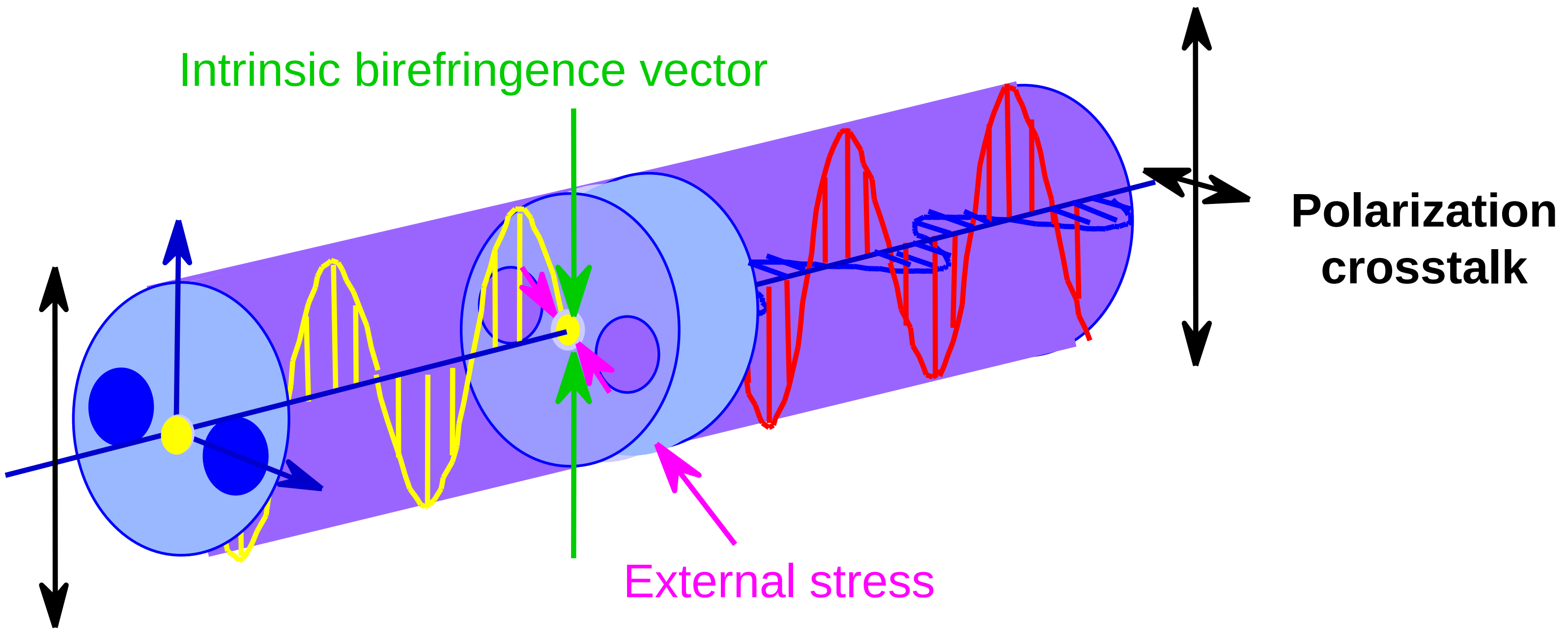
Fujikura PANDA fiber products and Basics of PM fibers

Fiber Optics Network Products Engineering Department

Fujikura Ltd.

How to preserve 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

Features of Fujikura PANDA fiber

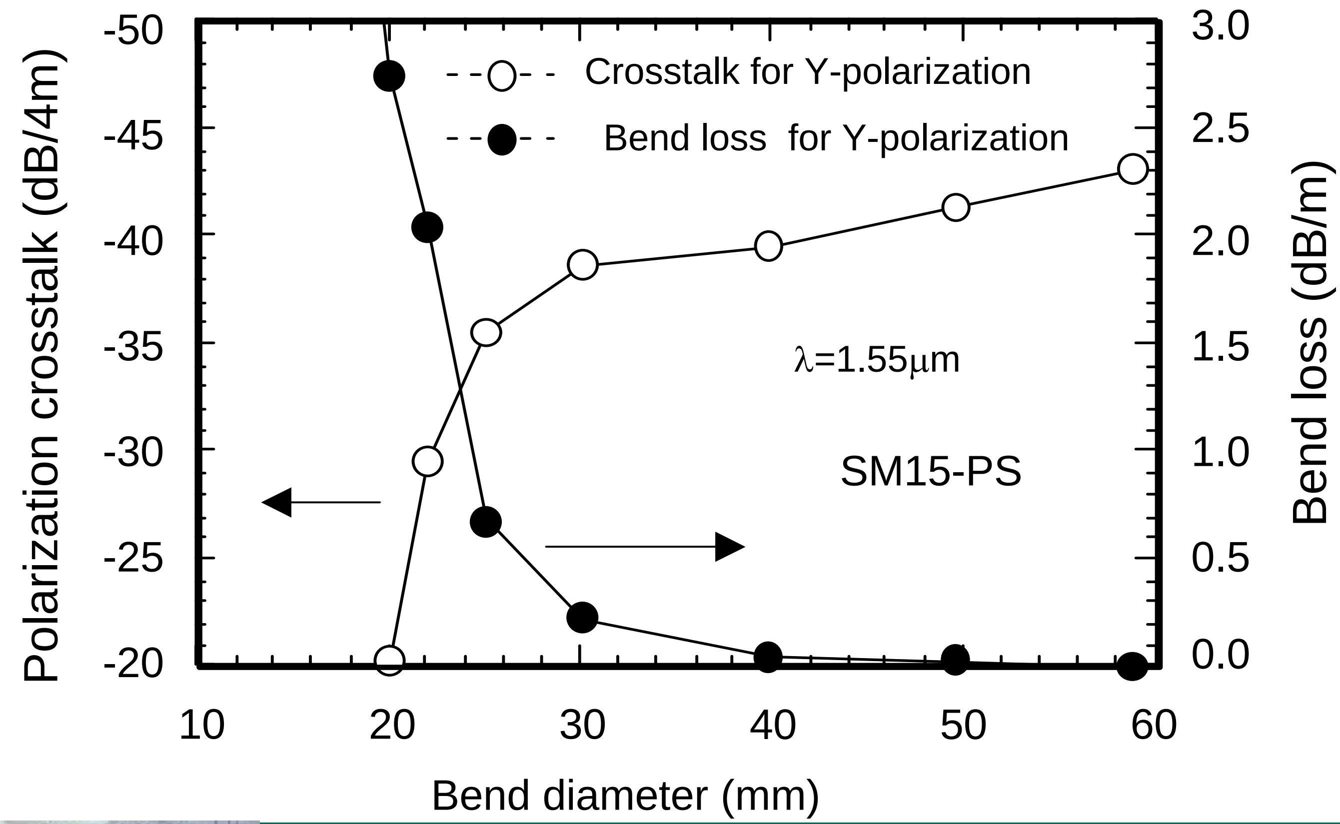
- Low attenuation
- Low polarization crosstalk
- Design and manufacturing flexibility
  - Any wavelength available.
  - Any types of single-mode fiber can be a PANDA fiber.
    - Erbium doped and Dispersion shift PANDA fibers
  - Easy optimization of birefringence and other parameters
- High dimensional symmetry and uniformity.
  - Suitable for splicing, connectorising, tail- assemblies and devices

Specifications for UV/UV PANDA fibers

	λc	MFD	Attenu -ation	Beat Length	Crosstal k	Cut-off Wavelength	Coating Structure	Coating diameter
	μm	+/-1.0 μm	Max. dB/km	Mm	Max. dB/100m	μm		μm
SM85-PS-U40A	0.85	5.5	3.0	1.0 -2.0	-30	0.65 -0.80	UV/UV	400+/-15
SM85-PS-U25A								245+/-15
SM98-PS-U40A	0.98	6.6	2.5	1.5 -2.7		0.80 -0.95		400+/-15
SM98-PS-U25A								245+/-15
SM13-PS-U40A	1.3	9.5	1.0	2.5 -4.0		1.10 -1.29		400+/-15
SM13-PS-U25A								245+/-15
SM14-PS-U40A	1.40 -1.49	9.8	1.0	2.8 -4.7		1.20 -1.38		400+/-15
SM14-PS-U25A								245+/-15
SM15-PS-U40A	1.55	10.5	0.5	3.0 -5.0		1.29 -1.45		400+/-15
SM15-PS-U25A								245+/-15

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
- Alternative from Nylon coating fiber
- Wavelength:0.85,0.98,1.3,1.45,1.55μm, DSF
- -40 to 85°C Operation temperature

Specifications for 900μm PANDA fibers

	λc	MFD	Attenu-ation	Beat Length	Cross talk	Cut-off Wavelength	Coating Structure	Diameter
	μm	+/-1.0 μm	Max. dB/km	mm	Max. dB/100m	μm		μm
SM85-PS-H90A	0.85	5.5	3.0	1.0 -2.0	-25	0.65 -0.80	UV/Polyesrer-elastomer(Black)	900 +/- 100
SM85-PS-N90A							UV/Polyamide(Black)	
SM98-PS-H90A	0.98	6.6	2.5	1.5 -2.7		0.80 -0.95	UV/Polyesrer-elastomer(Green)	
SM98-PS-N90A							UV/Polyamide(Green)	
SM13-PS-H90A	1.3	9.5	1.0	2.5 -4.0		1.10 -1.29	UV/Polyesrer-elastomer(Black)	
SM13-PS-N90A							UV/Polyamide(Black)	
SM14-PS-H90A	1.40 -1.49	9.8	1.0	2.8 -4.7		1.20 -1.38	UV/Polyesrer-elastomer(Black)	
SM14-PS-N90A							UV/Polyamide(Black)	
SM15-PS-H90A	1.55	10.5	0.5	3.0 -5.0		1.29 -1.45	UV/Polyesrer-elastomer(Black)	
SM15-PS-N90A							UV/Polyamide(Black)	

Specifications for PANDA fiber cords

	λc	MFD	Attenu-ation	Beat Length	Cross talk	Cut-off Wavelength	Coating Structure	Diameter
	μm	+/-1.0 μm	Max. dB/km	mm	Max. dB/100m	μm		mm
SM85-PS-C28A	0.85	5.5	3.0	1.0 -2.0	-25	0.65 -0.80	UV/Polyamide(Black)/ PVC (Black)*	2.8 +/- 0.2
SM98-PS-C28A	0.98	6.6	2.5	1.5 -2.7		0.80 -0.95	UV/Polyamide(Green)/ PVC(Black)*	
SM13-PS-C28A	1.3	9.5	1.0	2.5 -4.0		1.10 -1.29	UV/Polyamide(Black)/ PVC (Black)*	
SM14-PS-C28A	1.40 -1.49	9.8	1.0	2.8 -4.7		1.20 -1.38	UV/Polyamide(Black)/ PVC (Black)*	
SM15-PS-C28A	1.55	10.5	0.5	3.0 -5.0		1.29 -1.45	UV/Polyamide(Black)/ PVC (Black)*	

*Halogen free, flame resistance, 2mm diameter cord will be released on January 2005.

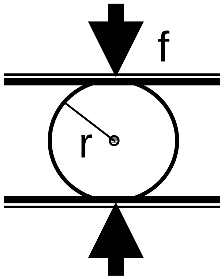
Specifications for Dispersion Shift PANDA fibers

	λc	MFD	Attenu-ation	Beat Length	Cross talk	Cut-off Wavelength	Coating Structure	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-H90A					-25		UV/Polyester-elastomer(Blue)	900 +/- 100
DS15-PS-N90A							UV/Polyamide(Blue)	
DS15-PS-C28A							UV/Polyamide(Blue)/PVC(Black)*	2800 +/- 200

*Halogen free, flame resistance, 2mm diameter cord will be released on January 2005.

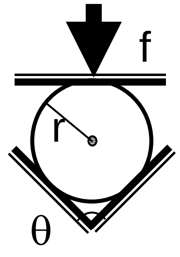
Features of RC-PANDA fibers 1

1.Higher birefringence for lateral pressure endurance



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

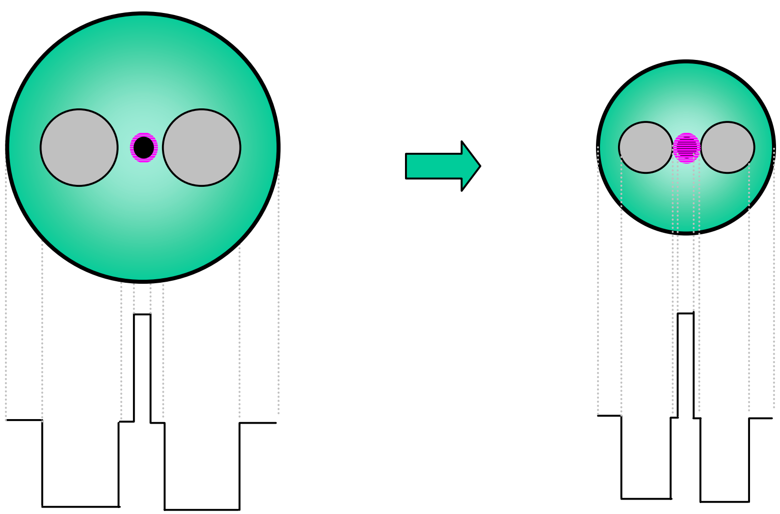
C:Photo Elastic constant
E:Young's modulus



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

Re-design Stress applying parts

2. Attenuation and MFD non-circularity optimization

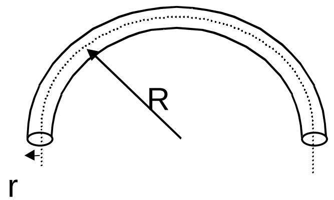


- B_2O_3, OH absorption increase
- MFD non-circularity increase

To improve above, reduce slightly MFD diameter.

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 design and achieve good results**

4. Splice loss optimizing

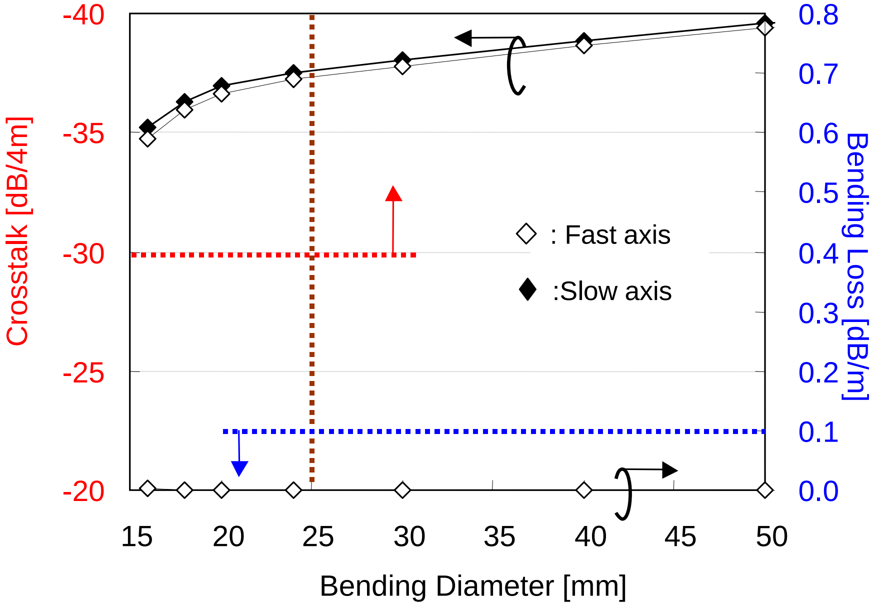
Telecom component
$\Rightarrow$ Need low splice loss with different major fiber splices

Requirement:
Splice loss < 0.1dB

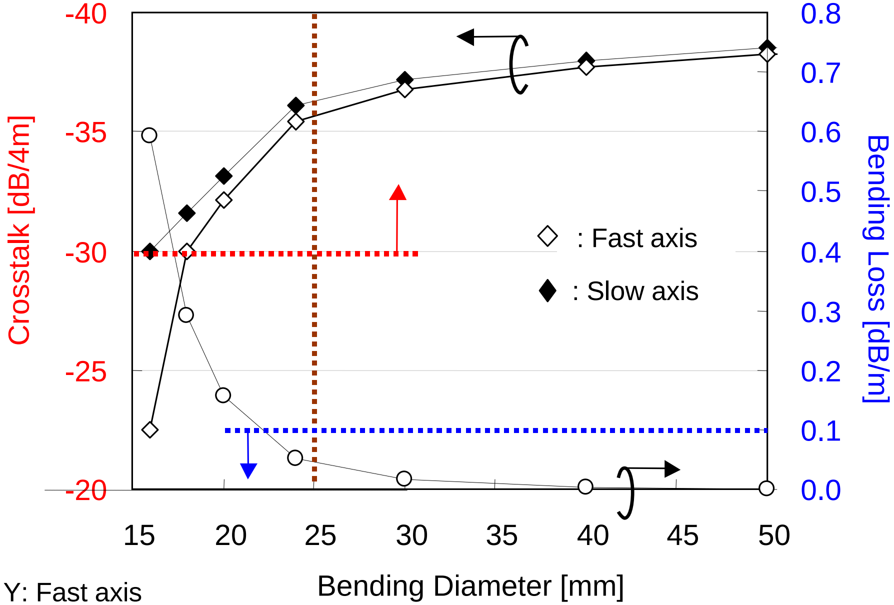
⇨ **MFD differences with other fibers are designed within slight level**

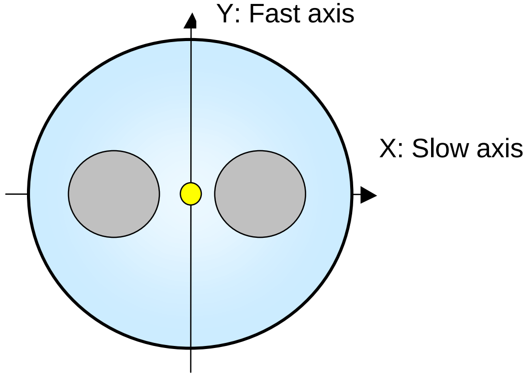
Attenuation and Crosstalk in 4m length bending

980nm RC-PANDA



1550nm RC-PANDA





Specifications for RC-PANDA fibers

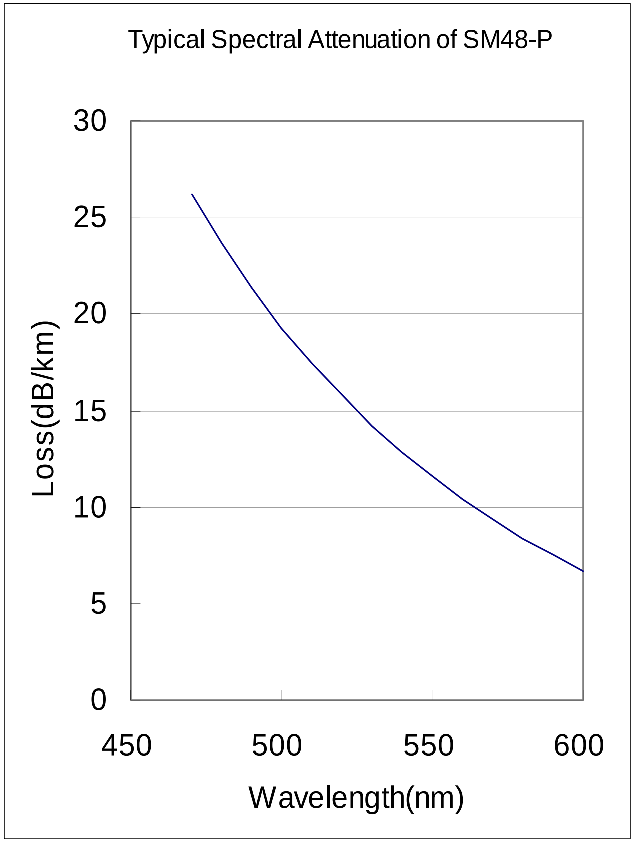
	λc	MFD	Attenu-ation	Beat Length	Cross Talk	Cut-off Wavelength	Coating Structure	Diameter
	μm	+/-1.0 μm	Max. dB/km	Mm	Max. dB/100m	μm		μm
RCSM98-PS-U17B	0.98	6.0	2.5	1.4 -2.6		0.80 -0.95		
RCSM13-PS-U17B	1.3	8.2	2.0	2.0 -3.5	-25	1.10 -1.29	**UV/UV**	**165+/-10**
RCSM14-PS-U17B	1.40 -1.49	9.0	2.0	2.3 -4.2		1.20 -1.38		
RCSM15-PS-U17B	1.55	9.5	2.0	2.5 -4.5		1.29 -1.45		

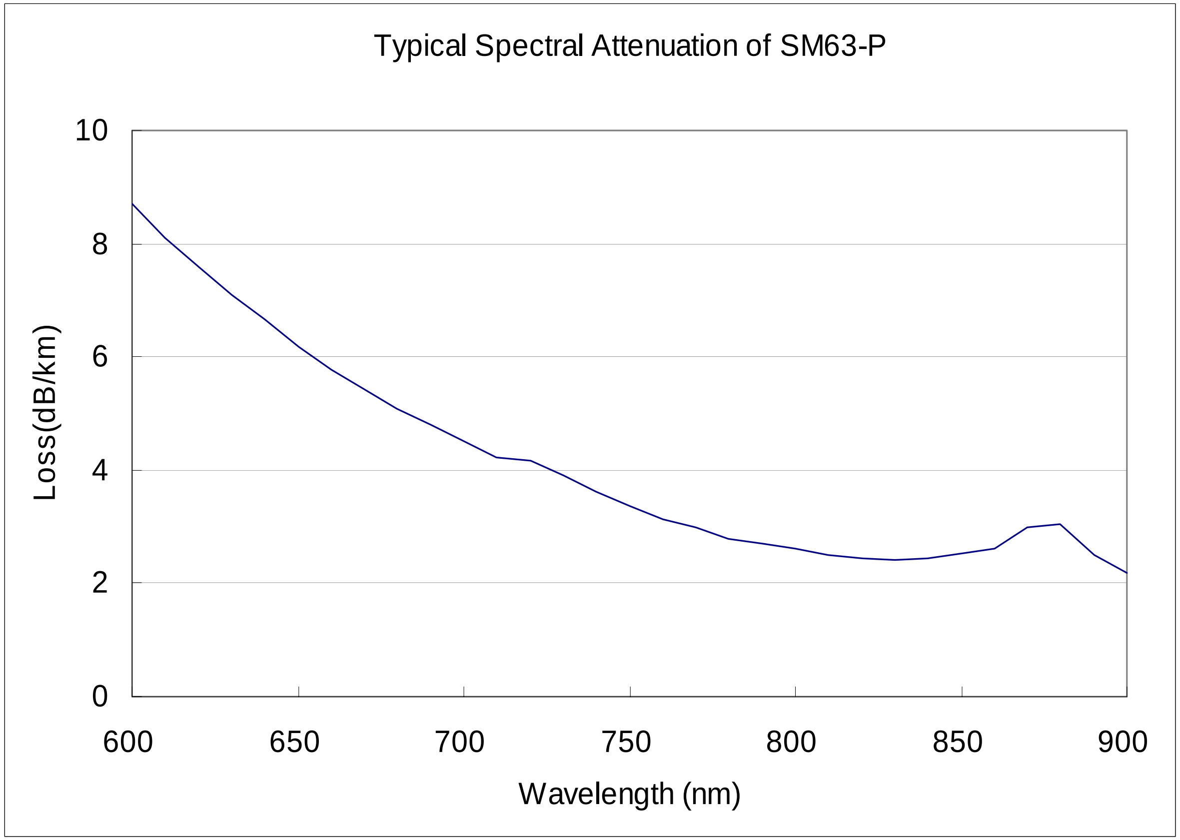
PANDA fibers for sensors

- Stable sensing against external perturbations
- Connecting fiber to sensor light source
- Suitable for faraday effect sensing fibers

  (UV/UV coating type of 0.63, 0.48μm were started to release)
- Blue laser cutoff wavelength is also available

Typical wavelength characteristics of sensor 0.48,0.63 PANDA





Specifications for sensor PANDA fibers

<table>
<tr><th rowspan="2"></th><th>λc</th><th>MF (Core) diameter</th><th>Attenu-ation</th><th>Beat Length</th><th>Cross-talk</th><th>Cut-off Wavelength</th><th>Coating Structure</th><th>Diameter</th></tr>
<tr><th>μm</th><th>+/-1.0 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>HA13-PS-U25A</td><td>1.3</td><td>5.5</td><td>2.0</td><td>2.5</td><td rowspan="7">-30</td><td>1.00 -1.29</td><td rowspan="2">UV/UV</td><td>245+/-15</td></tr>
<tr><td>RCHA85-PS-U17B</td><td>0.85</td><td>4.0</td><td>3.5</td><td rowspan="6">2.0</td><td>0.65 -0.80</td><td>165+/-10</td></tr>
<tr><td>SM63-PS-N90A</td><td rowspan="2">0.63</td><td rowspan="2">(4.0)</td><td rowspan="2">12</td><td rowspan="2">0.50 -0.62</td><td>UV/Poly-amide (Black)</td><td>900+/-100</td></tr>
<tr><td>SM63-PS-U40A</td><td>UV/UV</td><td>400+/-15</td></tr>
<tr><td>SC48-PS-N90A</td><td rowspan="3">0.48</td><td rowspan="3">(4.0)</td><td rowspan="3">30</td><td rowspan="3">0.40 -0.47</td><td>UV/Poly-amide (Black)</td><td>900+/-100</td></tr>
<tr><td>SC48-PS-U40A</td><td rowspan="2">UV/UV</td><td>400+/-15</td></tr>
<tr><td>SC48-PS-U25A</td><td>245+/-15</td></tr>
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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
  - SAP thermal expansion coefficient is less effective that temperature dependence should be stable

Specifications for low birefringence PANDA fibers

	λc	MFD	Attenu-ation	Beat Length	Cross talk	Cut-off Wavelength	Coating Structure	Diameter
	μm	+/-1.0 μm	Max. dB/km	mm	Max. dB/100m	μm		μm
SM98-PR-U25A-H	0.98	6.6	3.0	2.8 -4.9	-25	0.80 -0.95	UV/UV	**245+/-15**
SM14-PR-U25A-H	1.40 -1.49	9.8	1.0	4.1 -7.3		1.20 -1.38		
SM15-PR-U25A-H	1.55	10.5	0.5	4.4 -7.8		1.29 -1.45		

PANDA fiber tail assembly

- PANDA Connectors
  - FC connector
  - SC connector
- Custom-made Assembly
  - Special ferrule
  - Special tail assembly
    - -Rounded-end, Taper-end
    - -Metallic coating, AR coating

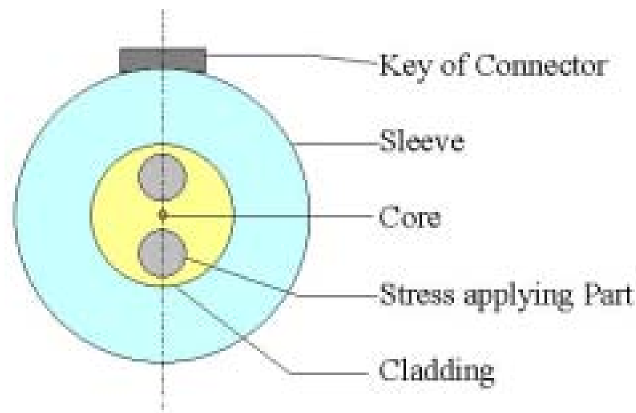
PANDA connectors

PANDA-FC Connector

PANDA-SC Connector

FC and SC Connector typical properties

Polishing	SPC	UPC	APC
Insertion Loss max	0.5dB	0.5dB	0.5dB
Return Loss min	40dB	50dB	60dB
Crosstalk max	-25dB	-25dB	-25dB
Axial Alignment typ	+/-3 deg	+/-3 deg	+/-3 deg



Polarization axis alignment

Other connectors, polishing and axis alignments are also available.

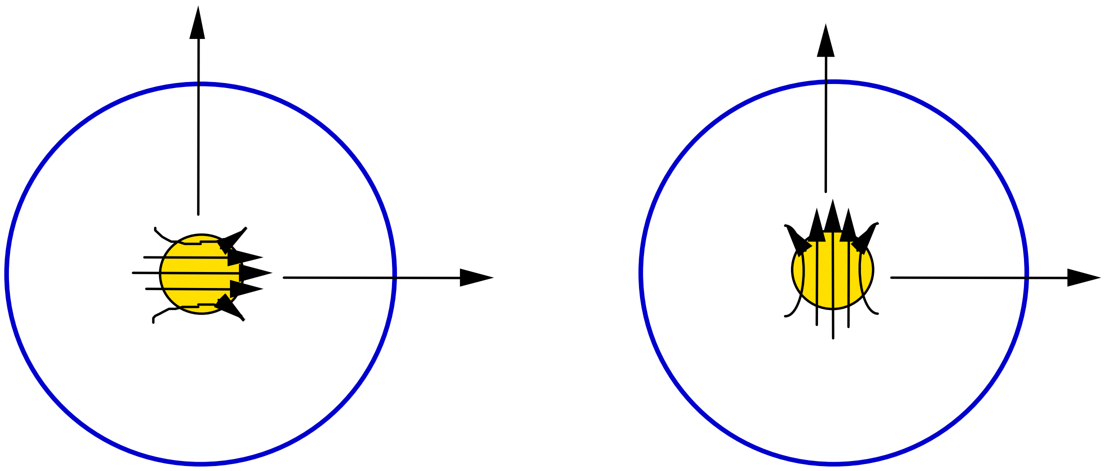
Basics of Polarization maintaining fibers

Fiber Optics Network Products Engineering Department

Fujikura Ltd.

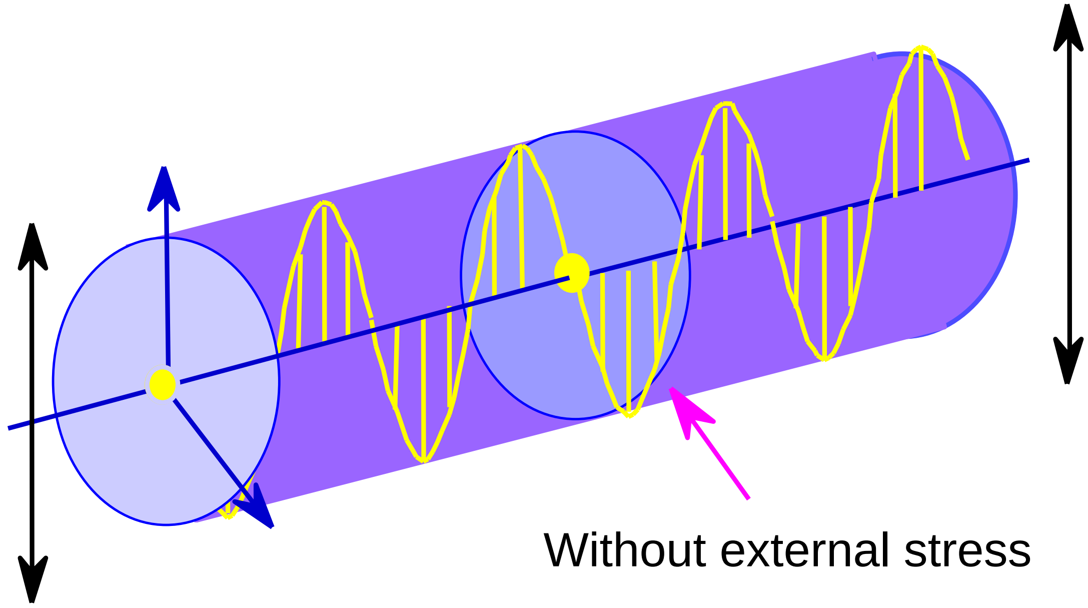
Polarization modes in ideal SM fiber

- 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 lift the degeneracy.



Polarization in ideal SM fiber

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



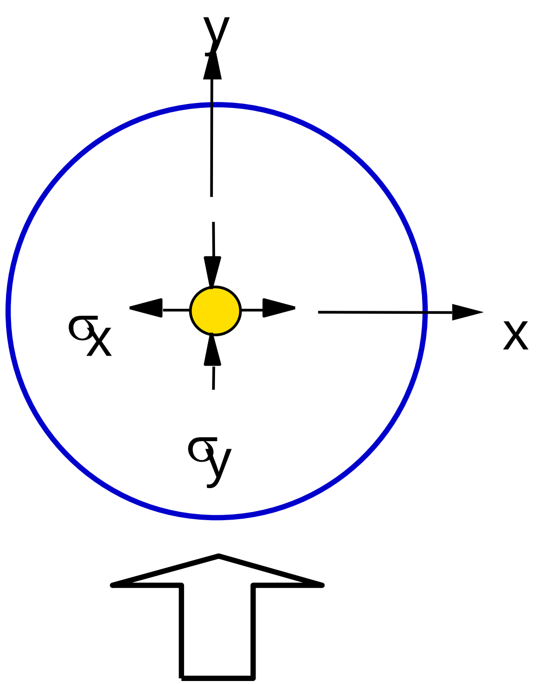
Without external stress

Stress-induced birefringence

- Rotationally asymmetrical stress changes refractive indices for two orthogonal polarization direction (birefringent axes): photo-elastic effect.
- As a result, the two orthogonal modes are separated: nx > ny, βx > βy: stress birefringence.

$$B = n_x - n_y = C(\sigma_x - \sigma_x)$$

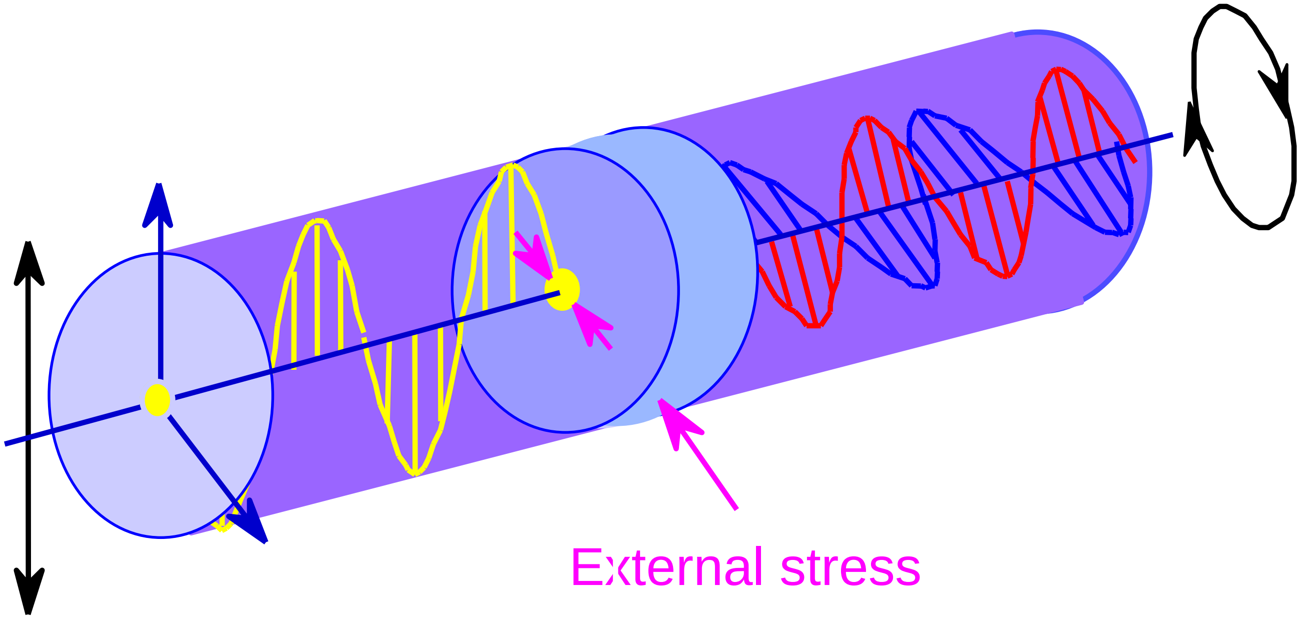
- C:Photo Elastic constant



External stress due to bend or lateral pressure

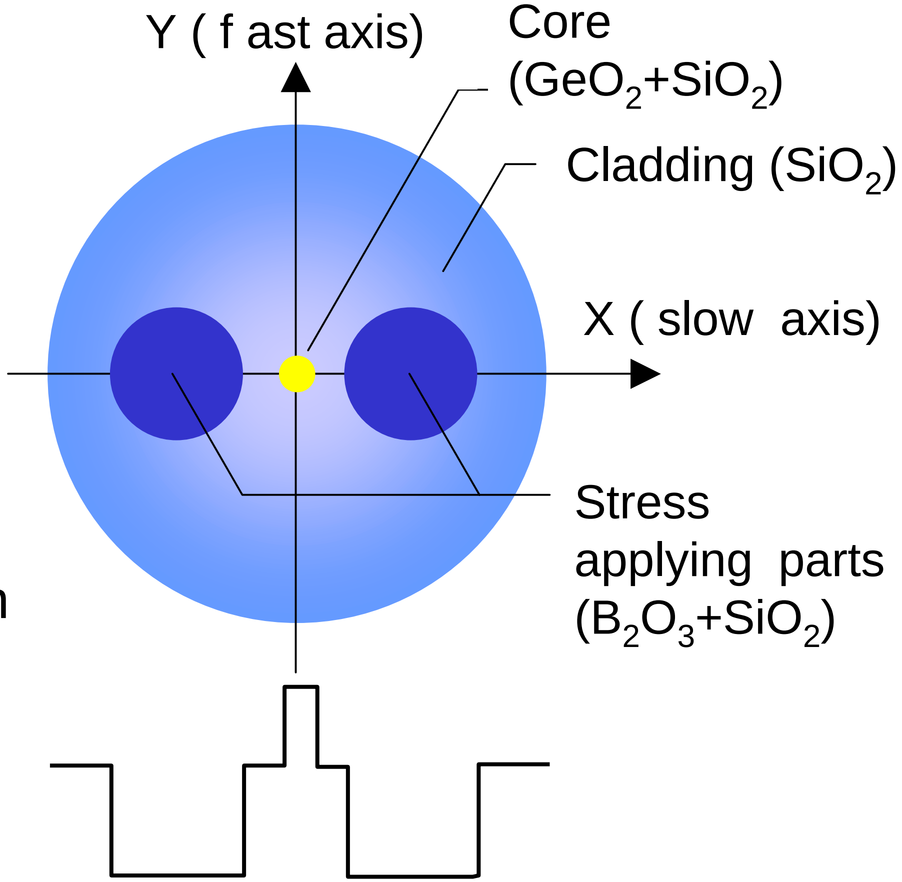
Polarization in actual SM fiber

- Stress-induce phase difference causes polarization change.
- State of polarization at output is not stable.



Structure of PANDA fiber

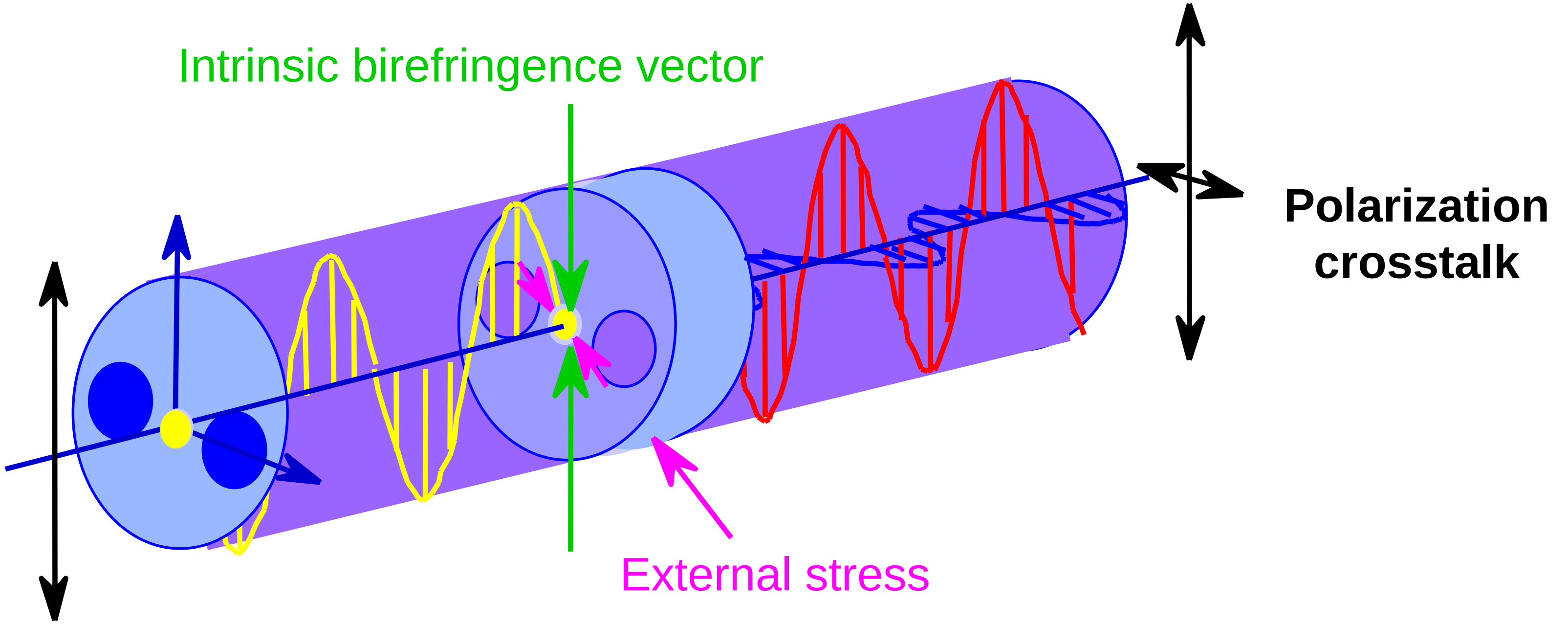
- Boron-doped SAP(Stress applying parts) have higher thermal coefficient of expansion than the cladding.
  - SAP: 3×10^{-6} / degree C
  - Cladding: 5×10^{-7} / degree C
- The SAP shrinks more than the cladding during cooling process of drawing.
- Tensile stress of SAP direction remains in the core induces large stress birefringence.



Refractive index profile
along x- direction

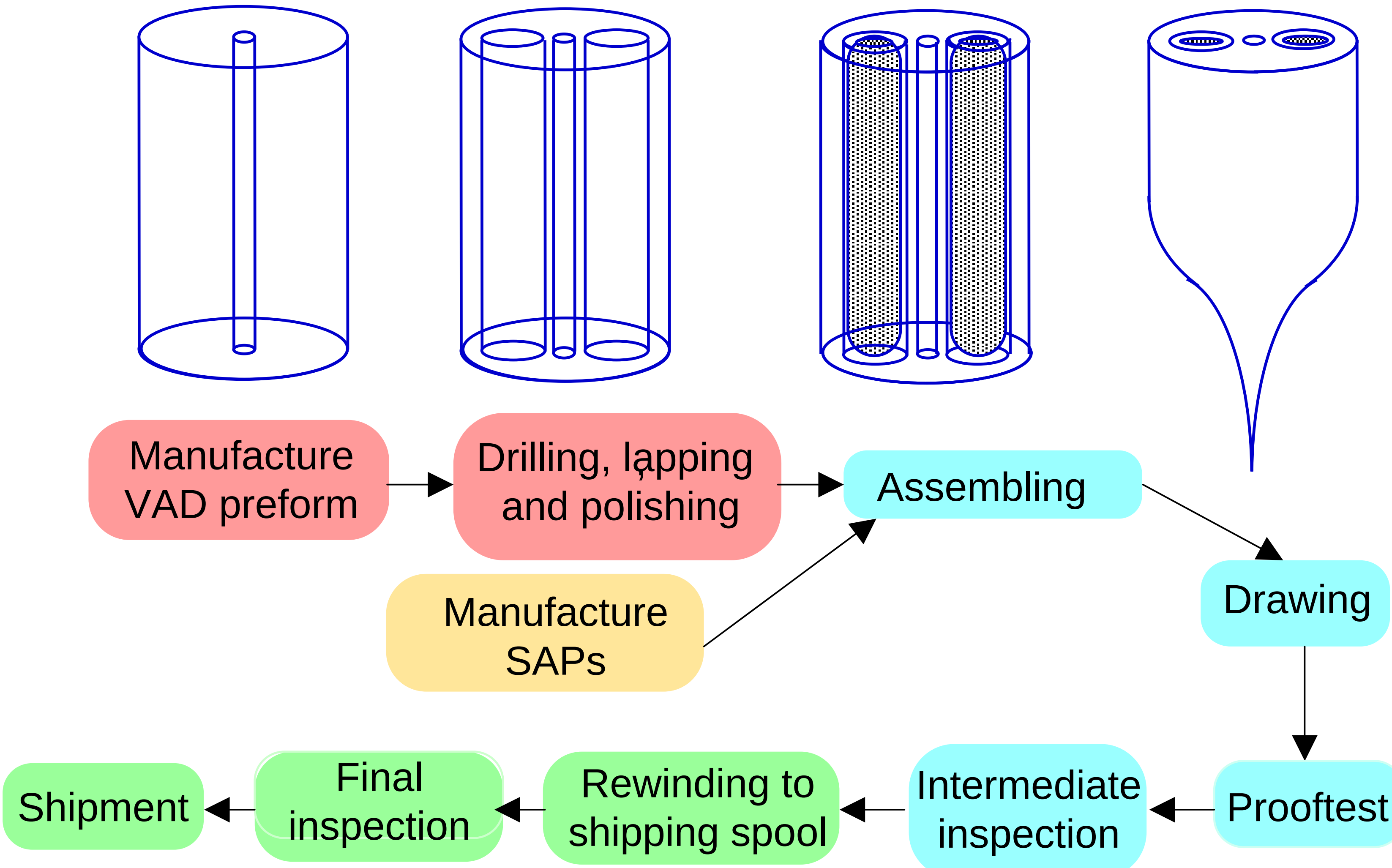
How to preserve polarization

- 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

Production process of Fujikura PANDA



Inspection items and methods on PANDA fiber

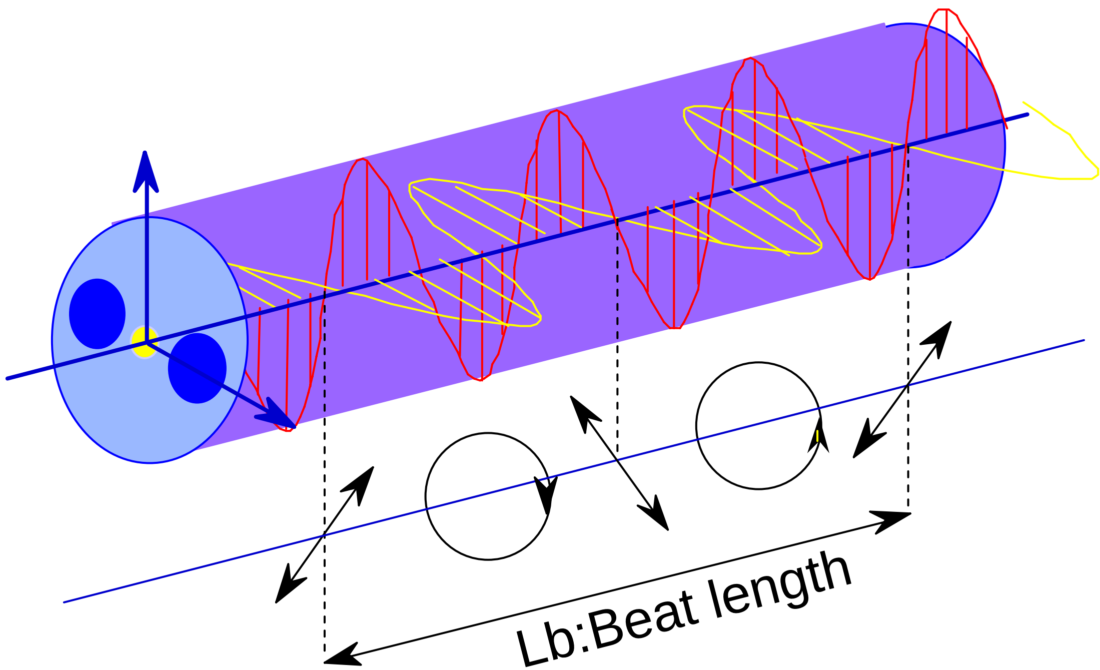
	Application	Method or technique	Reference
Fiber diameter	O / I / F	Grey scale	ITU-T G.650
Core offset	I / F	Grey scale	ITU-T G.650
Coat diameter	O / I	Microscope	---
Mode field diameter	I	Far-field pattern / Variable aperture	ITU-T G.650
Cutoff wavelength	I	Bend reference	ITU-T G.650
Attenuation	I	OTDR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

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

Beat length

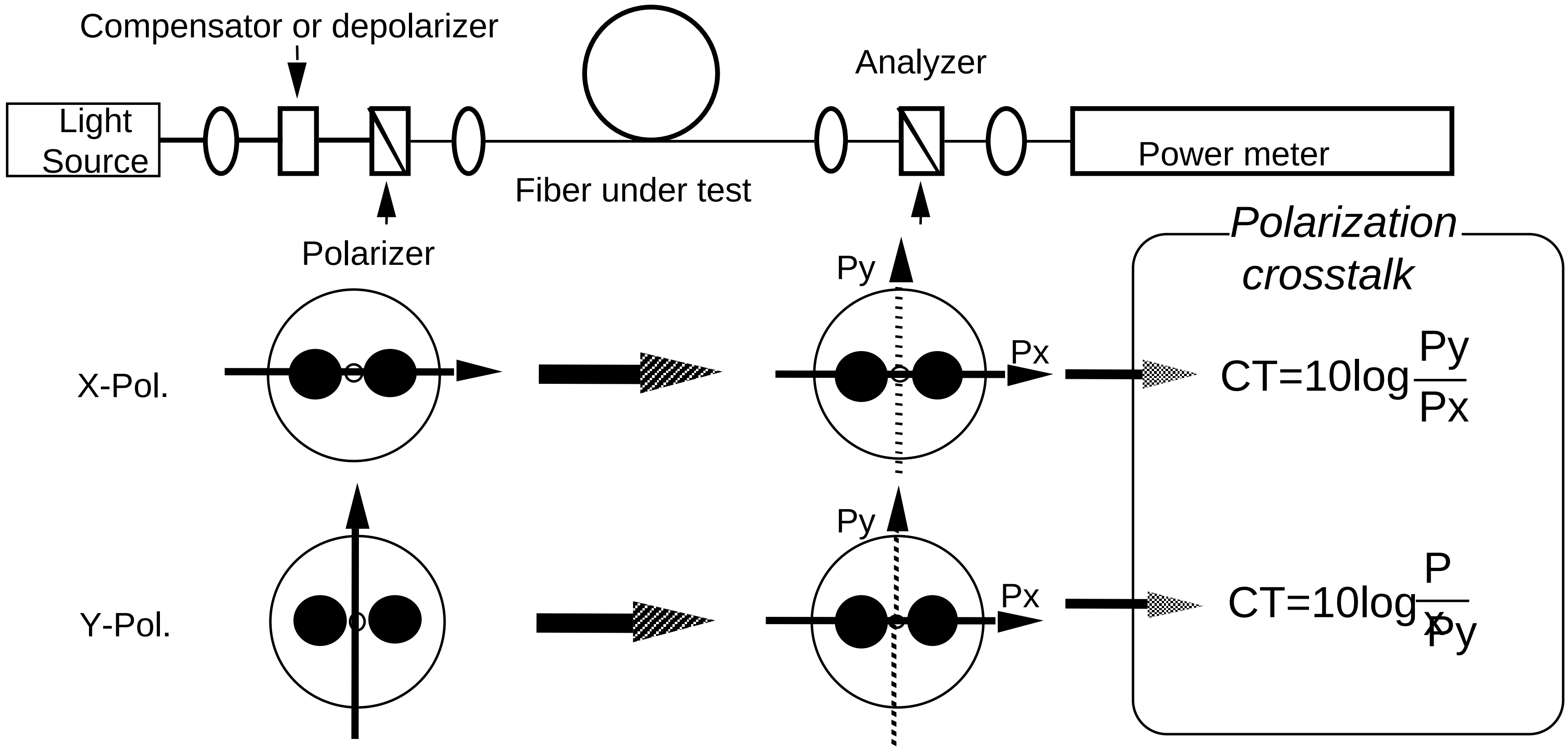
- Beat length *Lb* is one cycle of periodical polarization variation along a PM fiber.
- Related to modal birefringence as follows:

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



Measurement of polarization crosstalk

Measure the extinction ratio of output light while input linear polarization is launched into input.



Unit: dB

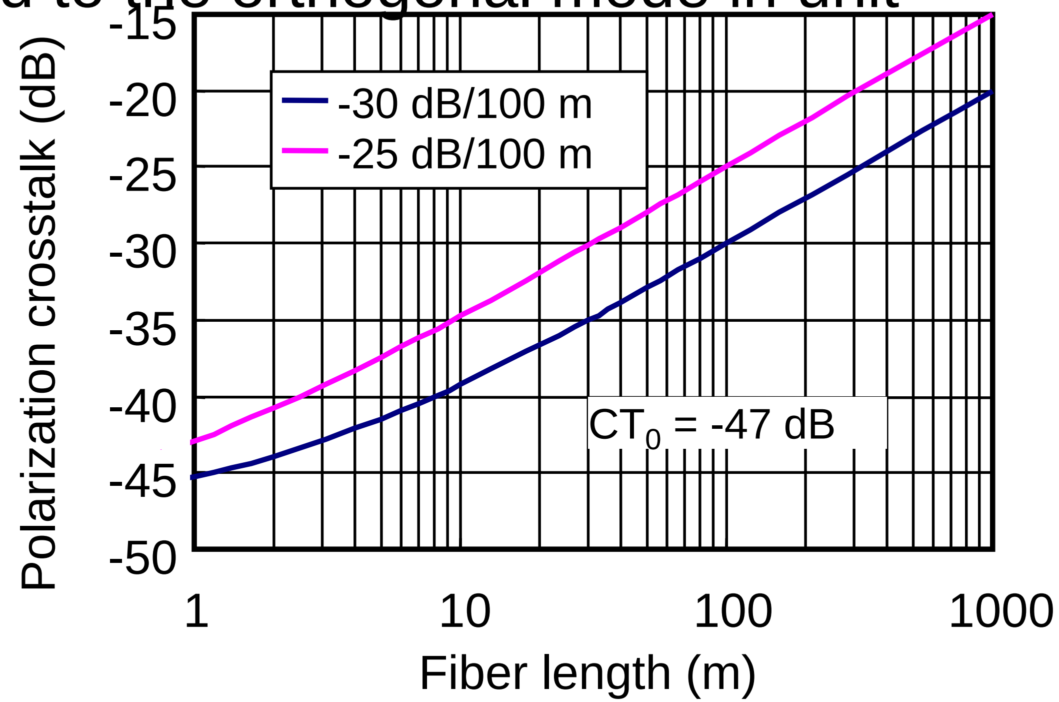
Power coupling coefficient

- 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

Summary of Fujikura PANDA fiber

- Low attenuation and low polarization crosstalk
- High reliability proofed in actual system and customer
- High dimensional symmetry and uniformity.
  - Suitable for splicing and connectorizing

- New series are released as ongoing developments
  - Flame retardant coating
  - 80 micron cladding
  - Sensing
    (SM48-P,SM63-P, RCHA85-P,HA13-P UV/UV series)
  - Low birefringence