Fiber amplifier utilizing an Yb-doped large-mode-area fiber with confined doping and tailored refractive index

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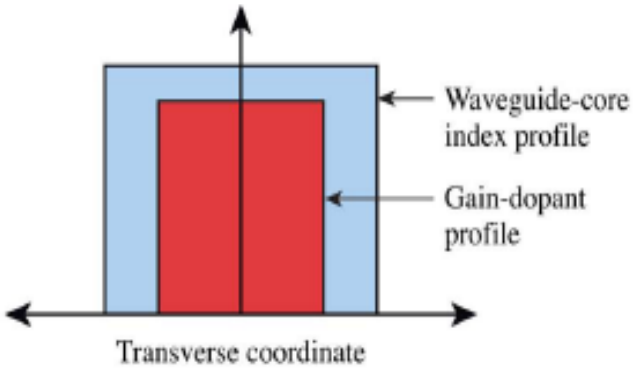
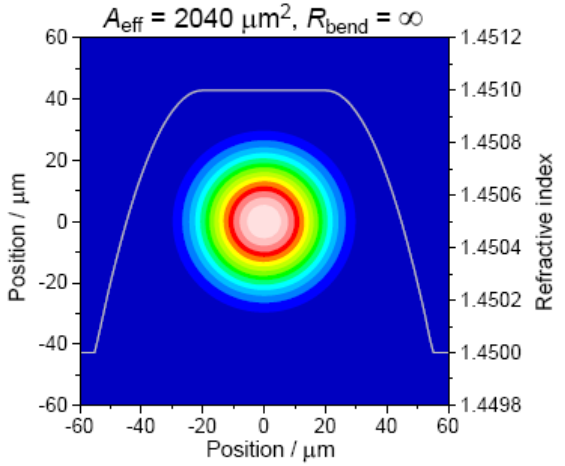
Outline

- **Motivation**
- **Manufacturing of the fibers**
- **Experimental results**
- **Summary**

Mode field area is limiting the peak powers of high power amplifiers



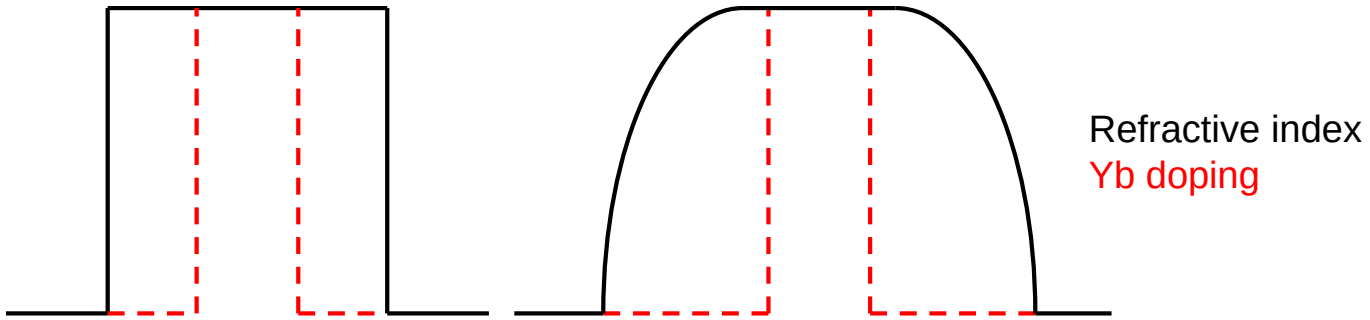


- **Marciante (1) suggests gain filtering to control LMA fiber beam quality**
  - **Achieved with 40-80% confined doping**

- **Farrow et al. (2) suggests index profiling to control LMA fiber beam quality**
  - **Reduced mode crunching when bent**
  - **Also gain filtered**

1) Marciante, IEEE Journal of selected topics in quantum electronics, 15(1), pp. 30-36 (2009)
2) Farrow, Hadley, Kliner, Koplow, SPIE 6453, pp. 63531C (2007)

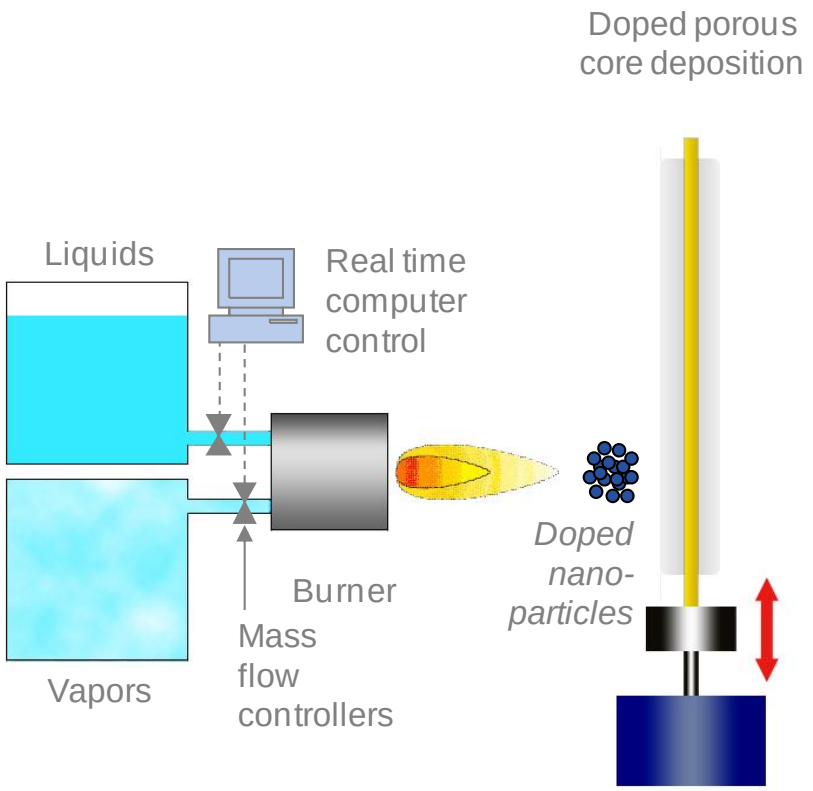
Objectives for the fiber geometries



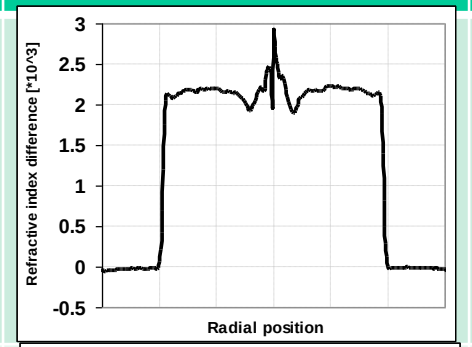
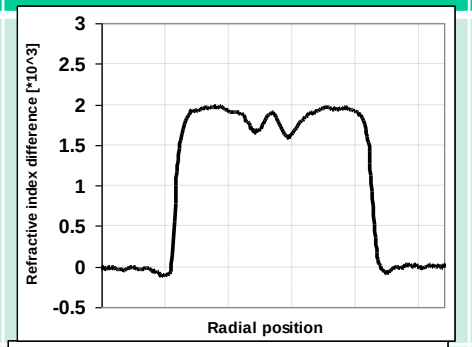
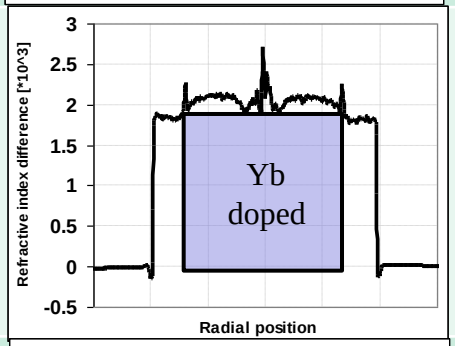
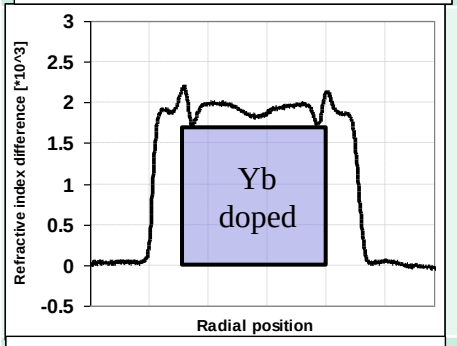
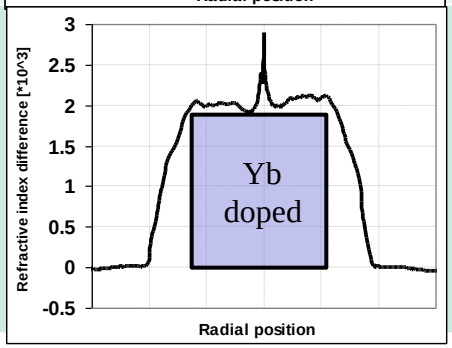
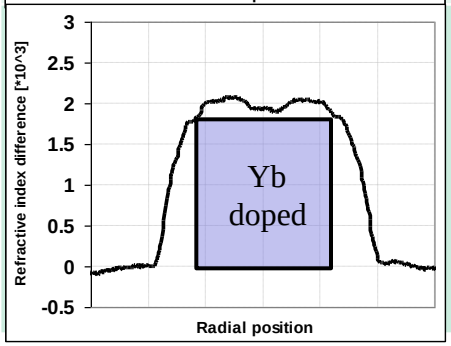
- **Yb doped – 60% confinement**
- **NA ~ 0.07**
- **Mode field diameter comparable to a 40µm step refractive index**

Refractive index and dopant tailoring is feasible with DND

- **Direct Nanoparticle Deposition (DND) – dopants are added prior to the formation of glass nanoparticles**
- **Outside deposition process – soot is deposited on a mandrel**
- **Real-time control of dopants – convenient radial index and dopant control**



Multiple different fibers were manufactured

Fiber	Preform RIP Doping profile	Fiber RIP	LAD v4.0 simulated MFD
Step index Yb-25/250DC			19.2µm (0.077 NA)
Step index Confined doped Yb-28/44/400DC			28.4µm (0.076 NA)
Tailored index Confined doped Yb-32/51/400DC			27.0µm (n/a NA)

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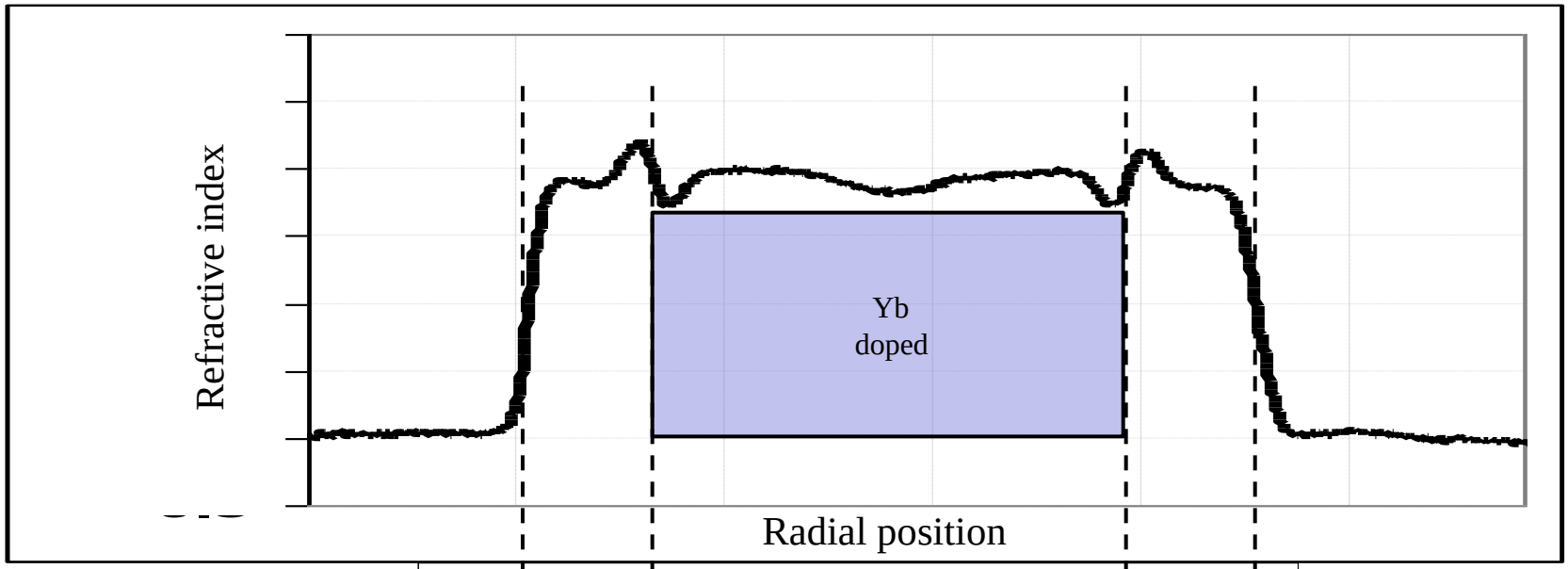
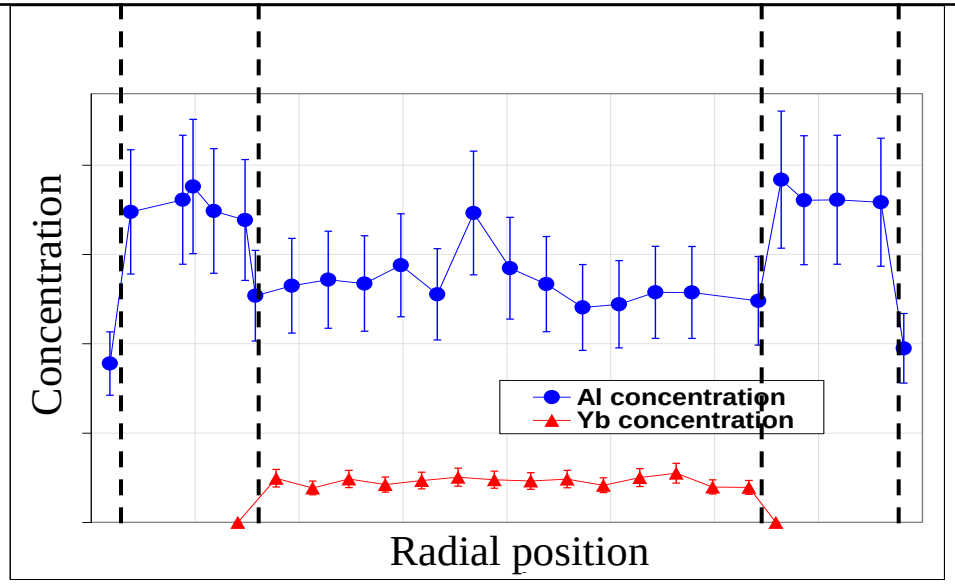
Gain tailoring requires control of multiple glass dopants simultaneously





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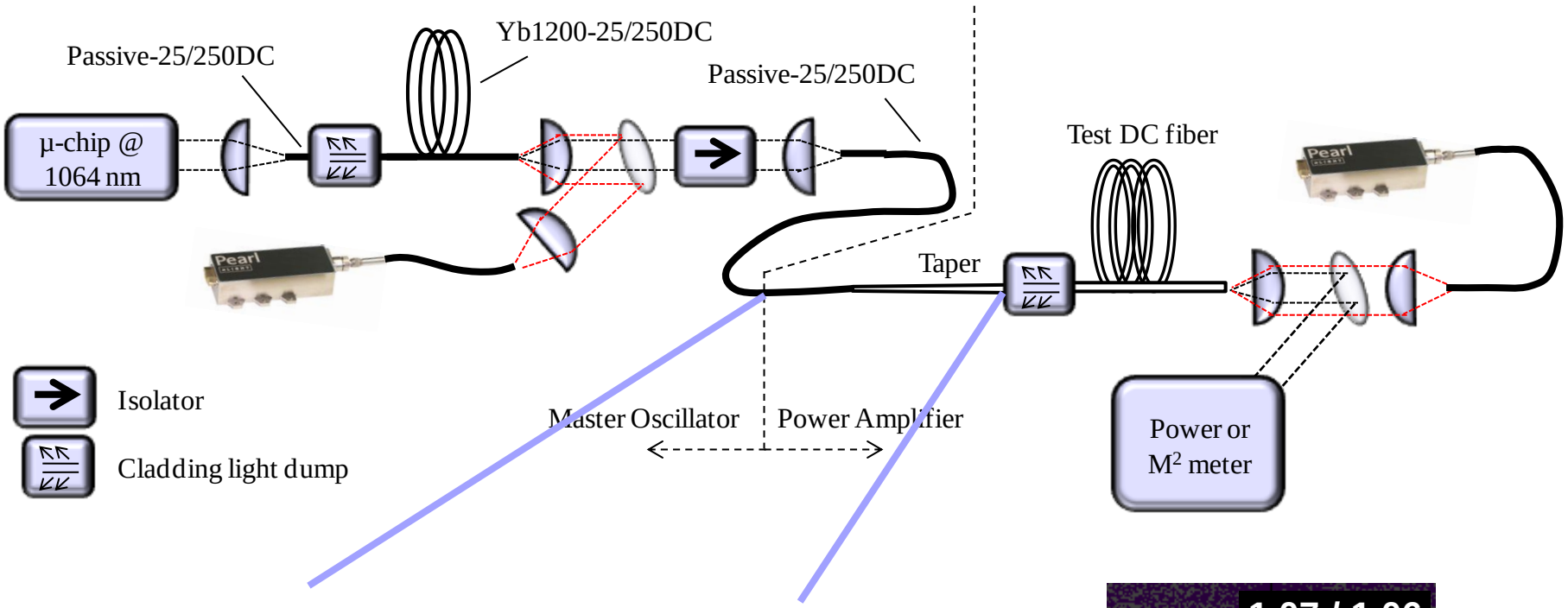
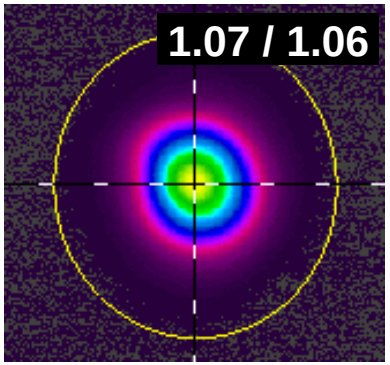
The fiber experiments were done with a pulsed seed source



- **25µm core**
- **500mW output power**

- **40µm core**
- **500mW output power**



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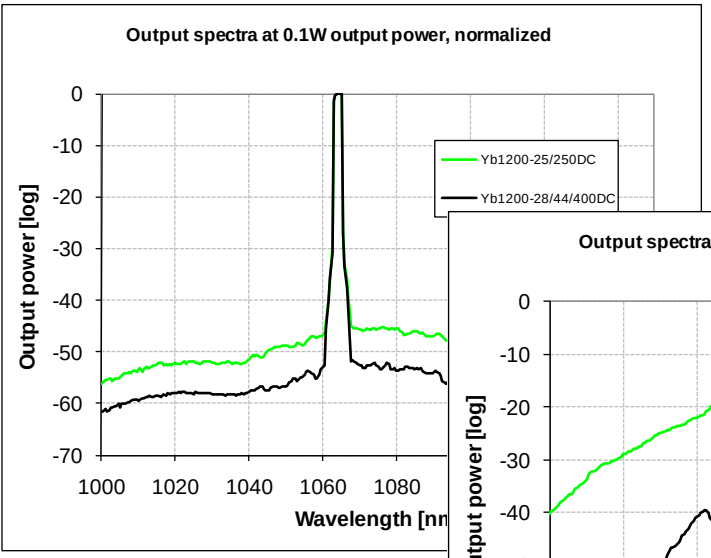
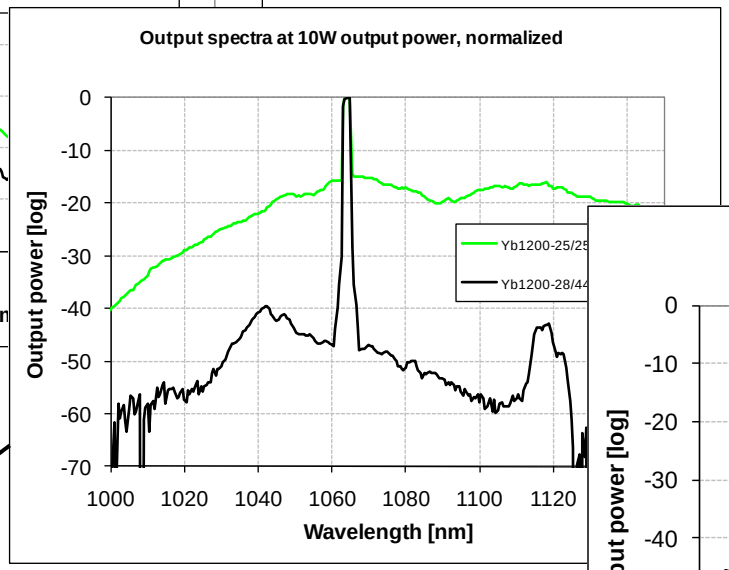
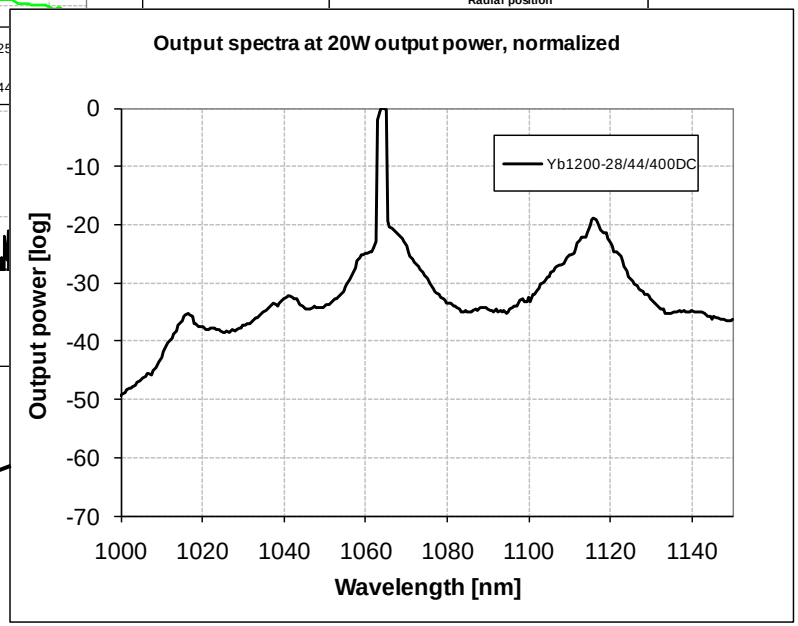
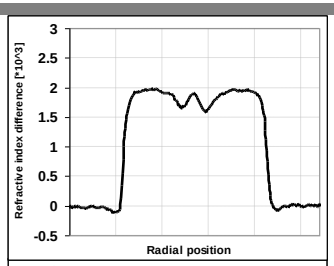
Confined doping with step index – less nonlinearities as expected

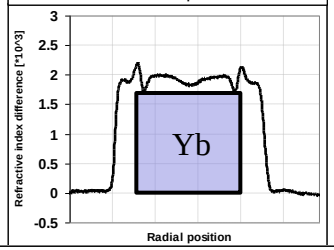








MFD 19.2µm



MFD 28.4µm

1.5ns, 50 kHz, 1064nm
→ ~200µJ, 125kW

1.5ns, 50 kHz, 1064nm
→ ~400µJ, 250kW

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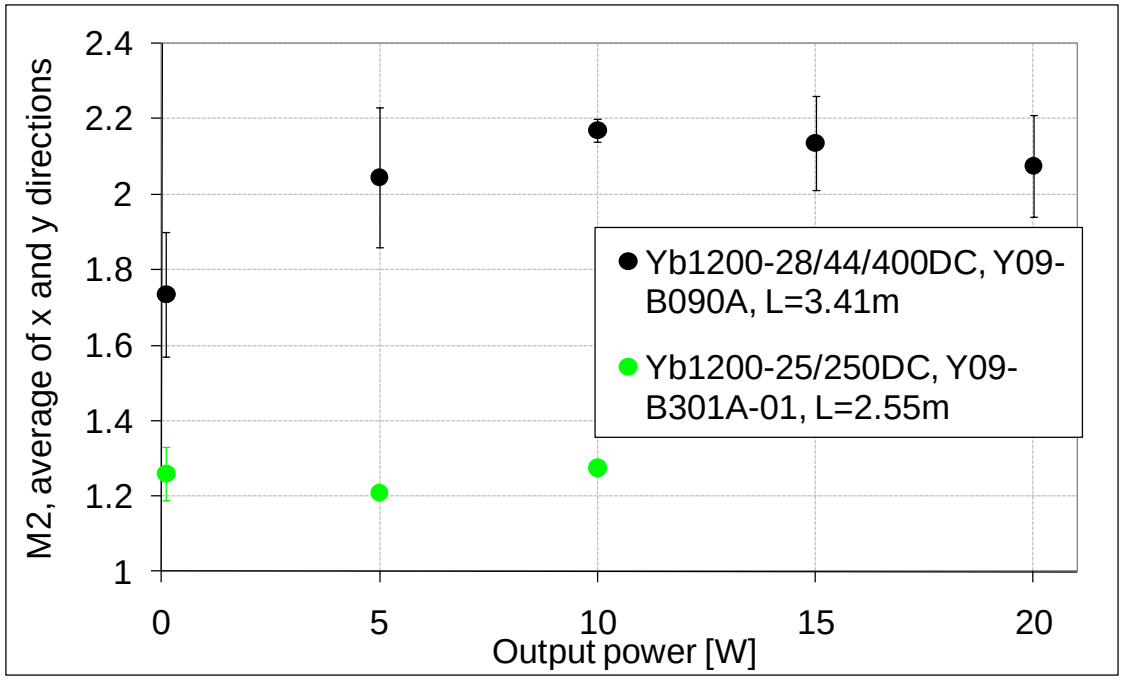
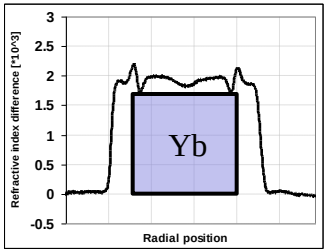
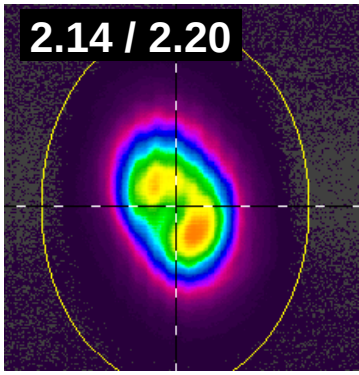
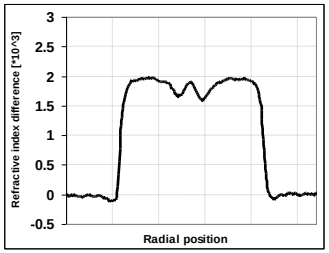
Gain tailoring with step index and - 16cm coiling diameter



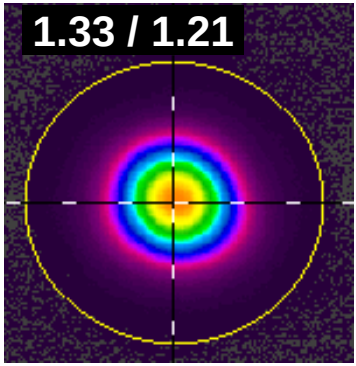


MFD 28.4µm





MFD 19.2µm



- **Gain does not increase the beam quality**
- **Multimoded signal launch conditions – mode quality was poor after the splice point in the 44µm fiber**

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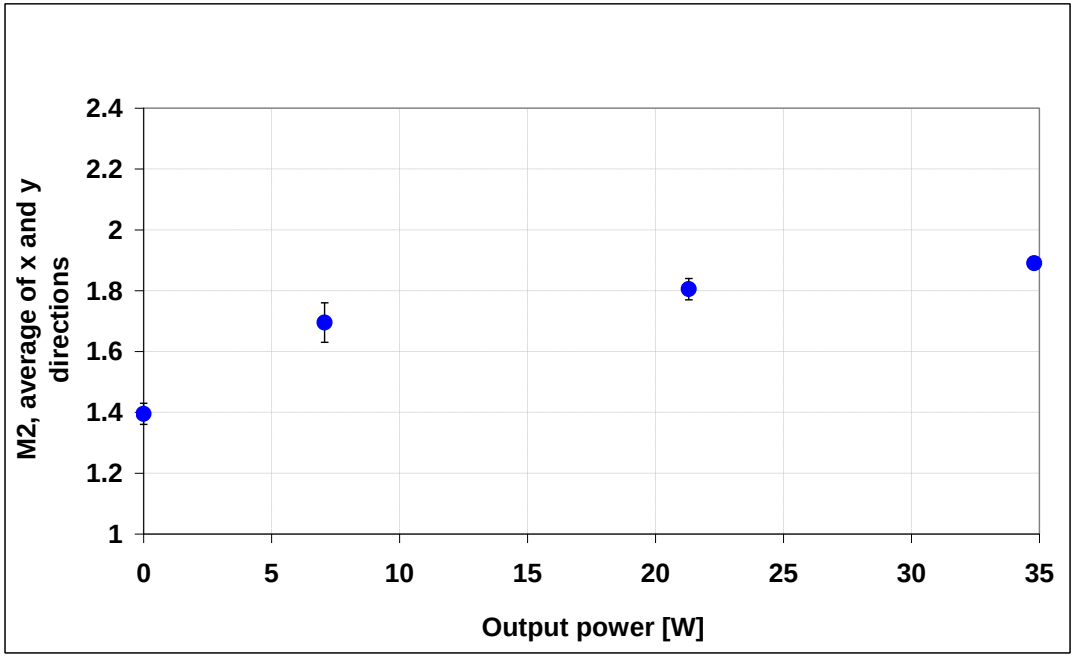
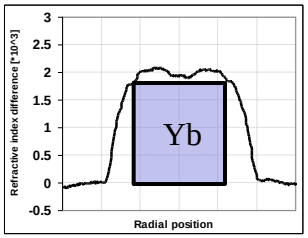
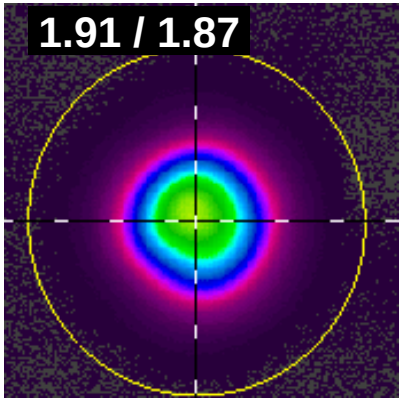
Gain tailored and index tailored – 16cm coiling diameter





MFD 27.0µm

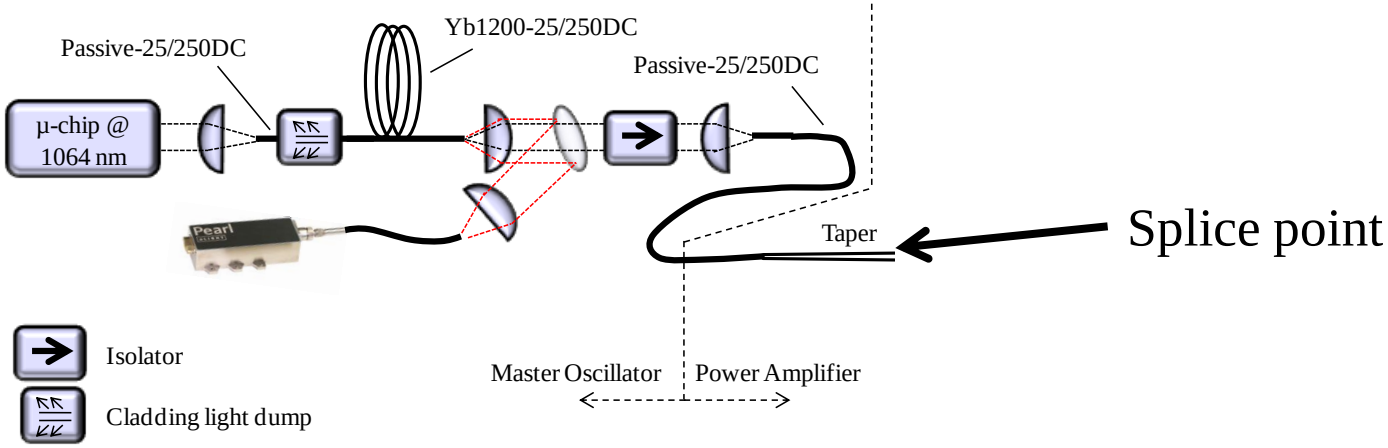


1.5ns, 50 kHz, 1064nm

→ ~700µJ, 450kW

- **Increased gain decreased beam quality**
- **Beam shape maintained symmetry**
- **Multimoded signal launch conditions – mode quality was poor after the splice point in the 51µm fiber**

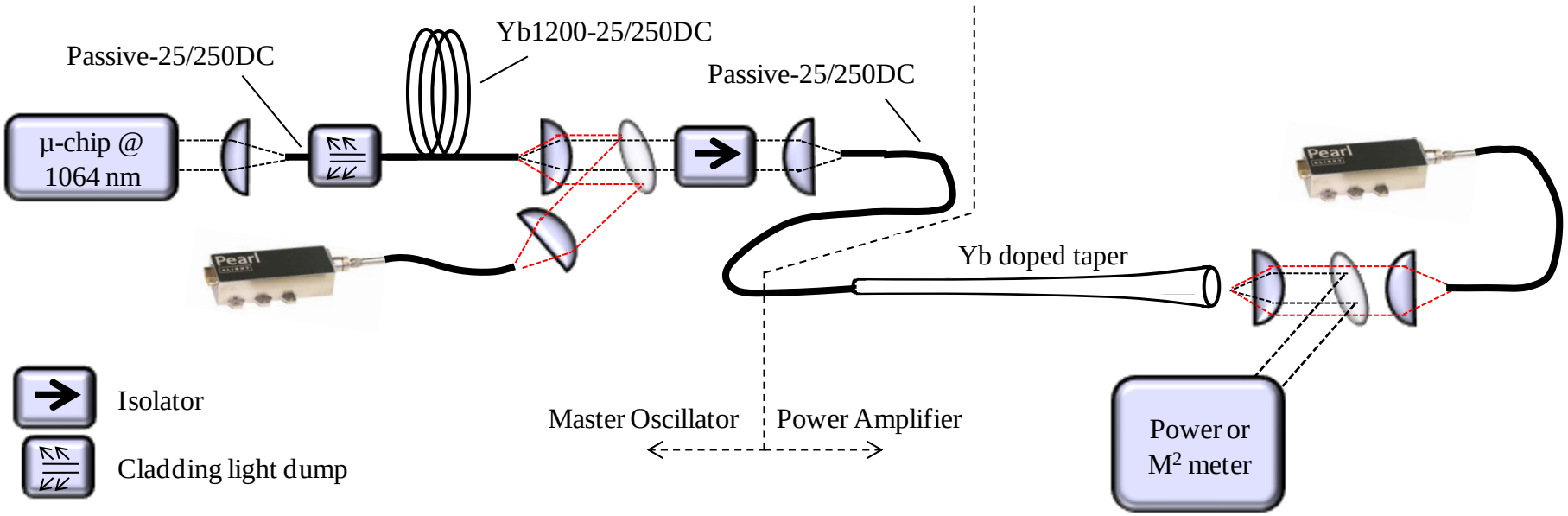
Splicing of the ~40µm LMA fibers was not optimized

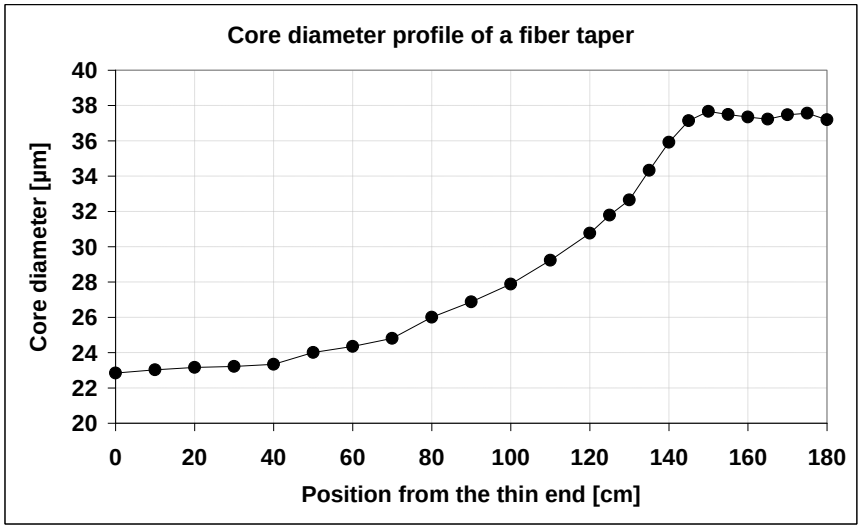


Fiber spliced to taper	M^2
None	<1.1
Passive, 40µm core	~1.2
Step index, confined Yb	~1.7
Tailored index, confined Yb	~1.4

- **Splice point decreases the beam quality**
- **The seed modal content was not comparable**
- **Splicing needs to be optimized to properly compare the fibers**

Removing the middle step





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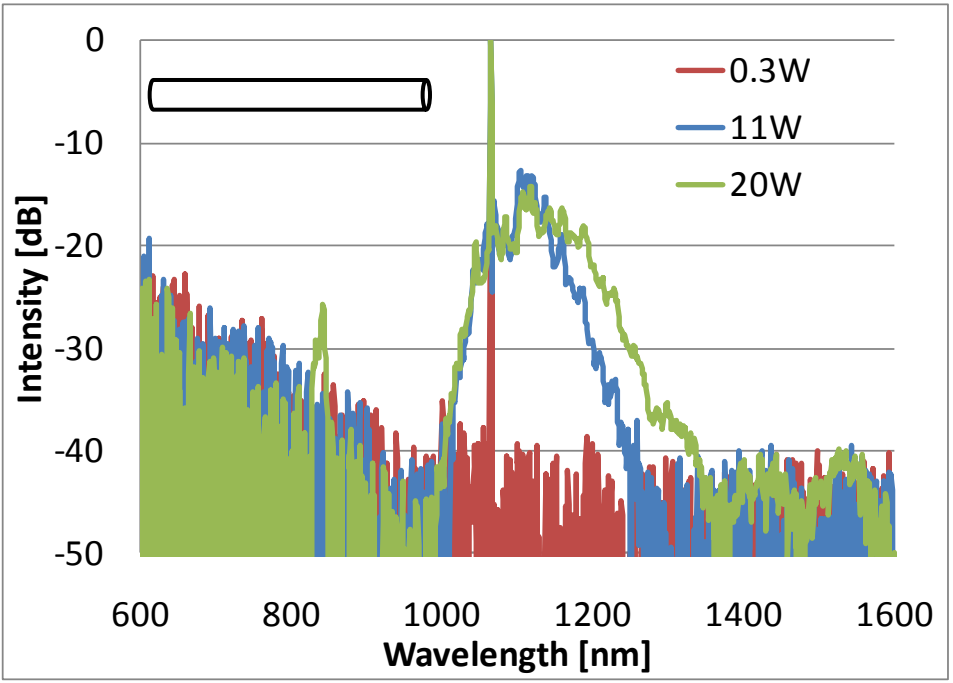
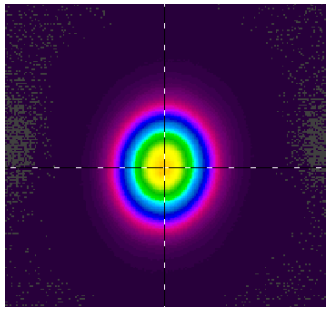
Active step index tapers show very good beam quality without coiling

Yb1200-25/250DC, 3m



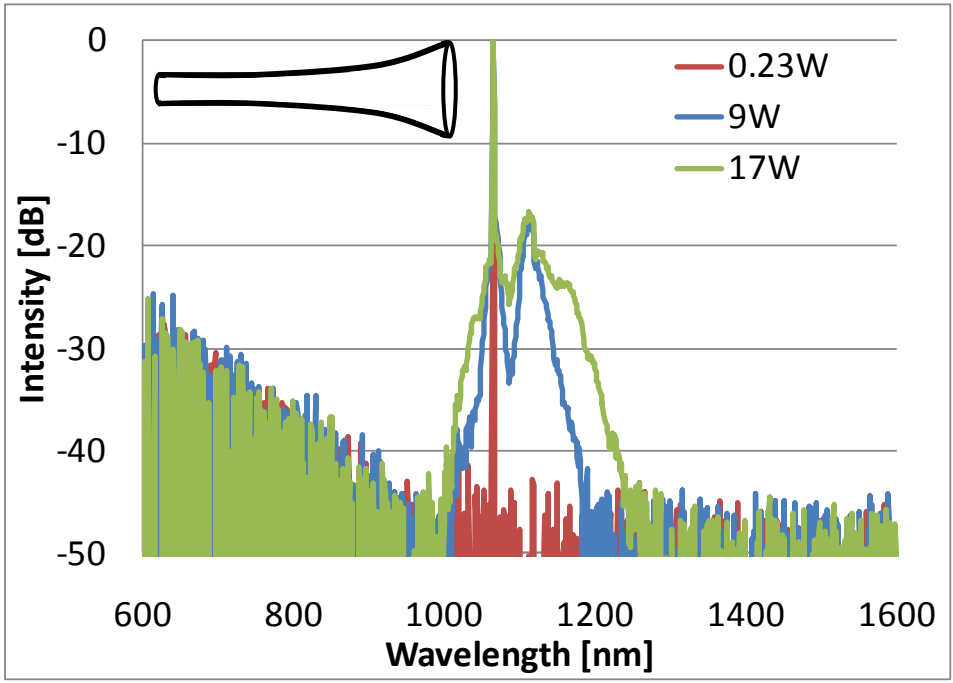


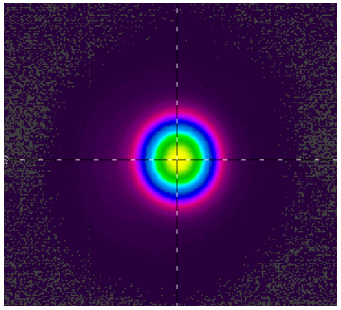
M^2: 1.06/1.10

1.5ns, 50 kHz, 1064nm

→ ~400µJ, 250kW

Yb1200-25/250-40/400DC-Taper, 3m





M^2: 1.12/1.13

1.5ns, 50 kHz, 1064nm

→ ~400µJ, 250kW

→ Reduced nonlinearities

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Summary

- **Manufacturing of index and dopant tailored cores is feasible**
  - Real-time control of multiple dopants with DND
- **Gain tailored fibers need to be studied further**
  - Launching conditions were not comparable – inconclusive results
  - Coiling of the active fiber was not studied
- **Active taper amplifier was extremely easy to operate**
  - Good beam quality from a 40µm diameter amplifier with minimal effort
- **The fibers are available – contact nLIGHT if you want to test them in a particular application**

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Thanks!

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