Introduction of PANDA fibers

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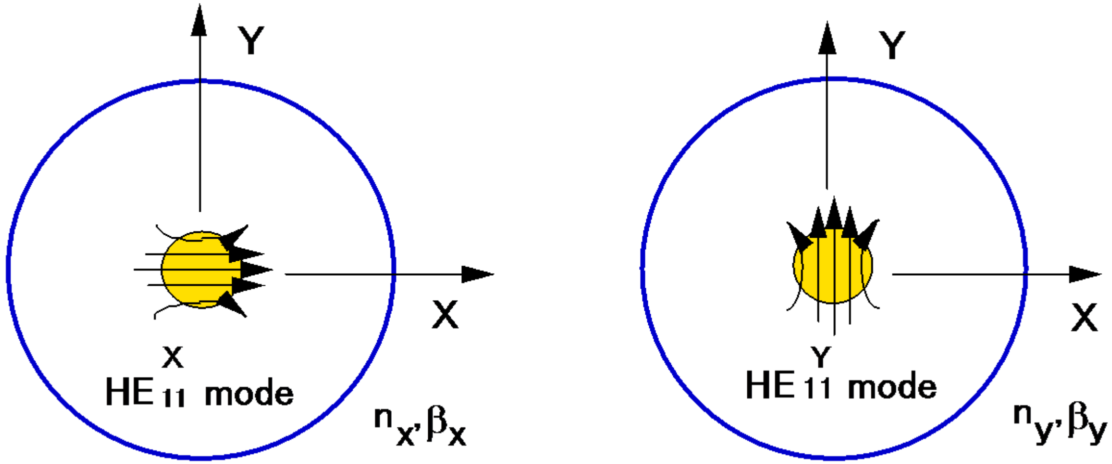
Contents

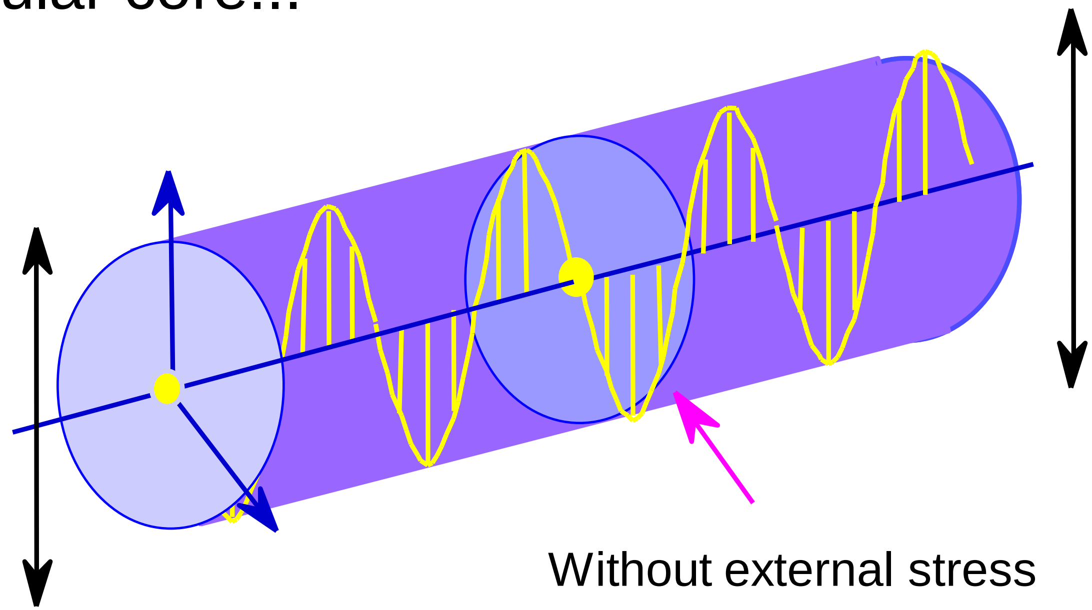
Polarization modes in ideal SM fiber

- 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

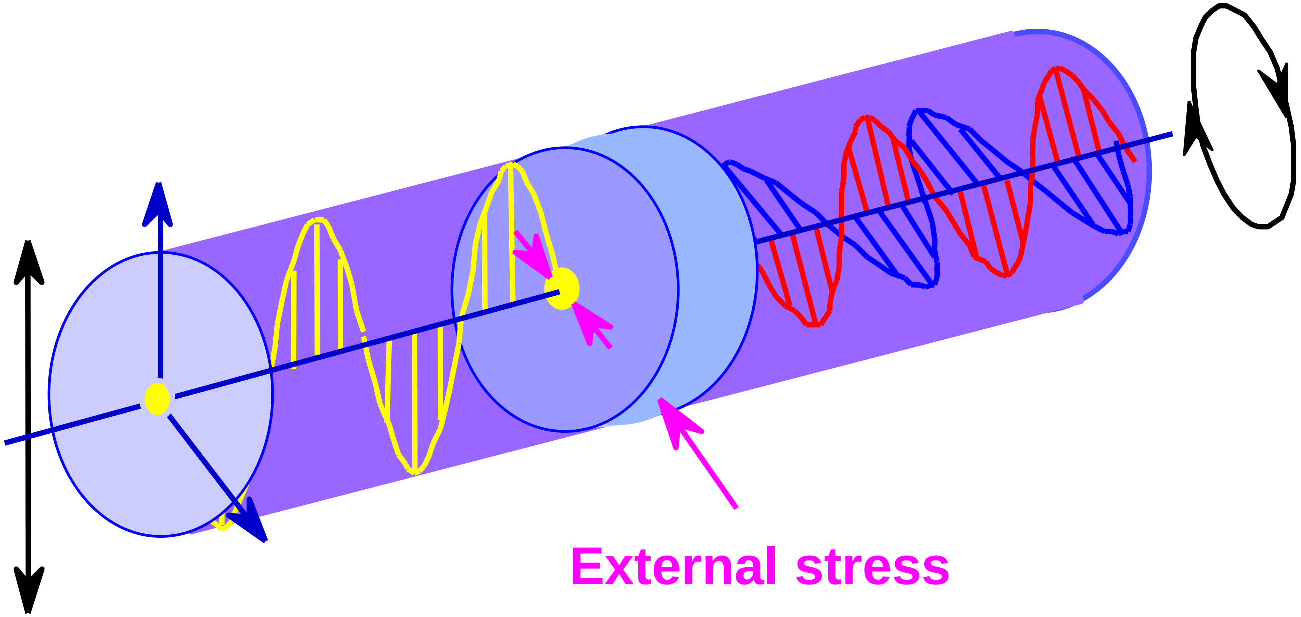
- An ideal SM fiber with perfect rotational symmetry is able to maintain any state of polarization.
- If any stress is induced on the fiber or a fiber has an non-circular core...



Without external stress

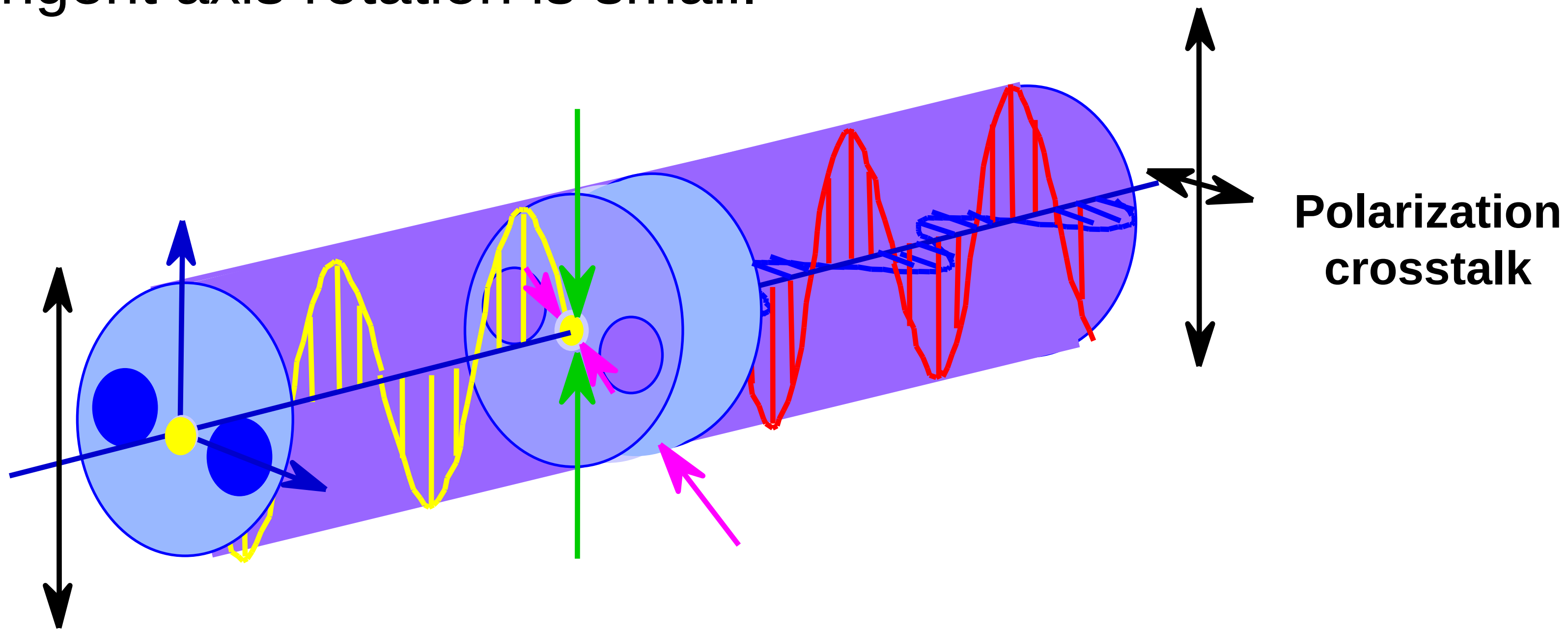
Polarization in actual SM fiber

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



How to maintain polarization

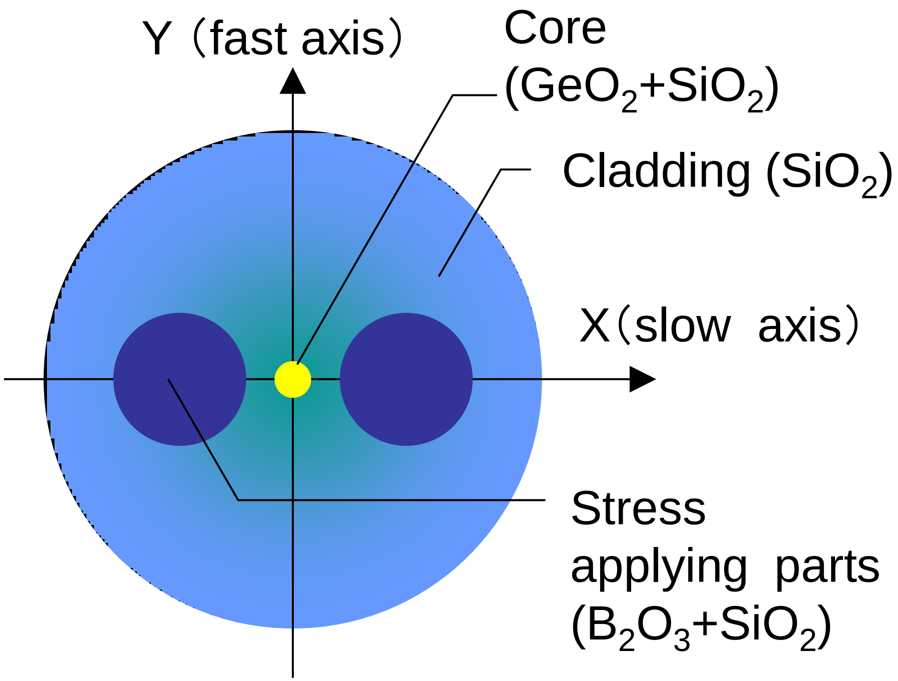
A fiber with high internal birefringence is able to maintain linear polarization against external perturbations since its birefringent axis rotation is small.

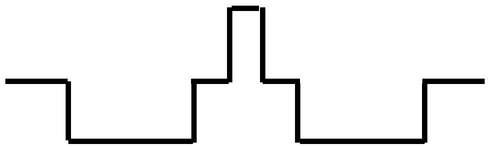


Birefringence induced by external stress << Intrinsic birefringence

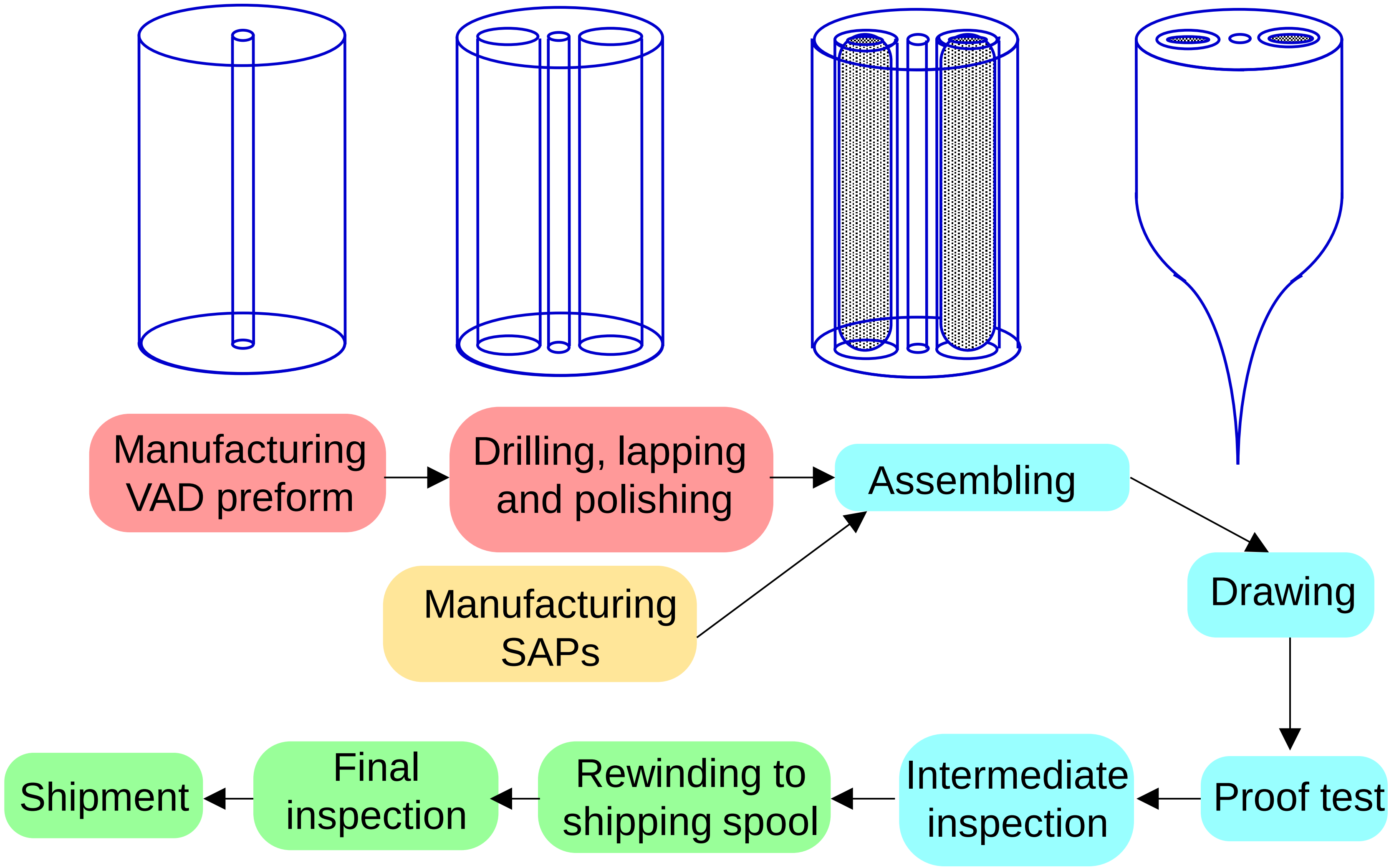
Structure of PANDA fiber

- 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.




Refractive index profile along x- direction

Production process of Fujikura PANDA



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Inspection items and methods on PANDA fiber

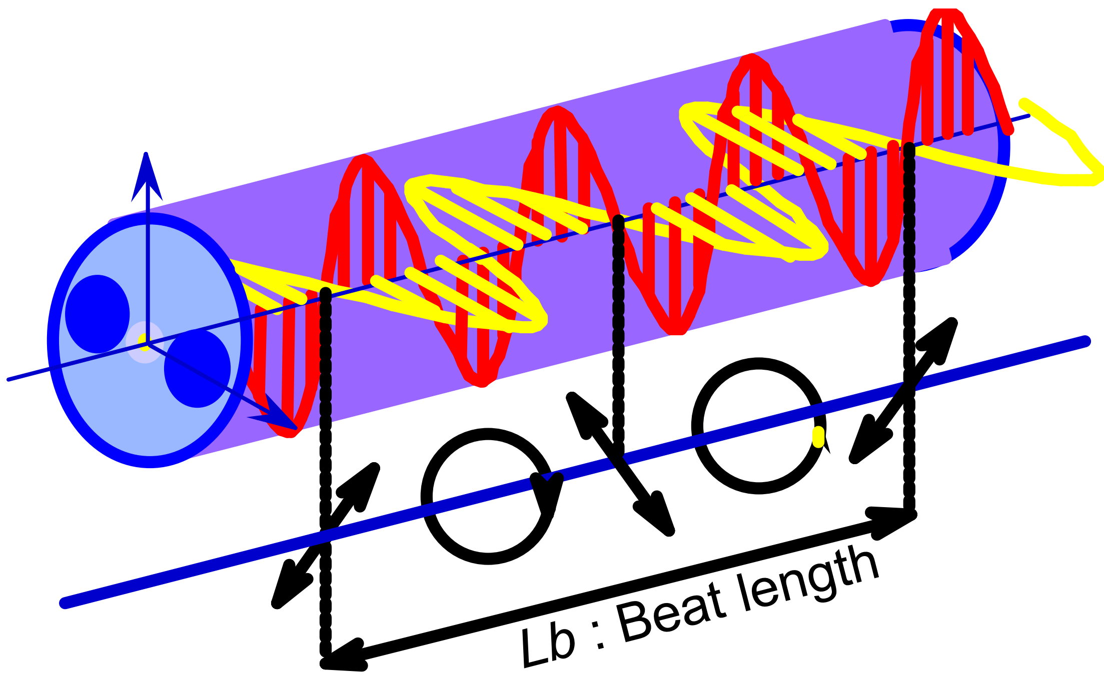
	Application	Method or technique	Reference
Fiber diameter	O / I / F	Gray scale	ITU-T G.650
Core offset	I / F	Gray scale	ITU-T G.650
Coating diameter	O / I	Microscope	---
Mode field diameter	I	Far-field pattern / Variable aperture	ITU-T G.650
Cutoff wavelength	I	Bend reference	ITU-T G.650
Attenuation	I	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

Beat length

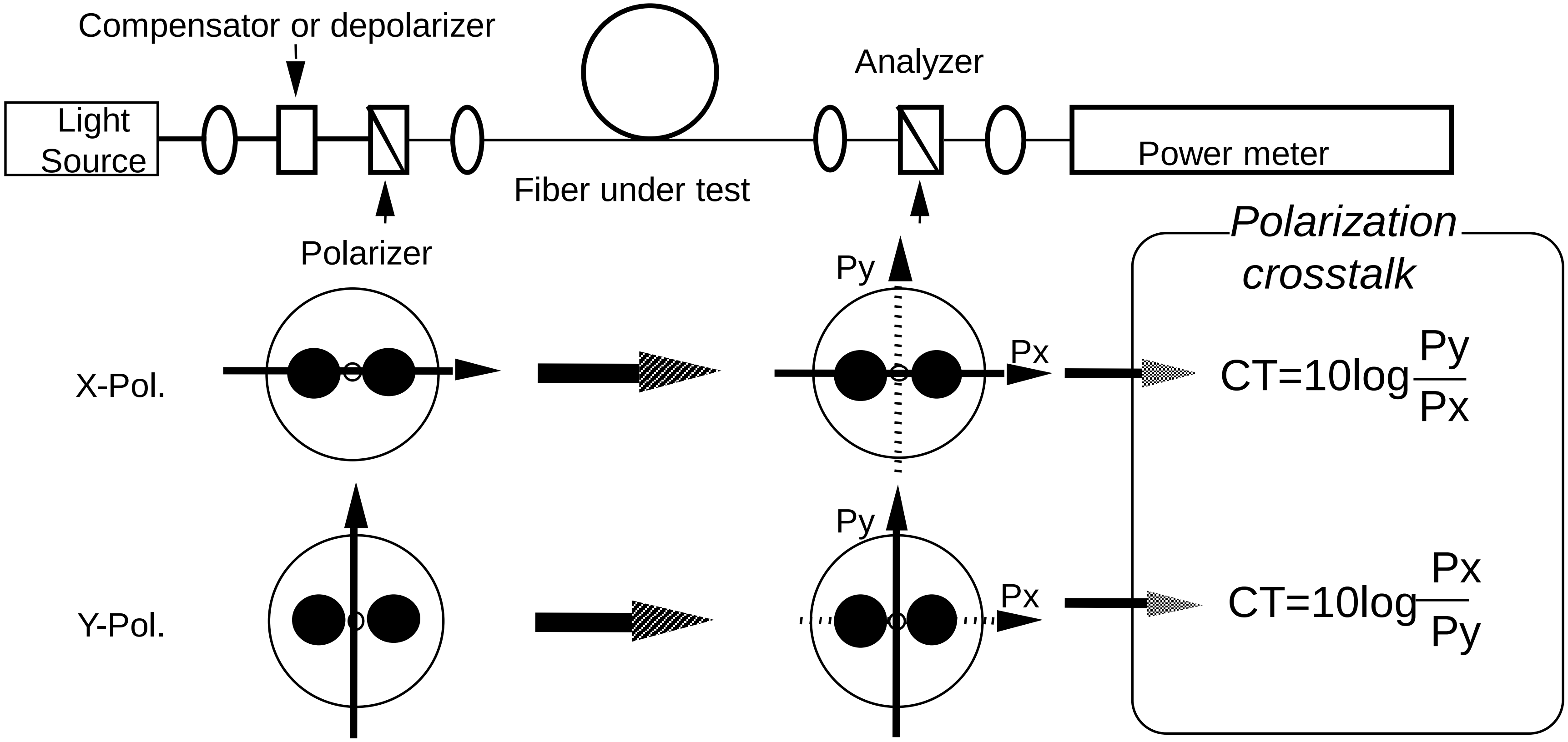
- Beat length *Lb* is the length which phase difference between X and Y polarization modes equals 2π along a PM fiber.
- Relation between beat length(*Lb*), birefringence(*B*), and wavelength(*λ*) is expressed by the following equation:

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



Measurement of polarization crosstalk

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



Unit: dB

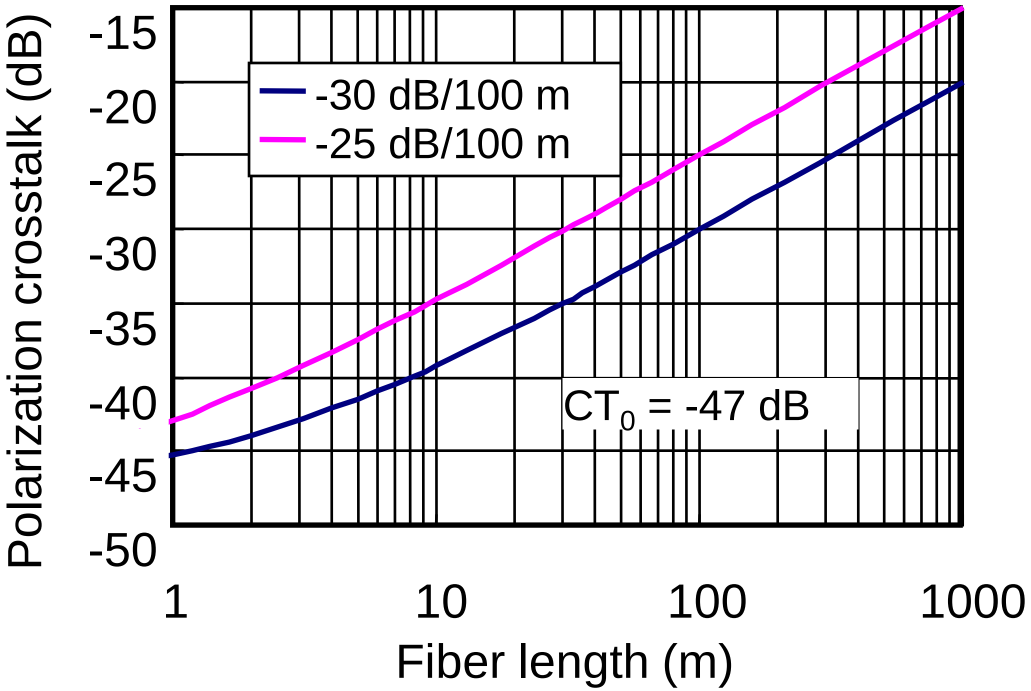
Power coupling coefficient

- 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

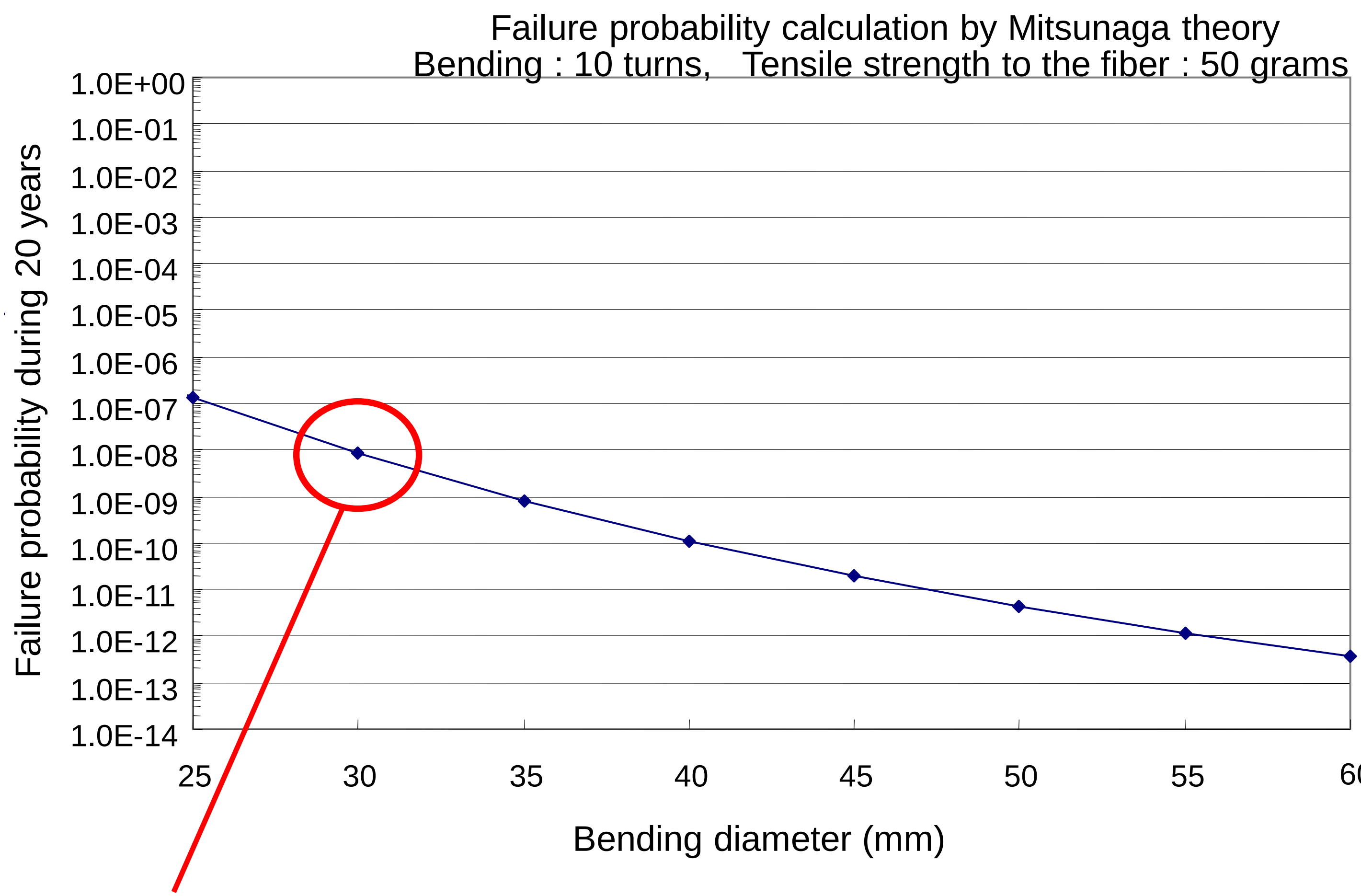
Stress : Tensile stress, Twisting stress

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.

PANDA fiber lineup

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

(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
SC : Pure Silica Core single mode fiber
HA : High NA single mode fiber

(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

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

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

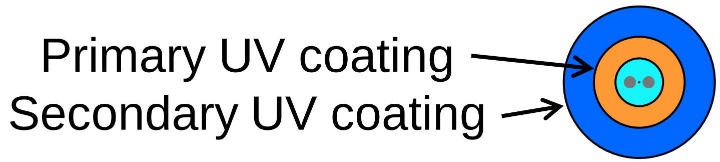
(6) Coating diameter:
17 : 165 μm
25 : 250 μm
40 : 400 μm
50 : 500 μm
90 : 900 μm

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

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

Lineup of coating type

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



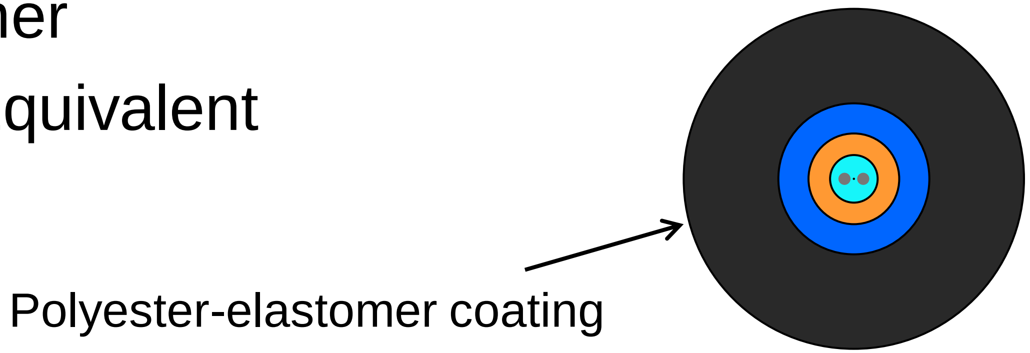
UV coating fiber

- UV/Polyester-elastomer coating

(Coating diameter 500 μm, 900 μm)

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

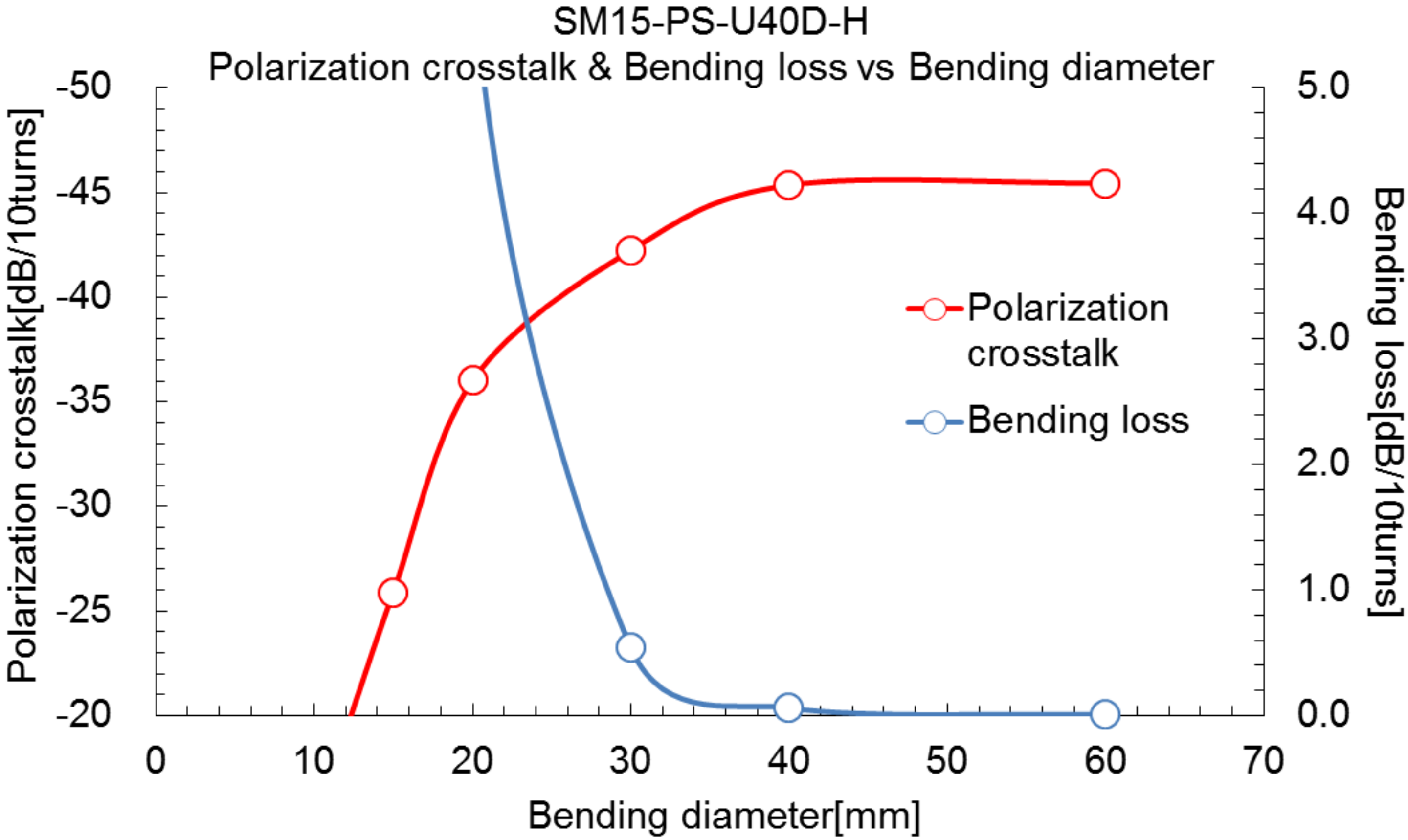
UL1581-VW1 Equivalent



UV/Polyester-elastomer coating

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

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		0.65 ~ 0.80	UV/Polyester-elastomer(Black)	
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	-30	1.13 ~ 1.27	UV/Polyester-elastomer(Black)	900 ± 100
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)	

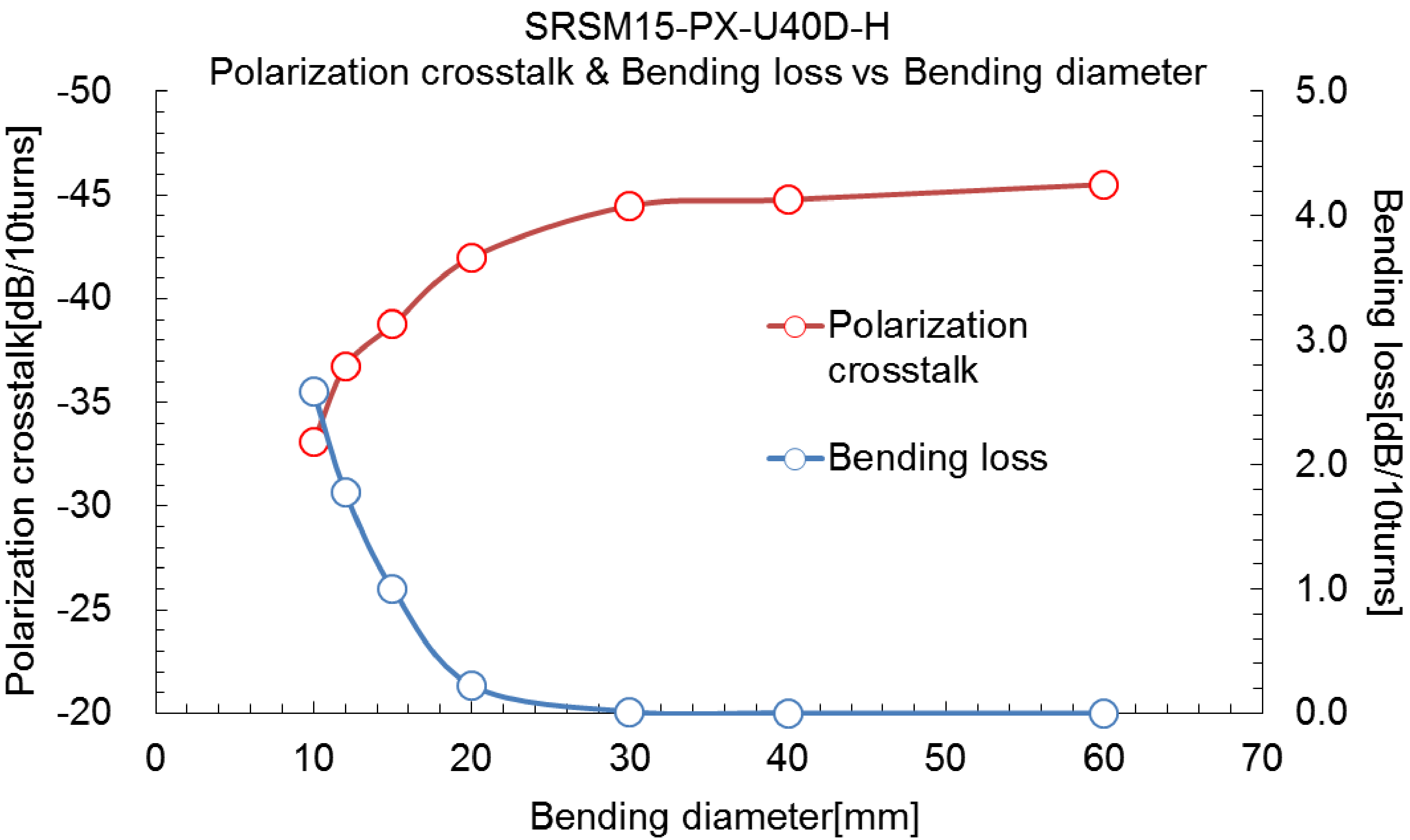
PANDA fiber allowing small bend radius (R ≥ 15 mm)

SRSM15 type PANDA fibers

- SR15 series SM fiber is widely spread as standard telecommunication fiber allowing small bend radius.
  And Fujikura has also released PANDA fibers with equivalent bending property.

- Widely spread 125 μm parts and accessories are usable.

SRSM15-PX-H bending properties



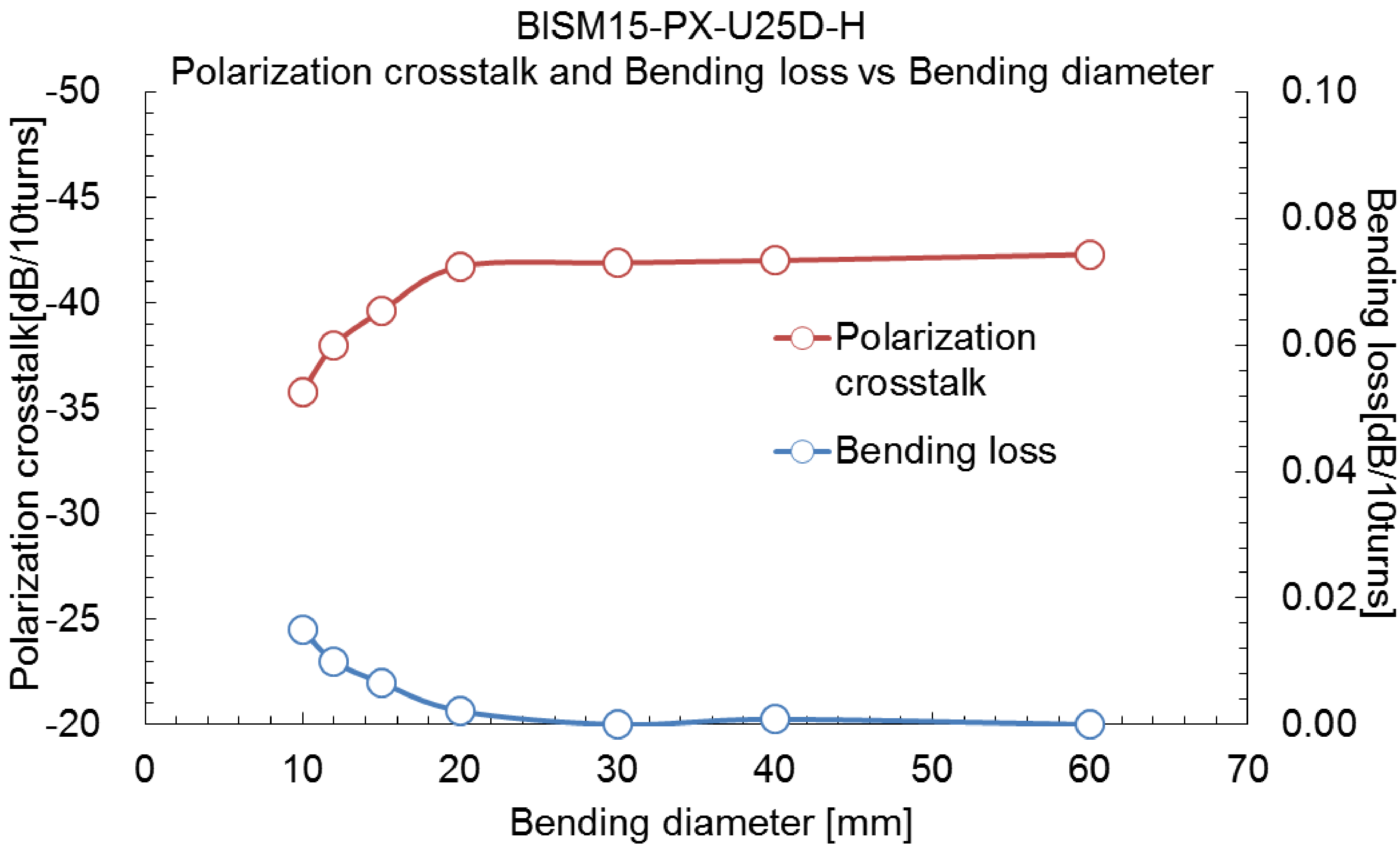
Specifications of SRSM15 type

Items	Unit	Specification
MFD at 1550 nm	µm	9.5 +/- 0.4
Attenuation at 1550 nm	dB/km	≤ 0.50
Bending loss (Bending diameter = 30 mm,10 turns at 1550 nm)	dB	≤ 0.50
Fiber cutoff wavelength	nm	≤ 1440
Beat length at 1550 nm	mm	2.0 - 5.0
Polarization crosstalk at 1550 nm	dB/100m	≤ -30
Bending Polarization crosstalk (Bending diameter = 30 mm,10 turns at 1550 nm)	dB	≤ -30
Coating SRSM15-PX-U25D-H SRSM15-PX-U40D-H SRSM15-PX-H50D-H SRSM15-PX-H90D-H	-	245 µm UV/UV 400 µm UV/UV 500 µm UV/Polyester-elastomer 900 µm UV/Polyester-elastomer
Proof level	%	≥ 2

PANDA fiber allowing small bend radius (R ≥ 7.5 mm)

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.

Bend performance of BISM type



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
Bending Polarization cross-talk	dB	≤ -30 Bending diameter =15 mm, 10 turns	≤ -30 Bending diameter ＝30 mm, 10 turns
Coating	-	250 μm 500 μm polyester-elastomer	250 μm UV, 400 μm UV, 500 μm, 900 μm polyester-elastomer
Proof level	%	≥ 2	≥ 2

NEW Thermally-diffused expanded core fiber

PANDA fiber with Thermally-diffused Expanded Core (TEC) has been releasd .
The PANDA fiber enables coupling silicon photonics device and standard PANDA fiber with low connection loss.

HA15-PS-U25D(TEC)

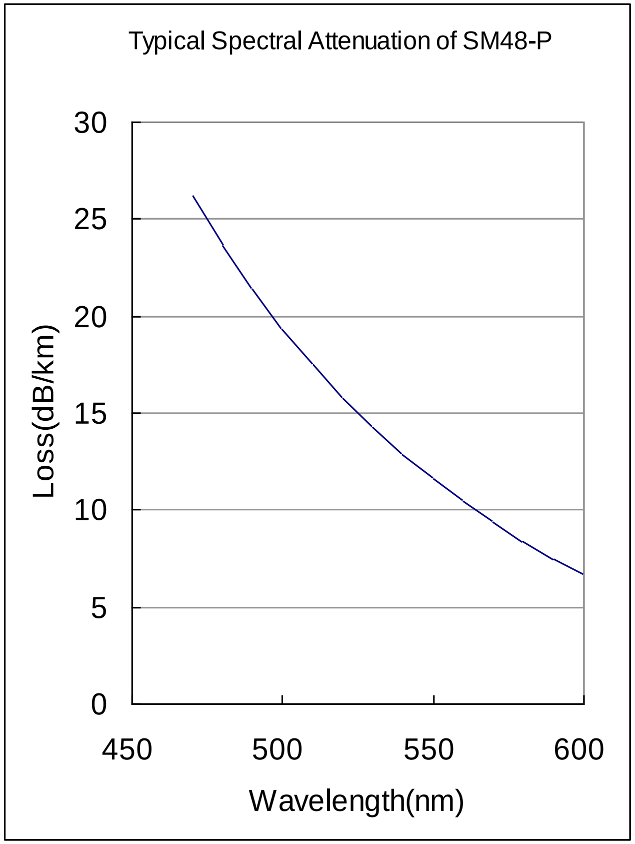
Items	Unit	Specification
MFD at 1550 nm	mm	4.0 +/- 0.3
Attenuation at 1550 nm	dB/km	≤ 30
Cutoff wavelength	nm	≤ 1480
Beat length at 1550 nm	mm	≤ 4.0
Polarization cross-talk at 1550 nm	dB/2m	≤ -35
Coating (UV / UV)	mm	245

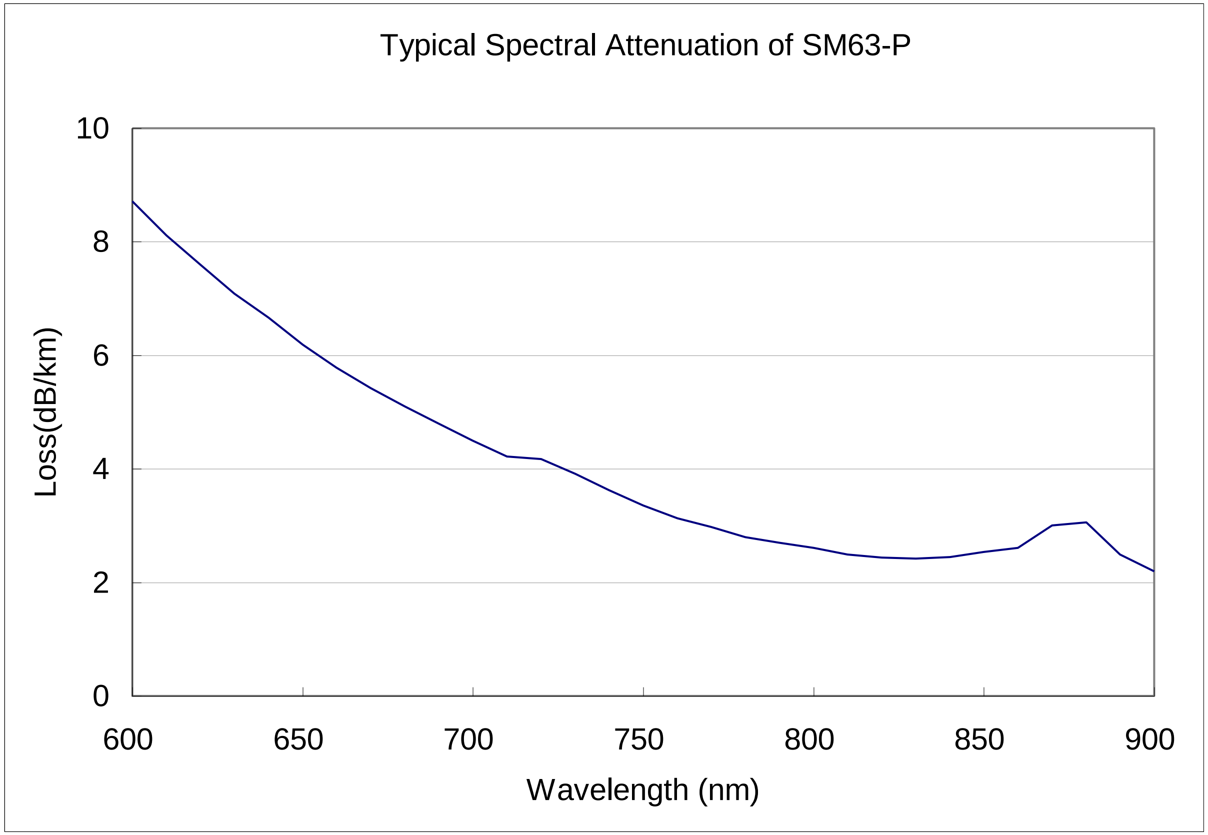
PANDA fibers for visible wavelength

- Suitable for the polarized mode transmission from various polarization sources

- Large 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





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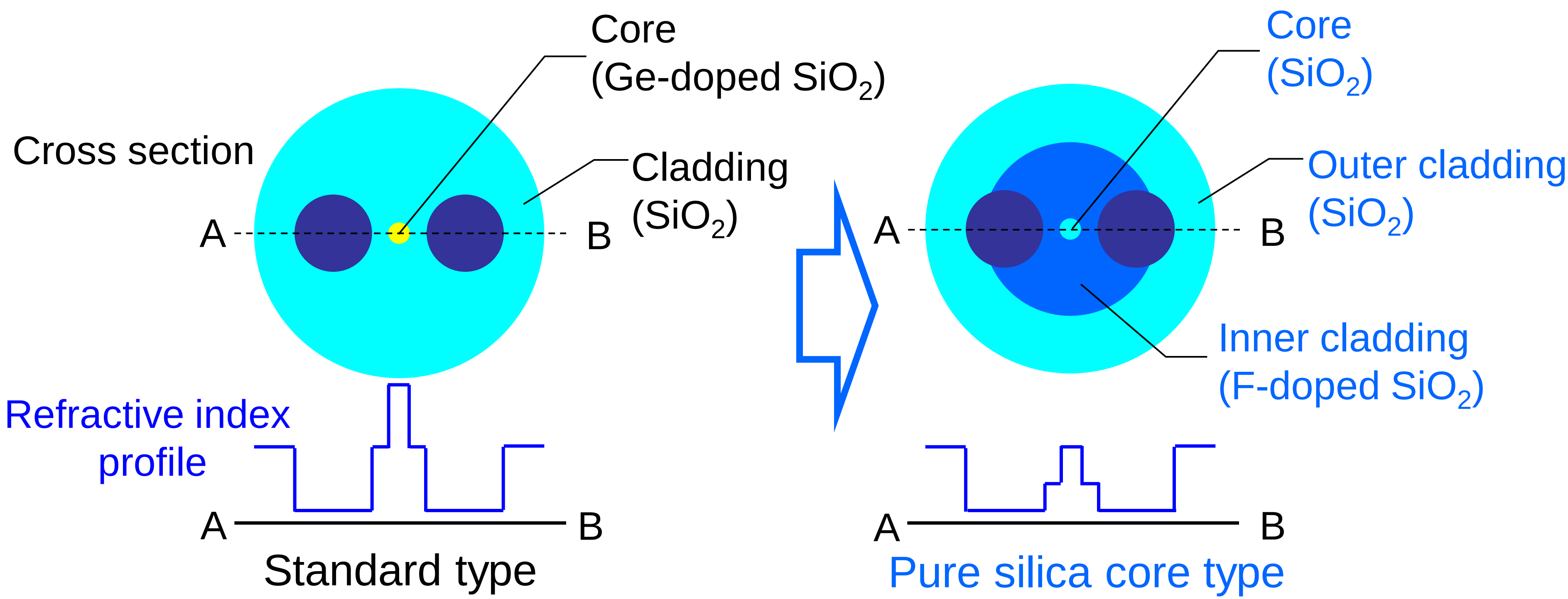
Specifications for PANDA fibers for visible wavelength

<table>
<tr><th rowspan="2"></th><th>λ_o</th><th>MFD</th><th>Att.</th><th>Beat length</th><th>Cross- talk</th><th>λ_c</th><th>Coating material</th><th>Coating diameter</th></tr>
<tr><th>µm</th><th>+/-0.5
µm</th><th>Max.
dB/km</th><th>Max.
mm</th><th>Max.
dB/100m</th><th>µm</th><th></th><th>µm</th></tr>
<tr><td>SM63-PS-H90D</td><td rowspan="3">0.63</td><td rowspan="3">4.5</td><td rowspan="3">12</td><td rowspan="5">2.0</td><td rowspan="5">-30</td><td rowspan="3">0.52
~ 0.62</td><td>UV/UV/Polyester elastomer(Black)</td><td>900
+/- 100</td></tr>
<tr><td>SM63-PS-U40D</td><td rowspan="2">UV/UV</td><td>400
+/- 15</td></tr>
<tr><td>SM63-PS-U25D</td><td>245
+/- 15</td></tr>
<tr><td>SM53-PS-H90D</td><td rowspan="2">0.53</td><td rowspan="2">4.2</td><td rowspan="2">15</td><td rowspan="2">0.45
~ 0.53</td><td>UV/UV/Polyester elastomer(Black)</td><td>900
+/- 100</td></tr>
<tr><td>SM53-PS-U40D</td><td>UV/UV</td><td>400
+/- 15</td></tr>
</table>

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)

	λ_o	MFD	Att.	Beat length	Cross-talk	λ_c	Coating material	Coating diameter
	μm	μm	Max. dB/km	Max. mm	Max. dB/100m	μm	-	μm
SC48-PS-H90D	0.48	4.0 ±0.5	30	2.0	-30	0.40 ~ 0.47	UV/UV/Polyester elastomer(Black)	900 ±100
SC48-PS-U40D							UV/UV	400 ±15
SC48-PS-U25D								245 ±15
SC40-PS-H90D	0.41	3.5 ±0.5	50	1.7		0.33 ~ 0.40	UV/UV/Polyester elastomer(Black)	900 ±100
SC40-PS-U40D							UV/UV	400 ±15
SC40-PS-U25D								245 ±15

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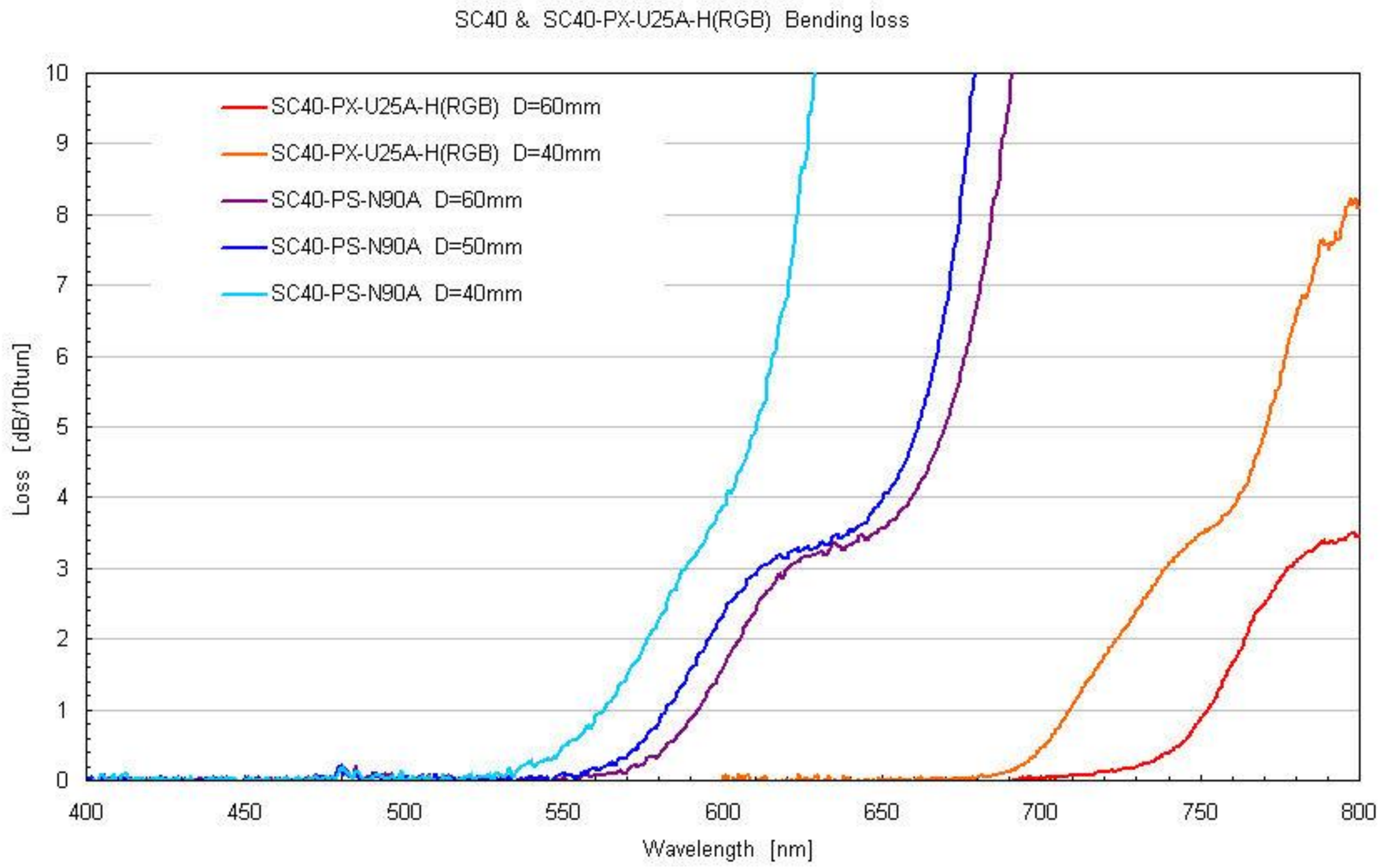
RGB PANDA fiber SC40-PX-U25A-H(RGB)

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	dB/km	mm	dB /10 turns	μm	-	μm
SC40-PX-H90D-H (RGB)	0.405 ~ 0.64	3.8 ± 1.0 at 630 nm 2.3 ± 0.6 at 405 nm	≤ 50	≤ 2.0 at 630 nm	≤ -30 Bending diameter 60 mm	≤ 0.40	UV/UV/ Polyester elastomer (Black)	900 ±100
SC40-PX-U40D-H (RGB)							UV/UV	400 ±15
SC40-PX-U25D-H (RGB)								245 ±15

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80 μm cladding diameter type

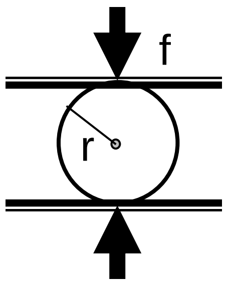
- Superiority in sensitivity to the external environment

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

- Space-saving

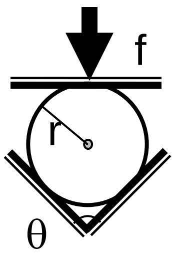
Features of RC-PANDA fibers (1)

1.Higher birefringence for lateral pressure endurance



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

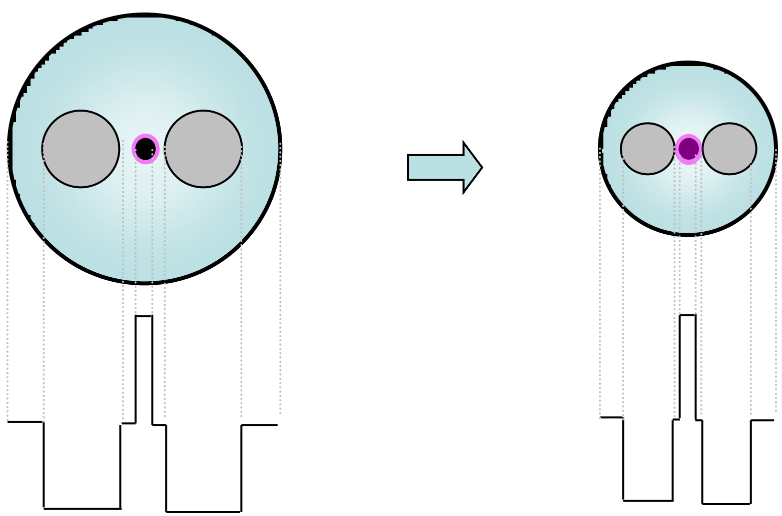
C:Photo Elastic constant
E:Young's modulus



$$B = 2C\left(1 - \cos\theta \cdot \sin(\theta/2)\right)\frac{f}{\pi \cdot E}\frac{1}{r}$$

Re-design Stress applying parts

2. Attenuation and MFD non-circularity optimization

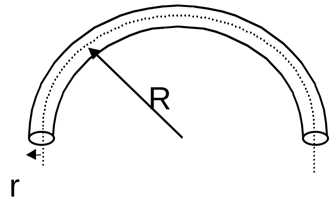


- B_2O_3, OH absorption increase
- MFD non-circularity increase

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

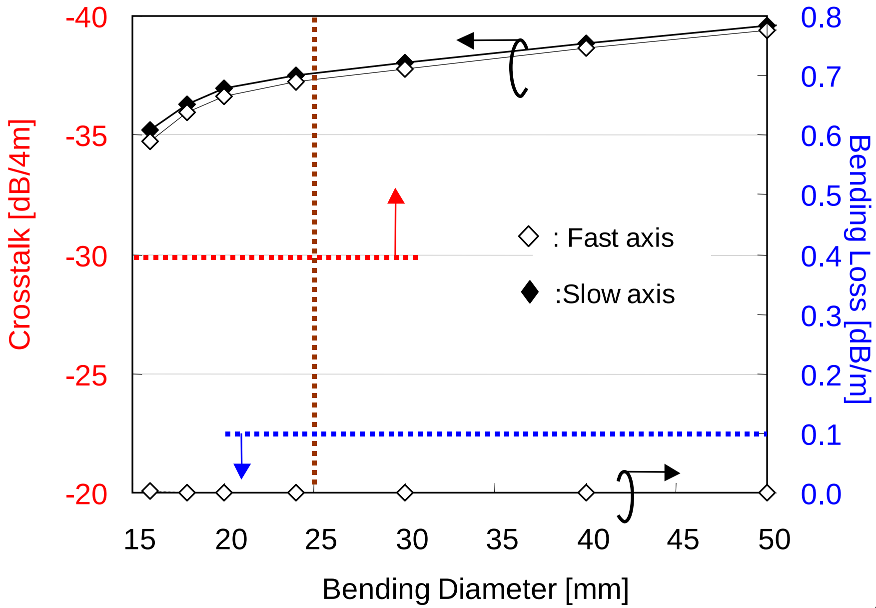
Telecom component
⇒ Need low splice loss with different major fiber splices

Requirement:
Splice loss < 0.1dB

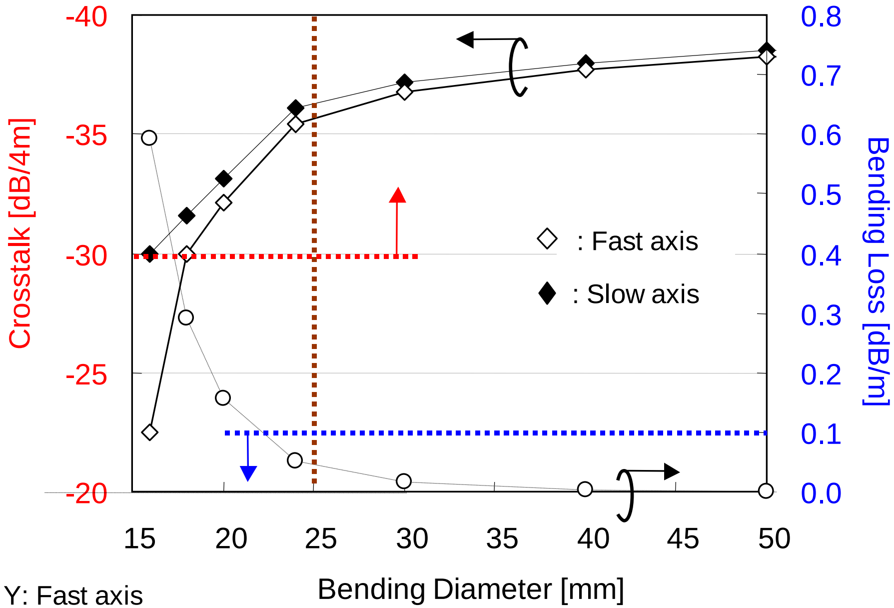
MFD differences with other fibers are designed to be small.

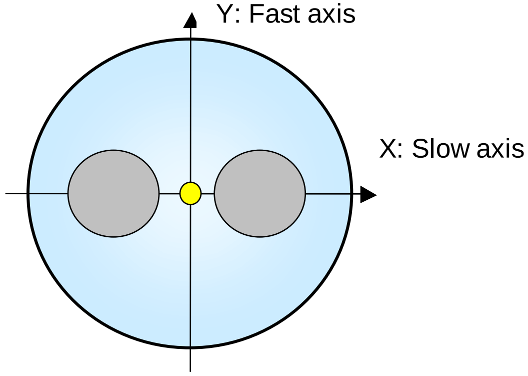
Attenuation and Crosstalk in 4m length bending

980nm RC-PANDA



1550nm RC-PANDA





Specifications for 80μm cladding

	λ_o	MFD	Att.	Beat length	Crosstalk	λ_c	Coating material	Coating diameter
	μm	μm	dB/km	mm	dB/100m	μm	-	μm
RCHA85-PS-U17C	0.85	3.5 +/-0.5	≤ 3.5	≤ 2.0	≤ -30	0.65 ~ 0.80	UV/UV	165 +/- 15
RCSM98-PS-U17C	0.98	6.0 +/-0.5	≤ 2.5	1.4 ~ 2.6	≤ -25	0.87 ~ 0.95		
RCSM13-PS-U17C	1.3	8.2 +/-0.5	≤ 2.0	2.0 ~ 3.5		1.10 ~ 1.29		
RCSM14-PS-U17C	1.40 ~ 1.49	9.0 +/-0.5	≤ 2.0	2.3 ~ 4.2		1.20 ~ 1.38		
RCSM15-PS-U17C	1.55	9.5 +/-0.5	≤ 2.0	2.5 ~ 4.5		1.29 ~ 1.45		
RCHA15-PS-U17C	1.55	6.0 +/-1.0	≤ 3.0	≤ 3.7	≤ -30	≤ 1.50		

New PANDA fiber allowing small bend radius (R ≥ 5 mm)

Since the allowable bending radius is 5 mm, the fiber is beneficial to miniaturize optical modules.

RC13-15-PX-U17EBL-M4

Items	Unit	Wave length	Specification
MFD	mm	1550 nm	4.0 +/- 0.3
		1310 nm	3.4 +/- 0.4
Attenuation	dB/km	1550 nm	≤ 30
		1310 nm	≤ 30
Cutoff wavelength	nm	-	≤ 1280
Beat length	mm	1550 nm	2.5 - 4.5
Polarization cross-talk	dB/100m	1550 nm	≤ -25
Coating (UV / UV)	mm	-	165 +/- 15
Coating color	–	-	Blue

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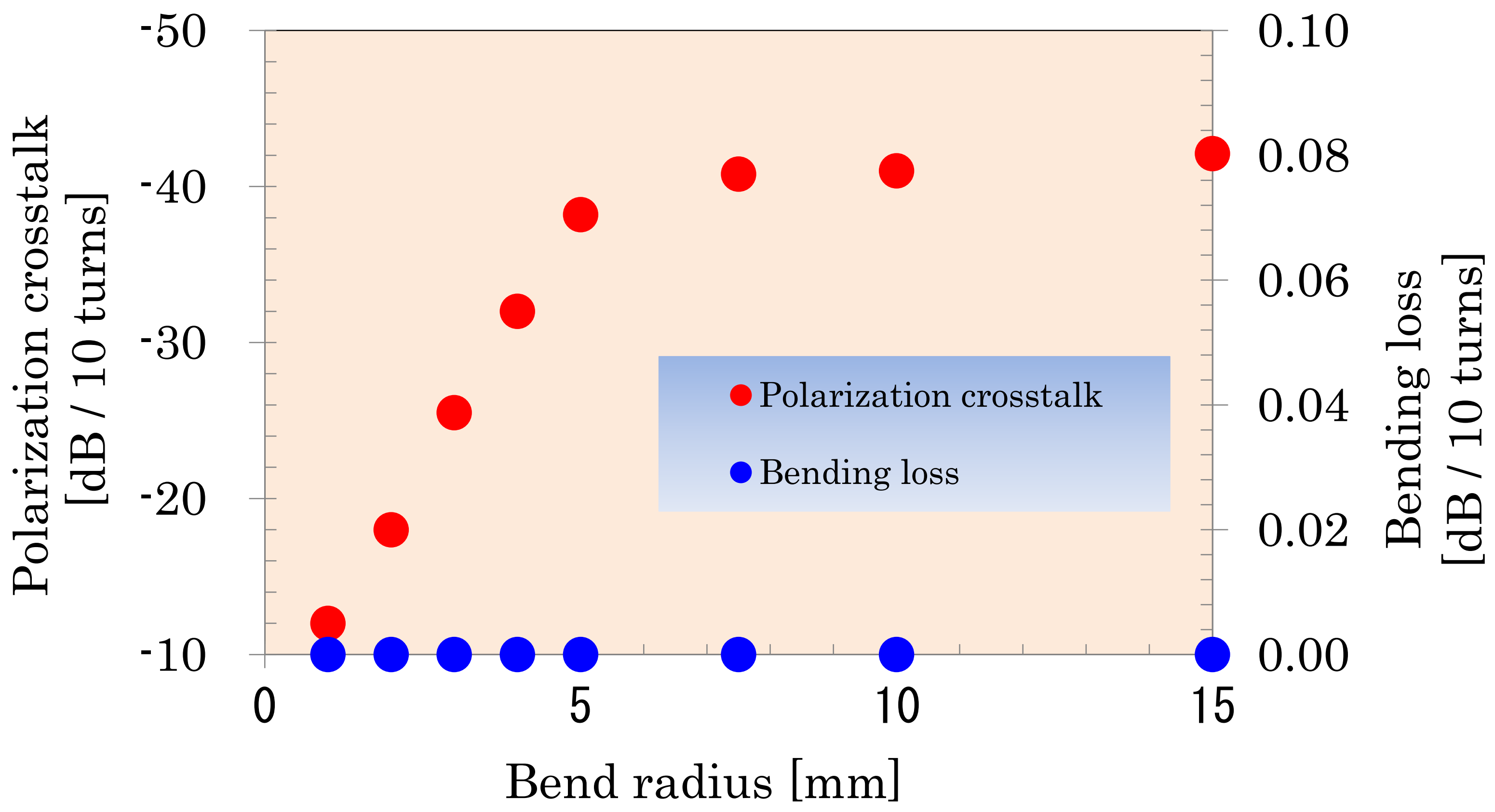
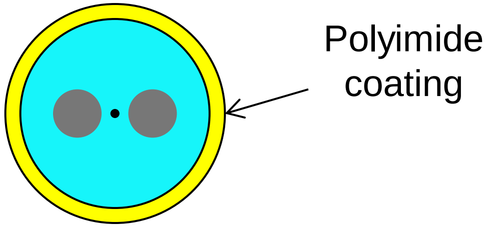
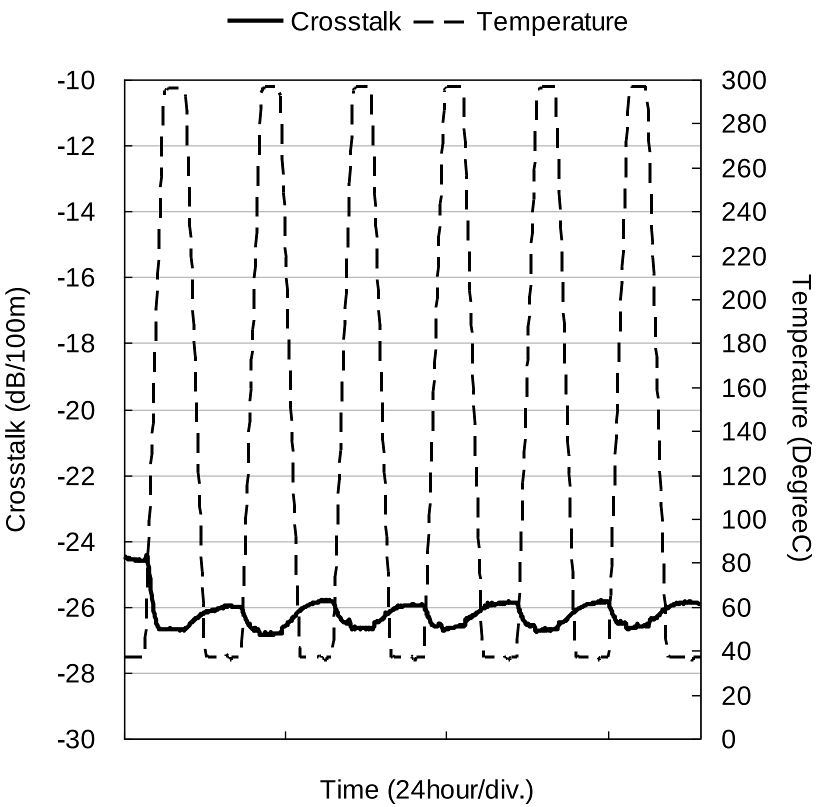
RC13-15-PX-U17EBL-M4 bending properties



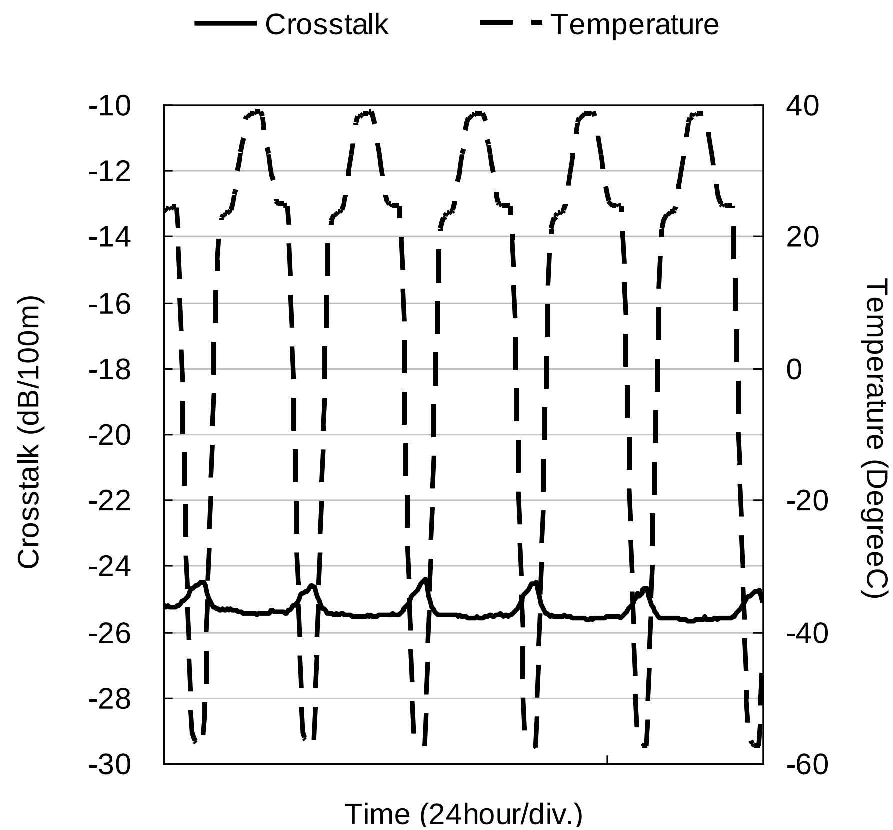
Polyimide coating type

- 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	dB/km	mm	dB/5m	µm	-	µm
SM98-PS-Y15	0.98	6.6 +/- 0.5	≤ 2.5	1.5 ~ 2.7	≤ -25	0.87 ~ 0.95	**Polyimide**	145 +/- 10
SRSM15-PS-Y15	1.55	9.4 +/- 1.0	≤ 2.0	≤ 4.0		≤ 1.44		

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 .

- Thermally-diffused expanded core fiber
- PANDA fiber allowing small bend radius (R ≥ 5 mm)

Fujikura is challenging for customer solutions to meet various needs.

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