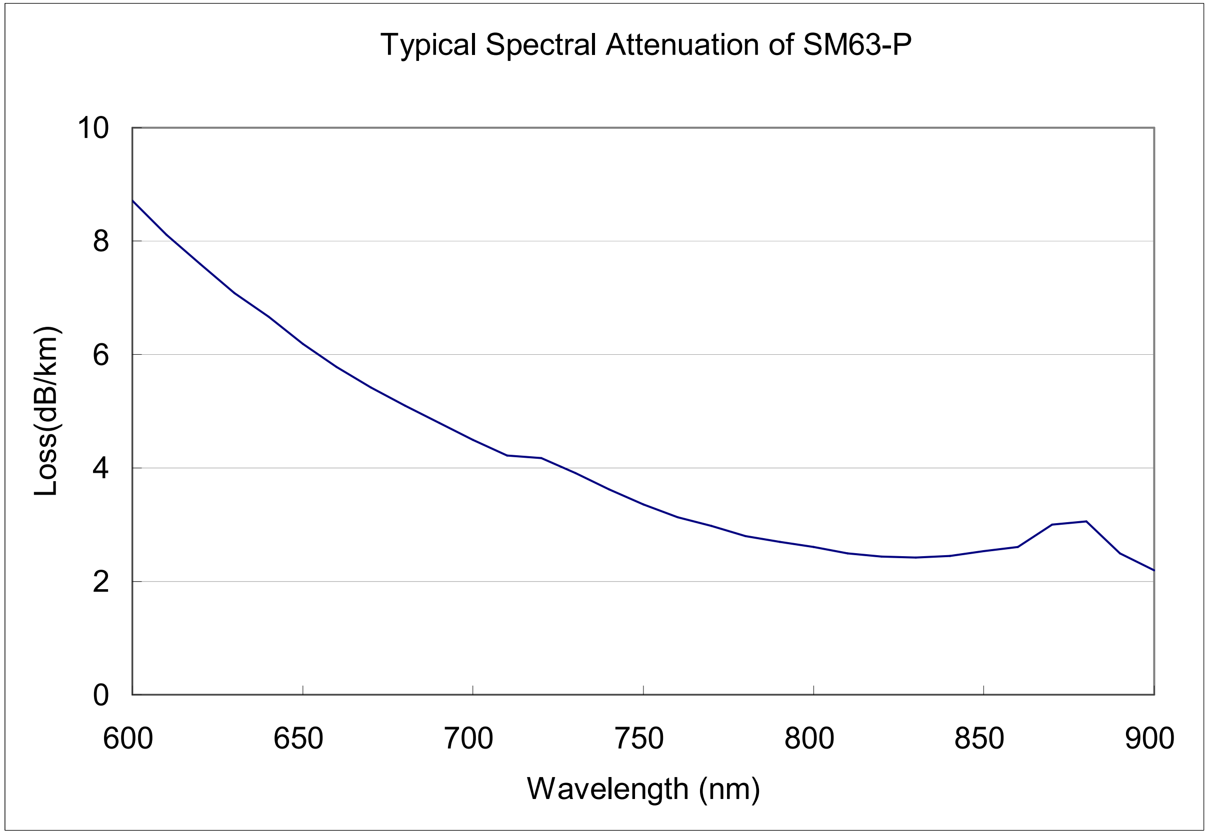
PANDA fibers for visible wavelength

- Suitable for the polarized mode transmission from various polarization sources

- Wide choice of PANDA fibers correspond to the wavelength of the source of light for various spectra

Typical wavelength characteristics of 0.48, 0.63 μm PANDA





Specifications for PANDA fibers for visible wavelength

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	μm	+/-0.5 μm	Max. dB/km	Max. mm	Max. dB/100m	μm		μm
SM63-PS-J20D	0.63	4.5	12	2.0	-30	0.52 - 0.62	UV/UV Polyester-elastomer(Black) /Polyolefin(Gray)	2.0 ±0.2 (mm)
SM63-PS-H90D							UV/UV Polyester-elastomer(Black)	900 ±100
SM63-PS-U40D							UV/UV	400 ±15
SM53-PS-J20D	0.53	4.2	15			0.45 - 0.53	UV/UV Polyester-elastomer(Black) /Polyolefin(Gray)	2.0 ±0.2 (mm)
SM53-PS-H90D							UV/UV Polyester-elastomer(Black)	900 ±100
SM53-PS-U40D							UV/UV	400 ±15

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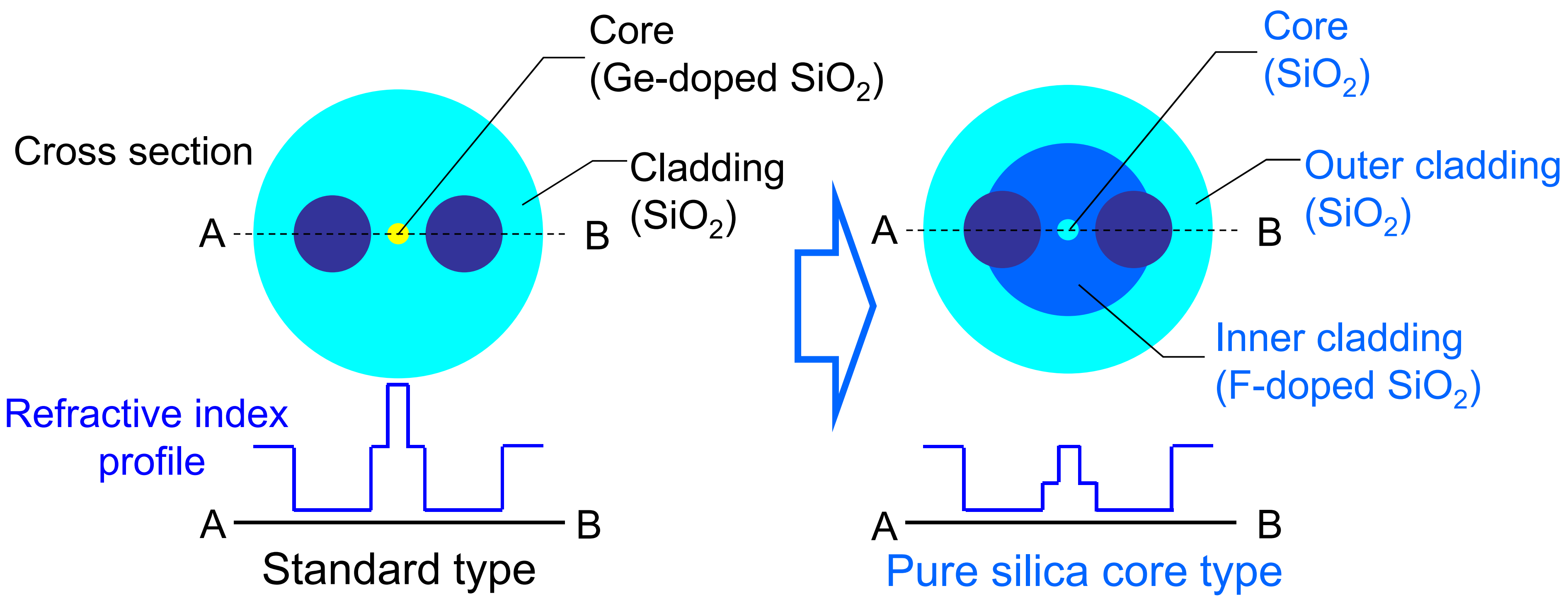
Pure silica core PANDA fibers

Standard Ge-doped silica core fibers may occur damage and color center in the core by high energy density of the visible light.

Pure silica core PANDA fibers are suitable for visible light transmission with the high energy because the fibers have few impurities and defects.



Specifications for pure silica core type (UV)

Release of SC53-PS-U40D for operating wavelength of 530 nm

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	μm	+/-0.5 μm	Max. dB/km	Max. mm	Max. dB/100m	μm	-	μm
SC53-PS-U40D	0.53	5.2 ±0.5	20	2.0	-30	0.52以下	UV/UV	400 ±15
SC48-PS-U40D	0.48	4.0 ±0.5	30			0.40 ~ 0.47		
SC48-PS-U25D								245 ±15
SC40-PS-U40D	0.41	3.5 ±0.5	50	1.7		0.33 ~ 0.40		400 ±15
SC40-PS-U25D								245 ±15

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Specifications for pure silica core type (900 μm, 2mm)

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	μm	+/-0.5 μm	Max. dB/km	Max. mm	Max. dB/100m	μm	-	mm
SC40-PS-H90D	0.41	3.5	50	1.7	-30	0.33 - 0.40	UV/UV Polyester-elastomer(Black)	900 ±100
SC40-PS-J20D							UV/UV Polyester-elastomer(Black) /Polyolefin(Gray)	2.0 ±0.2 (mm)
SC48-PS-H90D	0.48	4.0	30	2.0		0.40 - 0.47	UV/UV Polyester-elastomer(Black)	900 +/-100
SC48-PS-J20D							UV/UV Polyester-elastomer(Black) /Polyolefin(Gray)	2.0 ±0.2 (mm)

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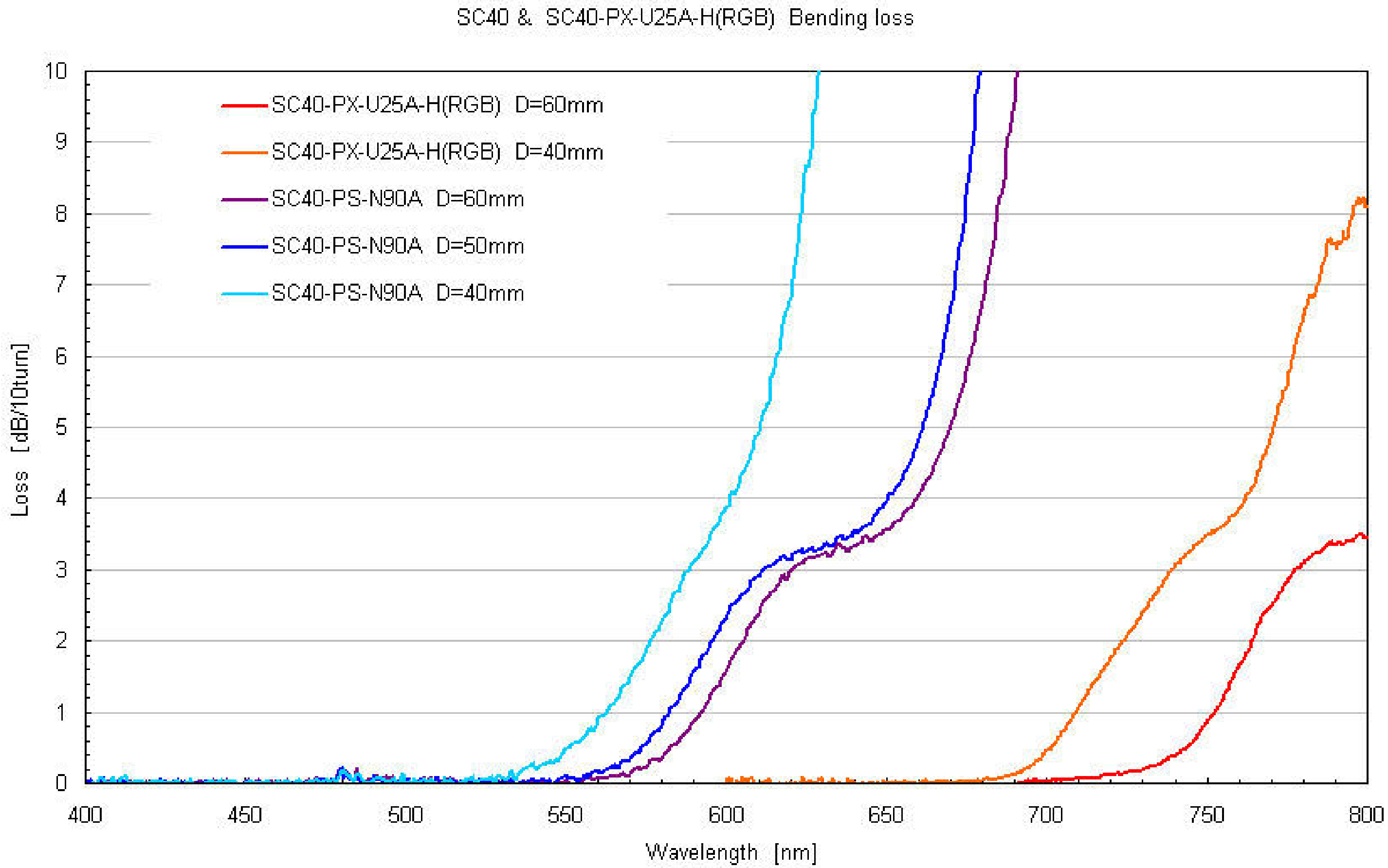
RGB PANDA fiber SC40-PX-U25A-H(RGB)

Bending performance with small bending diameter of RGB (visible light region) are improved completely.

– SC40 and RGB PANDA bending loss vs. wavelength



Specifications for RGB PANDA

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	μm	μm	Max. dB/km	mm	Max.	Max. μm		μm
SC40-PX-U25D-H (RGB)	0.405 - 0.64	3.8 ± 1.0 at 630 nm 2.3 ± 0.6 at 405 nm	50	Max. 2.0 at 630 nm	-30 dB /10 turns Bending diameter 60 mm	0.40	UV/UV	245 ± 15

Contents

80 μm cladding diameter type

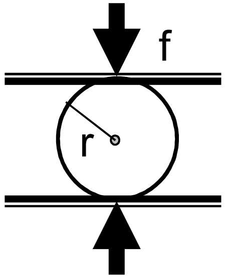
- Superiority in sensitivity to the external environment

- Higher durability in use of the small bend radius than a standard type

- Space-saving

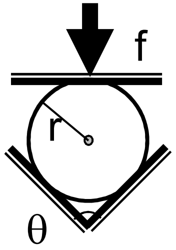
Features of RC-PANDA fibers (1)

1.Higher birefringence for lateral pressure endurance



$$B = 4C \frac{f}{\pi \cdot E} \frac{1}{r}$$

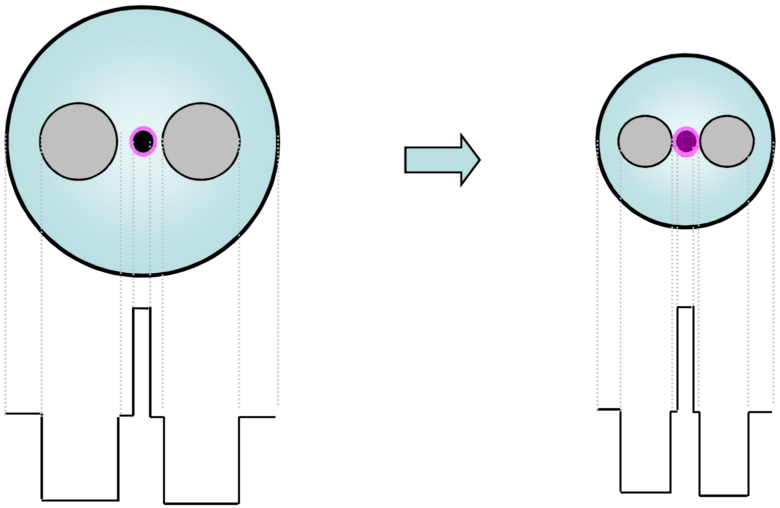
C:Photo Elastic constant
E:Young's modulus



$$B = 2C(1 - \mathrm{Cos}\theta \cdot \mathrm{Sin}\theta) \frac{f}{\pi \cdot E} \frac{1}{r}$$

Re-design Stress applying parts

2. Attenuation and MFD non-circularity optimization

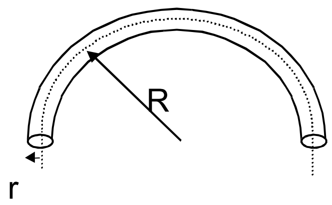


- B_2O_3 , OH absorption increase
- MFD non-circularity increase

To improve above, reduce slightly MFD.

Features of RC-PANDA fibers (2)

3. Smaller bending radius tolerance



$$B = \frac{1}{2} C \frac{r^2}{R^2}$$

•For good bending property,
Bending loss
Bending crosstalk
should be small both.

→ Higher aperture is redesigned to achieve the bending property

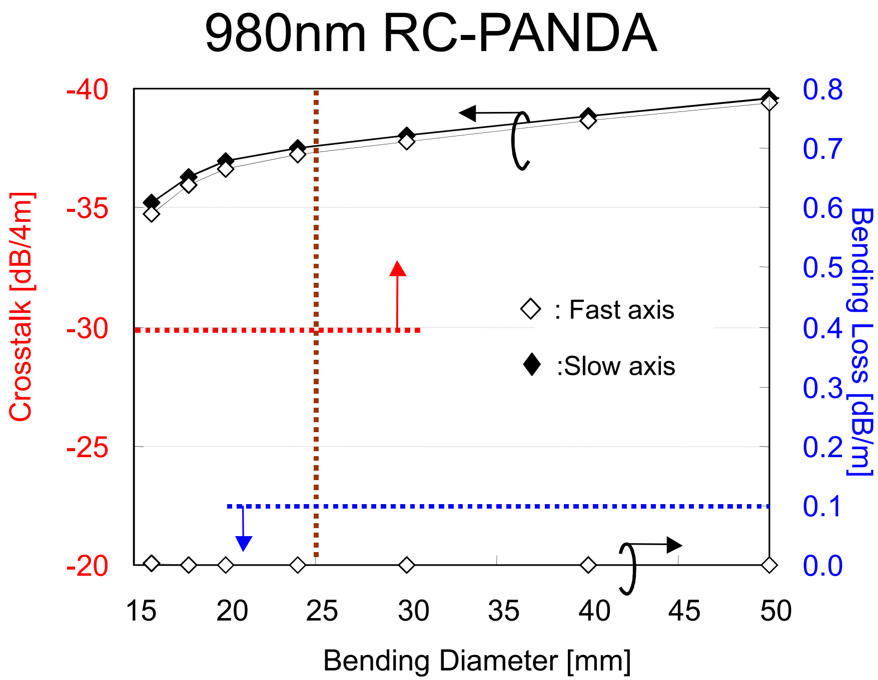
4. Splice loss optimizing

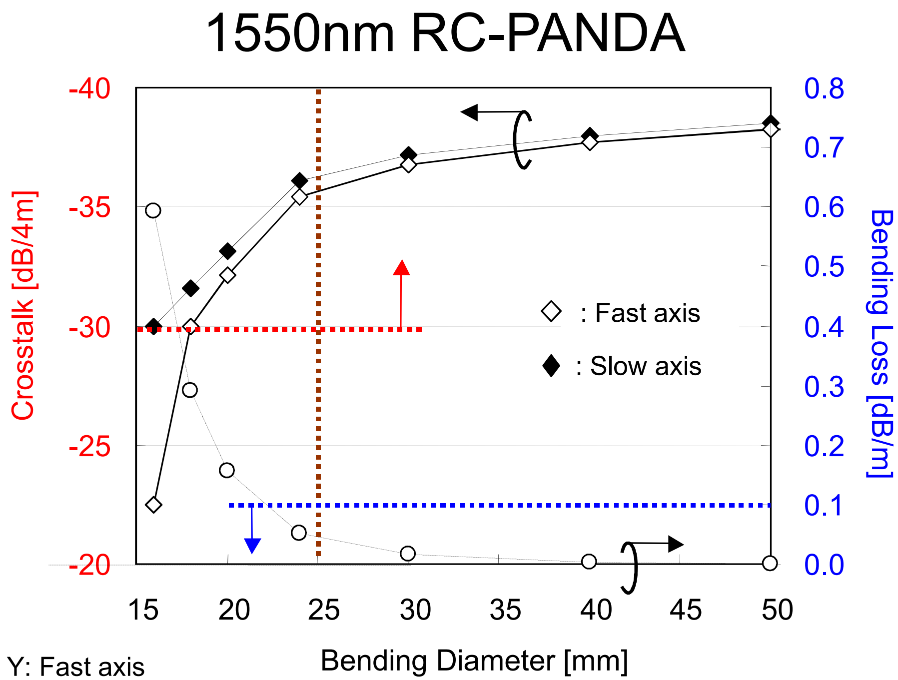
Telecom component
⇒ Need low splice loss with different major fiber splices

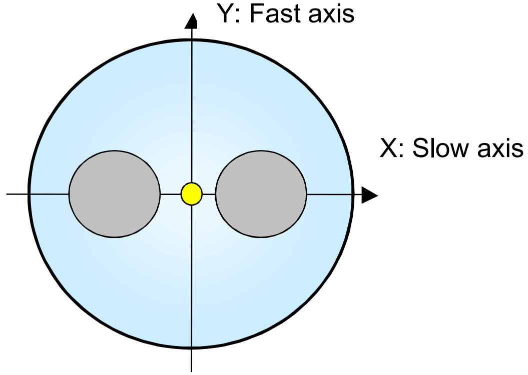
Requirement:
Splice loss < 0.1dB

→ MFD differences with other fibers are designed to be small.

Attenuation and Crosstalk in 4m length bending







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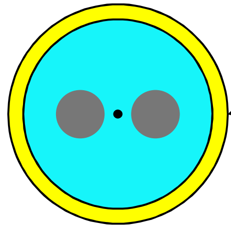
Specifications for 80μm cladding

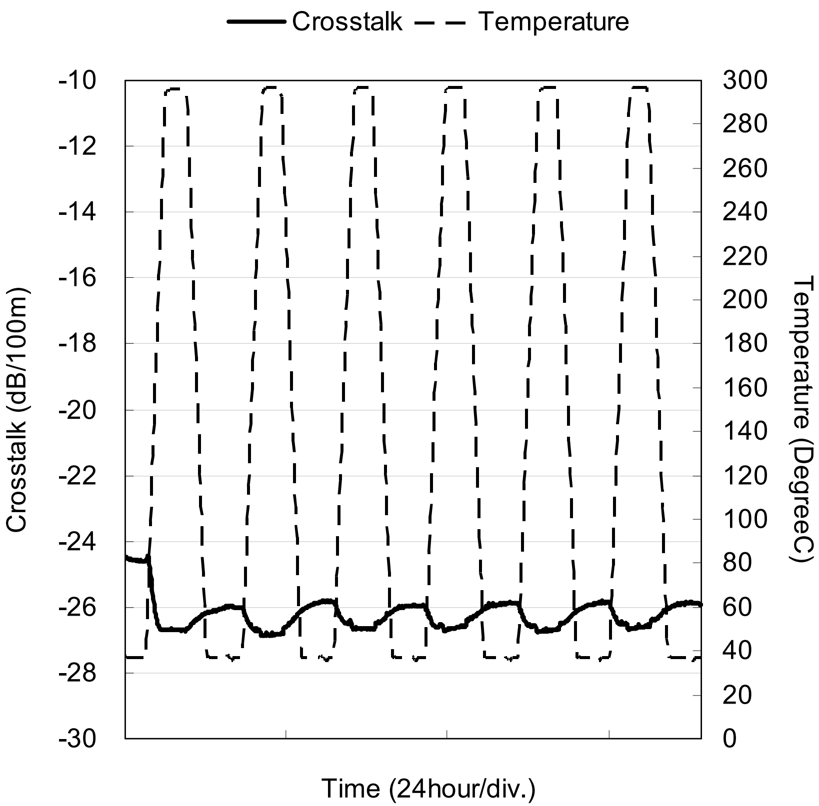
	λ_o	MFD	Att.	Beat length	Crosstalk	λ_c	Coating material	Coating diameter
	μm	+/-0.5 μm	Max. dB/km	mm	Max. dB/100m	μm	-	μm
RCHA85-PS-U17C	0.85	3.5	3.5	Max. 2.0	-30	0.65 - 0.80	UV/UV	165±10
RCSM98-PS-U17C	0.98	6.0	2.5	1.4 - 2.6	-25	0.87 - 0.95		
RCSM13-PS-U17C	1.3	8.2	2.0	2.0 - 3.5		1.10 - 1.29		
RCSM14-PS-U17C	1.40 -1.49	9.0	2.0	2.3 - 4.2		1.20 - 1.38		
RCSM15-PS-U17C	1.55	9.5	2.0	2.5 - 4.5		1.29 - 1.45		

Contents

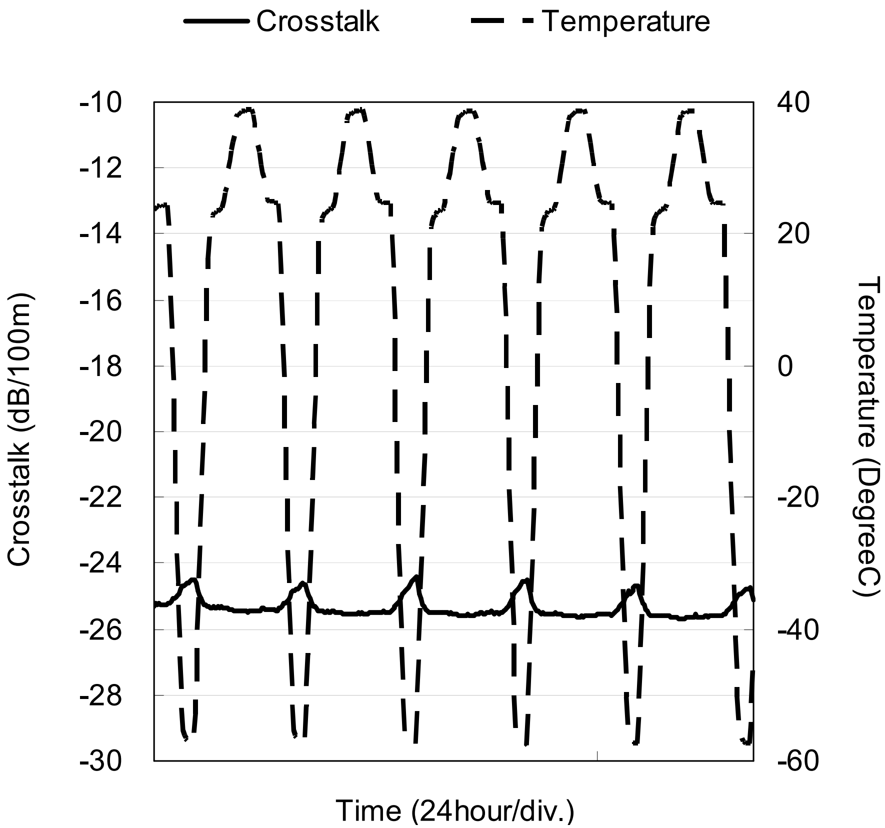
Polyimide coating type

- High heat resistance
- Suitable for fiber sensing
- Maintaining excellent crosstalk performance in wide range of temperature between -60 and +300 degC.





Temperature range +40 to +300 degC



Temperature range -60 to +40 degC

Specifications for Polyimide coating type

	λ_o	MFD	Att.	Beat length	Crosstalk	λ_c	Coating material	Coating diameter
	μm	μm	Max. dB/km	mm	Max.	Max. μm	-	μm
SM98-PS-Y15	0.98	6.6 ± 0.5	2.5	1.5 - 2.7	-25 dB/5m	0.87 - 0.95	**Polyimide**	145 ± 10
SRSM15-PS-Y15	1.55	9.4 ± 1.0	2.0	Max. 4.0		1.44		

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Fujikura PANDA fiber solutions

Fujikura PANDA fiber has the following strong points.

- Low transmission loss and excellent crosstalk by superior optical design and production technology
- High uniformity of dimensions by process control and the measurement in manufacturing process (Suitable for fusion splice, assembling of connector and manufacturing of optical devices)
- High reliability has been confirmed by actual system including the submarine cable transmission system.

Fujikura has already released following PANDA .

- For sensor (RGB, SC40-P, SC48-P, SM53-P, SM63-P, RCHA85-P, Polyimide type and HA-13)
- 80mm cladding type
- SRSM and BISM type
- Low birefringence type
- Pure silica core type

Fujikura is challenging for customer solutions to meet various needs.