Introduction of PANDA fibers

Contact information for technical matters
Fujikura Ltd.
Optical Fiber Division
http://www.fujikura.co.jp
E-mail: optodevice@jp.fujikura.com

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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: \( n_x = n_y, \beta_x = \beta_y \)
- Rotational asymmetries such as core ellipse or lateral stress induce birefringence and resolve the degeneracy.
- 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...
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

Polarization crosstalk

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

1. Manufacturing VAD preform
2. Drilling, lapping and polishing
3. Assembling
4. Drawing
5. Proof test
6. Intermediate inspection
7. Rewinding to shipping spool
8. Final inspection
9. Shipment

Manufacturing SAPs
### Inspection items and methods on PANDA fiber

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

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

- Beat length $L_b$ is the length which phase difference between X and Y polarization modes equals $2\pi$ along a PM fiber.
- Relation between beat length ($L_b$), birefringence ($B$), and wavelength ($\lambda$) is expressed by the following equation:

$$L_b = \frac{\lambda}{B}$$
Measurement of polarization crosstalk

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

\[
CT = 10 \log \left( \frac{Py}{Px} \right) \\
CT = 10 \log \left( \frac{Px}{Py} \right)
\]

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.

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

\[ \eta = \frac{P_y}{P_x} = 10^{\frac{CT}{10}} \]

\( L \): Fiber Length

![Graph showing the relationship between fiber length and polarization crosstalk.](image)
## Reliability performance

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

PANDA fiber failure probabilities after 2% proof test

Failure probability calculation by Mitsunaga theory
Bending : 10 turns, Tensile strength to the fiber : 50 grams

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

(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

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

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

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

(7) UV curable resin type:
E : UV/UV resin type E
D : UV/UV resin type D
C : UV/UV resin type C
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
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.
<table>
<thead>
<tr>
<th></th>
<th>λ₀</th>
<th>MFD</th>
<th>Att.</th>
<th>Beat length</th>
<th>Cross-talk</th>
<th>λₒ</th>
<th>Coating material</th>
<th>Coating diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>μm</td>
<td>+/-0.5 μm</td>
<td>Max. dB/km</td>
<td>mm</td>
<td>Max. dB/100m</td>
<td>μm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM85-PS-U40D</td>
<td>0.85</td>
<td>5.5</td>
<td>3.0</td>
<td>1.0</td>
<td>~ 2.0</td>
<td>0.65</td>
<td>~ 0.80</td>
<td>400±15</td>
</tr>
<tr>
<td>SM85-PS-U25D</td>
<td>0.98</td>
<td>6.6</td>
<td>2.5</td>
<td>1.5</td>
<td>~ 2.7</td>
<td>0.87</td>
<td>~ 0.95</td>
<td>245±15</td>
</tr>
<tr>
<td>SM98-PS-U40D</td>
<td>0.98</td>
<td>9.0</td>
<td>1.0</td>
<td>2.5</td>
<td>~ 4.0</td>
<td>1.13</td>
<td>~ 1.27</td>
<td>400±15</td>
</tr>
<tr>
<td>SM98-PS-U25D</td>
<td>1.3</td>
<td>9.8</td>
<td>1.0</td>
<td>2.8</td>
<td>~ 4.7</td>
<td>1.26</td>
<td>~ 1.38</td>
<td>245±15</td>
</tr>
<tr>
<td>SM14-PS-U40D</td>
<td>1.40</td>
<td>10.5</td>
<td>0.5</td>
<td>3.0</td>
<td>~ 5.0</td>
<td>1.30</td>
<td>~ 1.44</td>
<td>400±15</td>
</tr>
<tr>
<td>SM14-PS-U25D</td>
<td>1.55</td>
<td>10.5</td>
<td>0.5</td>
<td>3.0</td>
<td>~ 5.0</td>
<td>1.30</td>
<td>~ 1.44</td>
<td>245±15</td>
</tr>
</tbody>
</table>

Specifications for UV/UV PANDA fibers

Coating material: UV/UV

Coating diameter: 400±15 μm
## Specifications for 900 µm PANDA fibers

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>λ₀ (µm)</th>
<th>MFD (µm)</th>
<th>Att. (dB/km)</th>
<th>Beat length (mm)</th>
<th>Cross-talk (µm)</th>
<th>λₐ (µm)</th>
<th>Coating Material</th>
<th>Coating Diameter (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM85-PS-H90D</td>
<td>0.85</td>
<td>5.5</td>
<td>3.0</td>
<td>1.0 ~ 2.0</td>
<td>-30</td>
<td>0.65 ~ 0.80</td>
<td>UV/Polyester-elastomer(Black)</td>
<td>900 ± 100</td>
</tr>
<tr>
<td>SM98-PS-H90D</td>
<td>0.98</td>
<td>6.6</td>
<td>2.5</td>
<td>1.5 ~ 2.7</td>
<td></td>
<td>0.87 ~ 0.95</td>
<td>UV/Polyester-elastomer(Green)</td>
<td></td>
</tr>
<tr>
<td>SM13-PS-H90D</td>
<td>1.3</td>
<td>9.0</td>
<td>1.0</td>
<td>2.5 ~ 4.0</td>
<td></td>
<td>1.13 ~ 1.27</td>
<td>UV/Polyester-elastomer(Black)</td>
<td></td>
</tr>
<tr>
<td>SM14-PS-H90D</td>
<td>1.40 ~ 1.49</td>
<td>9.8</td>
<td>1.0</td>
<td>2.8 ~ 4.7</td>
<td></td>
<td>1.26 ~ 1.38</td>
<td>UV/Polyester-elastomer(Black)</td>
<td></td>
</tr>
<tr>
<td>SM15-PS-H90D</td>
<td>1.55</td>
<td>10.5</td>
<td>0.5</td>
<td>3.0 ~ 5.0</td>
<td></td>
<td>1.30 ~ 1.44</td>
<td>UV/Polyester-elastomer(Black)</td>
<td></td>
</tr>
</tbody>
</table>
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

SRSM15-PX-U40D-H
Polarization crosstalk & Bending loss vs Bending diameter

- Polarization crosstalk
- Bending loss

Bending diameter [mm]

Polarization crosstalk [dB/10turns]

Bending loss [dB/10turns]
## Specifications of SRSM15 type

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

BISM15-PX-U25D-H
Polarization crosstalk and Bending loss vs Bending diameter

-50
-45
-40
-35
-30
-25
-20
0
10
20
30
40
50
60
70

Polarization crosstalk[dB/10turns]
Bending diameter [mm]
Bending loss[dB/10turns]

- Polarization crosstalk
- Bending loss
## Specification of BISM type

Wavelength : 1550 nm

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>BISM15</strong></td>
</tr>
<tr>
<td>MFD</td>
<td>µm</td>
<td>9.0 +/- 0.4</td>
</tr>
<tr>
<td>Attenuation</td>
<td>dB/km</td>
<td>≤ 3.0</td>
</tr>
<tr>
<td>Bending loss</td>
<td>dB</td>
<td>≤ 1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bending diameter = 15 mm,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 turns</td>
</tr>
<tr>
<td>Cutoff wavelength</td>
<td>nm</td>
<td>≤ 1440</td>
</tr>
<tr>
<td>Beat length</td>
<td>mm</td>
<td>≤ 3.0</td>
</tr>
<tr>
<td>Bending Polarization cross-talk</td>
<td>dB</td>
<td>≤ -30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bending diameter = 15 mm,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 turns</td>
</tr>
<tr>
<td>Coating</td>
<td></td>
<td><strong>250 µm</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 µm polyester-elastomer</td>
</tr>
<tr>
<td><img src="https://www.fujikura.co.jp/Products/LaserFiber/OSA/Spec_500.jpg" alt="" /></td>
<td></td>
<td>500 µm, 900 µm polyester-elastomer</td>
</tr>
<tr>
<td>Proof level</td>
<td>%</td>
<td>≥ 2</td>
</tr>
</tbody>
</table>
**NEW** Thermally-diffused expanded core fiber

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

**HA15-PS-U25D(TEC)**

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

Typical Spectral Attenuation of SM48-P

Typical Spectral Attenuation of SM63-P
## Specifications for PANDA fibers for visible wavelength

<table>
<thead>
<tr>
<th></th>
<th>$\lambda_o$</th>
<th>MFD</th>
<th>Att.</th>
<th>Beat length</th>
<th>Cross- talk</th>
<th>$\lambda_c$</th>
<th>Coating material</th>
<th>Coating diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\mu m$</td>
<td>+/-0.5 $\mu m$</td>
<td>Max. dB/km</td>
<td>Max. mm</td>
<td>Max. dB/100m</td>
<td>$\mu m$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM63-PS-H90D</td>
<td>0.63</td>
<td>4.5</td>
<td>12</td>
<td>2.0</td>
<td>-30</td>
<td>0.52 ~ 0.62</td>
<td>UV/UV/Polyester elastomer(Black)</td>
<td>900 +/- 100</td>
</tr>
<tr>
<td>SM63-PS-U40D</td>
<td>0.63</td>
<td>4.5</td>
<td>12</td>
<td>2.0</td>
<td>-30</td>
<td>0.52 ~ 0.62</td>
<td>UV/UV</td>
<td>400 +/- 15</td>
</tr>
<tr>
<td>SM63-PS-U25D</td>
<td>0.53</td>
<td>4.2</td>
<td>15</td>
<td>2.0</td>
<td>-30</td>
<td>0.45 ~ 0.53</td>
<td>UV/UV/Polyester elastomer(Black)</td>
<td>245 +/- 15</td>
</tr>
<tr>
<td>SM53-PS-H90D</td>
<td>0.53</td>
<td>4.2</td>
<td>15</td>
<td>2.0</td>
<td>-30</td>
<td>0.45 ~ 0.53</td>
<td>UV/UV/Polyester elastomer(Black)</td>
<td>900 +/- 100</td>
</tr>
<tr>
<td>SM53-PS-U40D</td>
<td>0.53</td>
<td>4.2</td>
<td>15</td>
<td>2.0</td>
<td>-30</td>
<td>0.45 ~ 0.53</td>
<td>UV/UV</td>
<td>400 +/- 15</td>
</tr>
</tbody>
</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.

Cross section

Core (Ge-doped SiO$_2$)

Cladding (SiO$_2$)

Inner cladding (F-doped SiO$_2$)

Outer cladding (SiO$_2$)

Refractive index profile

A Standard type

B

A Pure silica core type

B
## Specifications for pure silica core type (UV)

<table>
<thead>
<tr>
<th></th>
<th>$\lambda_0$</th>
<th>MFD</th>
<th>Att.</th>
<th>Beat length</th>
<th>Cross-talk</th>
<th>$\lambda_c$</th>
<th>Coating material</th>
<th>Coating diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC48-PS-H90D</td>
<td>0.48</td>
<td>4.0</td>
<td>30</td>
<td>2.0</td>
<td>0.40 ~ 0.47</td>
<td>UV/UV/Polyester elastomer(Black)</td>
<td>900 ± 100</td>
<td></td>
</tr>
<tr>
<td>SC48-PS-U40D</td>
<td>0.48 ± 0.5</td>
<td>3.5</td>
<td>50</td>
<td>1.7</td>
<td>0.33 ~ 0.40</td>
<td>UV/UV/Polyester elastomer(Black)</td>
<td>400 ± 15</td>
<td></td>
</tr>
<tr>
<td>SC48-PS-U25D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UV/UV</td>
<td>245 ± 15</td>
<td></td>
</tr>
<tr>
<td>SC40-PS-H90D</td>
<td>0.41</td>
<td>3.5</td>
<td>50</td>
<td>1.7</td>
<td>0.33 ~ 0.40</td>
<td>UV/UV/Polyester elastomer(Black)</td>
<td>900 ± 100</td>
<td></td>
</tr>
<tr>
<td>SC40-PS-U40D</td>
<td>0.41 ± 0.5</td>
<td>3.5</td>
<td>50</td>
<td>1.7</td>
<td>0.33 ~ 0.40</td>
<td>UV/UV</td>
<td>245 ± 15</td>
<td></td>
</tr>
<tr>
<td>SC40-PS-U25D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UV/UV</td>
<td>245 ± 15</td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th></th>
<th>$\lambda_o$</th>
<th>MFD</th>
<th>Att.</th>
<th>Beat length</th>
<th>Cross-talk</th>
<th>$\lambda_c$</th>
<th>Coating material</th>
<th>Coating diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC40-PX-H90D-H (RGB)</td>
<td>0.405 ~ 0.64</td>
<td>3.8 ± 1.0 at 630 nm</td>
<td>≤ 50</td>
<td>≤ 2.0 at 630 nm</td>
<td>≤ -30 Bending diameter 60 mm</td>
<td>≤ 0.40</td>
<td>UV/UV/UV/ Polyester elastomer (Black)</td>
<td>900 ± 100</td>
</tr>
<tr>
<td>SC40-PX-U40D-H (RGB)</td>
<td>0.405 ~ 0.64</td>
<td>2.3 ± 0.6 at 405 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UV/UV</td>
<td>400 ± 15</td>
</tr>
<tr>
<td>SC40-PX-U25D-H (RGB)</td>
<td>0.405 ~ 0.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UV/UV</td>
<td>245 ± 15</td>
</tr>
</tbody>
</table>
80 \text{ \textmu m} \text{ 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
   \[ B = 4C \frac{f}{\pi \cdot E} \frac{1}{r} \]
   \[ B = 2C \left( 1 - \cos \theta \cdot \sin \left( \frac{\theta}{2} \right) \right) \frac{f}{\pi \cdot E} \frac{1}{r} \]
   C: Photo Elastic constant
   E: Young’s modulus
   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.

4. Splice loss optimizing

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

Requirement: Splice loss < 0.1dB

Higher aperture is redesigned to achieve the bending property

MFD differences with other fibers are designed to be small.
Attenuation and Crosstalk in 4m length bending

980nm RC-PANDA

1550nm RC-PANDA

Bending Diameter [mm]

Crosstalk [dB/4m]

Bending Loss [dB/m]

Y: Fast axis

X: Slow axis

Diamond: Fast axis

Diamond: Slow axis
## Specifications for 80µm cladding

<table>
<thead>
<tr>
<th></th>
<th>$\lambda_o$</th>
<th>MFD</th>
<th>Att.</th>
<th>Beat length</th>
<th>Crosstalk</th>
<th>$\lambda_c$</th>
<th>Coating material</th>
<th>Coating diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>µm</td>
<td>µm</td>
<td>dB/km</td>
<td>mm</td>
<td>dB/100m</td>
<td>µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCHA85-PS-U17C</td>
<td>0.85</td>
<td>3.5</td>
<td>≤ 3.5</td>
<td>≤ 2.0</td>
<td>≤ -30</td>
<td>0.65</td>
<td>-</td>
<td>µm</td>
</tr>
<tr>
<td>RCSM98-PS-U17C</td>
<td>0.98</td>
<td>6.0</td>
<td>≤ 2.5</td>
<td>1.4</td>
<td>~ 2.6</td>
<td>0.87</td>
<td>UV/UV</td>
<td>165 +/- 15</td>
</tr>
<tr>
<td>RCSM13-PS-U17C</td>
<td>1.3</td>
<td>8.2</td>
<td>≤ 2.0</td>
<td>2.0</td>
<td>~ 3.5</td>
<td>1.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCSM14-PS-U17C</td>
<td>1.40</td>
<td>9.0</td>
<td>≤ 2.0</td>
<td>2.3</td>
<td>~ 4.2</td>
<td>1.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCSM15-PS-U17C</td>
<td>1.55</td>
<td>9.5</td>
<td>≤ 2.0</td>
<td>2.5</td>
<td>~ 4.5</td>
<td>1.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCHA15-PS-U17C</td>
<td>1.55</td>
<td>6.0</td>
<td>≤ 3.0</td>
<td>≤ 3.7</td>
<td>≤ -30</td>
<td>1.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Items</th>
<th>Unit</th>
<th>Wave length</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFD</td>
<td>mm</td>
<td>1550 nm</td>
<td>4.0 +/- 0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1310 nm</td>
<td>3.4 +/- 0.4</td>
</tr>
<tr>
<td>Attenuation</td>
<td>dB/km</td>
<td>1550 nm</td>
<td>≤ 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1310 nm</td>
<td>≤ 30</td>
</tr>
<tr>
<td>Cutoff wavelength</td>
<td>nm</td>
<td>-</td>
<td>≤ 1280</td>
</tr>
<tr>
<td>Beat length</td>
<td>mm</td>
<td>1550 nm</td>
<td>2.5 - 4.5</td>
</tr>
<tr>
<td>Polarization cross-talk</td>
<td>dB/100m</td>
<td>1550 nm</td>
<td>≤ -25</td>
</tr>
<tr>
<td>Coating (UV / UV)</td>
<td>mm</td>
<td>-</td>
<td>165 +/- 15</td>
</tr>
<tr>
<td>Coating color</td>
<td>–</td>
<td>-</td>
<td>Blue</td>
</tr>
</tbody>
</table>
RC13-15-PX-U17EBL-M4 bending properties

Polarization crosstalk [dB / 10 turns]

Bend radius [mm]

Bending loss [dB / 10 turns]

-10
-20
-30
-40
-50
0
10
20
30
40
50

0.00
0.02
0.04
0.06
0.08
0.10

0 5 10 15

Polarization crosstalk
Bending loss
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

<table>
<thead>
<tr>
<th></th>
<th>$\lambda_0$</th>
<th>MFD</th>
<th>Att.</th>
<th>Beat length</th>
<th>Crosstalk</th>
<th>$\lambda_c$</th>
<th>Coating material</th>
<th>Coating diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\mu$m</td>
<td>$\mu$m</td>
<td>dB/km</td>
<td>mm</td>
<td>dB/5m</td>
<td>$\mu$m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM98-PS-Y15</td>
<td>0.98</td>
<td>6.6</td>
<td>$\pm$0.5</td>
<td>$\leq 2.5$</td>
<td>1.5 $\sim$ 2.7</td>
<td>$\leq -25$</td>
<td>0.87 $\sim$ 0.95</td>
<td>Polyimide</td>
</tr>
<tr>
<td>SRSM15-PS-Y15</td>
<td>1.55</td>
<td>9.4 $\pm/\mp$1.0</td>
<td>$\leq 2.0$</td>
<td>$\leq 4.0$</td>
<td>$\leq 1.44$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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.