Large Core Optical Fibers and Their Applications

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Structure of the talk

- Background
- Leakage Channel Fiber Design Issues
- Fabricated Passive LCFs
- Multi-core LCFs
- Active LCFs
- Concludes

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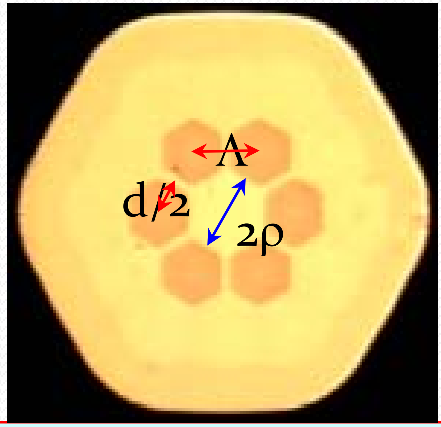
Background

- Peak power of fiber lasers limited by fiber nonlinearity:
  - Self-Phase Modulation (SPM).
  - Stimulated Raman Scattering (SRS).
  - Stimulated Brillouin Scattering (SBS).
- Mitigated by large-core fiber designs.

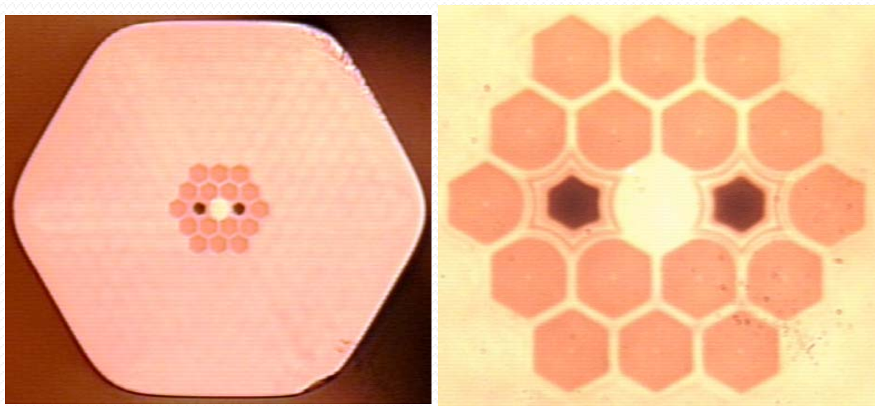
Key Benefits of Leakage Channel Fibers

- Enables accurate differential mode loss control.
- Enables robust single mode operation beyond 50μm core diameter.
- Improved bend loss performance.
- Compatible with cladding pumping.
- Easy implementation of polarization maintaining fiber.
- Capable of all glass design, which significantly improves ease of fabrication and use.

Conventional Fiber with Enclosed Core Boundary



Leaky nature of the LCF design enables implementation of differential mode loss



Replace two features with stress rods for polarization maintaining LCF

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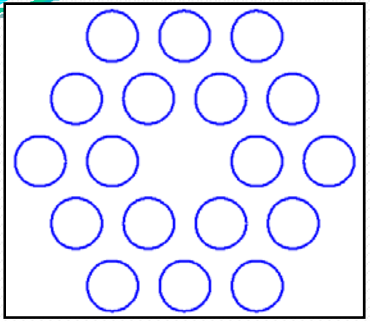
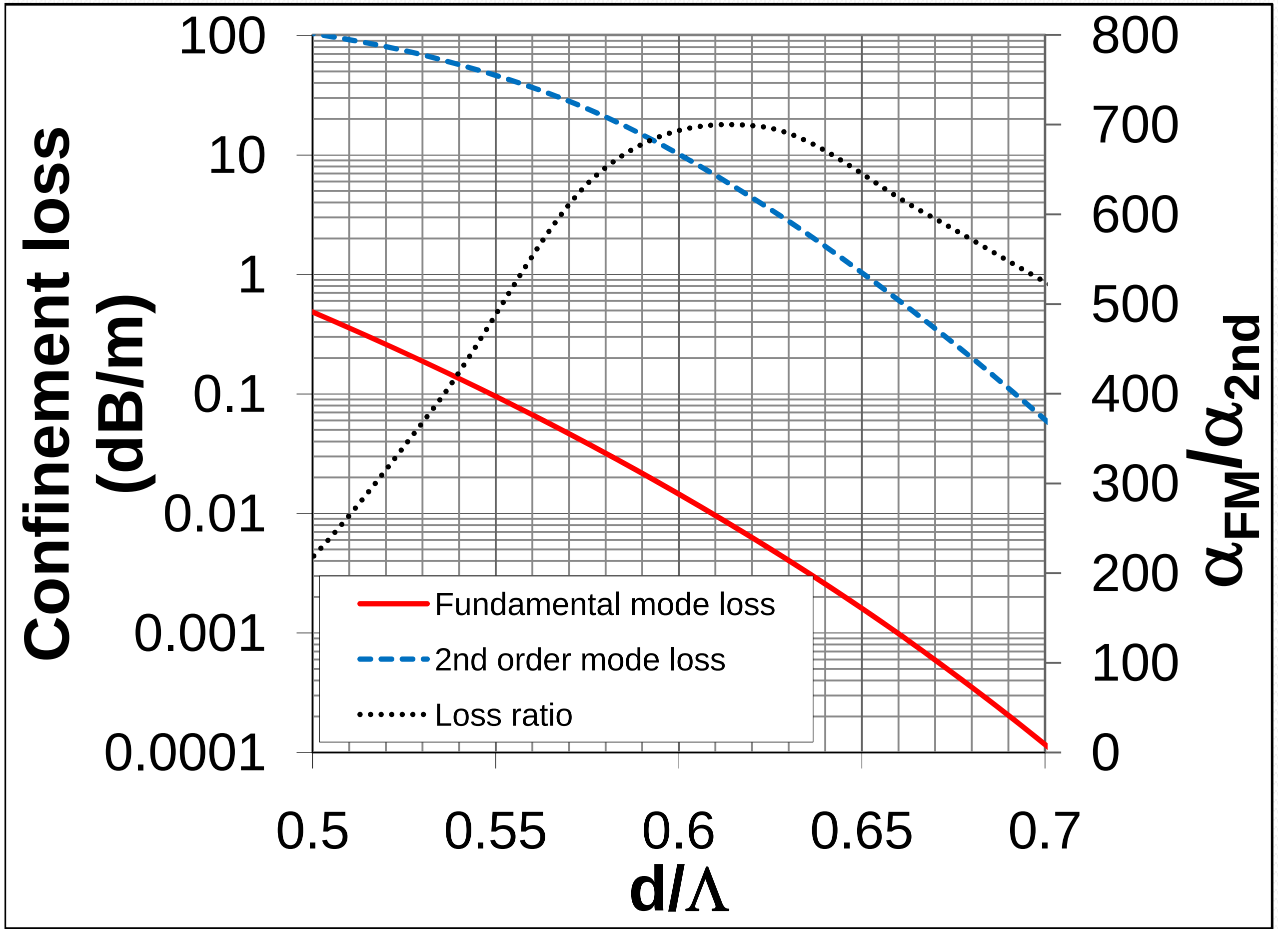
All Glass LCFs with Two Layers of Features

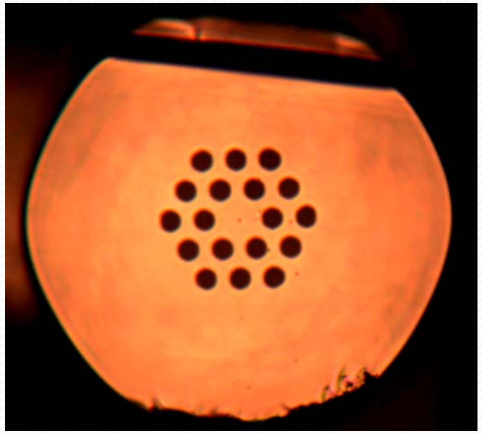


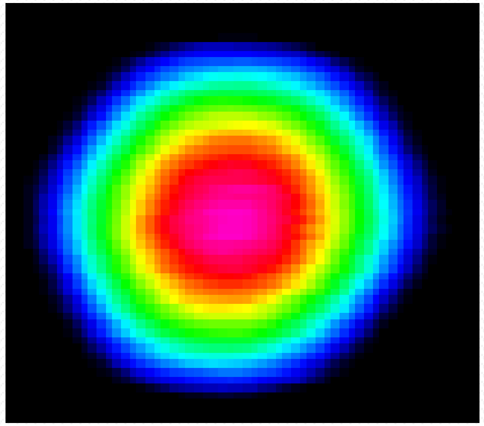
2ρ=50μm, Δn=1.2×10^{-3}



Δn=1.2×10^{-3}

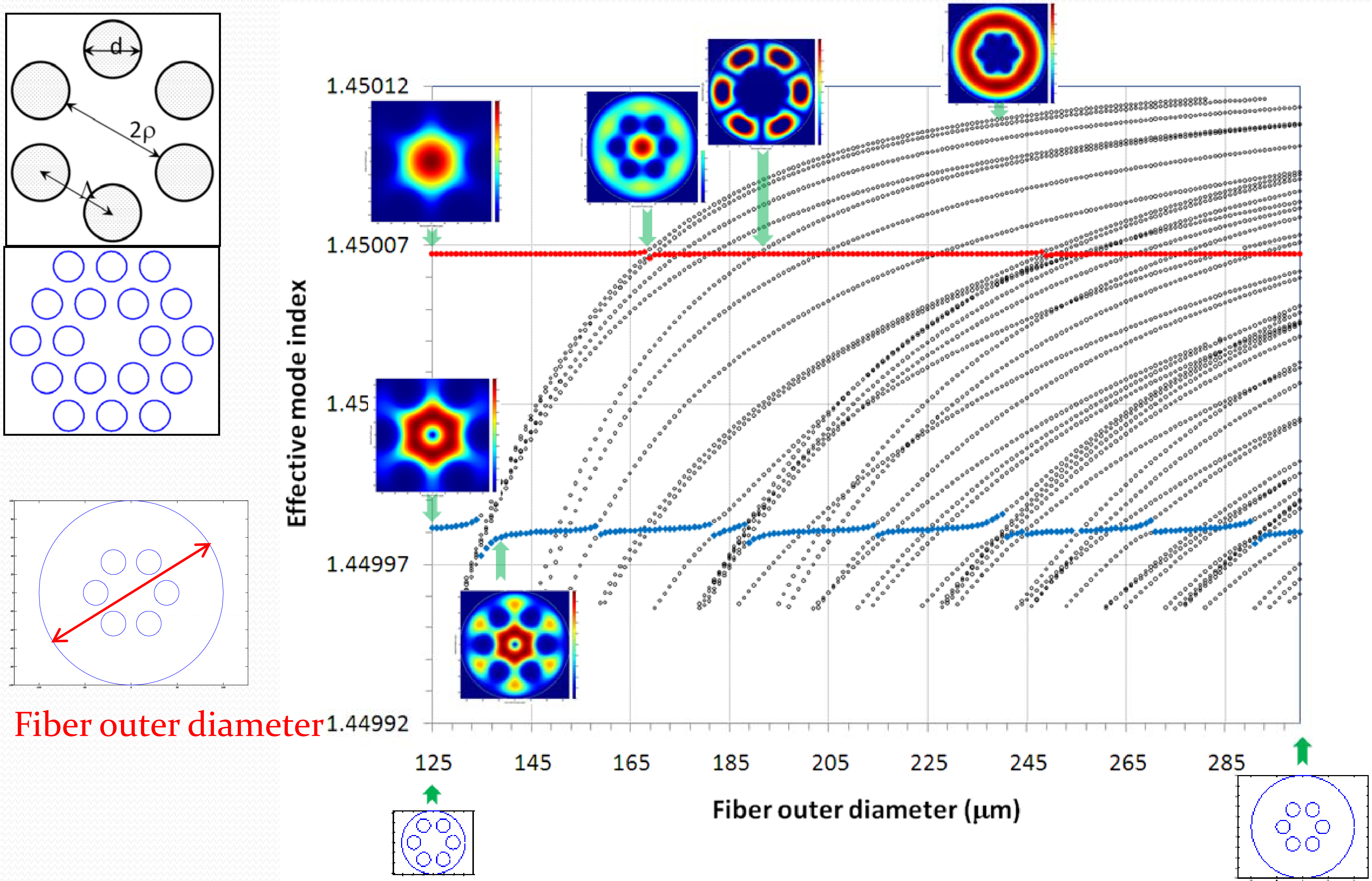
2ρ=45μm, d/Λ=0.6





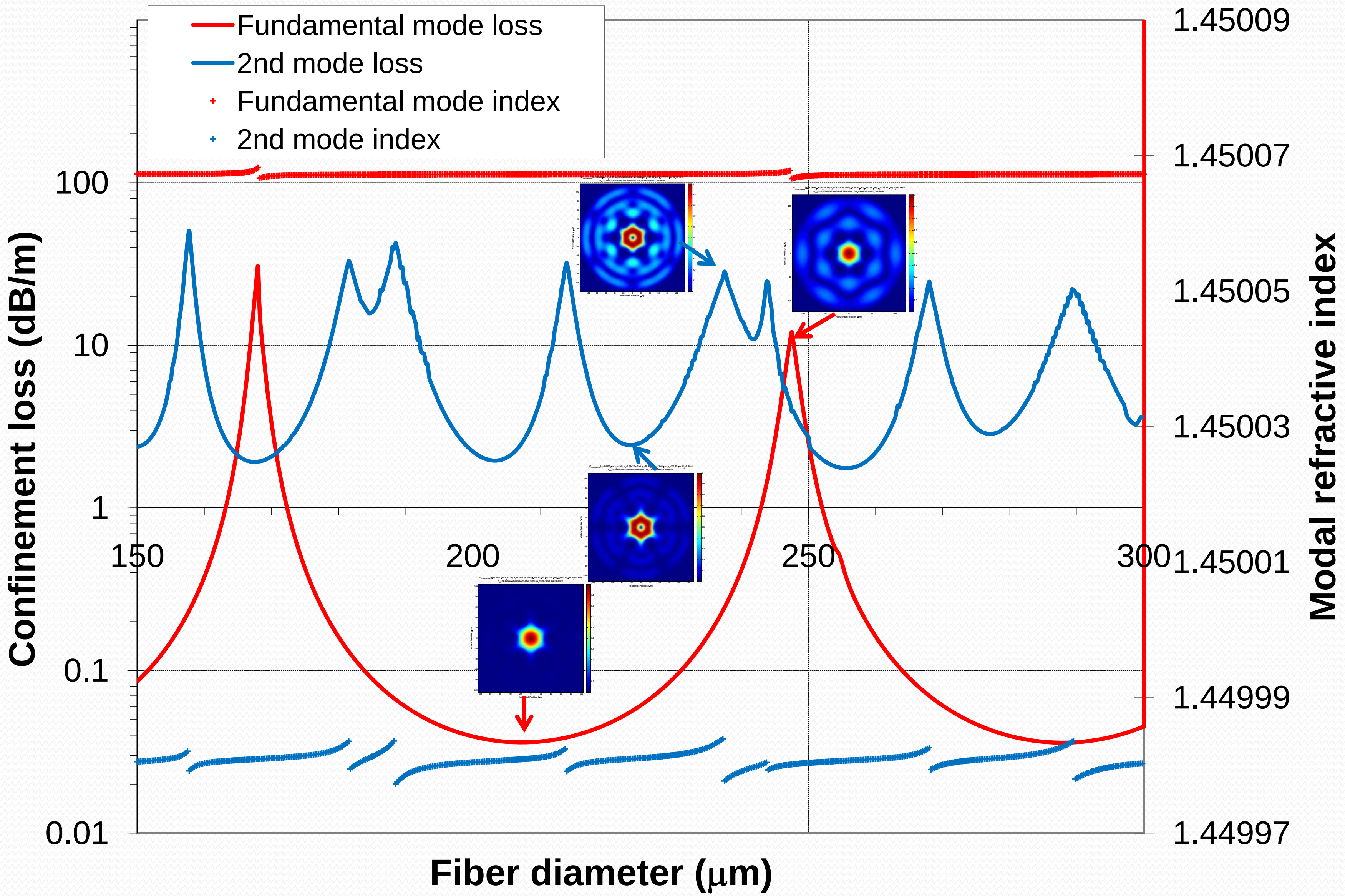
Cladding Resonance:

Effect of fiber outer diameter



Cladding Resonance:

effect of fiber outer diameter



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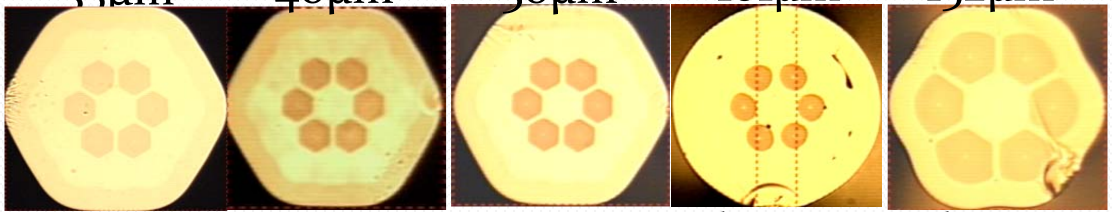
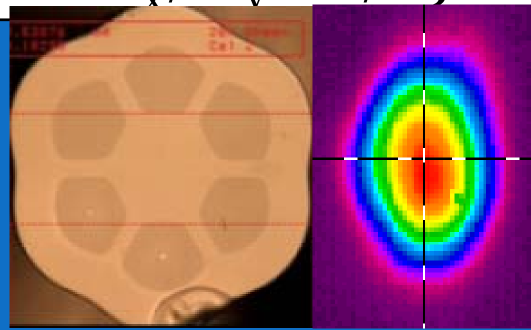
Core Diameter Scaling: passive LCFs

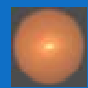
35μm 40μm 50μm 101μm 152μm



d/Λ=0.9 d/Λ=0.9 d/Λ=0.9 d/Λ=0.8 d/Λ=0.9

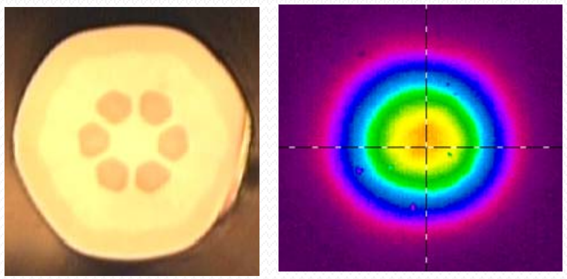
2ρ= 183.3μm, d/Λ=0.8,
M^2_x / M^2_y =1.22/1.23



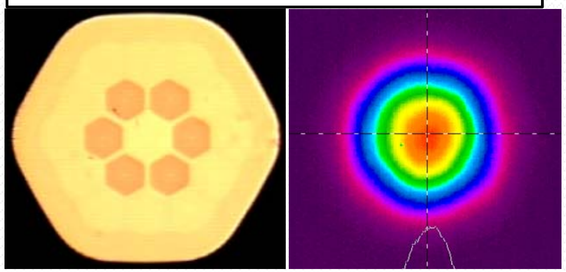


Conventional SMF

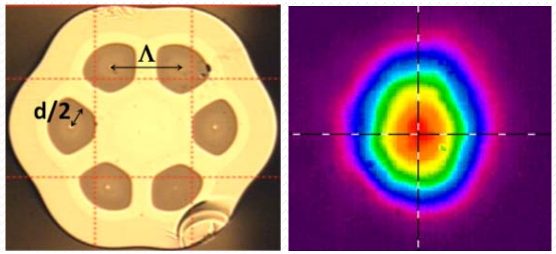
Core diameter = 52.7μm
d/Λ=0.8
Flat to flat OD = 254.2μm
Effective area = 1548μm²
Pump abs= 11dB/m at 976nm
Test length =~3m
M^2_x/ M^2_y =1.17/1.18



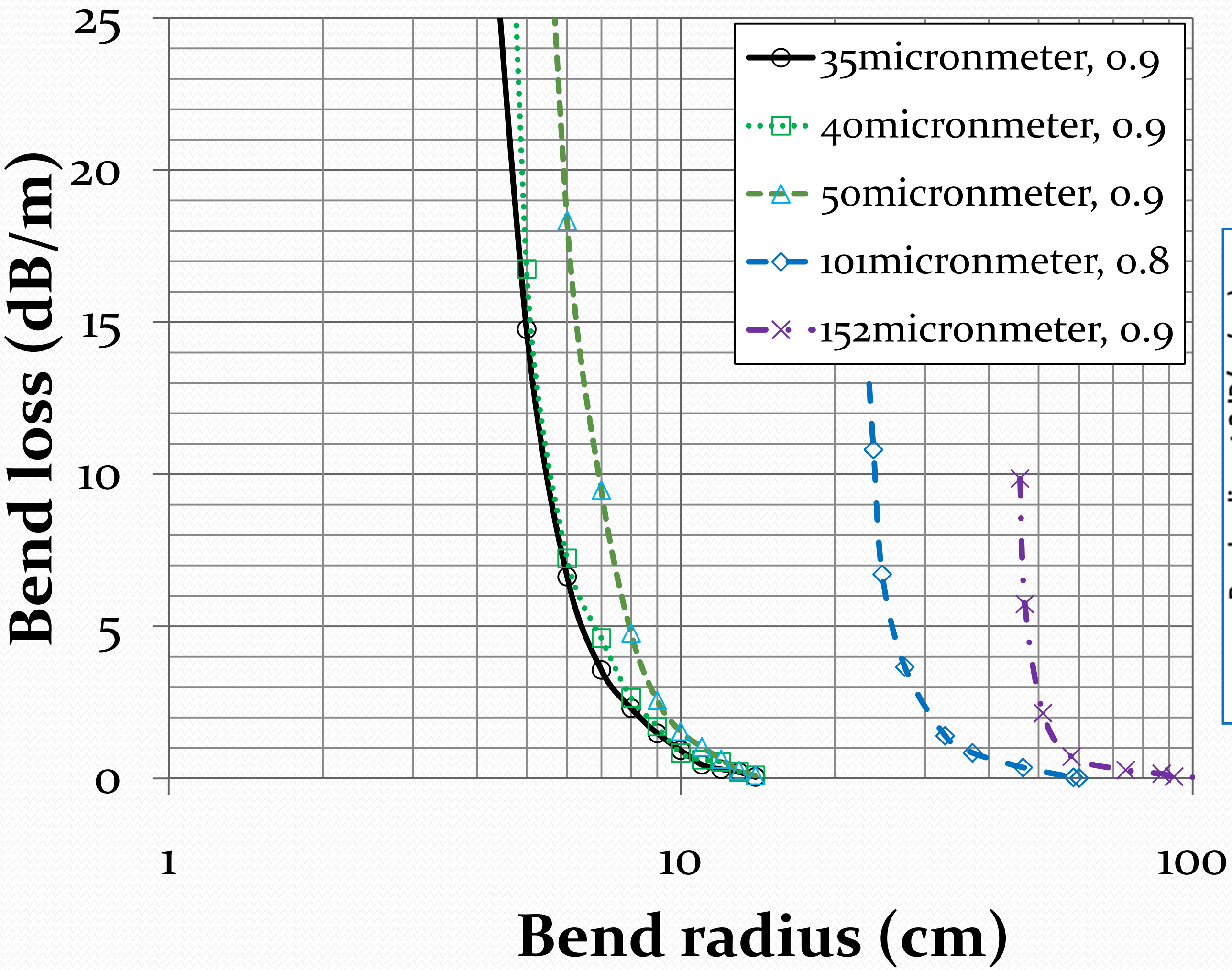
Core diameter = 101μm
d/Λ=0.9
Flat to flat OD = 487.2μm
Effective area = 5117μm²
Passive fiber
Test length = ~6m
M^2_x / M^2_y =1.26/1.29



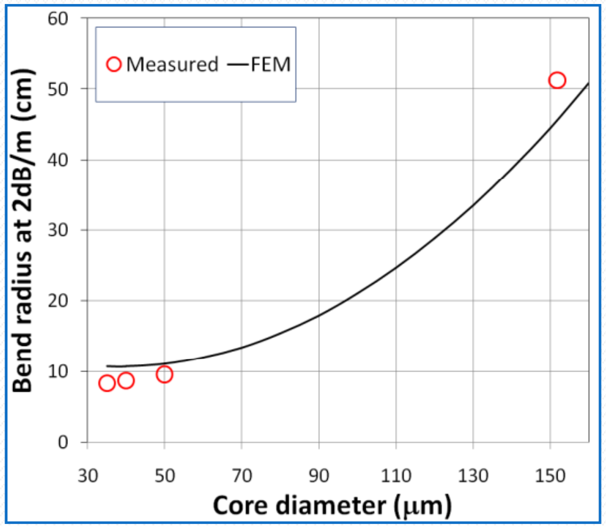
Core diameter = 168.2μm
d/Λ=0.7
Flat to flat OD = 436.4μm
Effective area = 13737μm²
Passive fiber
Test length = ~1m
M^2_x /M^2_y =1.13/1.14



Bend Loss of All Glass LCFs



d/Λ=0.9



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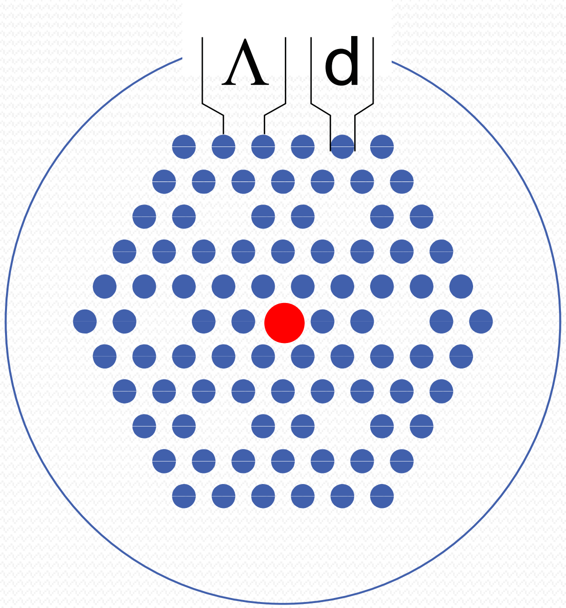
Motivation:
Power Scaling of Fiber Lasers

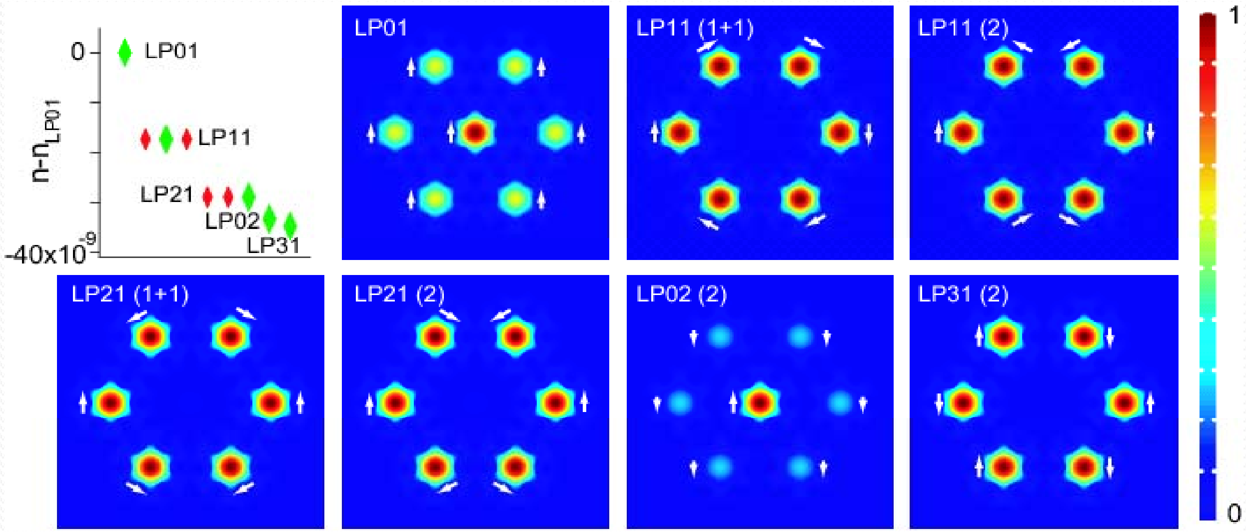
Hard limit for scaling fiber cores:
~5 MW peak power -> self focusing occurs independent of mode size.

-> Coherent or incoherent combining of fiber lasers required

Mode Structure



in the absence of index fluctuations and stress



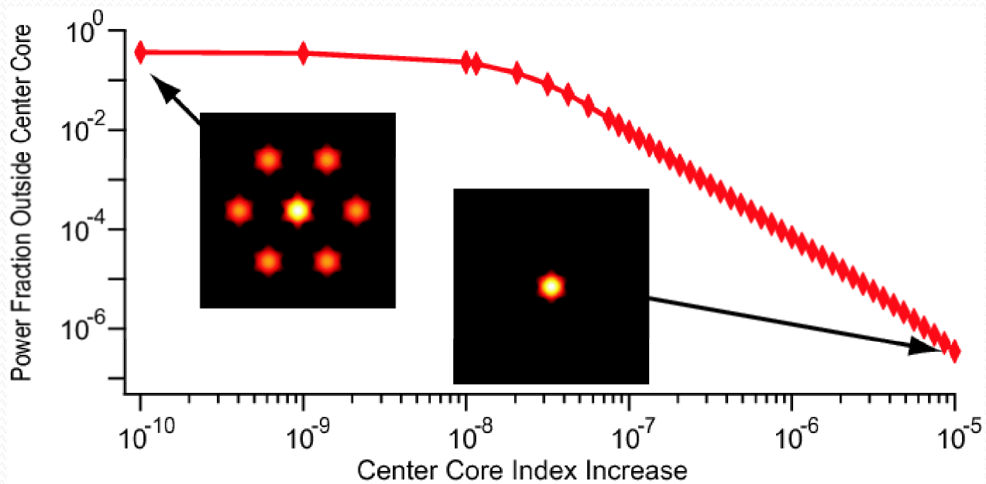
← 0.6 →

weaker guiding of higher order modes

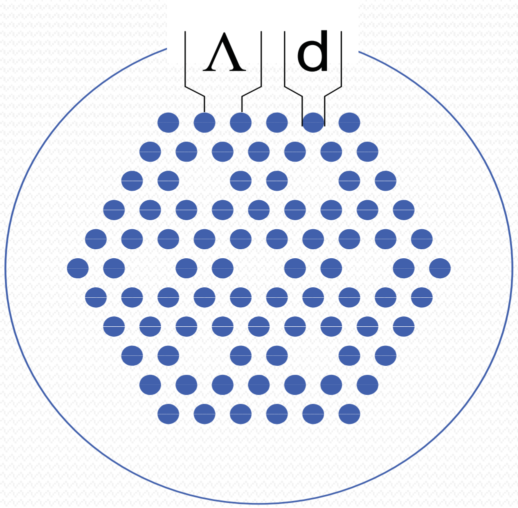
d/Λ

less core-core coupling

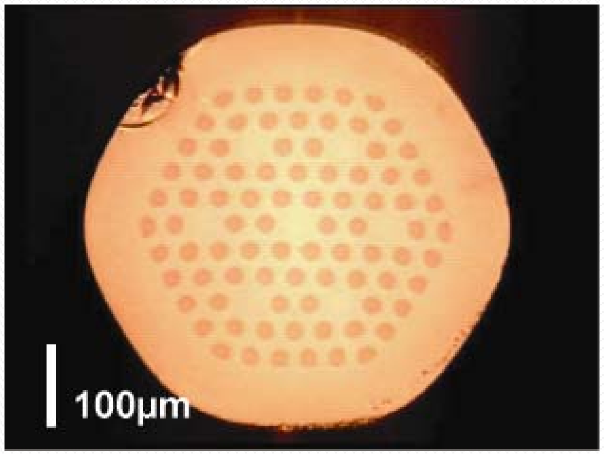
Increase center core index

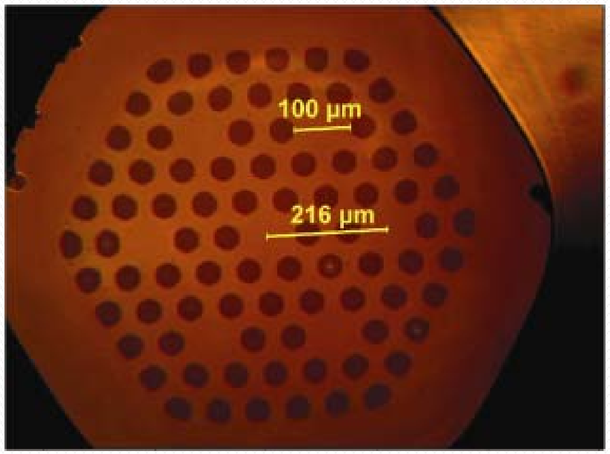


Fiber Design & Fabrication



- seven leakage channel cores
- silica with low index fluoride glass rods.
- refractive index difference $\Delta n = 0.0012$.
- fill-factor of the cores: 19.8 %.



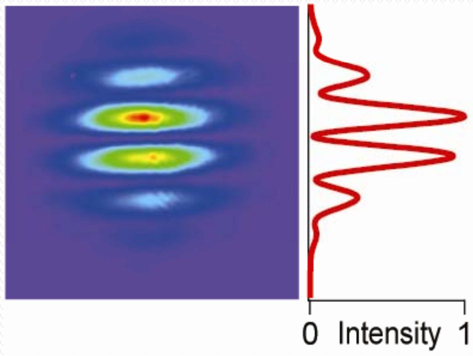


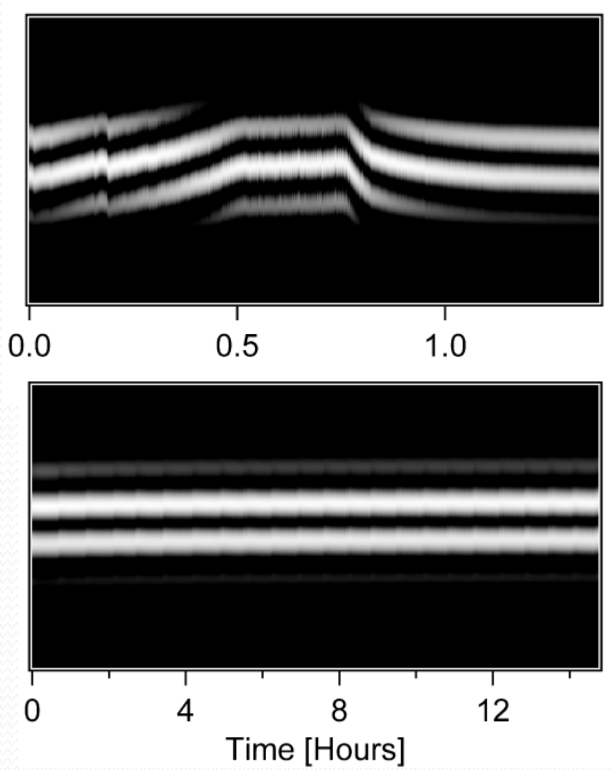
	50 µm core diameter	100 µm core diameter
Effective mode-field area	1300 µm² per core	3700 µm² per core
	9700 µm² combined	26000 µm² combined

Phase stability

Interference pattern of two beams in adjacent cores

→ nearly 100 % fringe modulation depth





heating experiment: 18 cm heated to 300 ºC

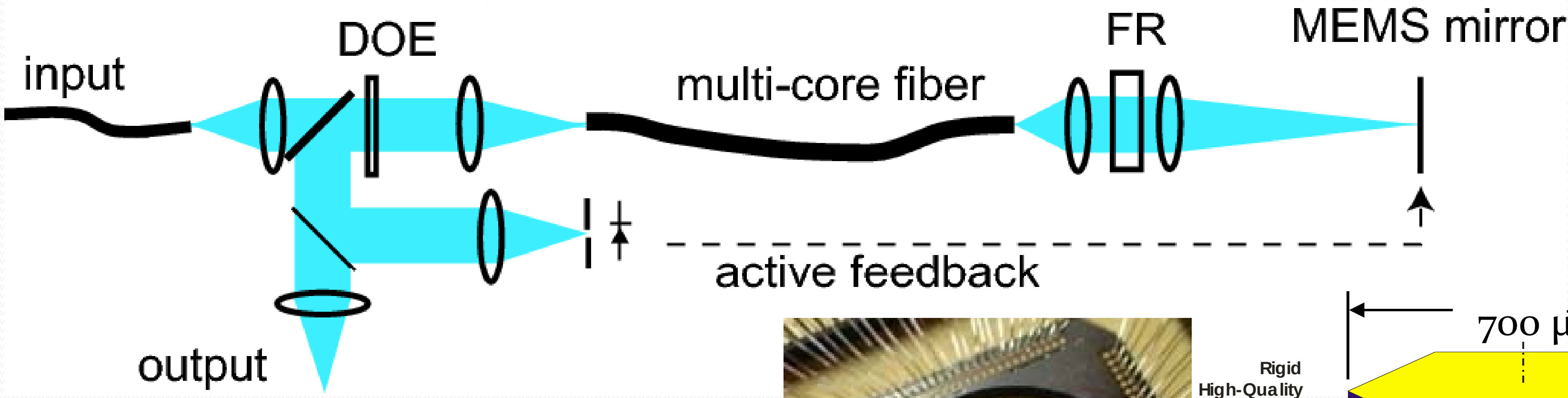
→ maximum phase delay of 1.3 λ.

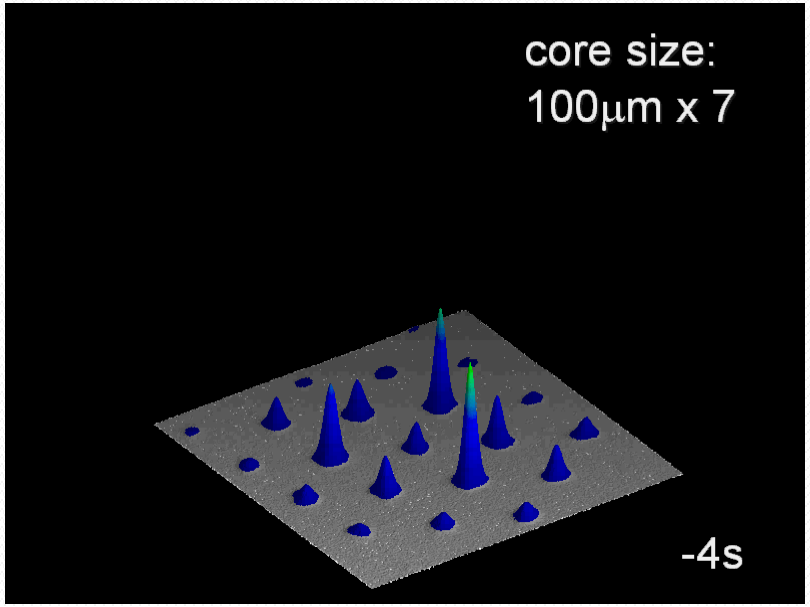
→ excellent thermal coupling.

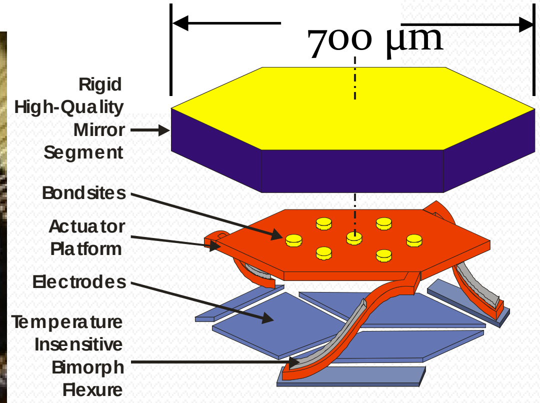
long term measurement

→ λ / 10 phase delay during 14 hours.

Experimental setup





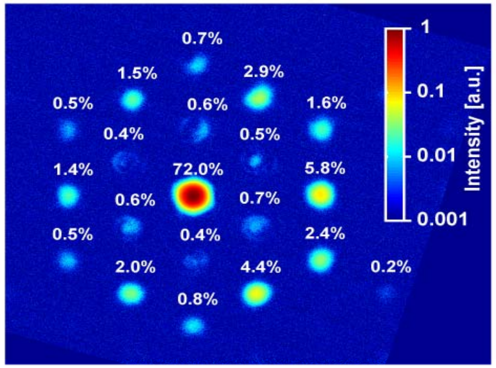


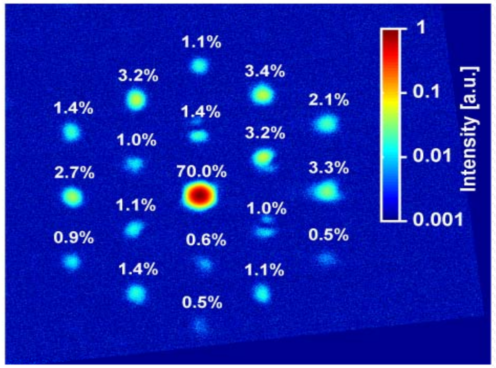
active feedback:
stochastic parallel
gradient-descent algorithm

Combination efficiency

50 µm-core fiber

100 µm-core fiber

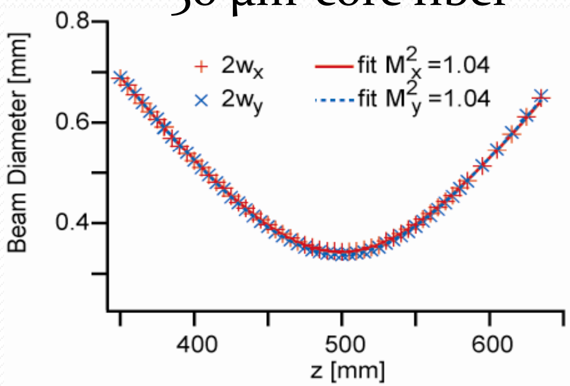




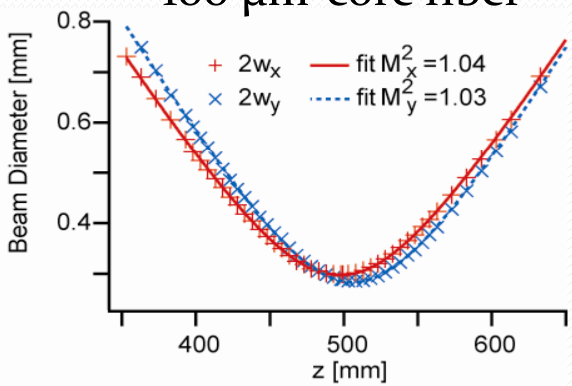
→ 88 % of the theoretical limit

→ 85 % of the theoretical limit

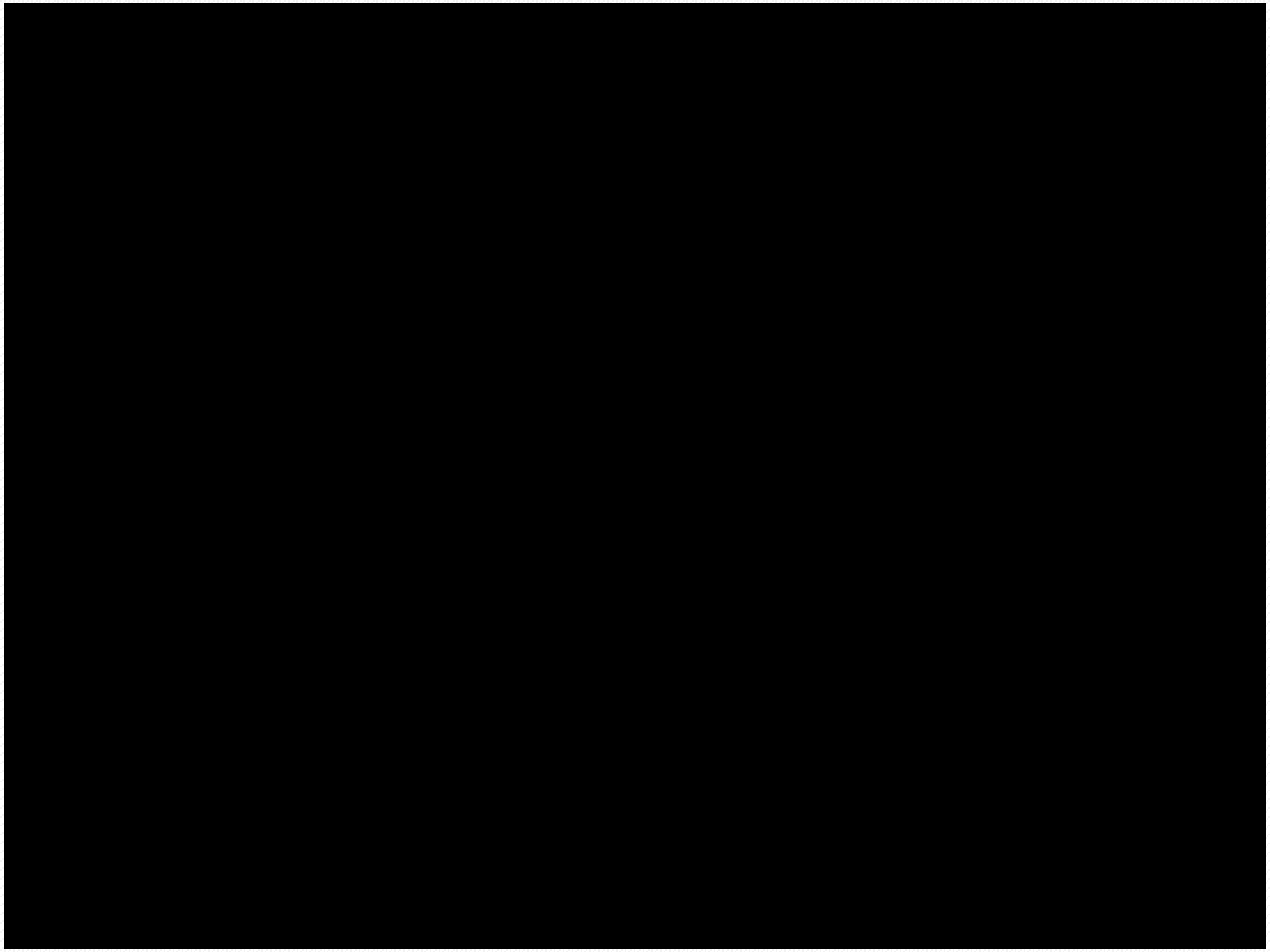
50 µm-core fiber



100 µm-core fiber

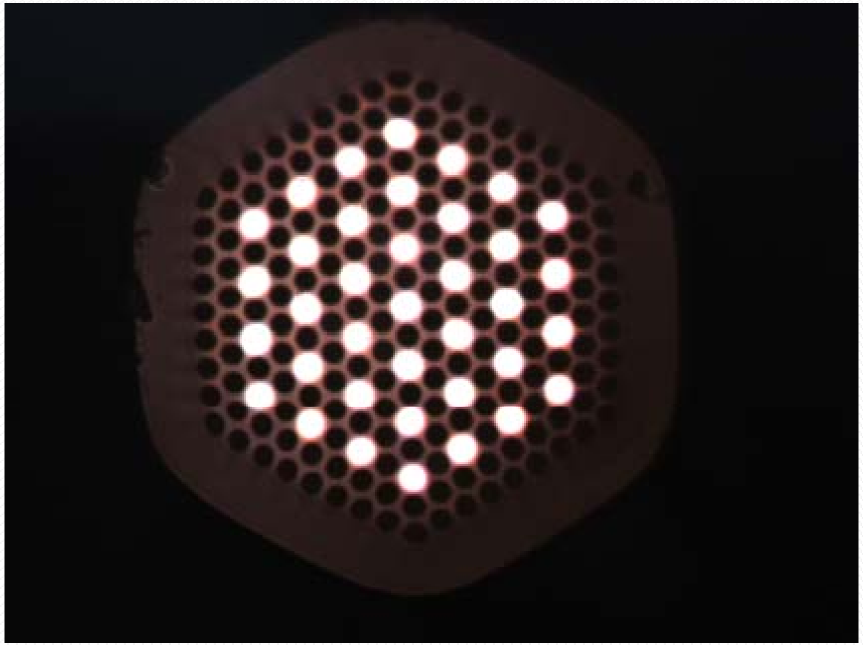


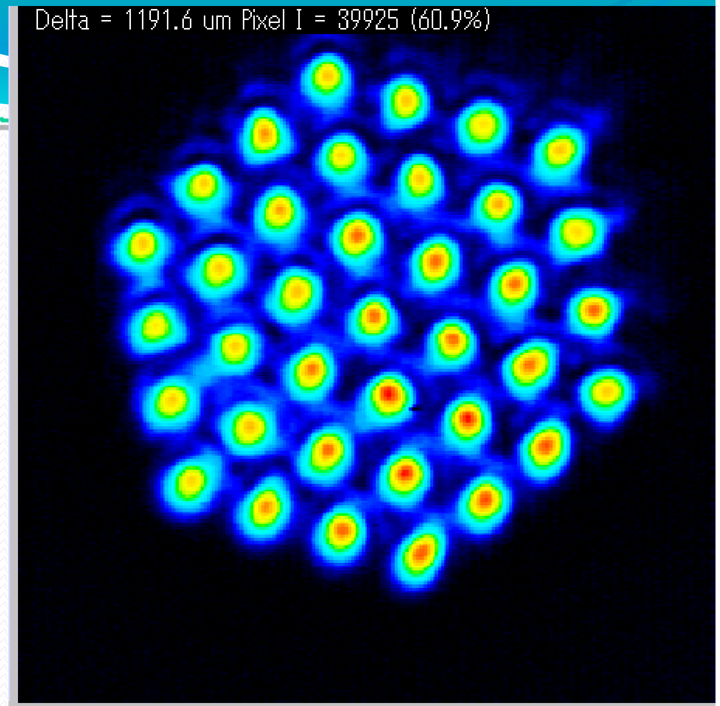
Of course, nothing new here…

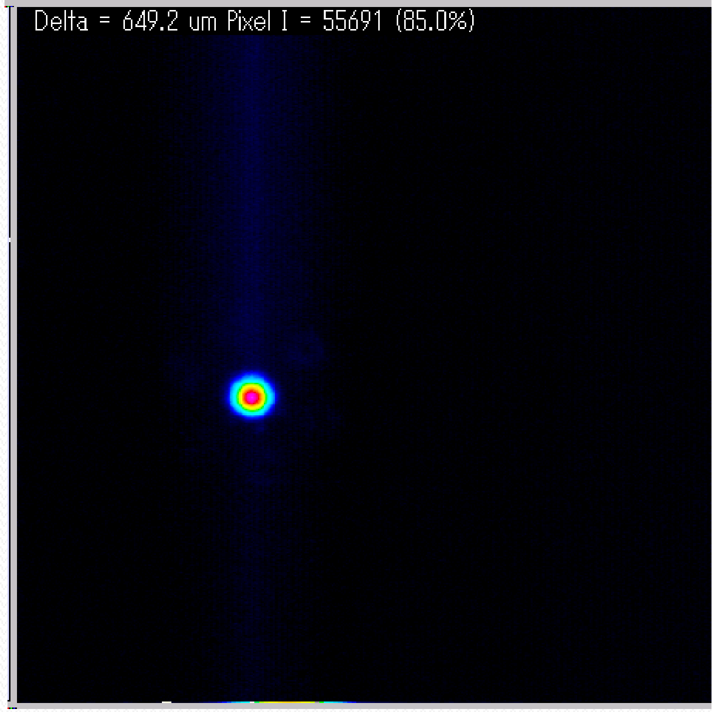


Outlook

- 37 core fiber → 0.14mm² effictive mode field area







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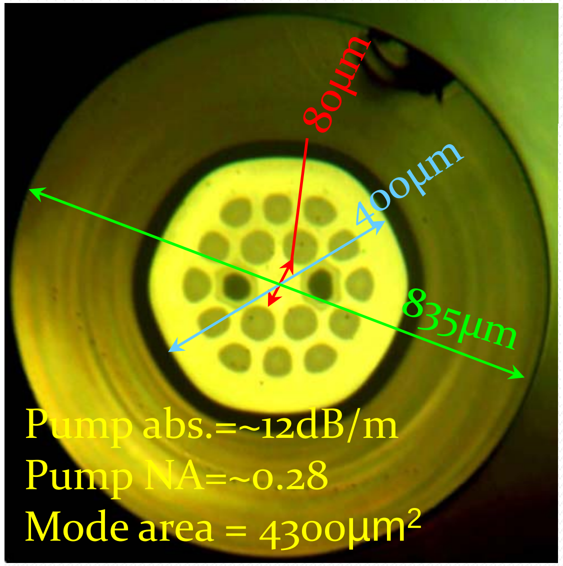
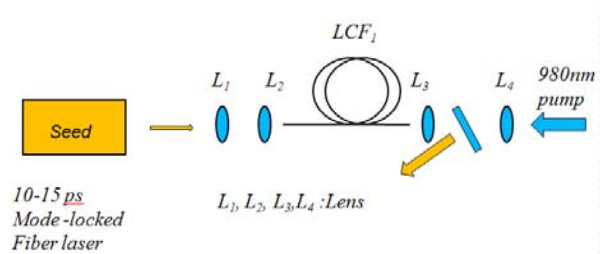
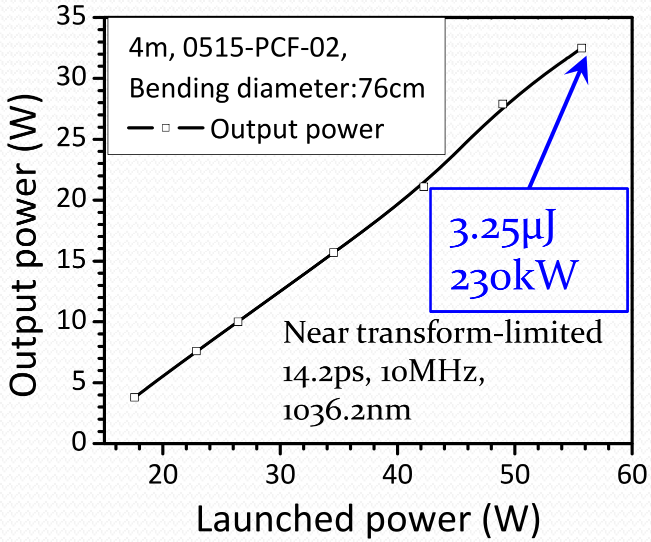
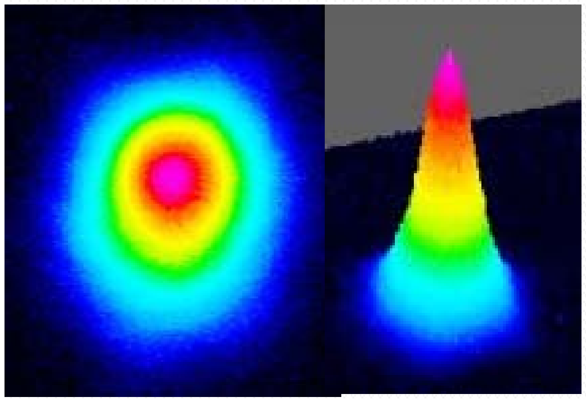
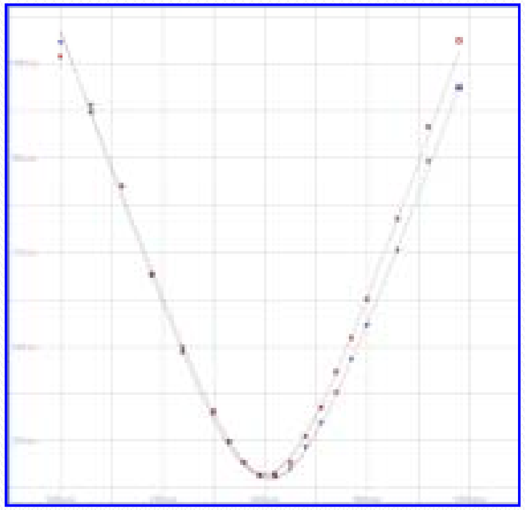
Active All Glass DC PM 80µm LCFs, 14ps Seed

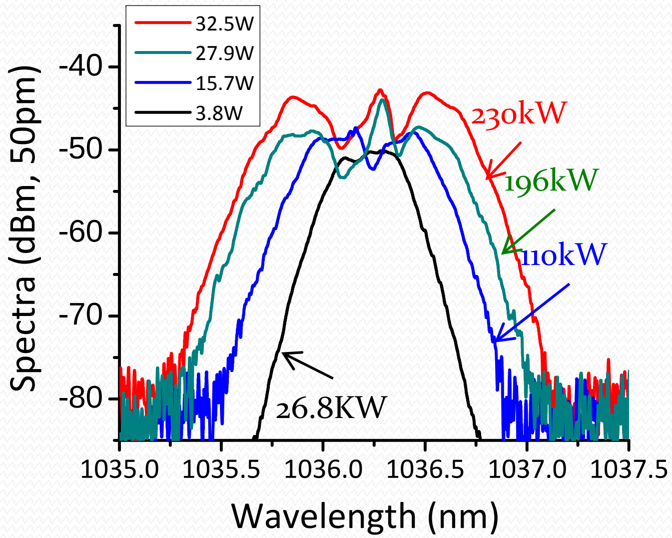




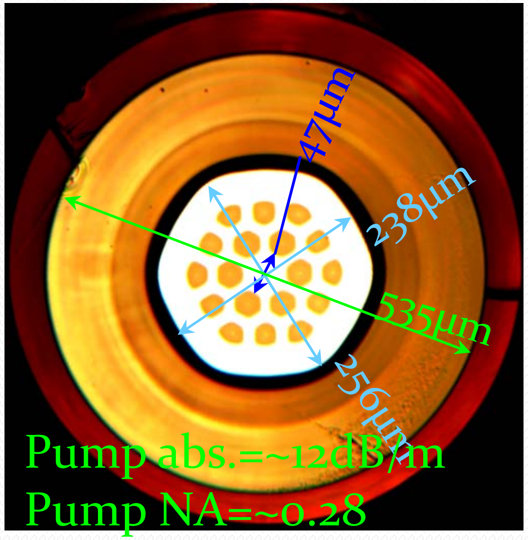


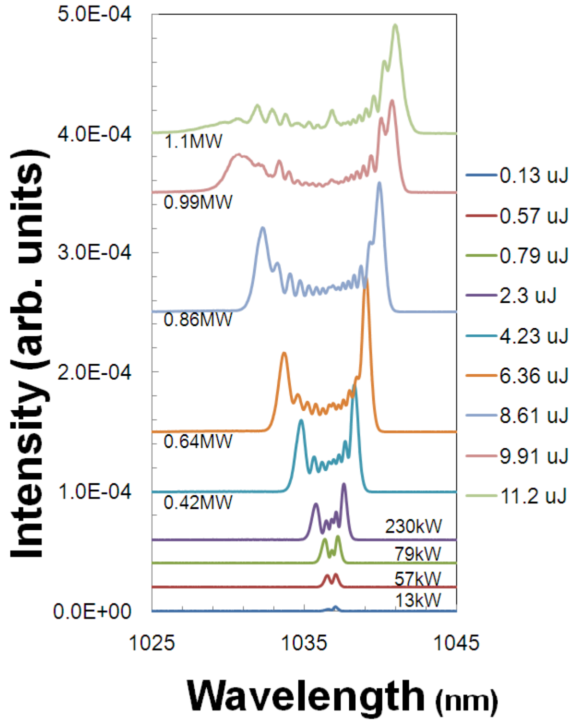


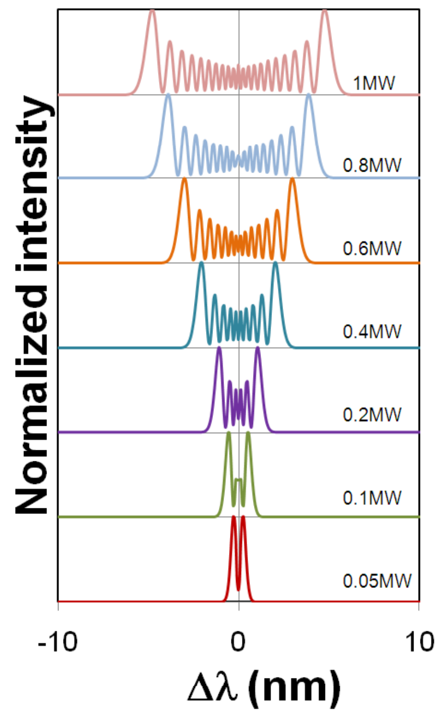


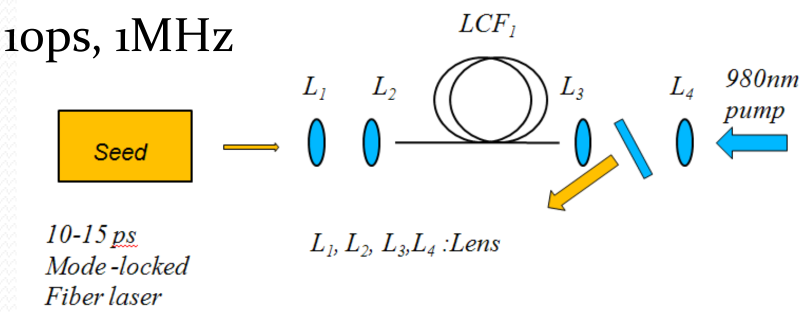


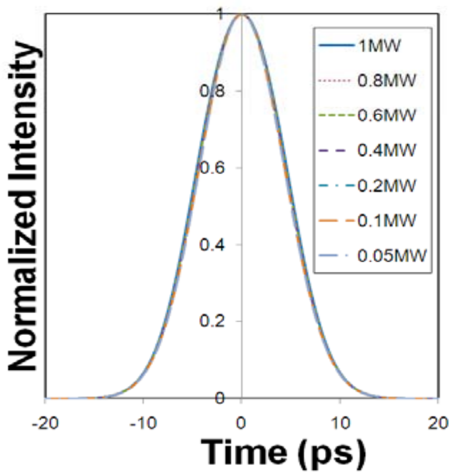
Leakage channel fibers

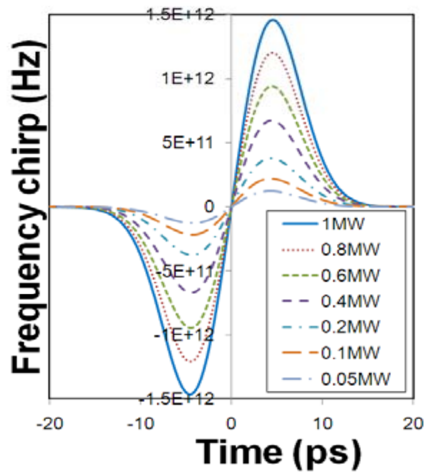






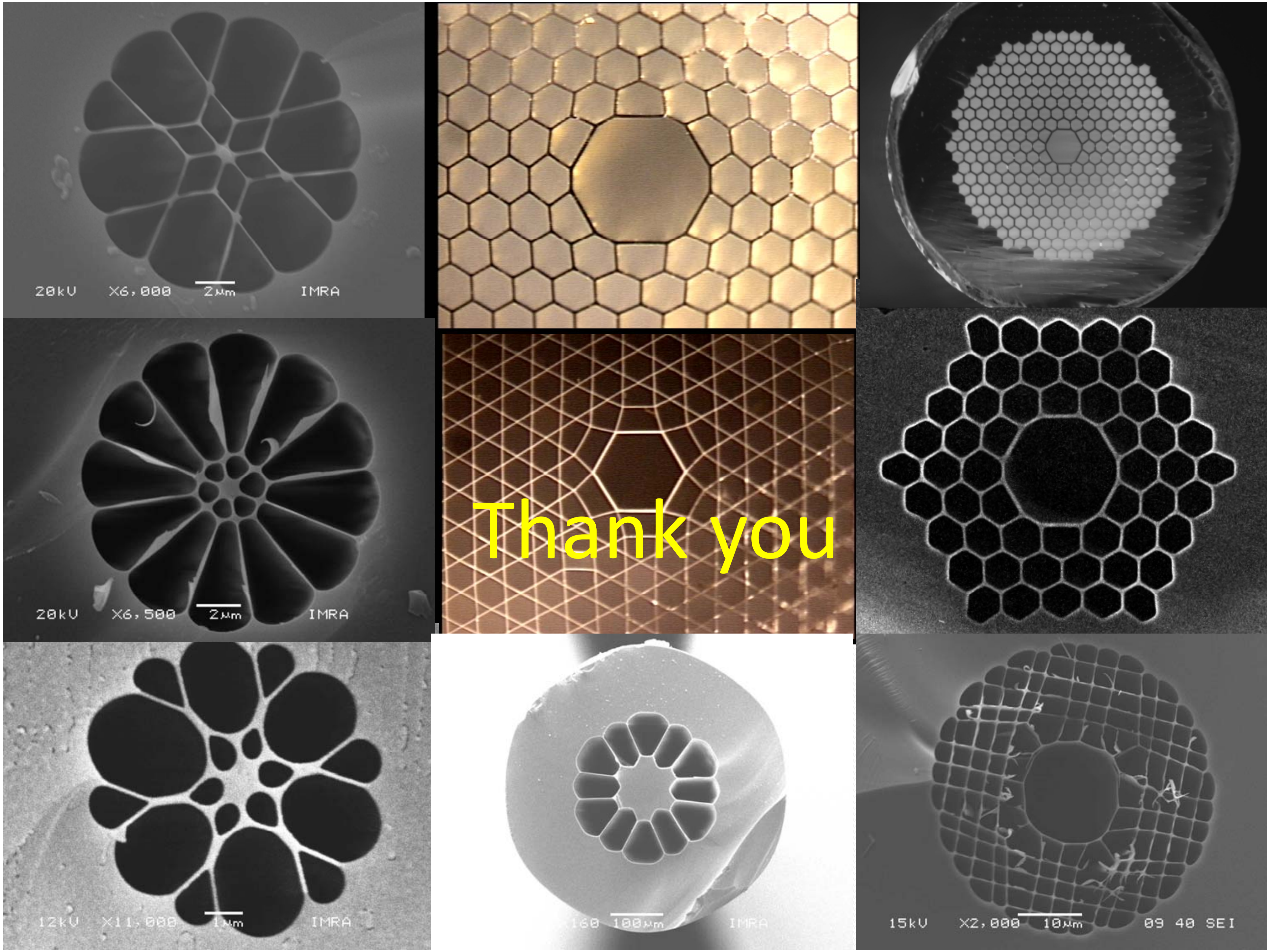






Conclusions

- LCF is effective for extending core diameter beyond conventional designs
- Demonstrated passive LCFs with core diameters up to 180μm, an effective mode area of ~16000 μm^2.
- Demonstrated active PM LCFs with core diameter up to 80μm, an effective mode area of ~4300 μm^2.
- Fabrication of multi-core LCFs with effective mode areas up to 26,000 μm^2.


20kV X6,000 2μm IMRA
20kV X6,500 2μm IMRA
Thank you
12kV X11,000 1μm IMRA
160 100μm IMRA
15kV X2,000 10μm 09 40 SEI