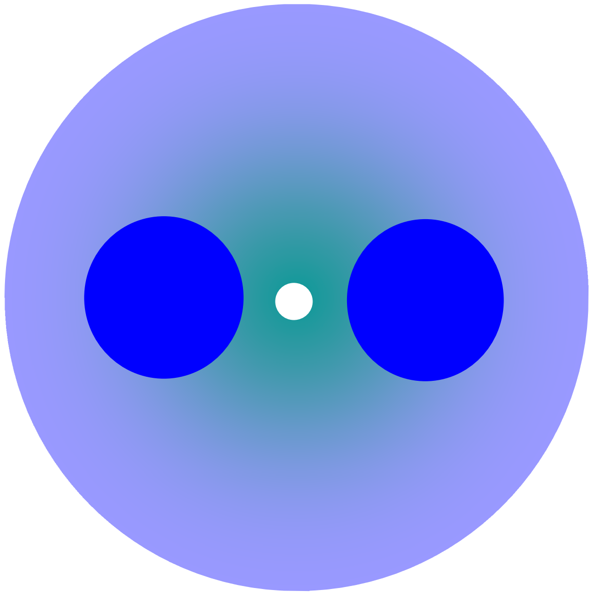
B-13D0096

Introduction of PANDA fibers



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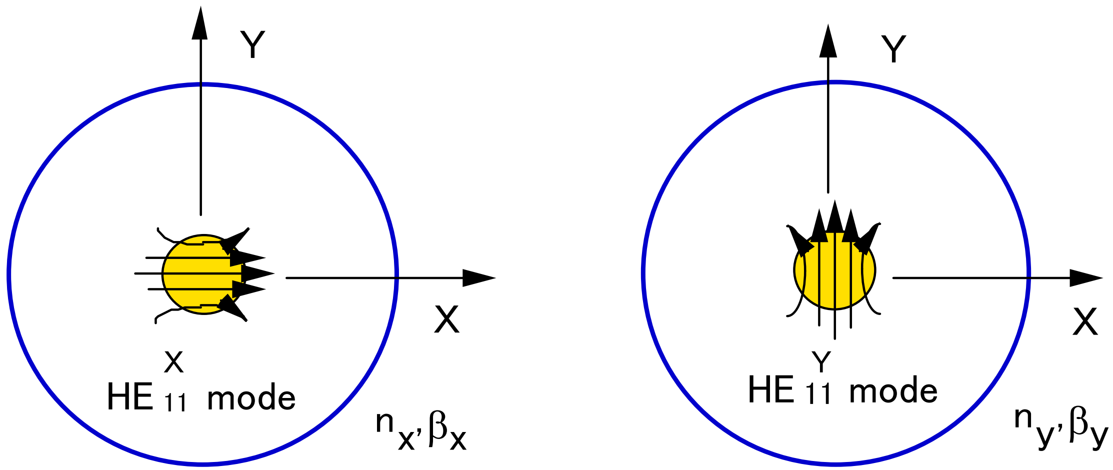
Aug. 2013

Contents

- Basics of Polarization maintaining fibers
- Lineup of PANDA (**Polarization**-maintaining AND Absorption-reducing) fibers
  - UV/UV coating
  - 900 μm coating
  - 2 mm cord
  - SR15 type
  - 80 μm type
  - PANDA fibers for sensor
  - Polyimide coating
  - Low birefringence PANDA fibers
  - 500 μm coating
- Conclusion

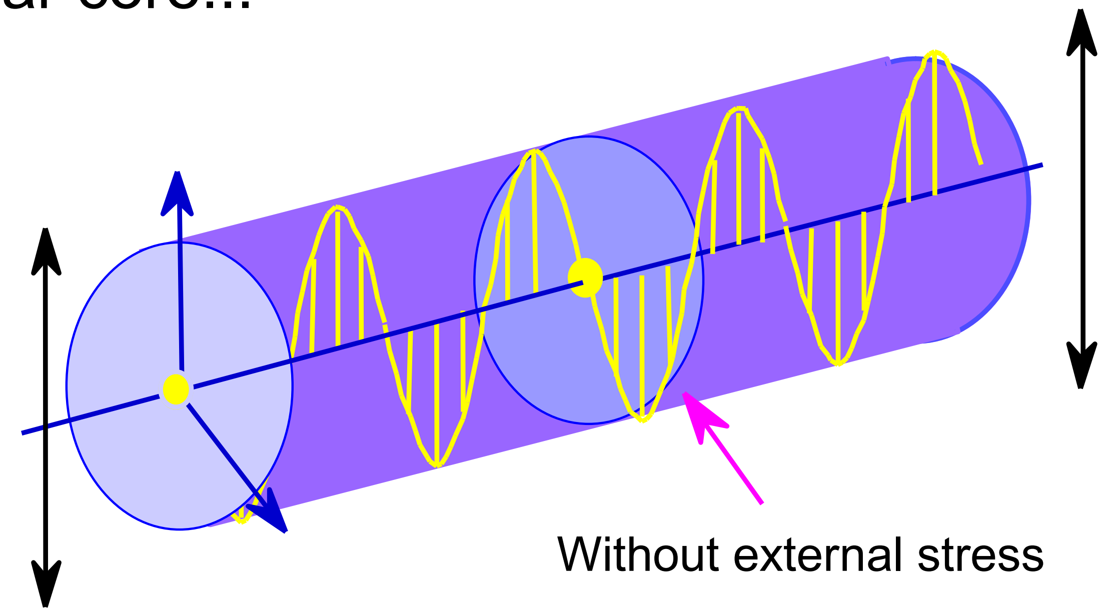
Polarization modes in ideal SM fiber

- A single-mode (SM) fiber has 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.



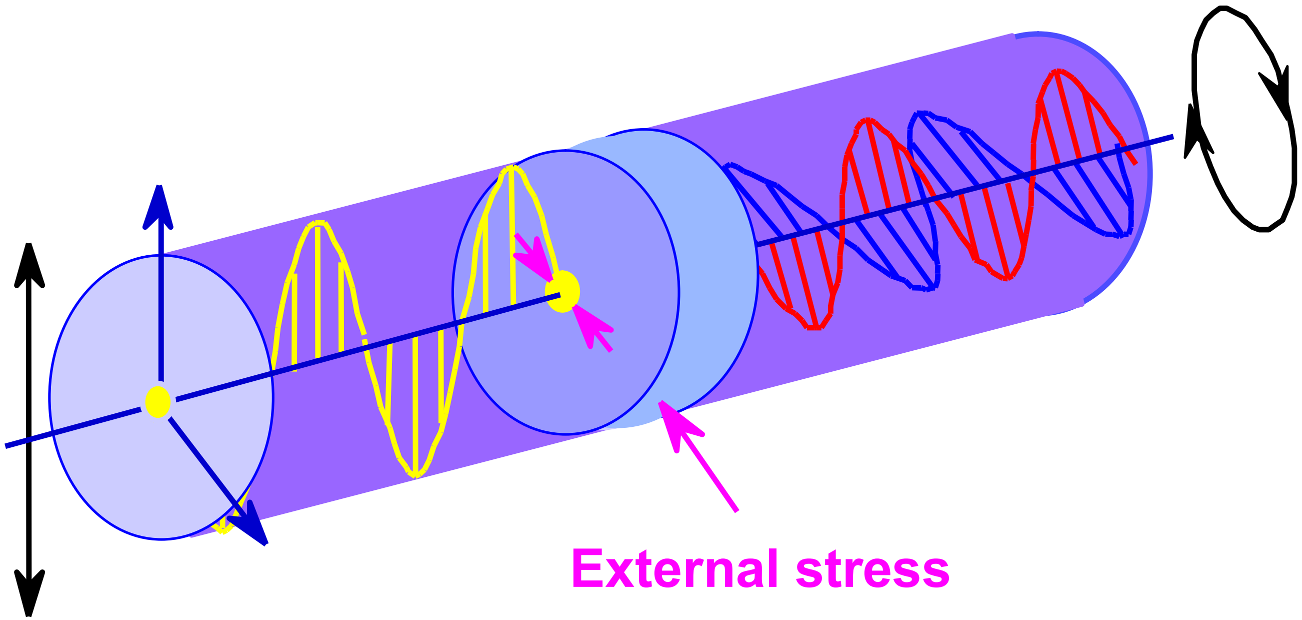
Polarization in ideal SM fiber

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



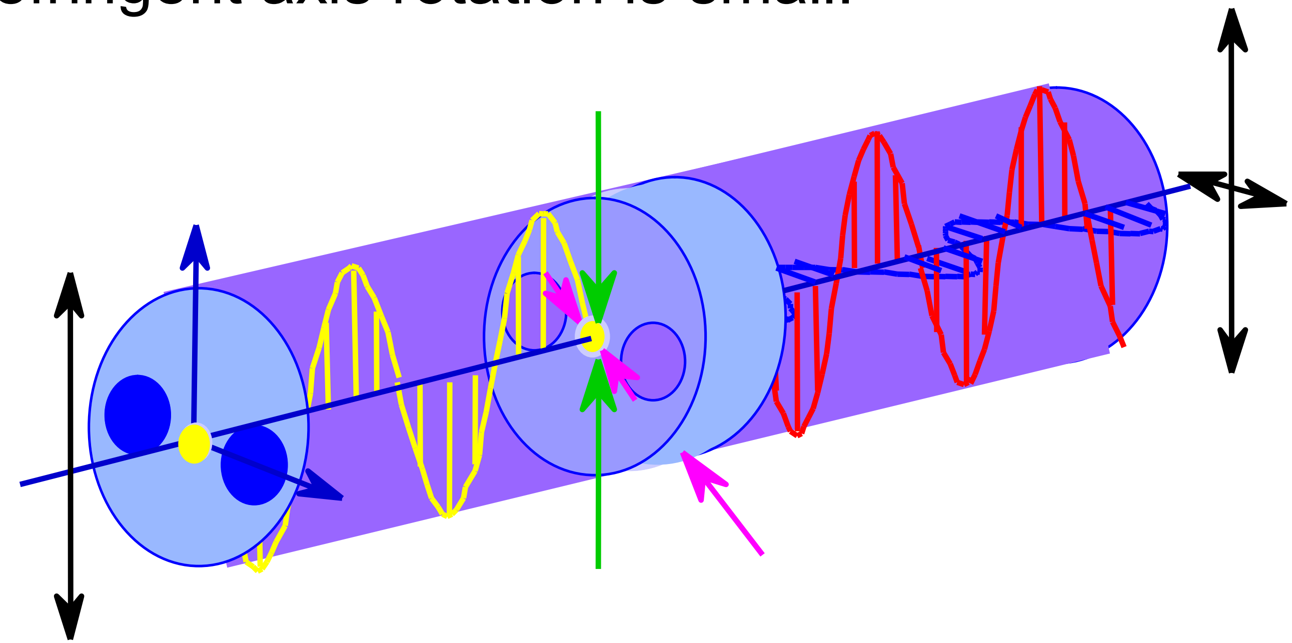
Polarization in actual SM fiber

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



How to maintain polarization

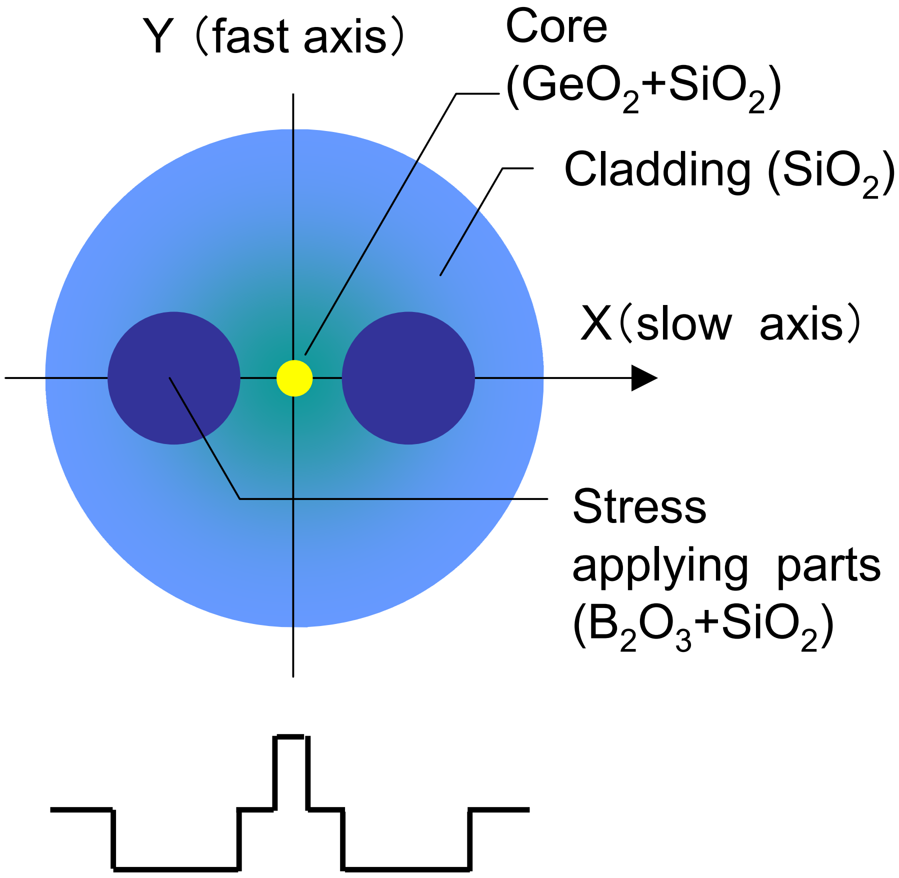
- A fiber with high internal birefringence can maintain linear polarization against external perturbations since its birefringent axis rotation is small.



Birefringence induced by external stress << Intrinsic birefringence

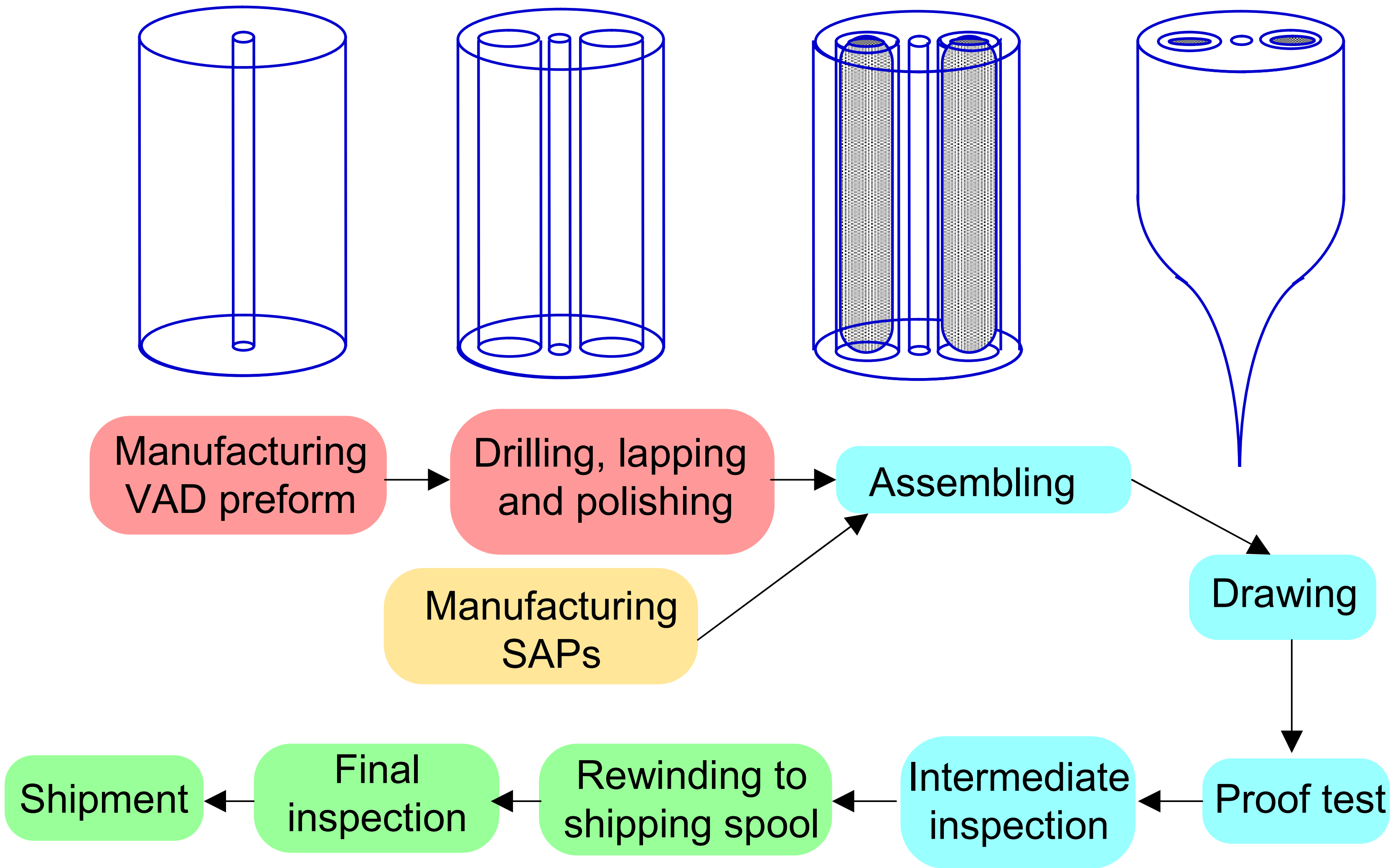
Structure of PANDA fiber

- 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 of SAP direction remains in the core induces large stress birefringence.



Refractive index profile along x- direction

Production process of Fujikura PANDA



Inspection items and methods on PANDA fiber

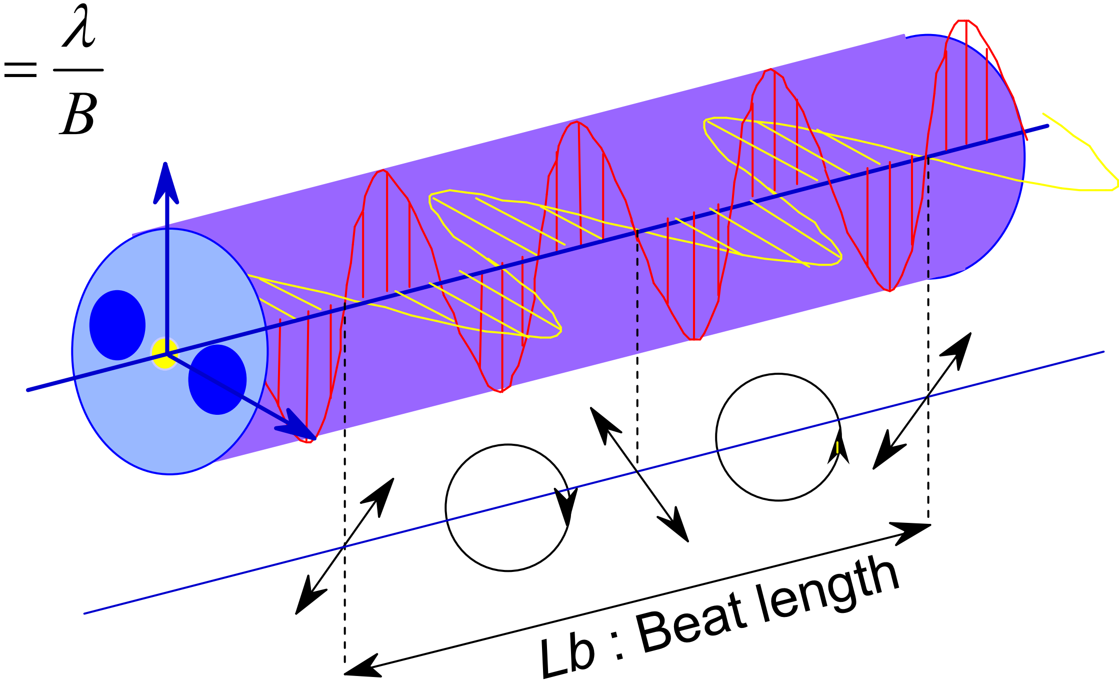
	Application	Method or technique	Reference
Fiber diameter	O / I / F	Gray scale	ITU-T G.650
Core offset	I / F	Gray scale	ITU-T G.650
Coating diameter	O / I	Microscope	---
Mode field diameter	I	Far-field pattern / Variable aperture	ITU-T G.650
Cutoff wavelength	I	Bend reference	ITU-T G.650
Attenuation	I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

Beat length

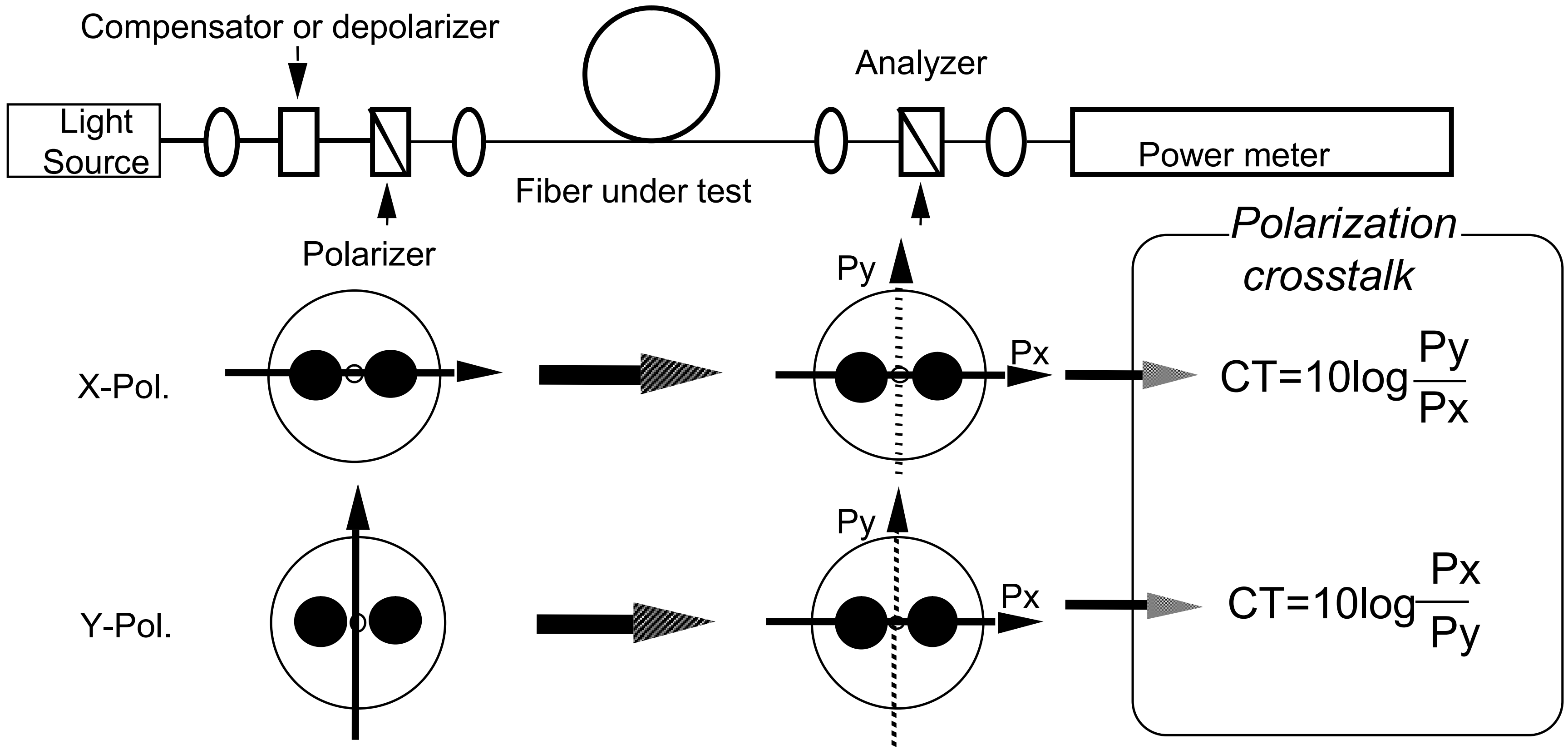
- Beat length *Lb* is one cycle of periodical polarization variation along a PM fiber.
- Related to modal birefringence as follows:

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



Measurement of polarization crosstalk

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



Unit: dB

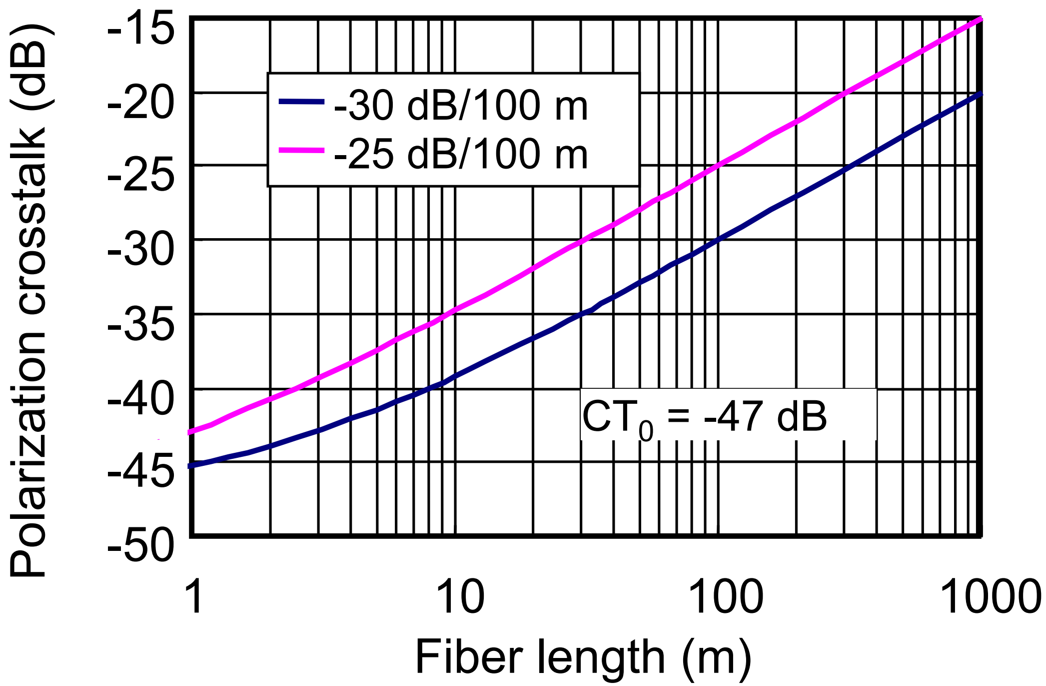
Power coupling coefficient

- 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	UL1591 VW-1	For reference, Flame retardant 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

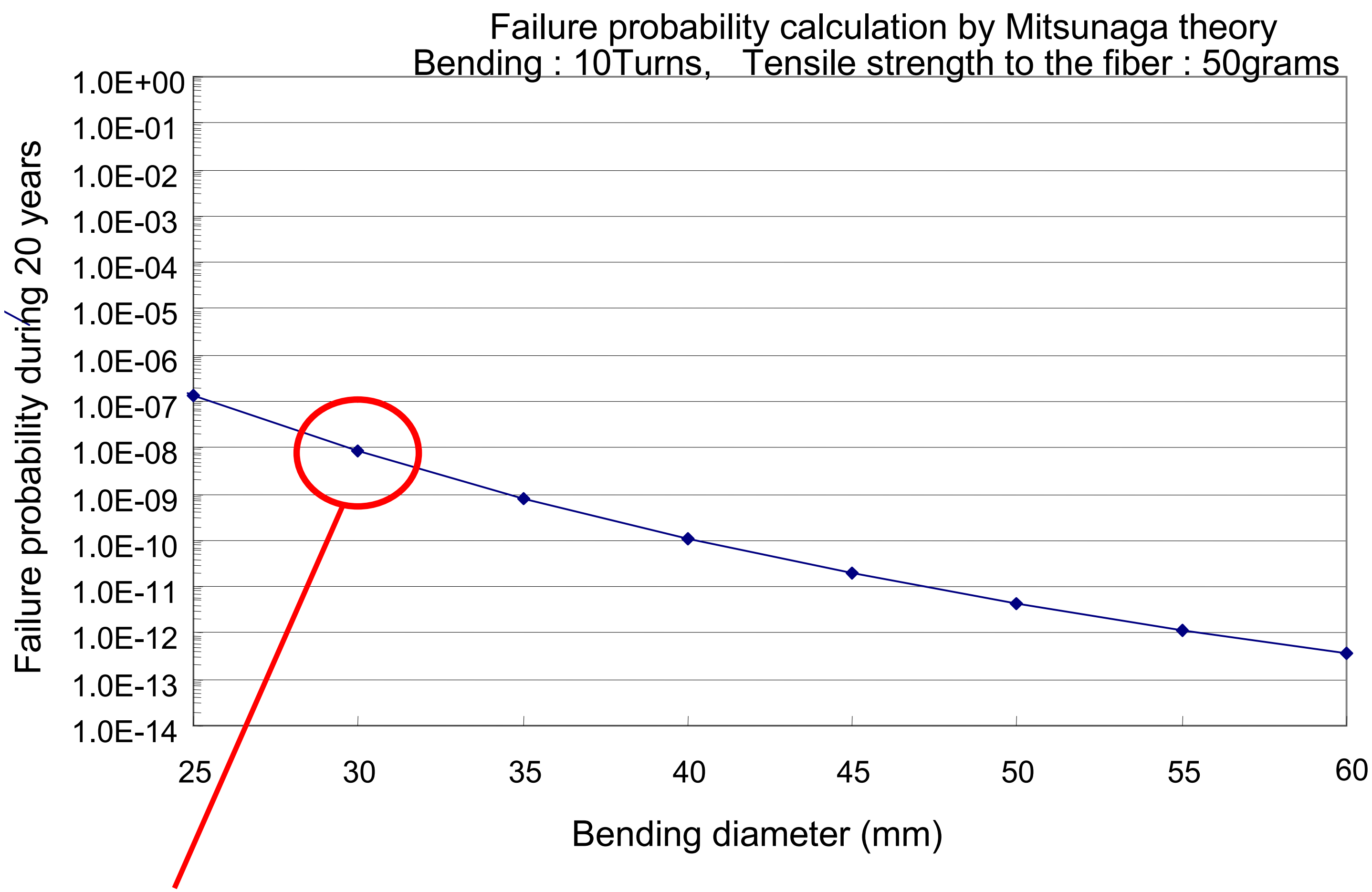
Stress : Tensile stress, Twisting stress

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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  - 80 μm type
  - PANDA fibers for sensor
  - Polyimide coating
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  - 500 μm coating
- Conclusion

PANDA fiber lineup

(2) Product type:
SM: Single Mode fiber
SRSM: Small Radius Single Mode fiber
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 fiber—Polyolefin cord

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

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

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

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

(4)PS:standard,
PX: Extra,
PR: Reduced polarization

(6)Coating Dia.:
17: 165μm
25: 250μm
40: 400μm
90: 900μm
20: 2.0mm

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

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

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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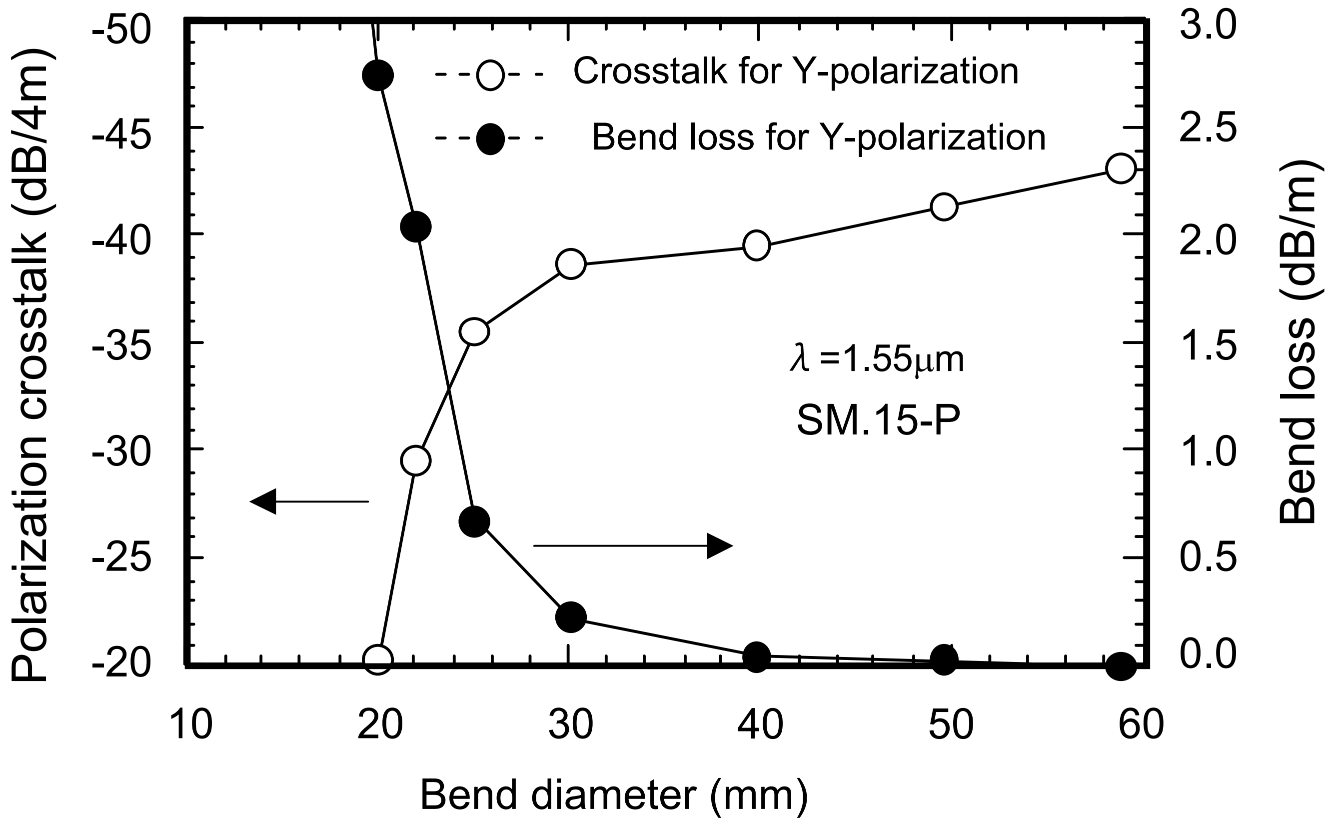
Bend performance of 125μm cladding PANDA

- 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.



Flame retardant PANDA fiber

- UL94-V-0 Polyester-elastomer Resin over coating
- UL1581-VW1 Flame retardant
- Wavelength: 0.85, 0.98, 1.3, 1.45, 1.55μm, DSF

Specifications for 900μm 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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Lead and Halogen free PANDA cords (1)

- Polyolefin coating for RoHS directive compatible
- IEC60332-3-C flame-retardant

	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-J20D	0.41	3.5	50	1.7	-30	0.33 ~ 0.40	UV/ Polyester-elastomer(Black)/ Polyolefin(Gray)	2.0 ± 0.2
SC48-PS-J20D	0.48	4.0	30	2.0		0.40 ~ 0.47		
SC53-PS-J20D	0.53	4.2	15			0.45 ~ 0.53		
SC63-PS-J20D	0.63	4.5	12			0.52 ~ 0.62		

Lead and Halogen free PANDA cords (2)

	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	2.5	3.0 ~ 5.0		1.30 ~ 1.44		

Specifications for Dispersion Shifted PANDA fibers

	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

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Contents

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PANDA fiber lineup for small bending diameter

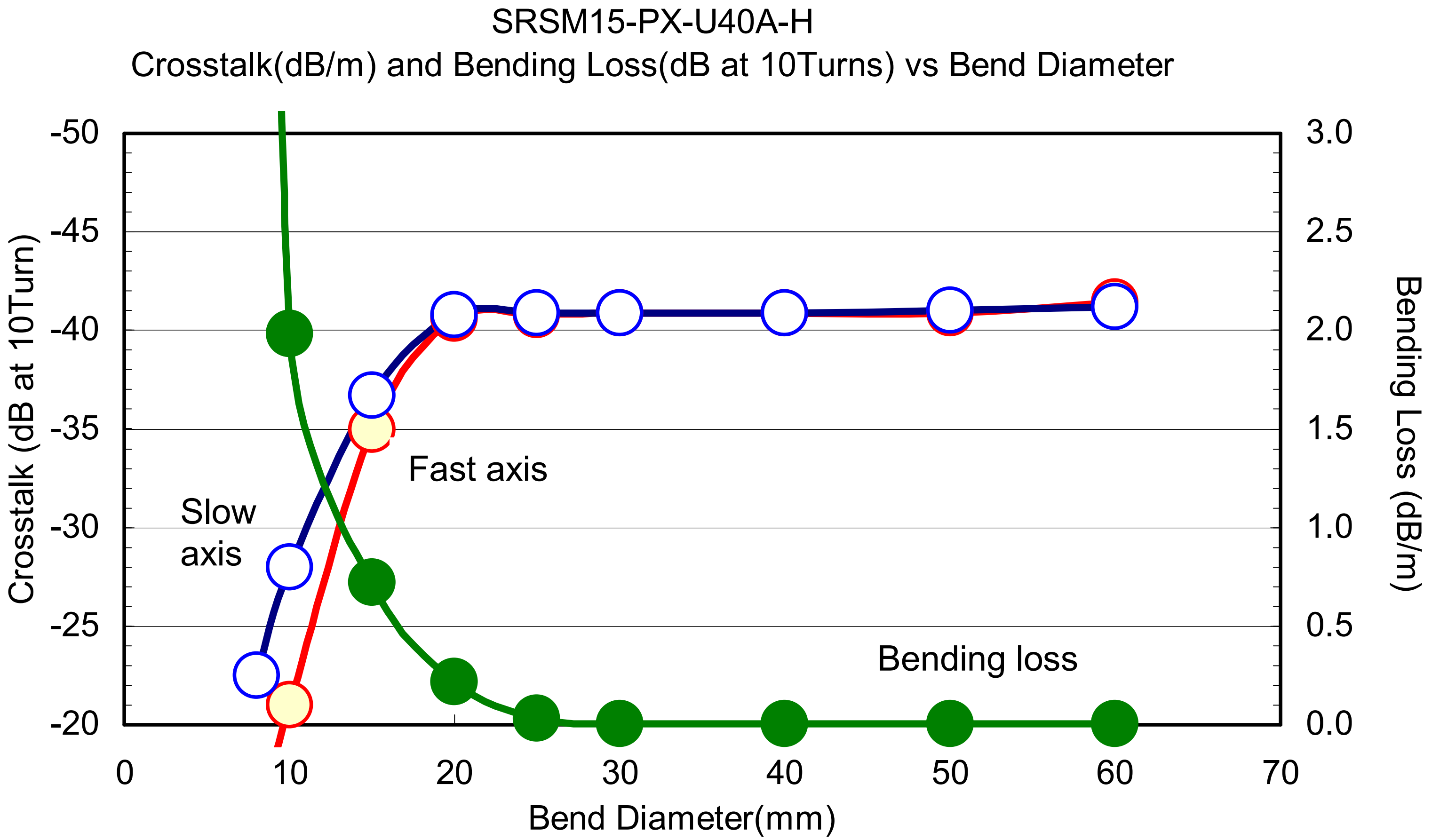
- SR15 type PANDA fibers
  - SR15 series SM fibers have been widely released and spread as standard telecommunication cable.
  - Fujikura has SR15 type PANDA fibers.
  - Widely spread 125 μm parts and accessories usable.
  - Splice properties to SR15 series are very good.

- 80 μm cladding PANDA fibers
  Suitable for several hundreds meters or 80 μm SMF connecting usages.

125μm small radius PANDA specifications

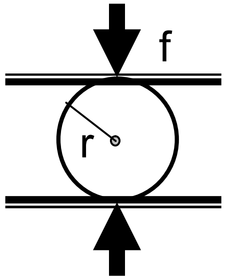
Items		Unit	Specification
MFD	at 1550nm	μm	9.5 +/- 0.4
Attenuation	at 1550nm	dB/km	Less than 0.50
Bending loss (Bending diameter = 30mm, 10 turns at 1550nm)		dB	Less than 0.50
Fiber cutoff wavelength		nm	Less than 1440
Beat length	at 1550nm	mm	2.0 ~ 5.0
Polarization crosstalk	at 1550nm	dB/100m	Less than -30
Bending Polarization crosstalk	at 1550nm	dB	Less than -30 Bending diameter = 30mm, 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

SRSM15-PX-H bending properties



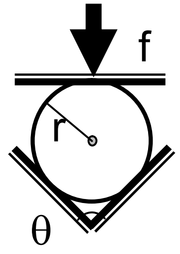
Features of RC-PANDA fibers (1)

1.Higher birefringence for lateral pressure endurance



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

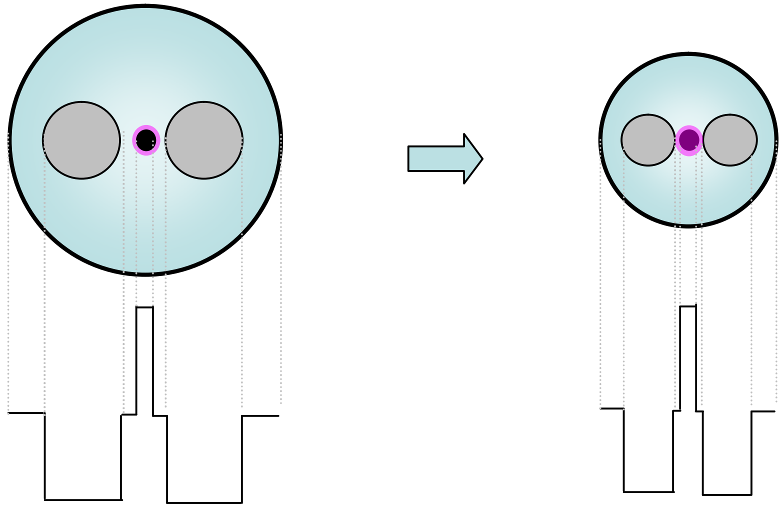
C:Photo Elastic constant
E:Young’s modulus



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

Re-design Stress applying parts

2. Attenuation and MFD non-circularity optimization

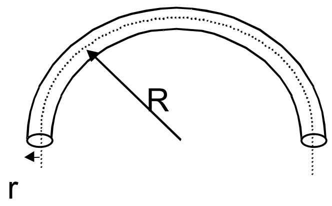


- B_2O_3 , OH absorption increase
- MFD non-circularity increase

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

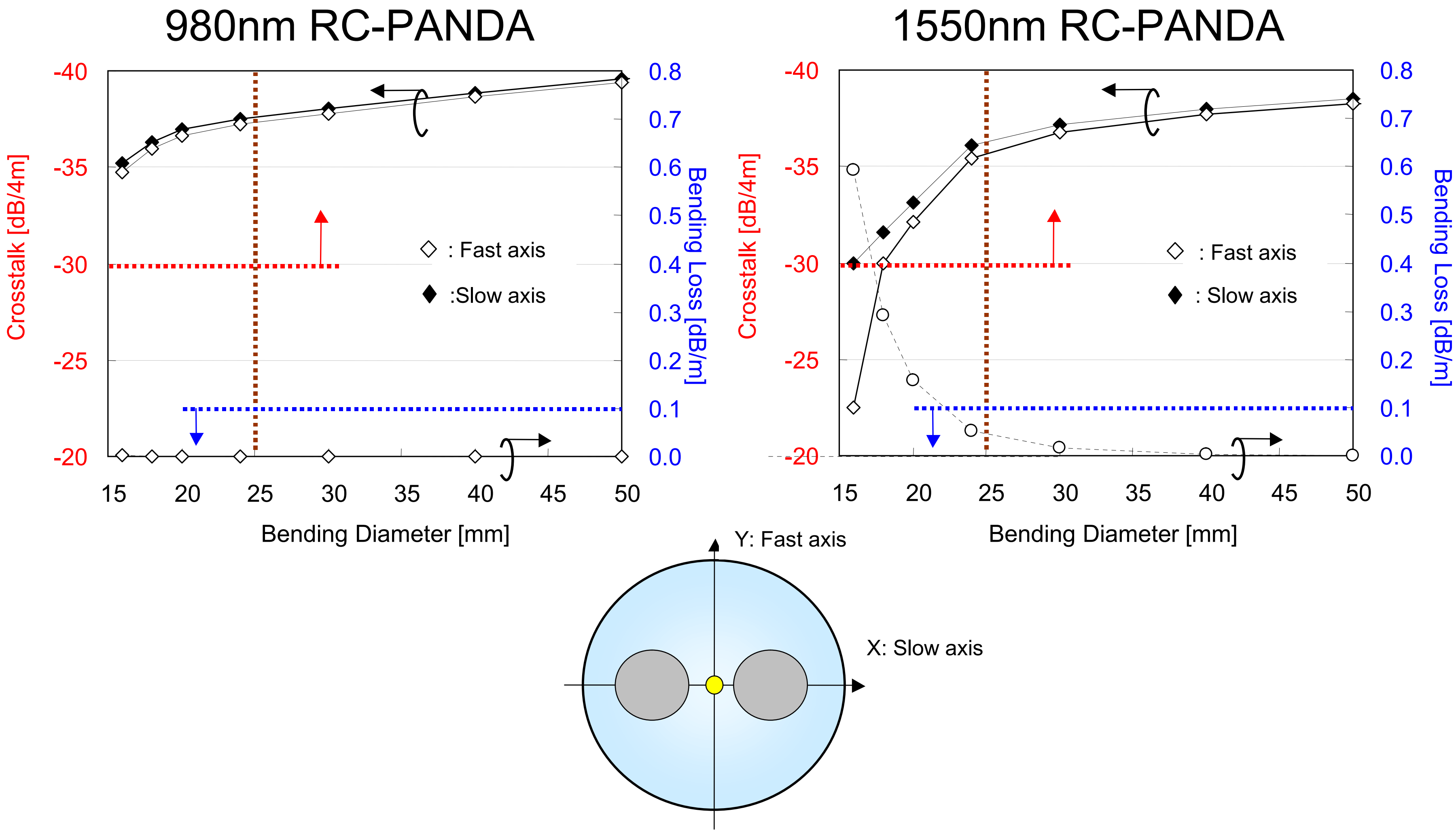
4. Splice loss optimizing

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



Specifications for RC-PANDA fibers

	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
RCSM98-PS-U17C	0.98	6.0	2.5	1.4 ~ 2.6	-25	0.87 ~ 0.95	UV/UV	165 ± 10
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		

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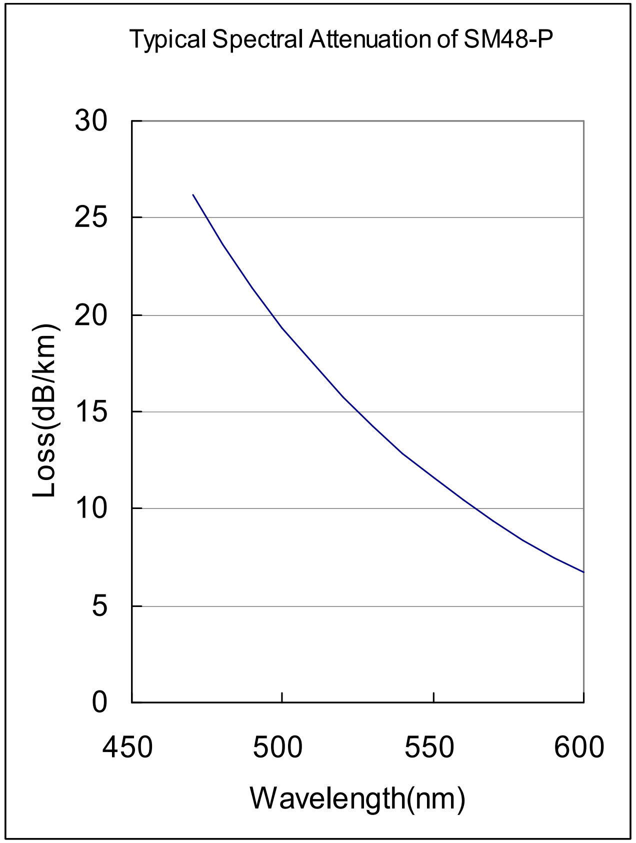
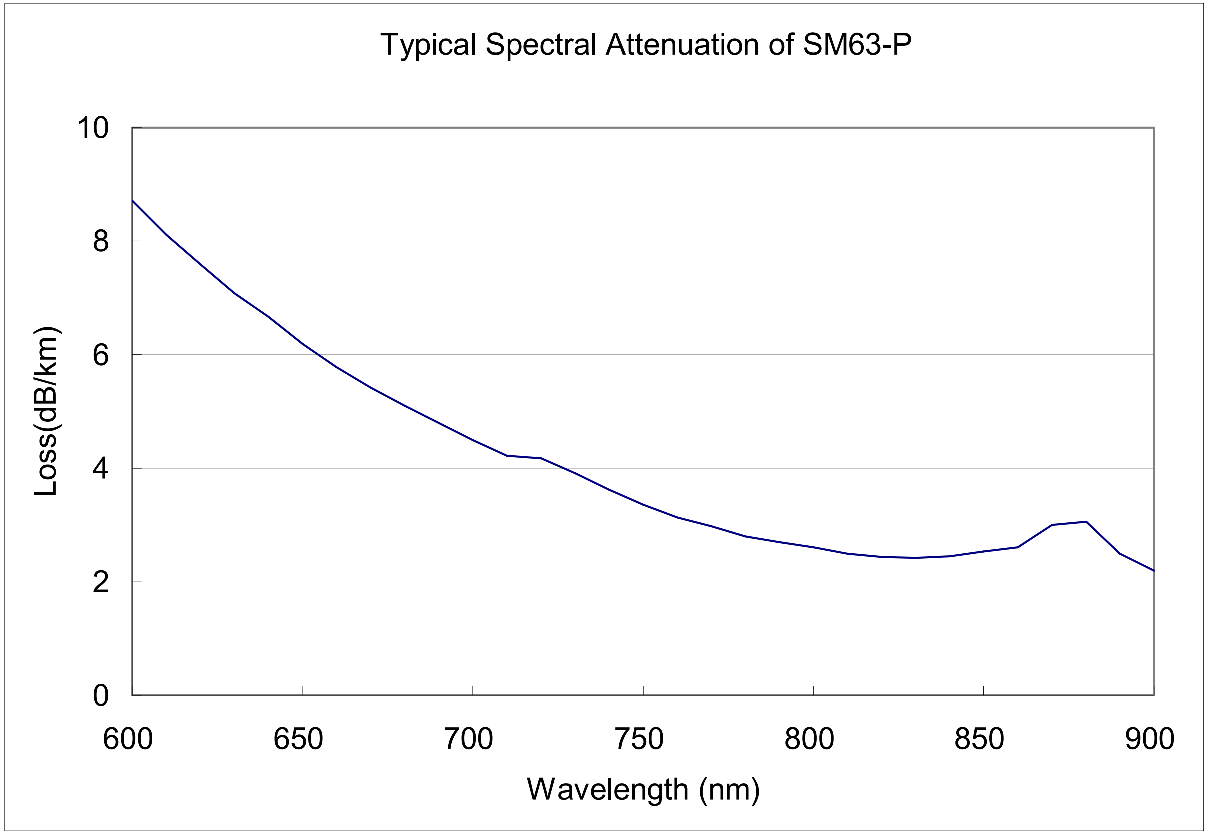
PANDA fibers for sensors

- Stable sensing against disturbance
- Suitable for connecting fiber to sensor light source
- Suitable for Faraday effect sensing fibers
- RGB full-band wavelength is released
- Polyimide coating 0.98, 1.55 μm PANDA are released

Typical wavelength characteristics of sensor 0.48, 0.63 PANDA





Specifications for sensor PANDA fibers (1)

	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
HA13-PS-U25D	1.3	5.5 +/-1.0	2.0	2.5	-30	1.00 ~1.29	UV/UV	245 +/-15
RCHA85-PS-U17C	0.85	3.5 +/-0.5	3.5	2.0		0.65 ~0.80		165 +/-10
SM63-PS-H90D	0.63	4.5 +/-0.5	12			0.52 ~ 0.62	UV/ Polyester-elastomer(Black)	900 +/-100
SM63-PS-U40D							UV/UV	400 +/-15
SM53-PS-H90D	0.53	4.2 +/-0.5	15			0.45 ~ 0.53	UV/ Polyester-elastomer(Black)	900 +/-100
SM53-PS-U40D							UV/UV	400 +/-15

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Specifications for sensor PANDA fibers (2)

	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
SC48-PS-H90D	0.48	4.0	30	2.0	-30	0.40 ~ 0.47	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	50	1.7		0.33 ~ 0.40	UV/ Polyester-elastomer(Black)	900 +/-100
SC40-PS-U40D							UV/UV	400 +/-15
SC40-PS-U25D								245 +/-15

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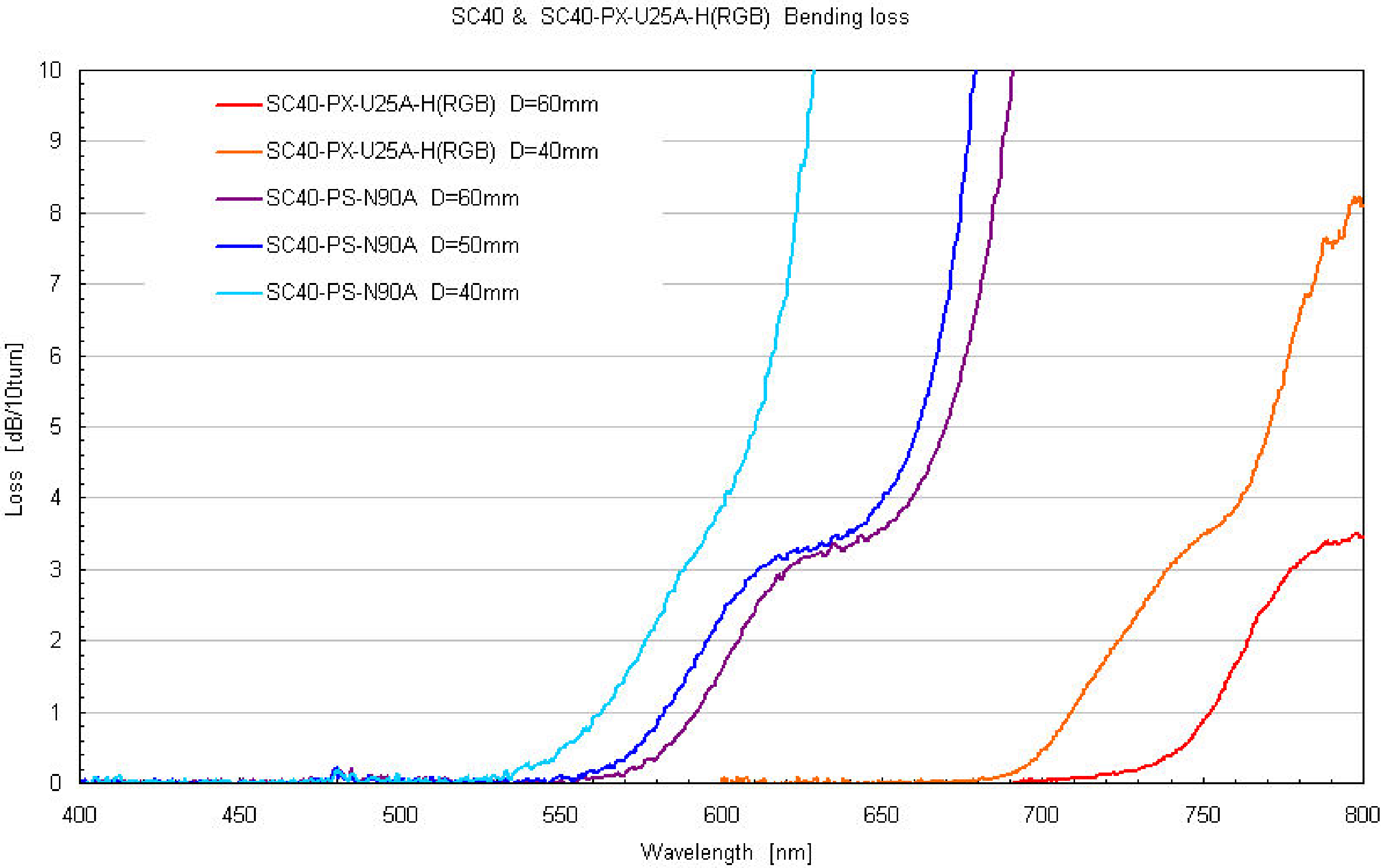
RGB PANDA fiber SC40-PX-U25A-H(RGB)

- **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	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	-30dB /10 turns Bending diameter 60mm	0.40	UV/UV	245 ± 15

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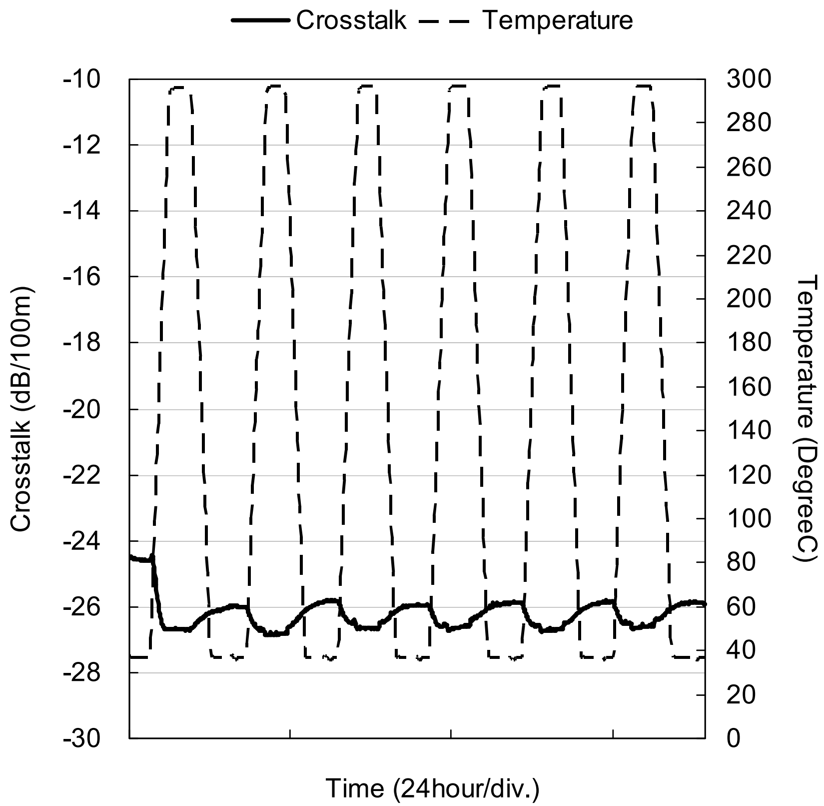
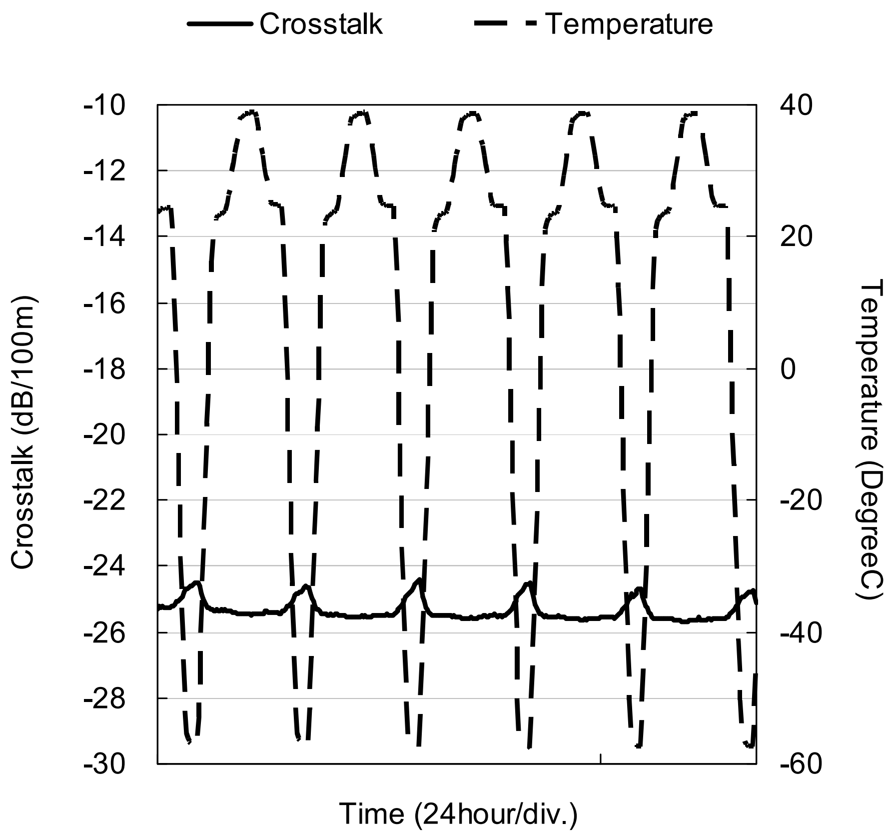
Polyimide PANDA fiber SRSM15-PS-Y15

- Wide temperature range -60 to +300 degC .
  - Crosstalk vs. High and low temperature cycling





Specifications for Polyimide PANDA

	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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Low birefringence PANDA fiber

- Optimized birefringence for polarization devices
  - Suitable for temperature sensitive polarization devices
  - SAPs (Stress applying parts) interval is widely located
  - Lower birefringence than standard PANDA fibers
  - Smaller thermal expansion SAP is used to achieve low temperature dependence

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
SM98-PR-U25D-H	0.98	6.6	3.0	2.8 ~ 4.9	-25	0.80 ~0.95	UV/UV	245 +/- 15
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		

Specifications of 500μm coating SR15 type PANDA fibers

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

Fujikura PANDA fiber solutions

Fujikura has been developing below new PANDA fibers for customer solutions.

- For Blue LD, Blue LED products designers
  SC40-P, SC48-P, SM63-P･UV/UV coating series
- For RoHS compliant PANDA cord users
  Lead-free, non-halogen PANDA cord series
- For telecommunications designers using laser diode or modulator
  UV coating series
- For users like a telephone office requiring flame retardant PANDA fibers
  Flame-retardant series
- For users requiring 15mm winding diameter PANDA fibers
  SRSM15 series
  80 μm cladding diameter series
- For PANDA coupler manufacturers requiring lower temperature dependence
  Low birefringence series

Fujikura is challenging for customer solutions to meet various needs.