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High-power pulsed amplifier with low pulse deformation, excellent beam quality and higher energy extraction using special designed ytterbium double cladding fibre having high and flat absorption with negligible photodarkening

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- Application: marking, drilling, etc.
- Pulsed output power sought :
 - 10's to 100's of ns
 - 10's to 100's of kHz
 - 5 W to 30 W
 - mJ range
 - $M^2 \sim 1$ to 2
- Pulsed fiber laser solution: compact, low cost, efficient

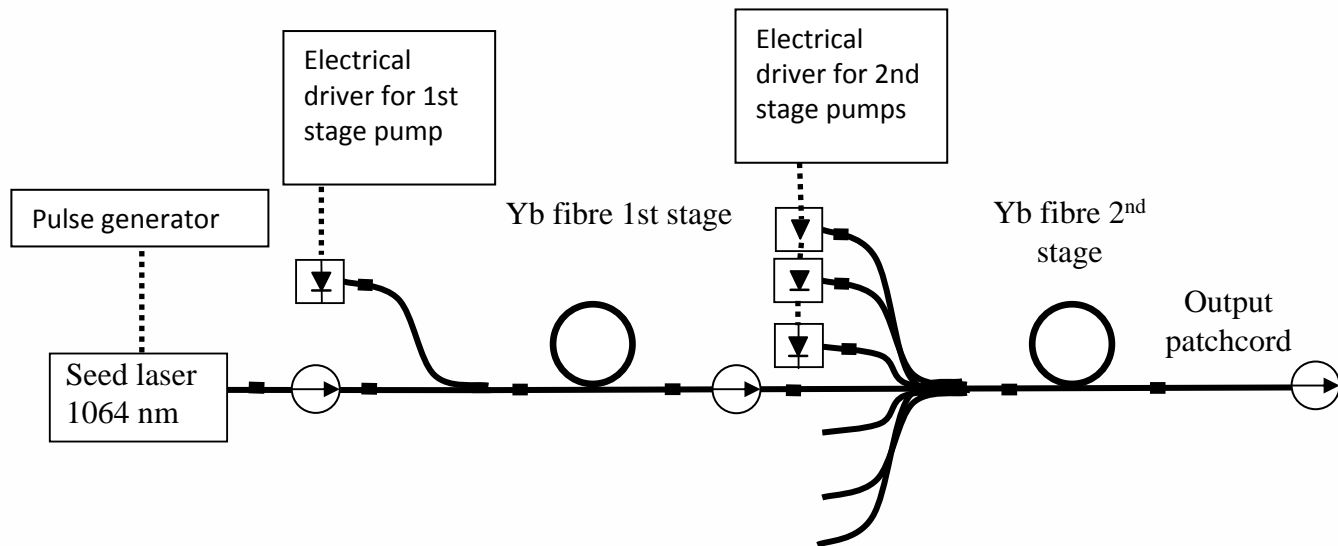
Ytterbium doped fibre is a key component

- Low non-linear effects
 - Large mode area
 - Short fiber length
- Stable output power over time
- Control of pulsed shape
- Industrial use
 - Easy to package and simple pumping
 - Stable configuration

Pedestal phosphosilicate ytterbium DCOF

- Why ?
 - Higher extraction and saturation energy
 - Higher and flat absorption
 - Lower photodarkening
 - Bend insensitive
 - Excellent beam quality

Output power : 10W, 0.5 mJ, 20 kHz



Symbols :

■ Splice and recast

▾ pump diode

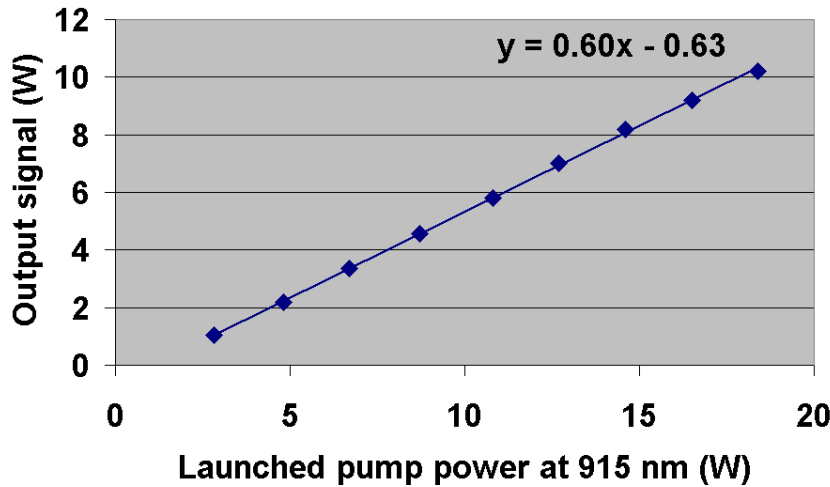
⊙ isolator

..... Electrical connections

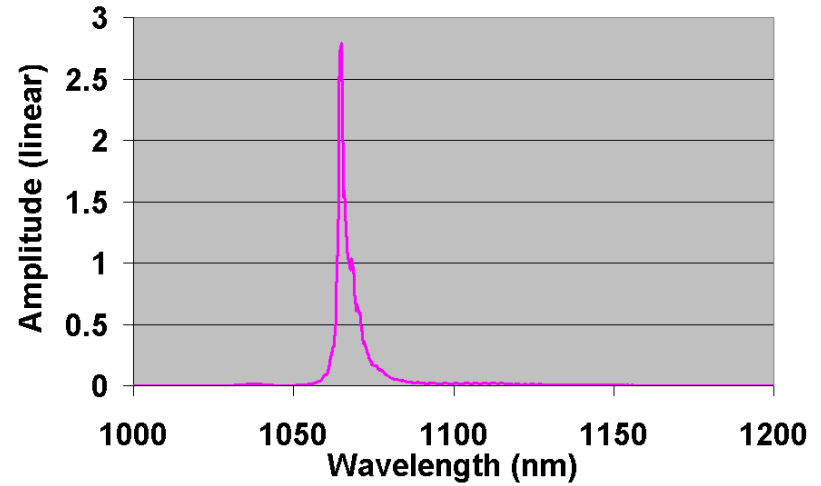
— Optical fibre

Core = 20 μm ; L=4m

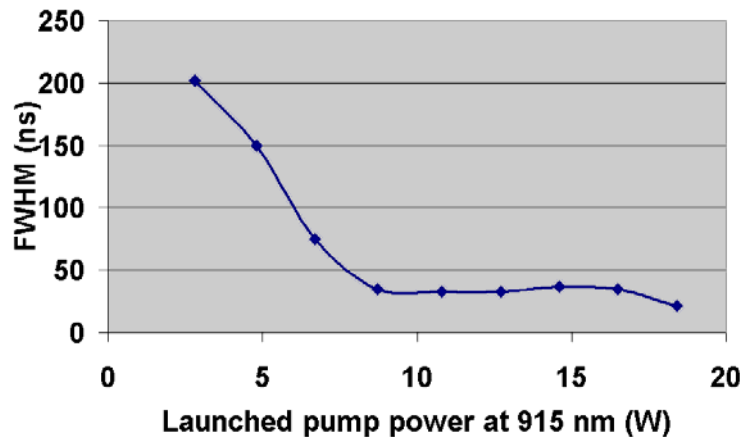
Slope efficiency



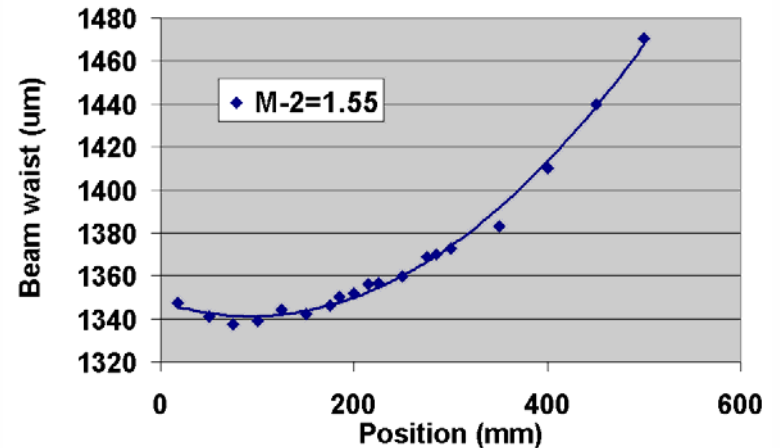
Output spectrum at 10 W



Output pulsewidth



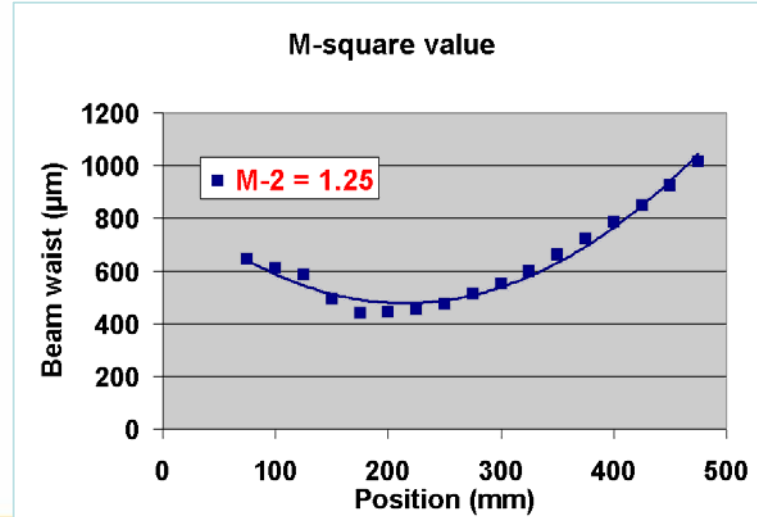
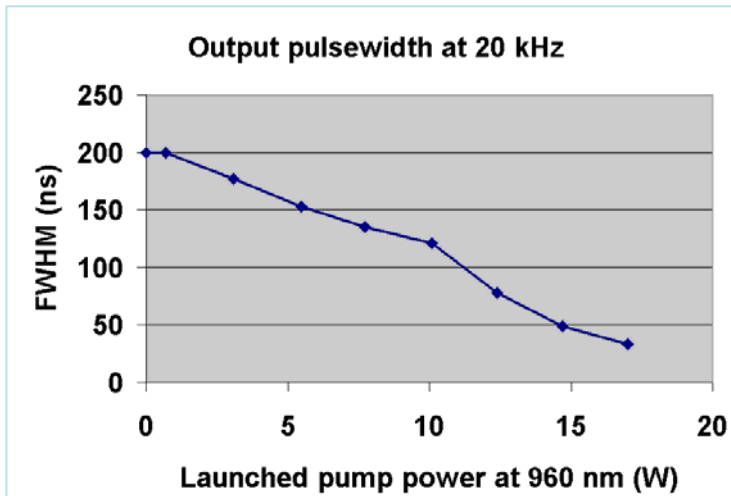
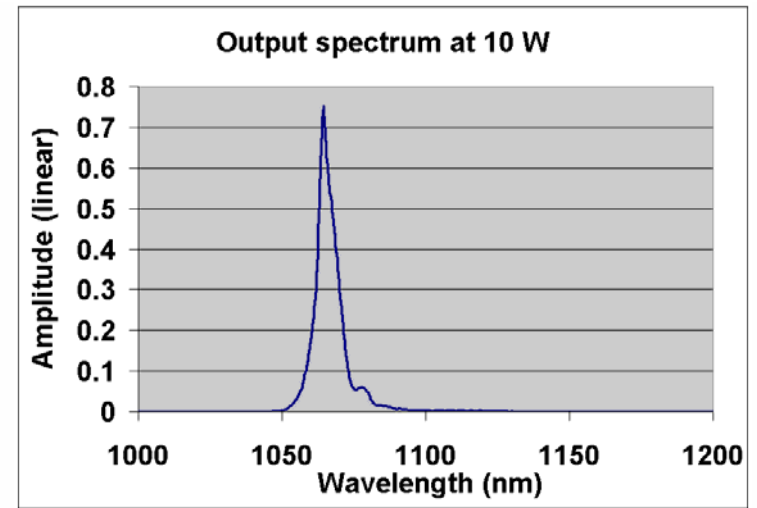
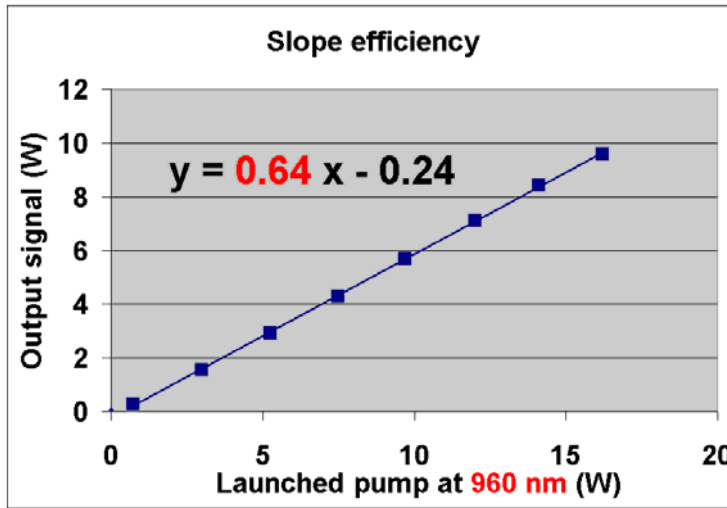
M-square value



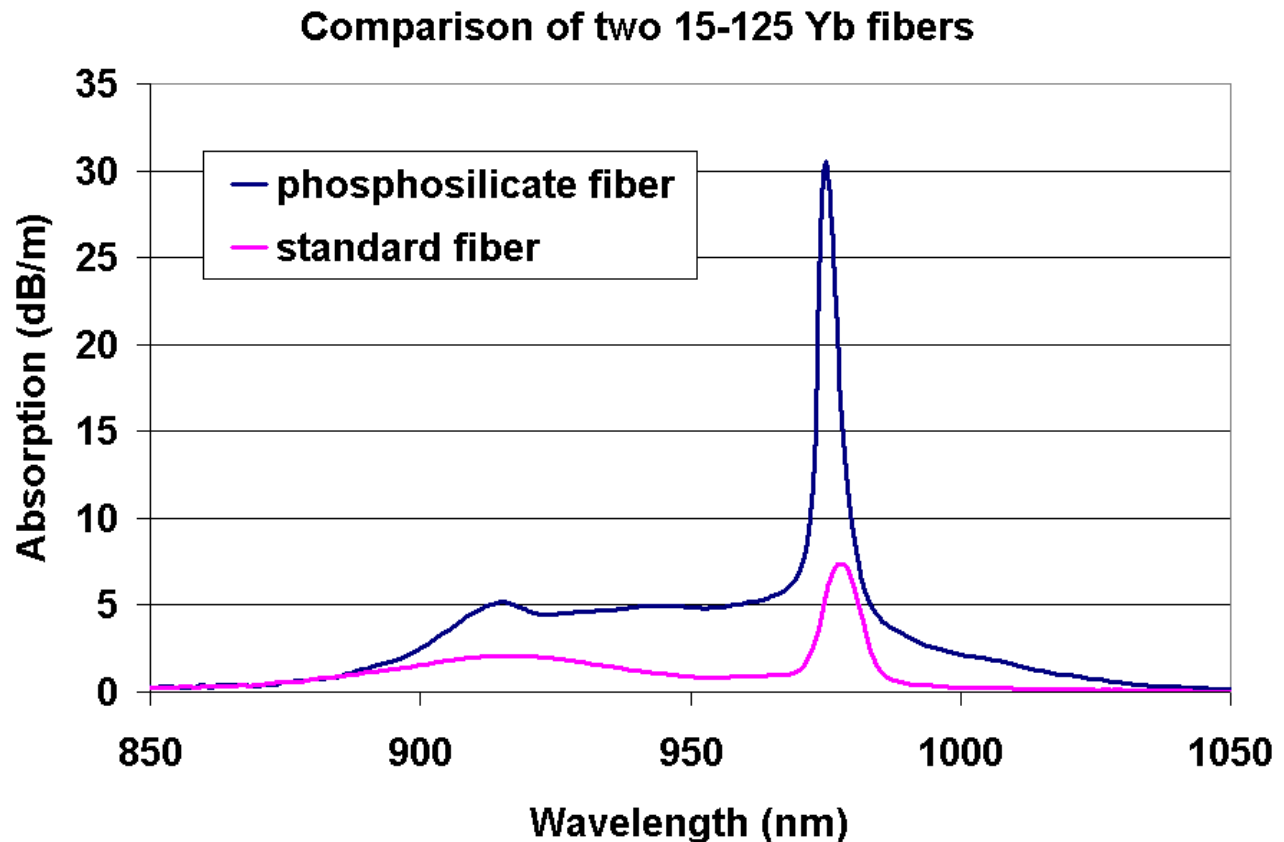
Phosphosilicate 10/125 Yb fiber

Core = 10 μm ; L=4m

Why 10 μm Si-P is better than 20 μm Si-Al fiber?

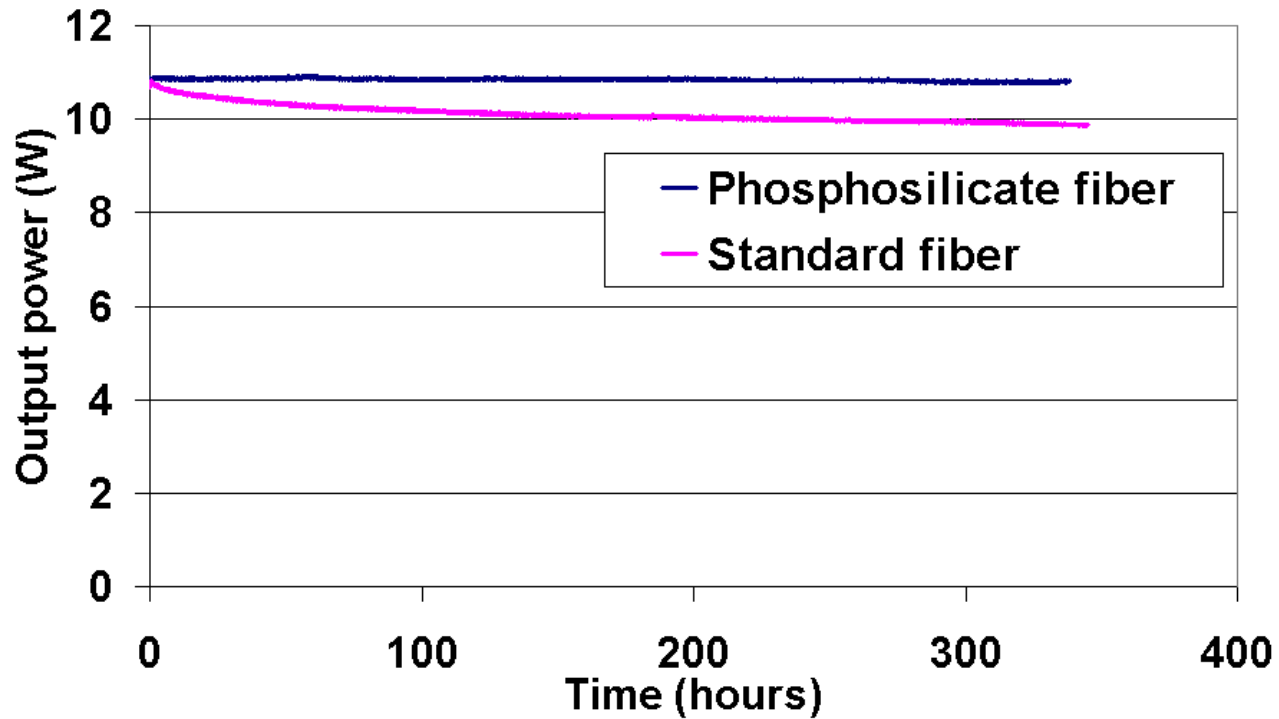


- ▶ 2.5 times more absorption at 915 nm
 - ▶ 4 times more absorption at 960 and 976 nm
- Shorter fiber length = lower non-linear effects



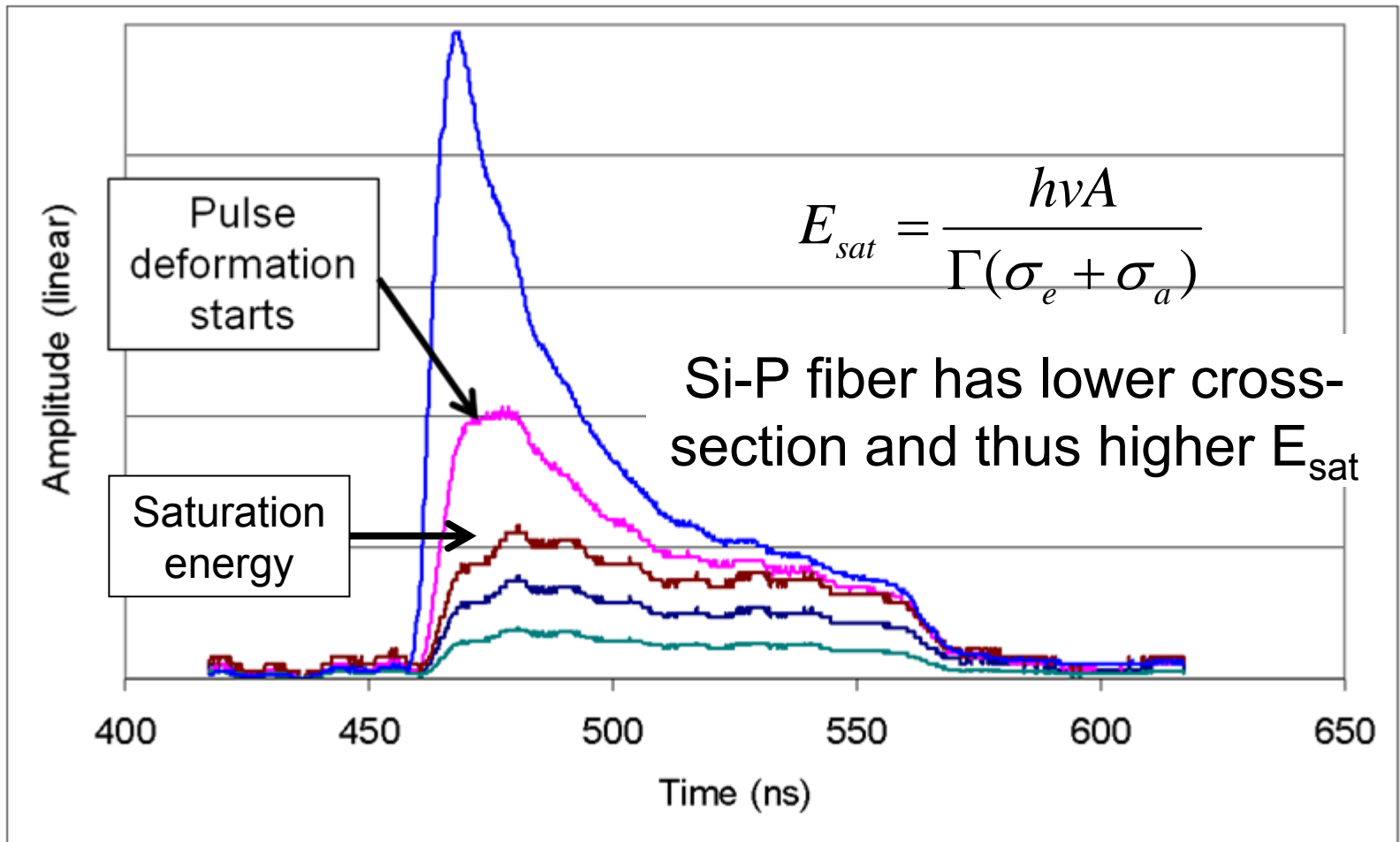
No photodarkening with higher absorption for phosphosilicate fiber

Long term testing of 10W pulsed amplifier
at 40 kHz/100ns



Saturation energy (E_{sat})

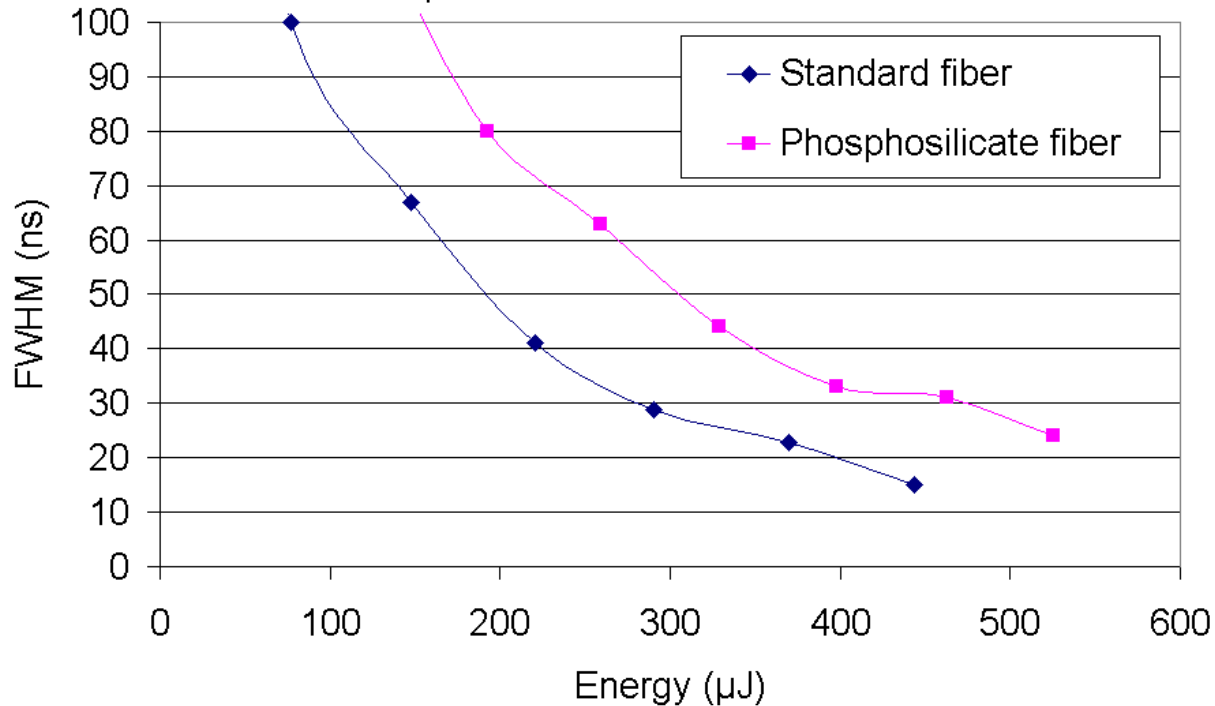
Important to control pulse shape in pulsed amplifier



Two times less pulse shortening with phosphosilicate fiber

► Easier to control pulseshape

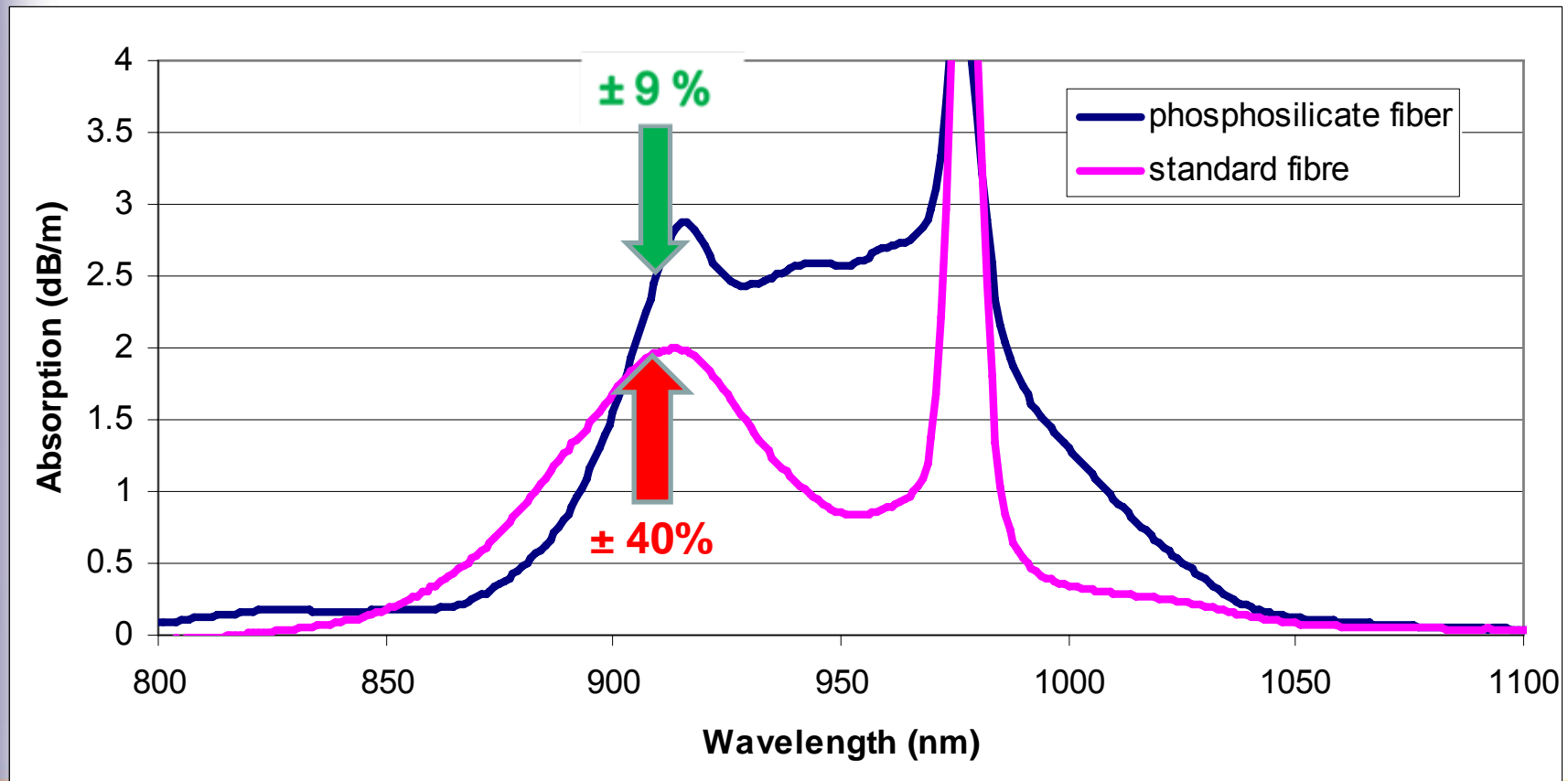
Output pulsewidth at 20 kHz with 200 ns input square pulse with 15-125 Yb fiber



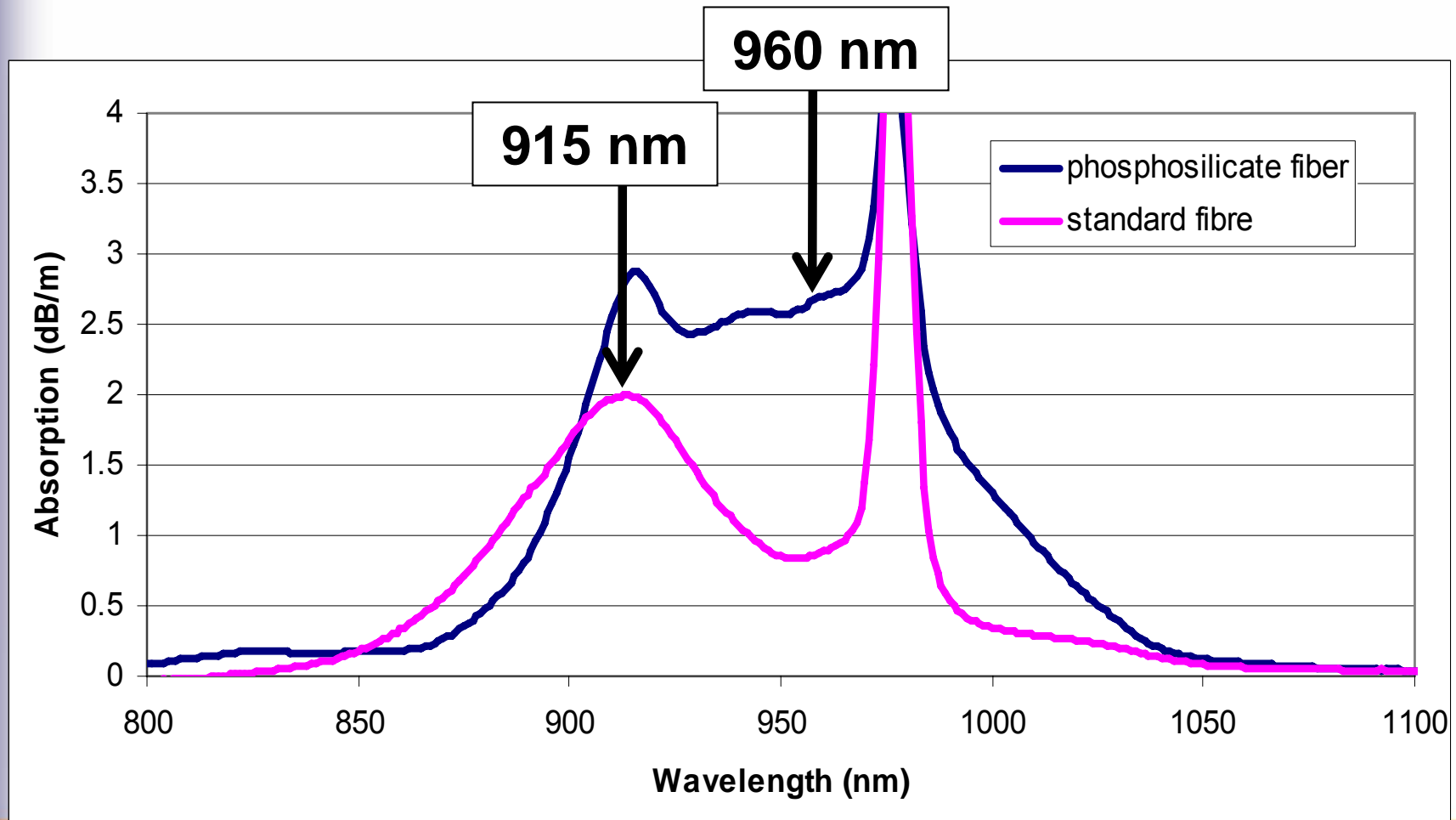
Ref: US Patent 5,173,456: *Phosphate glass useful in high energy lasers*

Flat absorption: no pump tuning necessary

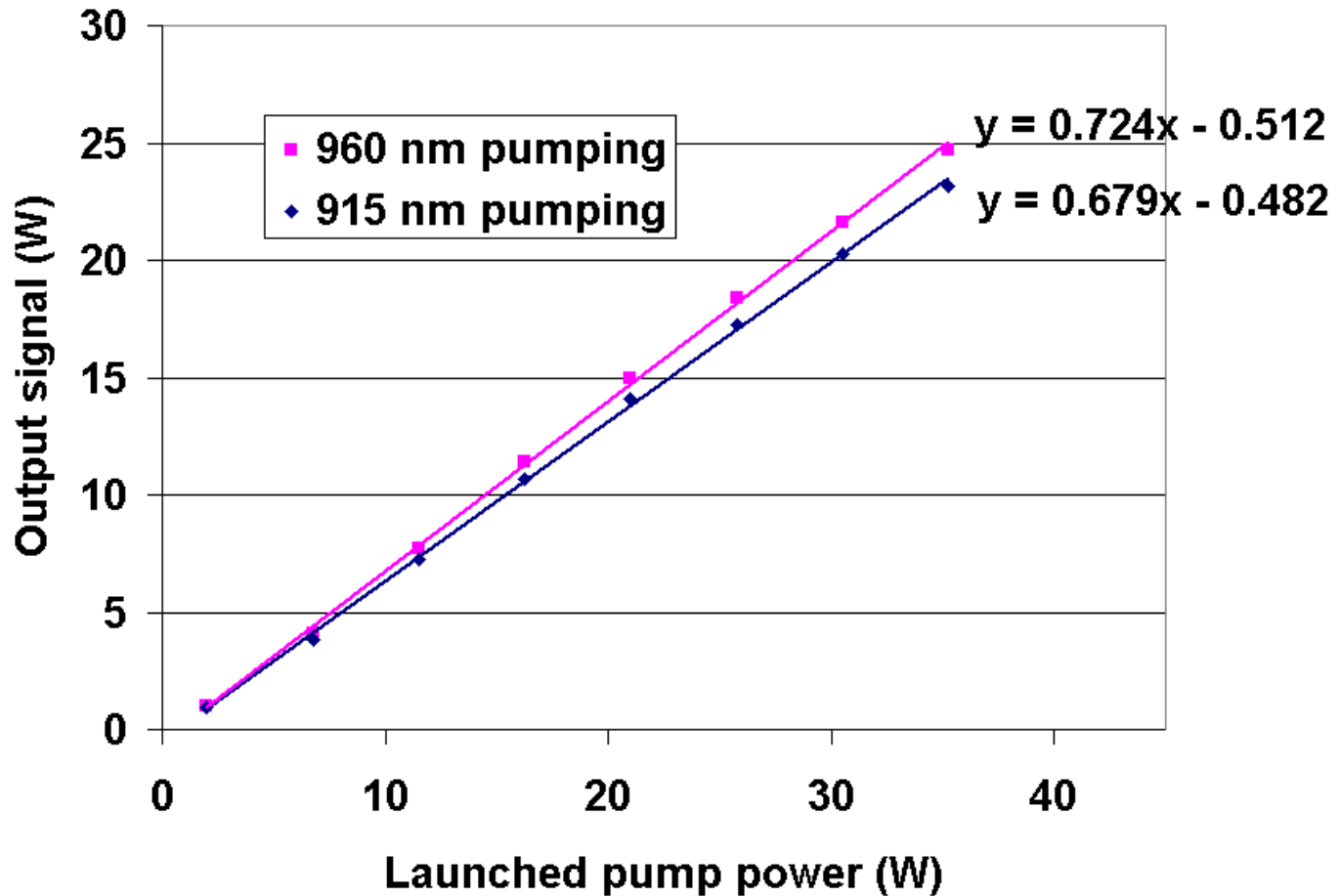
- ▶ Inexpensive fan cooling of pump diodes



960 nm pumping possible without increased non-linear effects

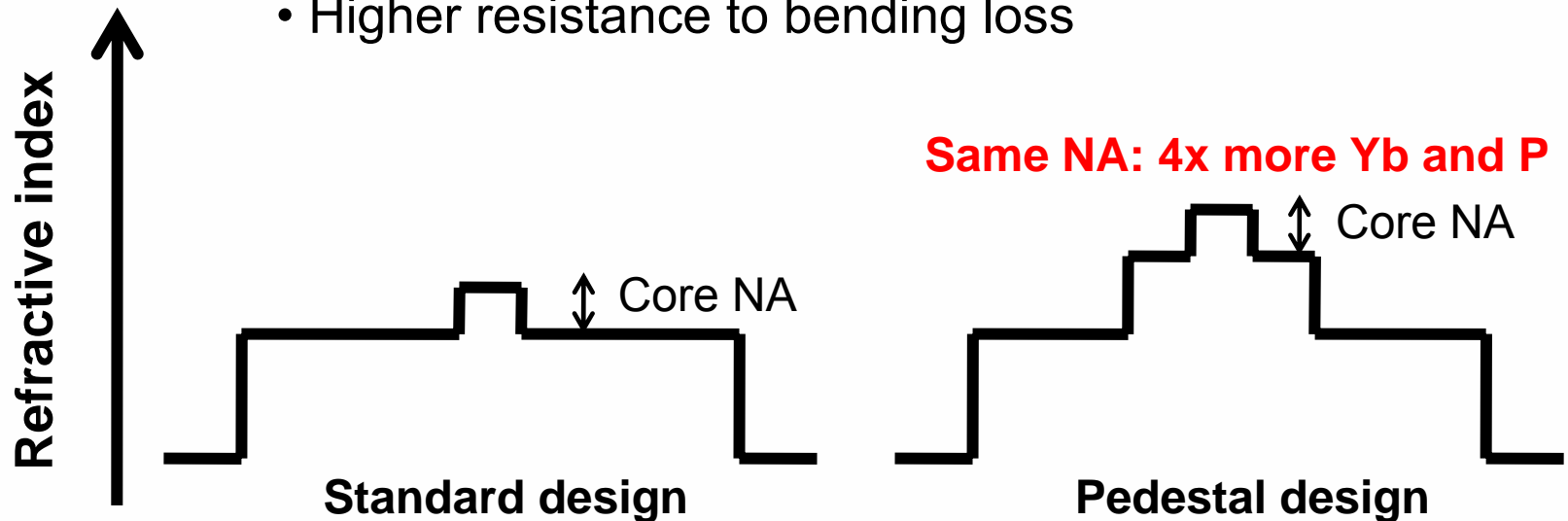


More efficient system with 960 nm pumping
→ due to lower quantum defect
→ decrease pump diode cost



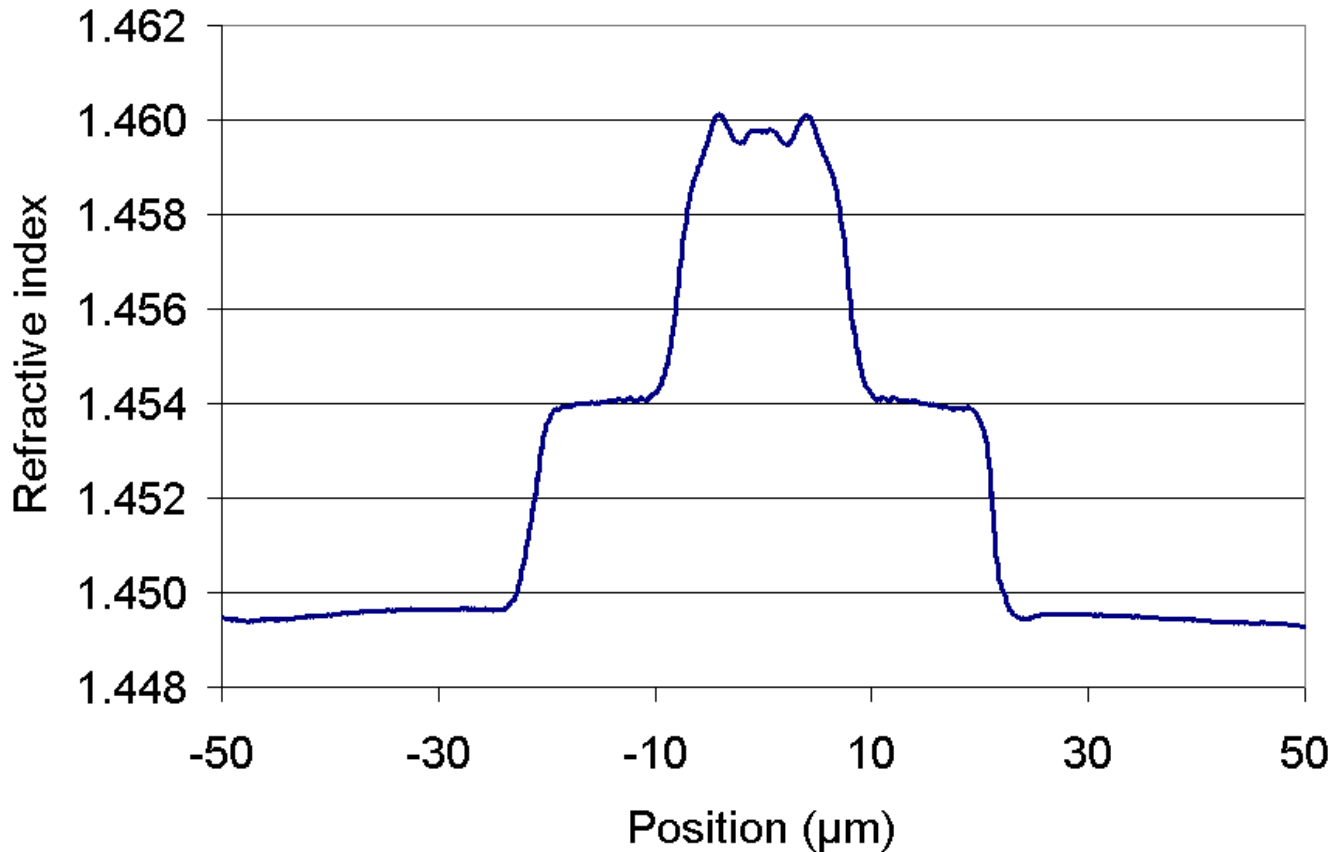
Pedestal design

- Increase doping level : Yb and P
- Maintain a reduced core numerical aperture
 - increase mode area: decrease non-linear effects
 - reduce number of modes: improve beam quality
 - reduce ASE generated
- Spliceable to standard fiber : < 0.1 dB loss
- Higher resistance to bending loss



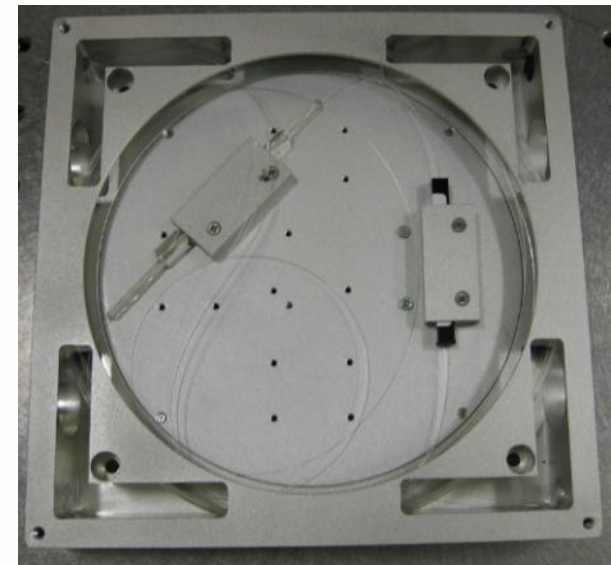
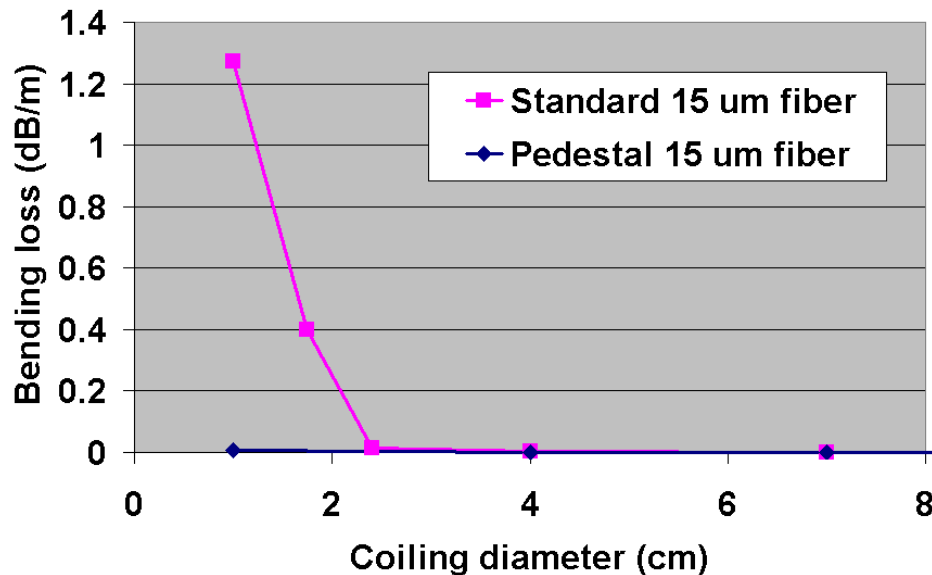
Reference: INO Patent US6941053 2003 and US7068900 2005
Triple-clad rare-earth doped optical fiber and applications

Pedestal phosphosilicate refractive index profile



Bending resistant due to pedestal design

▶ Easier to package



- Benefits of the Pedestal phosphosilicate ytterbium fiber for pulsed fiber application:
 - Highest absorption without photodegradation
 - Reduced non-linearities
 - Flat absorption for more stable pumping
 - Higher slope efficiency with 960 nm pumping
 - Higher energy extraction
 - Less pulse deformation and pulseshaping requirement
 - Higher beam quality
 - Bend resistant design for easier packaging

Thank you for your attention



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