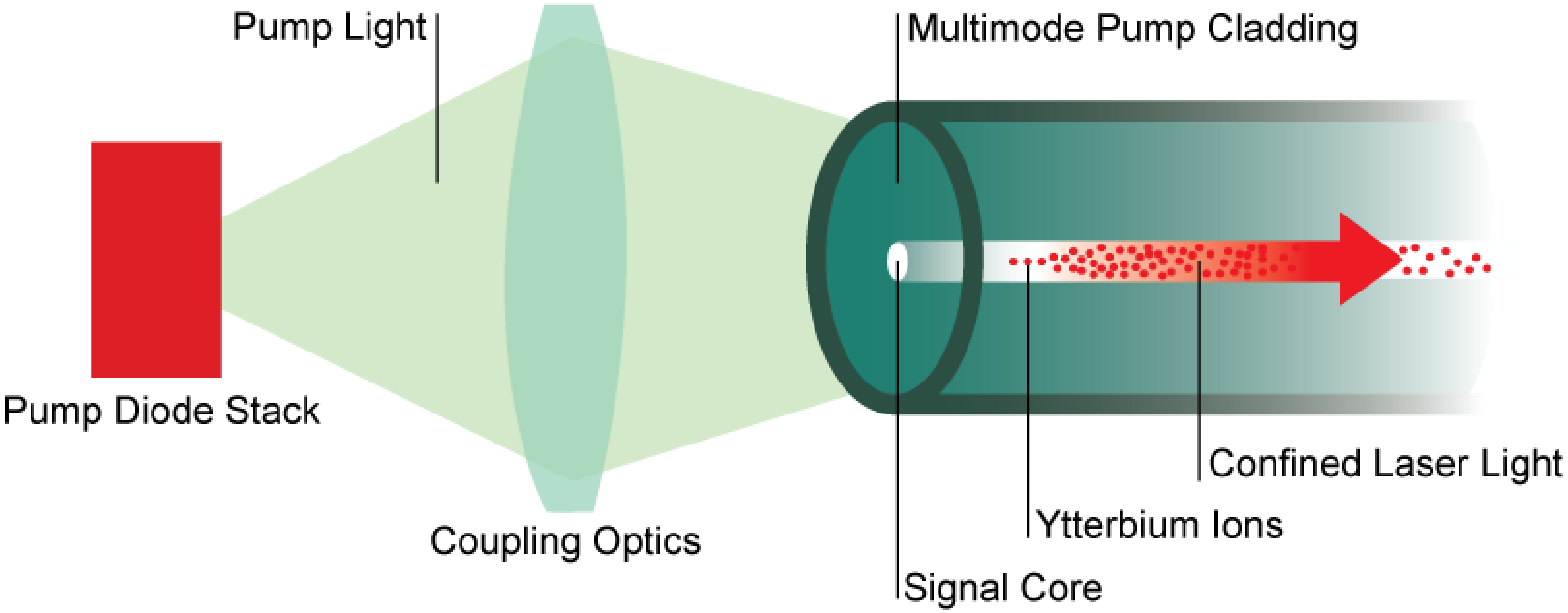
AFL

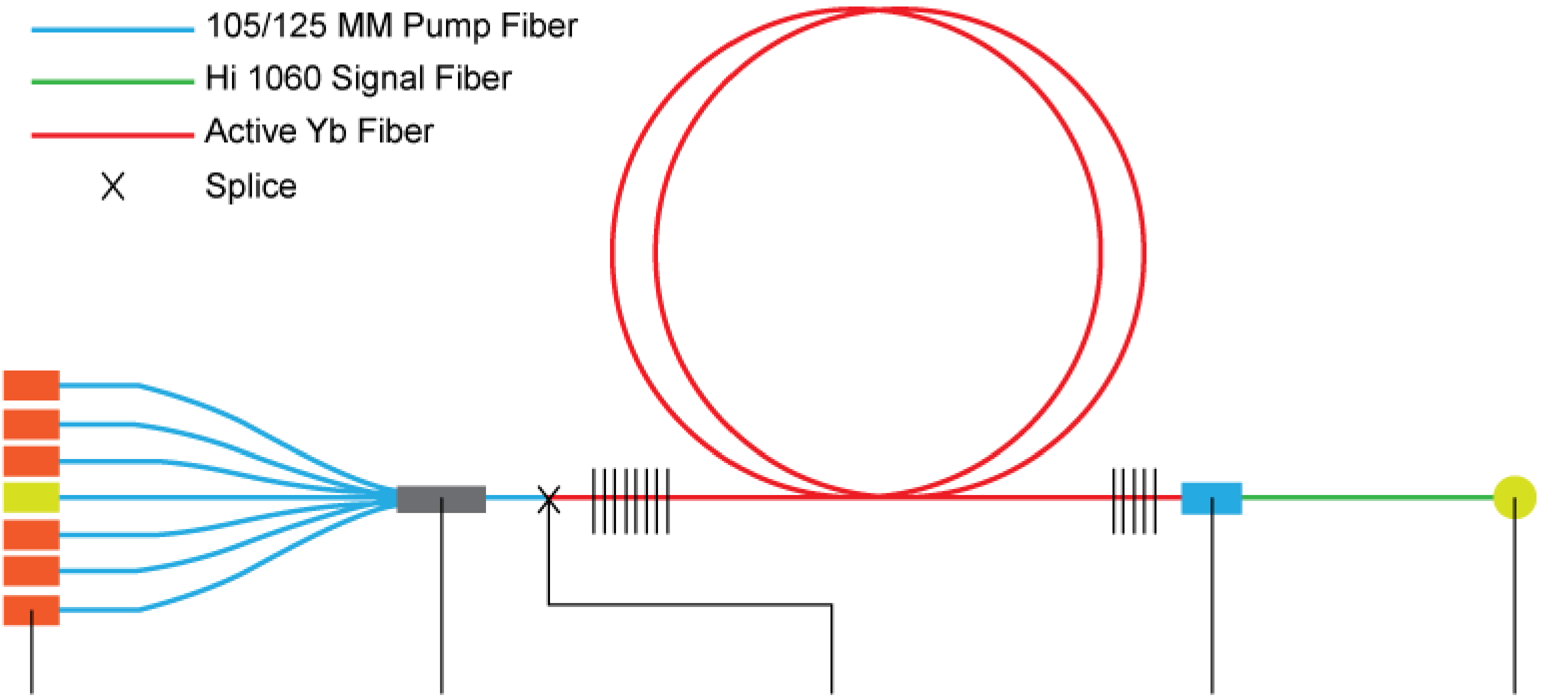
Applications for the LZM-100

Fiber Laser Construction



- Multiple pump diodes are used to inject light into the cladding area of a LDF fiber
- The highly doped LDF core absorbs the pump energy as it crosses through the core
- The core emits power at the output wavelength via stimulated emission

Typical Fiber Laser Components



🟦 105/125 MM Pump Fiber
🟩 Hi 1060 Signal Fiber
🟥 Active Yb Fiber
X Splice

Axicon taper
for Laser chip coupling
by LZM-100

Low loss pump
combiners 7:1, 19:1,
37:1, 61:1, etc.
by LZM-100

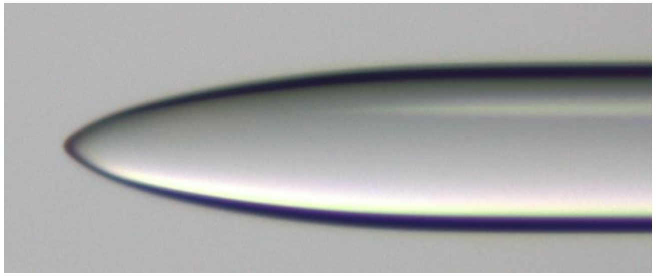
Critical Splices of
Double Clad Fiber
with PM alignment
by LZM-100

Mode field
adapters (MFA)
by LZM-100

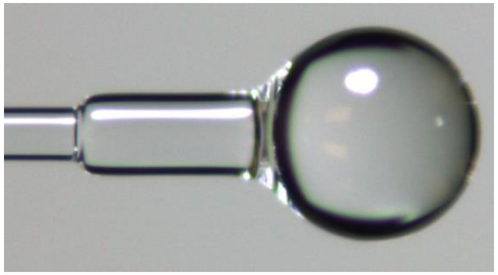
End-cap or
ball-lens
by LZM-100

Typical Requirement for Components

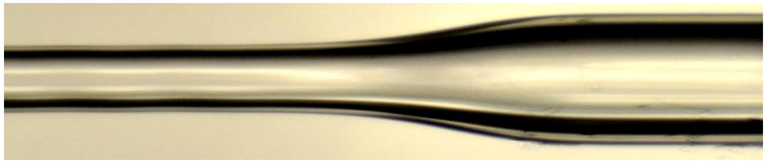
- Typical requirements for the components
  - Lowest possible loss, no contamination, no power leakage
  - Low manufacturing cost
  - Consistent performance



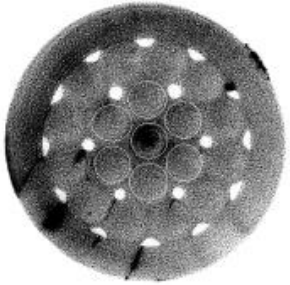
Tapered Axicon with LZM-100



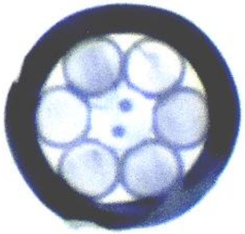
80 µm fiber with 320 µm coreless ball-lens using LZM-100



Tapered capillary made with the LZM-100



Cross section of 19 into 1 combiner with LZM-100



Cross section of 6+1 PM combiner with LZM-100

Tapered Fused Bundle

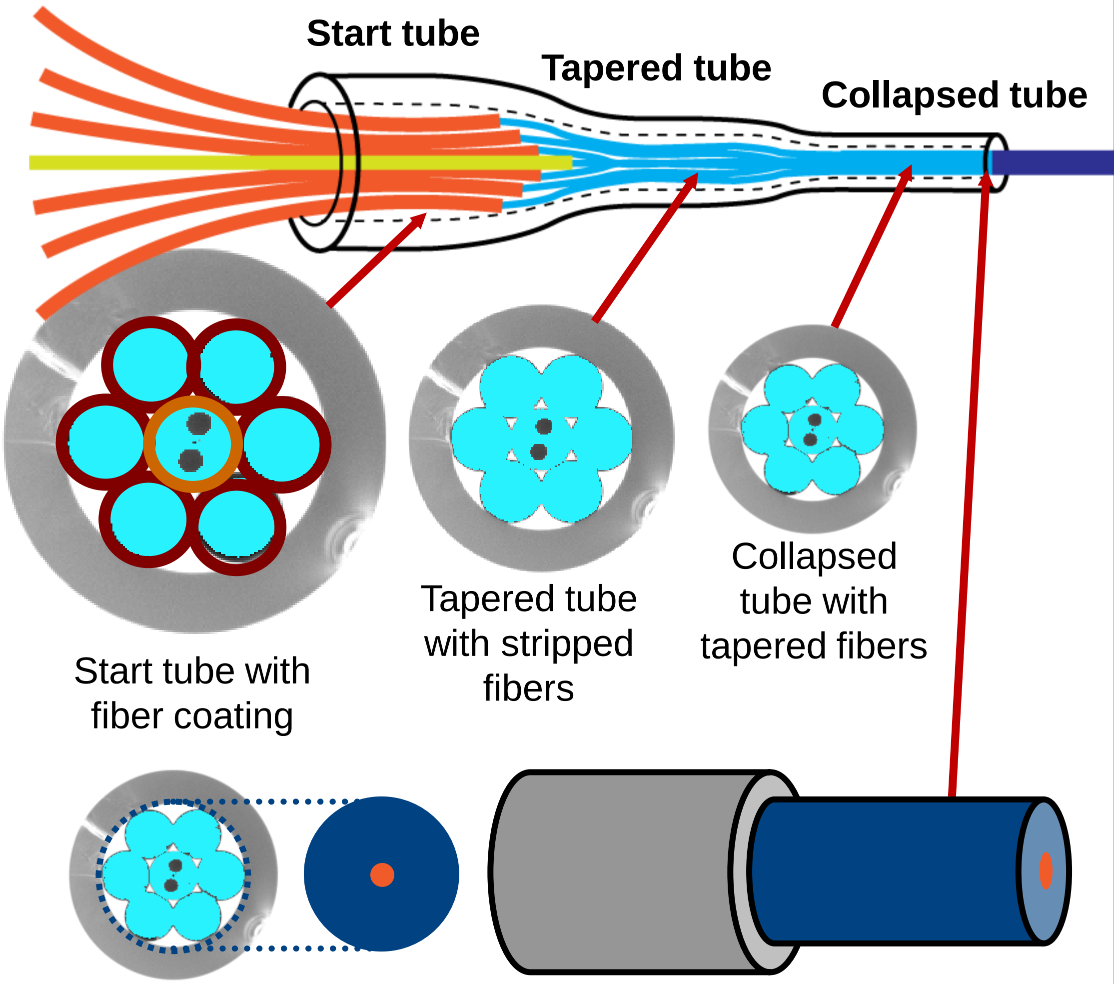
Tube inner diameter ~ (2L+1.2)x$OD_{coating}$

Outer Diameter (OD) ~ ID x 1.4

L: Layer of fiber; N: Number of fibers

- L=1, N=7, assuming OD_{fiber} = 250 µm
  - ID ~ 800 µm, OD ~ 1120 µm,
  - Taper length 10 – 20 mm
- L=2, N=19,
  - ID ~ 1300 µm, OD ~ 1820 µm
  - Taper length 16 – 25 mm
- L=3, N=37,
  - ID ~ 1800 µm, OD ~ 2520 µm
  - Taper length 22 – 30 mm
- L=5, N=91,
  - ID ~ 2800 µm, OD ~ 392 0 µm
  - Taper length 35 – 45 mm
- Where $N = 6\times\sum_{i=1}^{L} i + 1$

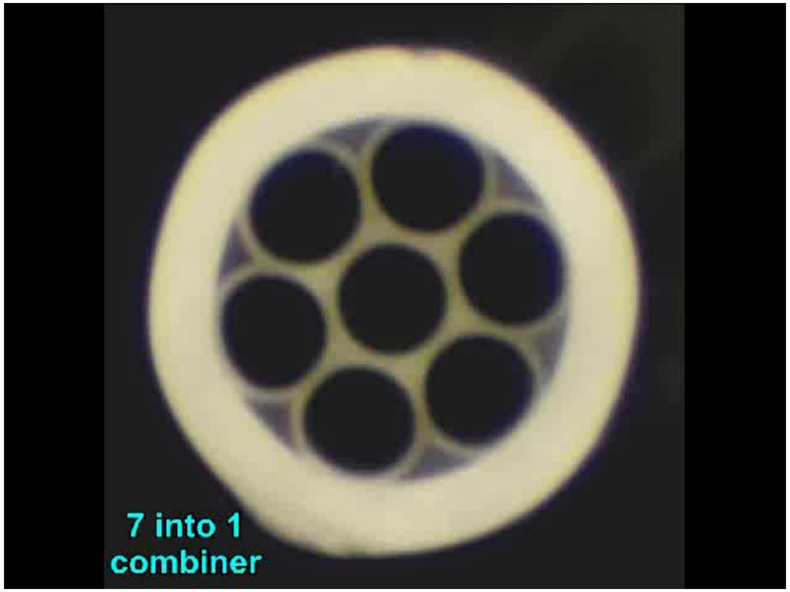
A typical tapered fused bundle

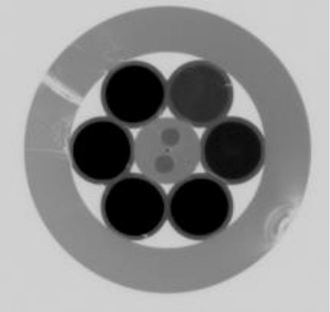


ID of the collapsed tube should match or slightly smaller than the fiber glass OD for DCF to achieve lower splice loss

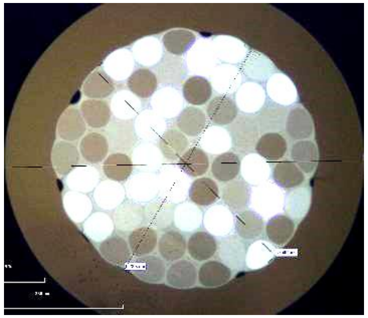
Combiners with Large Fiber Counts

- Combiner is a key component for fiber laser system, spatial division multiplex for telecomm, etc.
- Many different combiner types have been processed with LZM-100
  - 5 + 1 into 1
  - 6 + 1 into 1
  - 7 into 1
  - 19 into 1
  - 37 into 1
  - 61 into 1
- Basic rules for the combiner design
  - Geometric rule: bundle OD ≤ Output fiber OD for carrying pump power
  - Brightness conservation: NAin x TR ≤ NAout





6+1 into 1 combiner

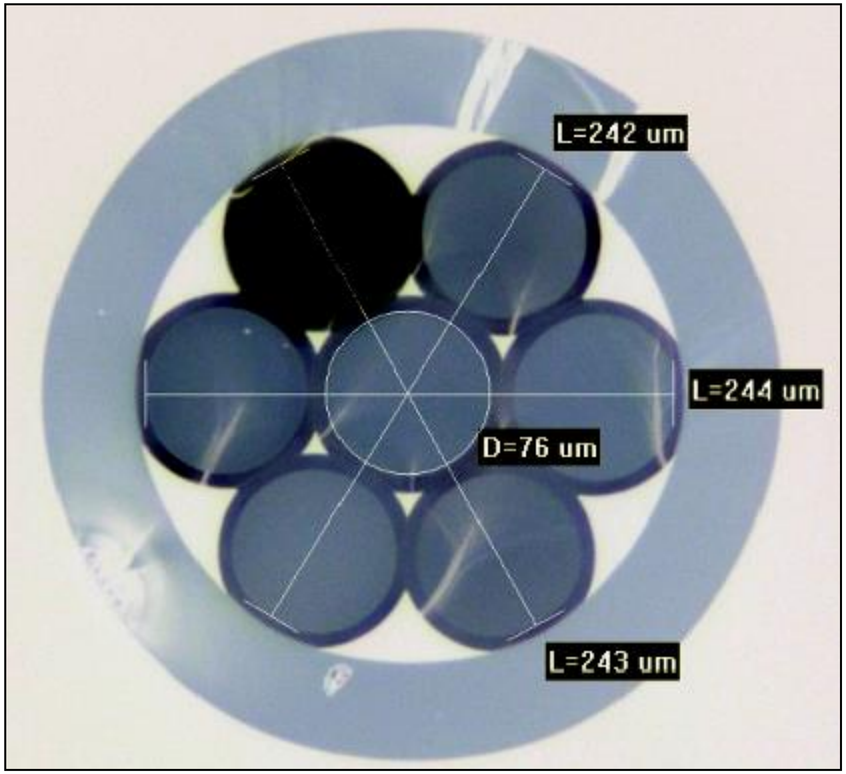


61 into 1 combiner

Loss Example of 980 nm 7 into 1 Combiner

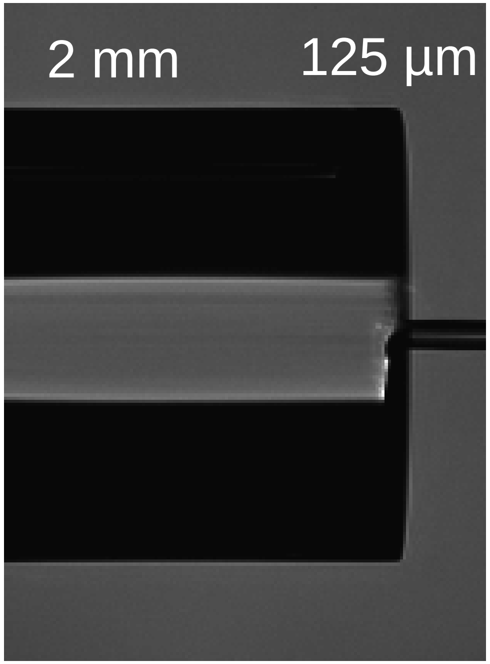
- 7 into 1 combiner made with LZM-100
- Combiner taper ratio TR = 1.67
- Meet the rule of TR x $NA_{input} < NA_{output}$ (1.67 x 0.22 = 0.37 < 0.46)
- Max loss = 0.2% (0.01 dB) within measurement noise after packaging

Combiner:	R10 TC7	
Input:	105/125 0.22 NA	
Output:	25/250 0.46 NA	

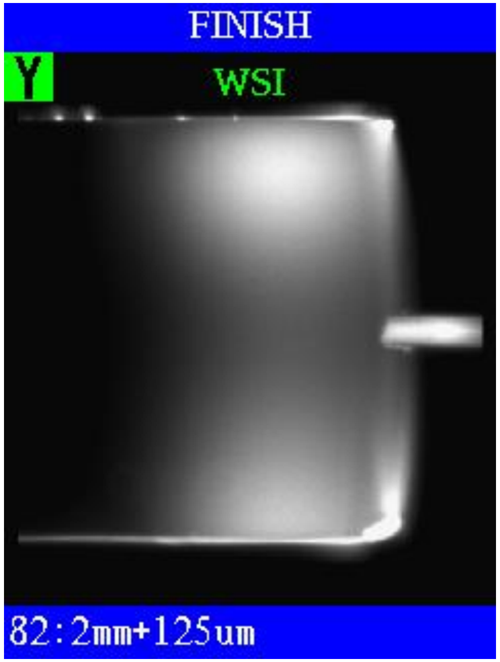


End-cap Splicing

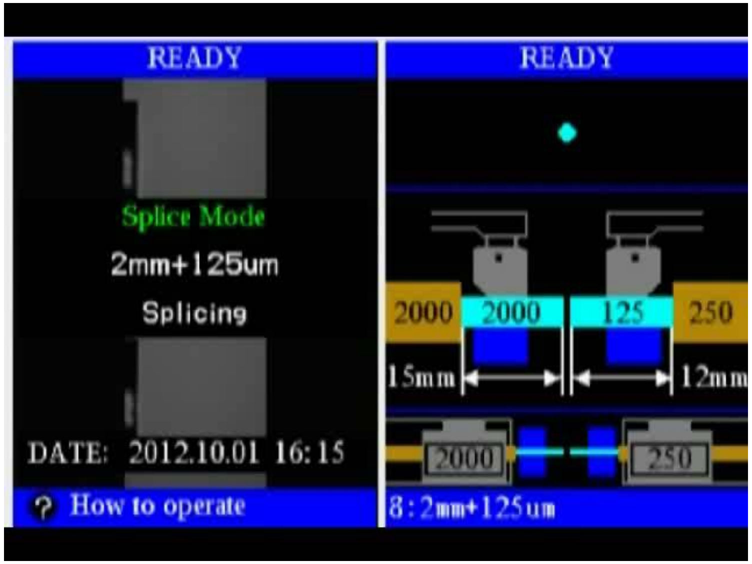
- End-cap splicing with LZM-100 with offsite measurement
- Very high beam quality was achieved with measured M2 value1.08 to 1.1.
- The splice loss was too low to be measured due to equipment noise
- No temperature change at splices during high power test in kW range



Cold splice image



Warm splice image

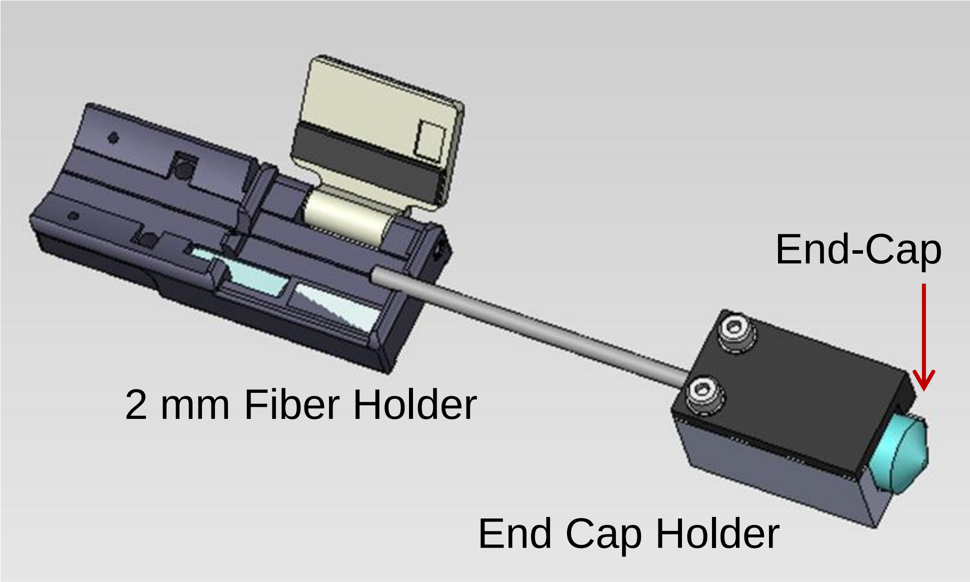


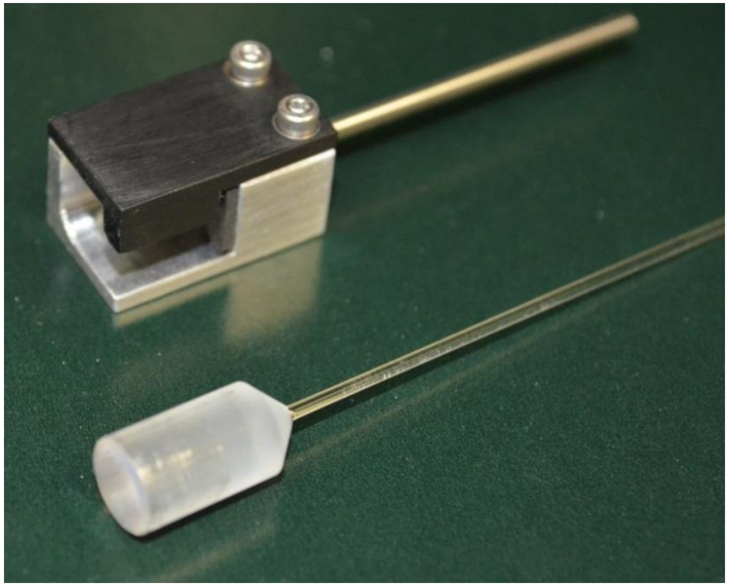
Splice Mode
2mm+125um
Splicing

DATE: 2012.10.01 16:15

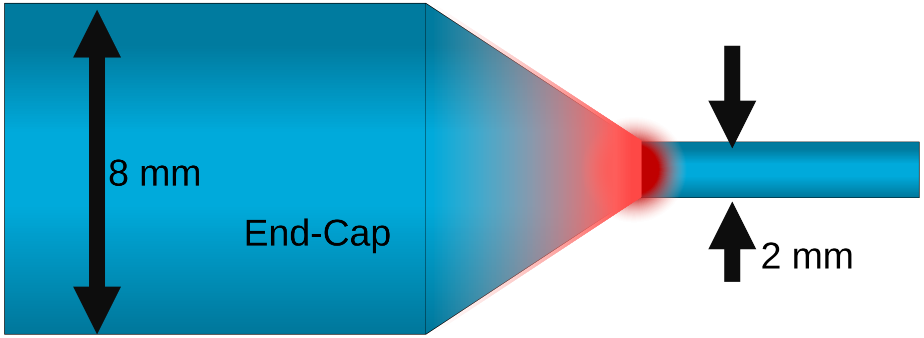
Video

End-cap Splicing with LZM-100

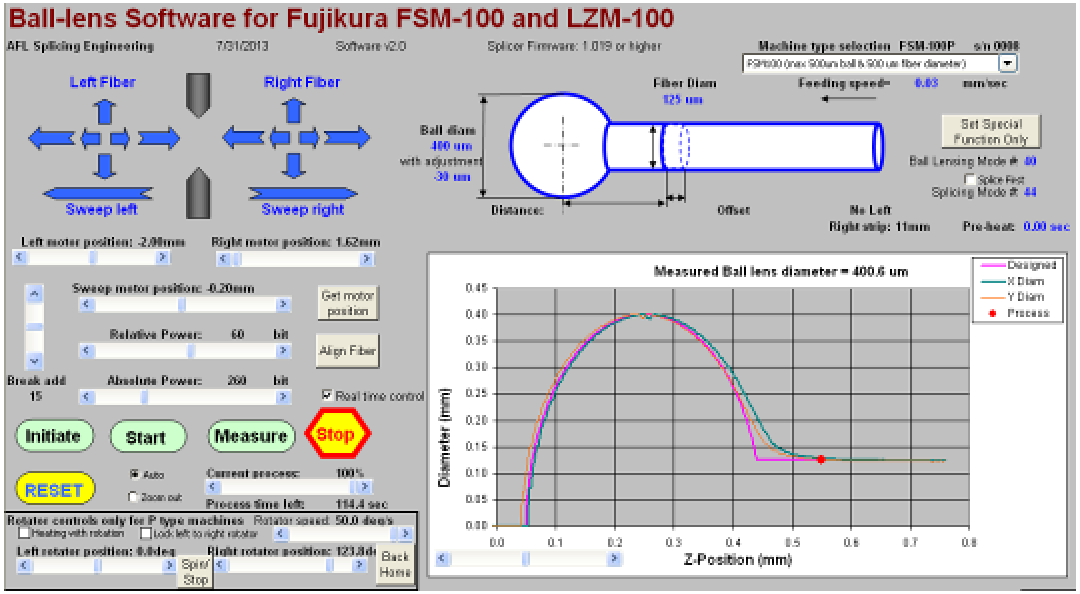




Sample of end-cap holder and spliced end-cap of 8 mm



Different Lens Made with LZM-100



Ball-lens Software for Fujikura FSM-100 and LZM-100

AFL Splicing Engineering 7/31/2013 Software v2.0 Splicer Firmware: 1.019 or higher

Machine type selection FSM-100P s/n 0008

FSM100 (max 900um ball & 900 um fiber diameter)

Fiber Diam 125 um

Feeding speed= 0.03 mm/sec

Ball diam 400 um with adjustment -30 um

Ball Lensing Mode # 40

☐ Splice First

Splicing Mode # 44

No Left

Right strip: 11mm

Pre-heat: 0.00 sec

Left motor position: -2.00mm

Right motor position: 1.62mm

Sweep motor position: -0.20mm

Relative Power: 60 bit

Absolute Power: 260 bit

Break add 15

☑ Real time control

● Auto

○ Zoom out

Current process: 100%

Process time left: 114.4 sec

Rotator controls only for P type machines Rotator speed: 50.0 deg/s

☐ Heating with rotation ☐ Lock left to right rotator

Left rotator position: 0.0deg

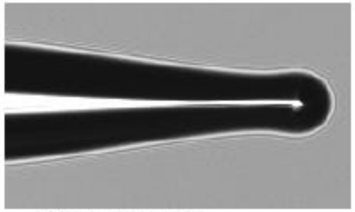
Right rotator position: 123.8de

Measured Ball lens diameter = 400.6 um

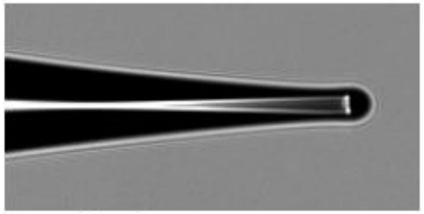
- User friendly software for making ball lens
- Ball size tested up to 2.5 mm diameter
- Largest ball to fiber ratio 1:4.3 (350 µm ball on 80 µm fiber)
- Splicing to coreless fiber and ball-lensing in one run

Different Lens Made with LZM-100

Convex lens

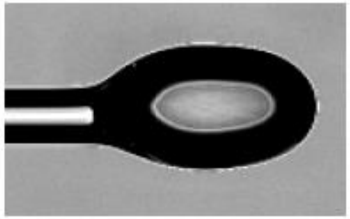


Small ball

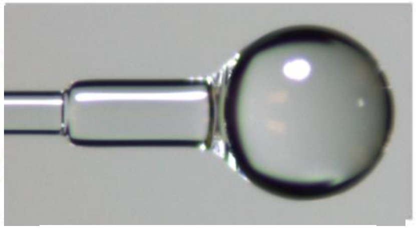


Probe

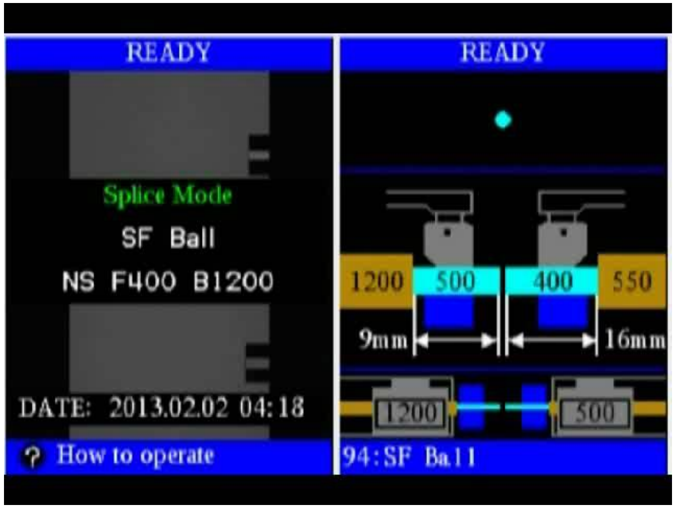
Large ball



Elongated ball



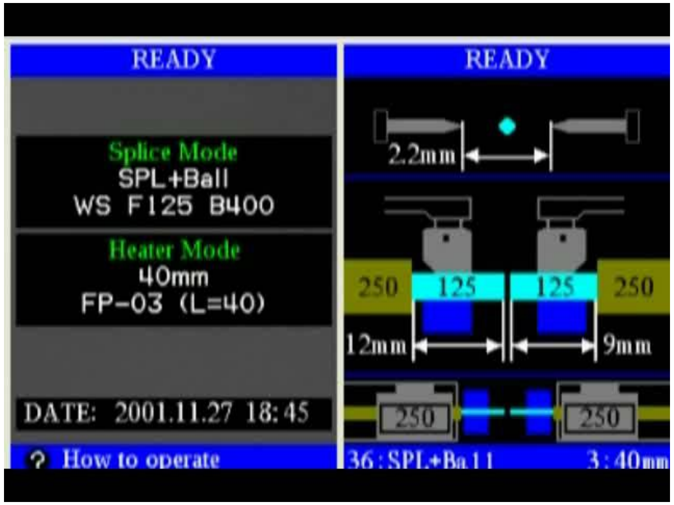
Spliced ball lens



READY
Splice Mode
SF Ball
NS F400 B1200
DATE: 2013.02.02 04:18
How to operate

READY
1200 500 400 550
9mm 16mm
1200 500
94:SF Ball

1200 µm Ball



READY
Splice Mode
SPL+Ball
WS F125 B400
Heater Mode
40mm
FP-03 (L=40)
DATE: 2001.11.27 18:45
How to operate

READY
2.2mm
250 125 125 250
12mm 9mm
250 250
36:SPL+Ball 3:40mm

Video Ball with Splice

Multi-core Fiber Splicing for Telecom SDM

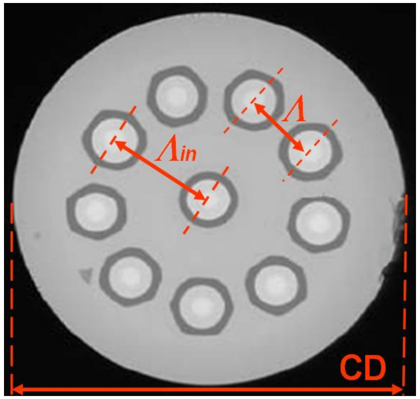
$$\Gamma = C\frac{(d-\Lambda_{in})^2+(\theta\Lambda_{in})^2}{\omega^2}(dB)$$

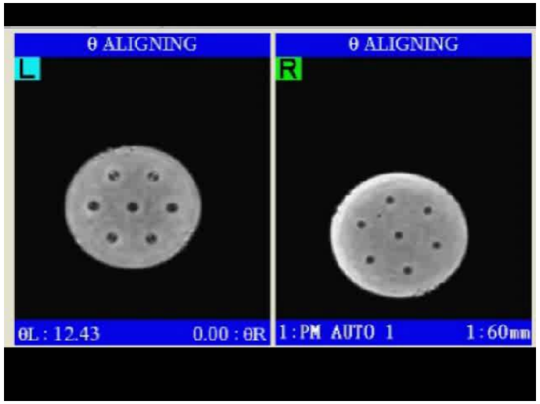
Γ : estimated splice loss
C : constant ($C = 10\mathrm{Log}_{10}e = 4.34$)
ω : mode field radius
d : cladding offset between
MCF and SMF

θ : rotation alignment error
CD: cladding diameter
Λ : center distance between side-core to side core
Λ_{in} : distance between side-core center to fiber center

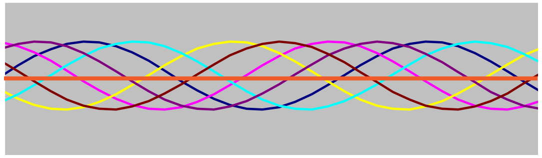
- This equation assumes the fiber geometry is as designed, cladding alignment is perfect ($d = \Lambda_{in}$), MFD matches for MCF and SMF (ω = 5 µm), and Λ_{in} = 60 µm by design

- Thus, 1 deg angle offset will cause 0.19 dB loss, 2 deg ~ 0.76 dB loss





Splicing spun multicore fiber



Spun multicore fiber

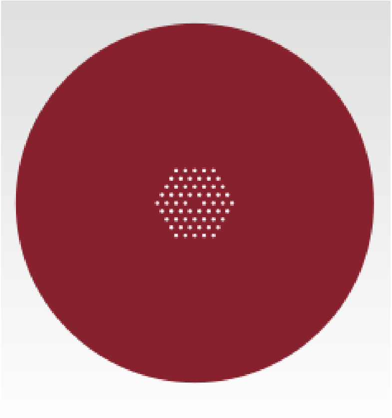
Processing of Low Melting Point Fibers

- SMF28 melts ~ 1800° C
  - Ordinary splicing
- Z-fiber melts ~ 1600° C
  - Splicing with lower power

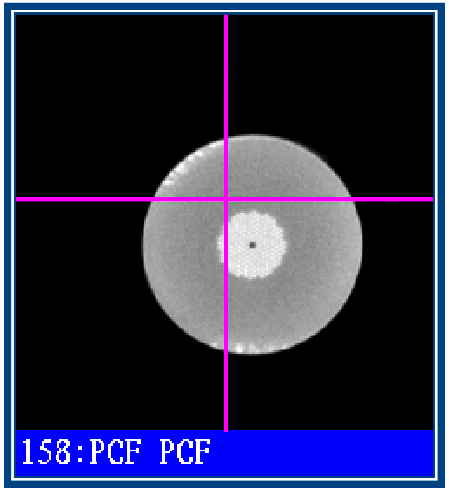
125 µm Zblan fiber splicing

- Chalcogenide fiber melts ~ 200 - 700° C
  - Very hard to splice with ordinary fusion splicers
  - Vaporized if no big offset
- Zblan fiber melts ~ 250° C
  - Impossible to splice with ordinary fusion splicers
  - Vaporized immediately
  - Very hard to cleave and handling

Aligning and Splicing Photonic Crystal Fiber (PCF)

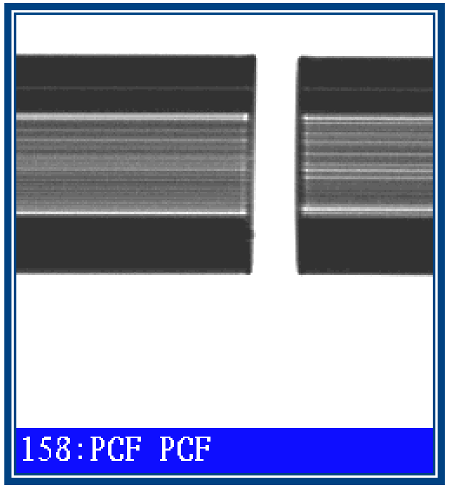


PCF with extremely small effective areas and high nonlinear coefficients for super continuum



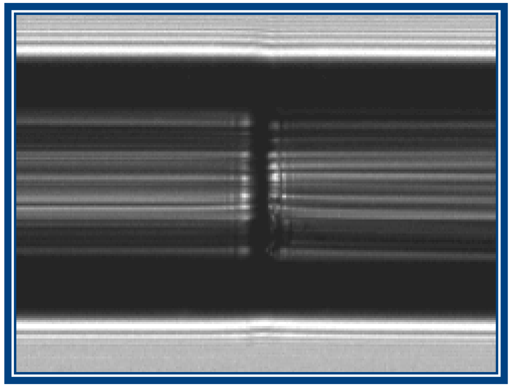
158:PCF PCF

Manual alignment with end-view

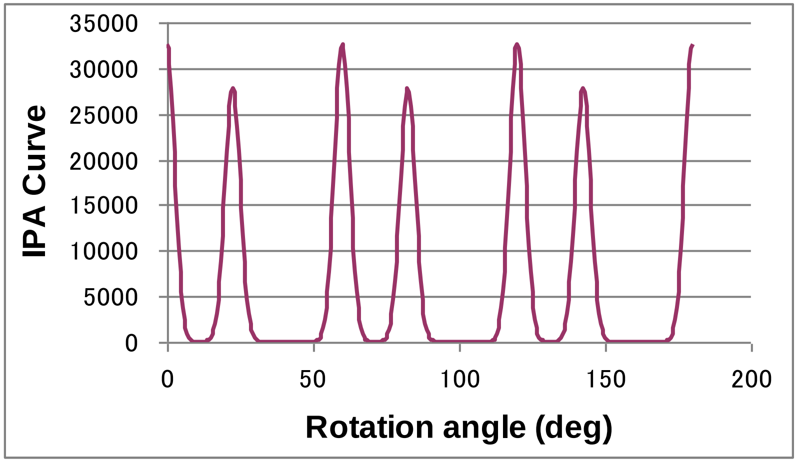


158:PCF PCF

Auto alignment
with side-view IPA method



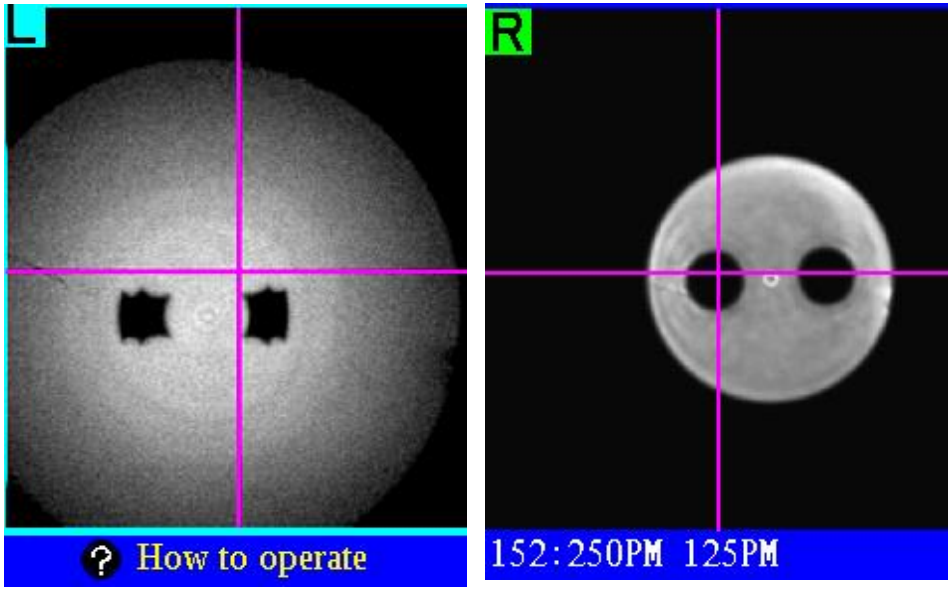
After splicing (no hole collapse)
with LZM-100



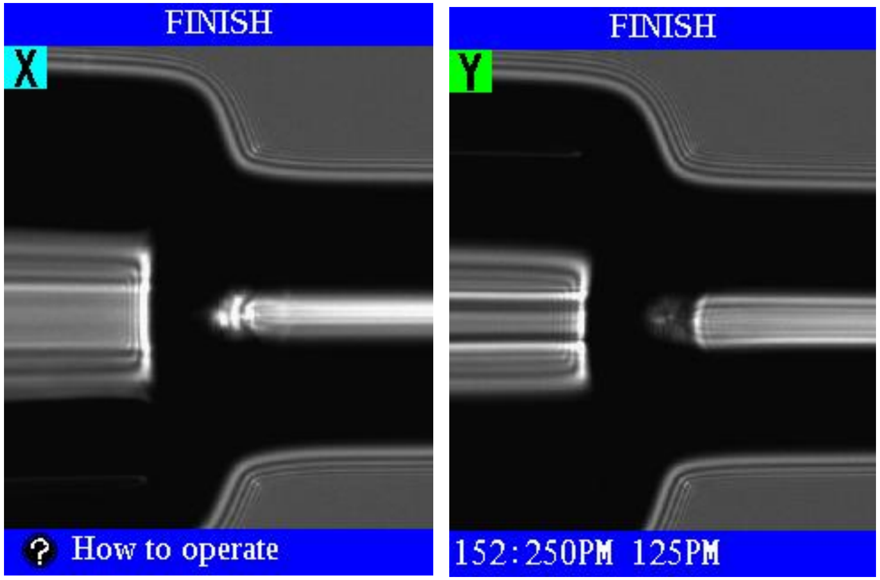
IPA curve for rotation alignment

Photonic Crystal PM Fiber Splicing

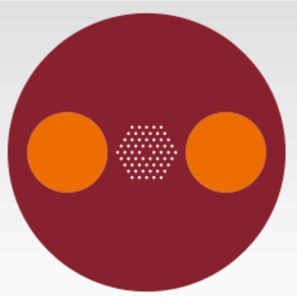
Photonic crystal fiber aligning and splicing with end-view



End-view alignment

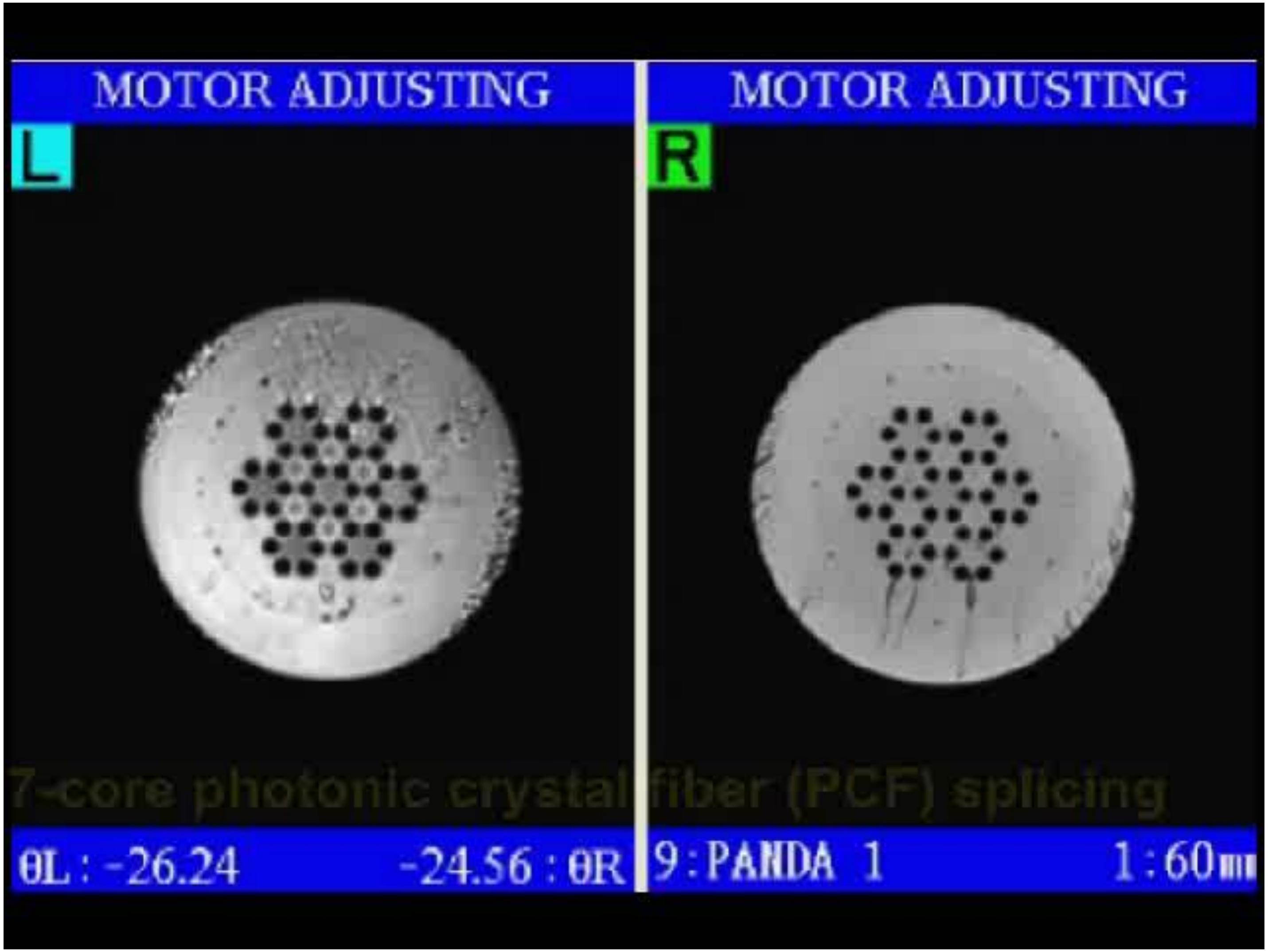


After splicing



- 250 µm large core high power PM photonic crystal fibers spliced to 125 µm Panda fiber
- End-view manual PM alignment or side-view IPA automated PM alignment.
- Feedback core alignment with LZM-100 GPIB port

LZM 7-Core PCF Splice



7-core photonic crystal fiber (PCF) splicing

θL : -26.24 -24.56 : θR

9:PANDA 1 1:60mm

AFL

We connect.™