Fiber lasers: The next generation

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and SPI Lasers

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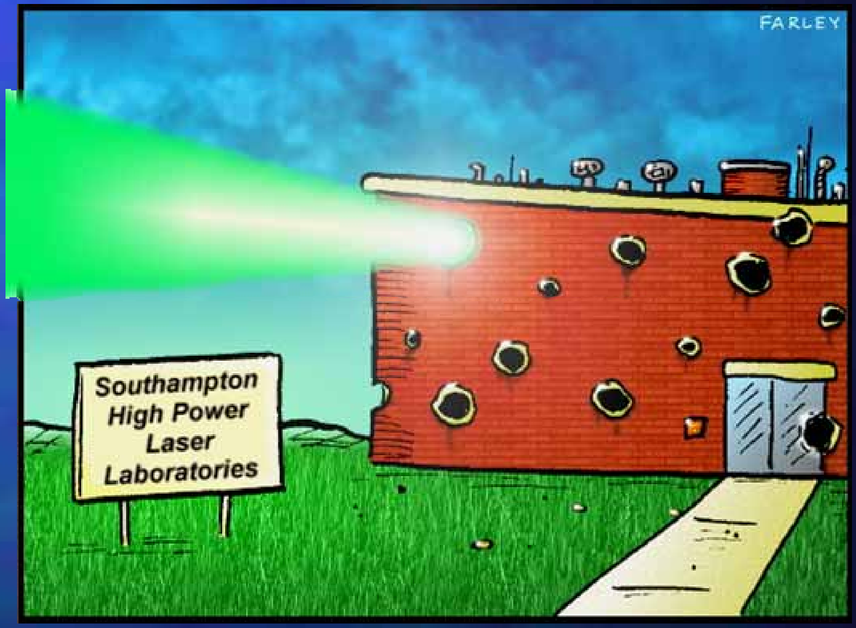
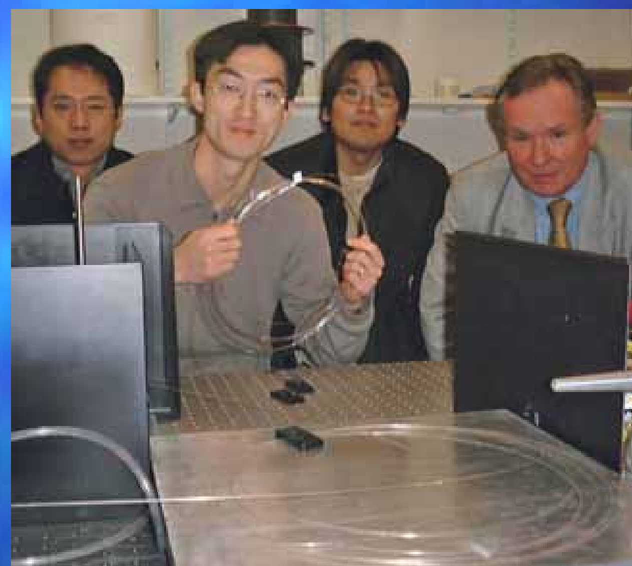
kW fibre laser



No connection!

After the telecoms EDFA
The fibre laser – another fibre revolution?

Fibre laser 1985

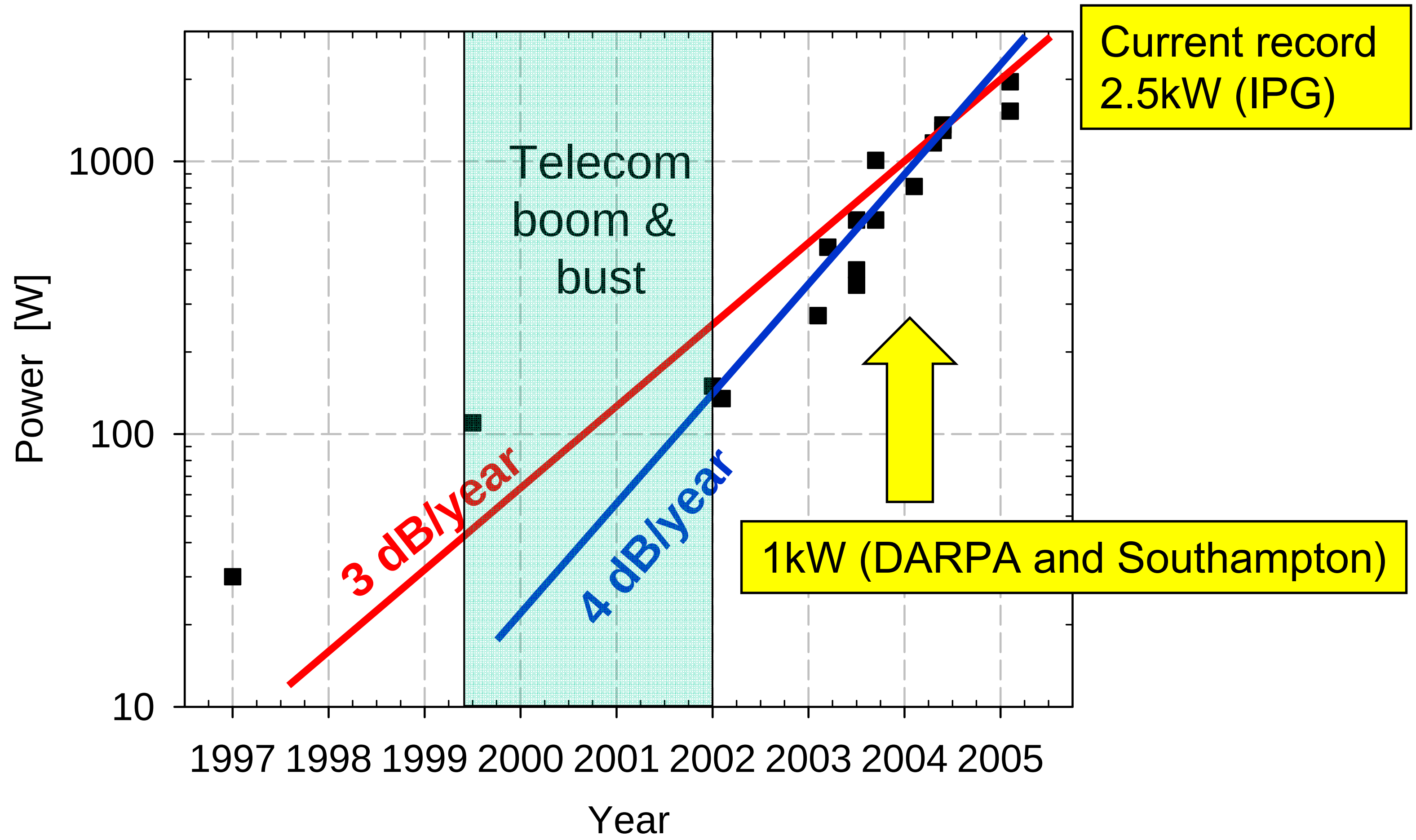


Fibre laser 2006

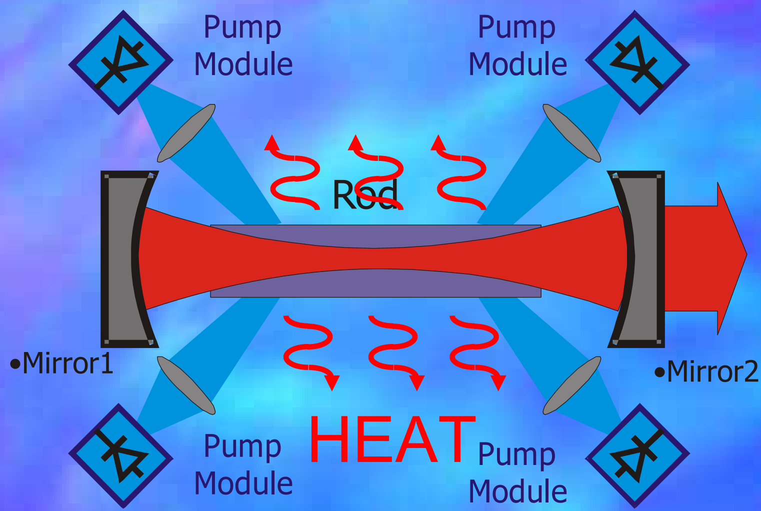
21th anniversary of the invention of the diode-pumped silica fibre laser

Gapontsev's Law
Fiber Laser Power doubles every year

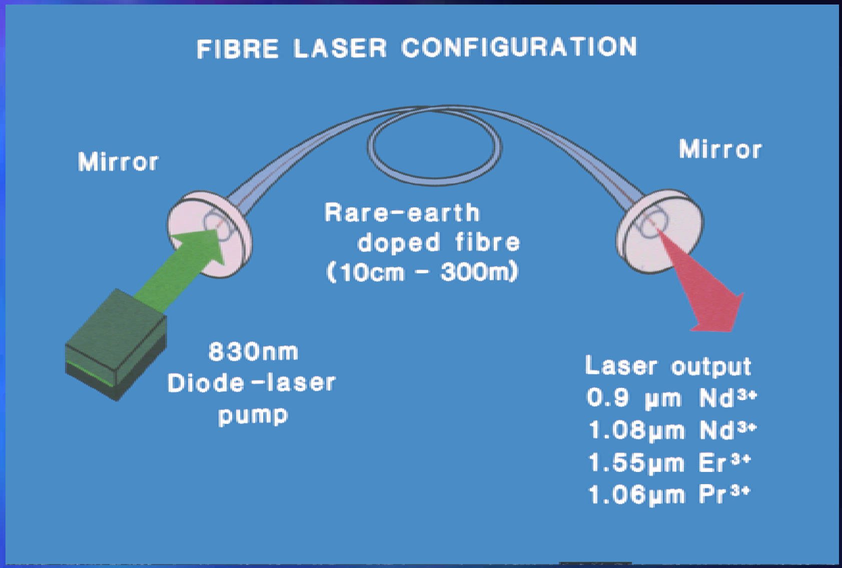
Major Players:
- SPI
- ORC
- IPG
- Jena



Power output limited by available diode pumps, not by fiber



Conventional Laser



Fibre laser (1986)

What is a fibre laser?

Fiber lasers withstand heat because:

- ❑ Large surface area
- ❑ Core is close to heatsink
- ❑ Guided mode resists thermal distortion
- ❑ Silica has excellent heat resistance

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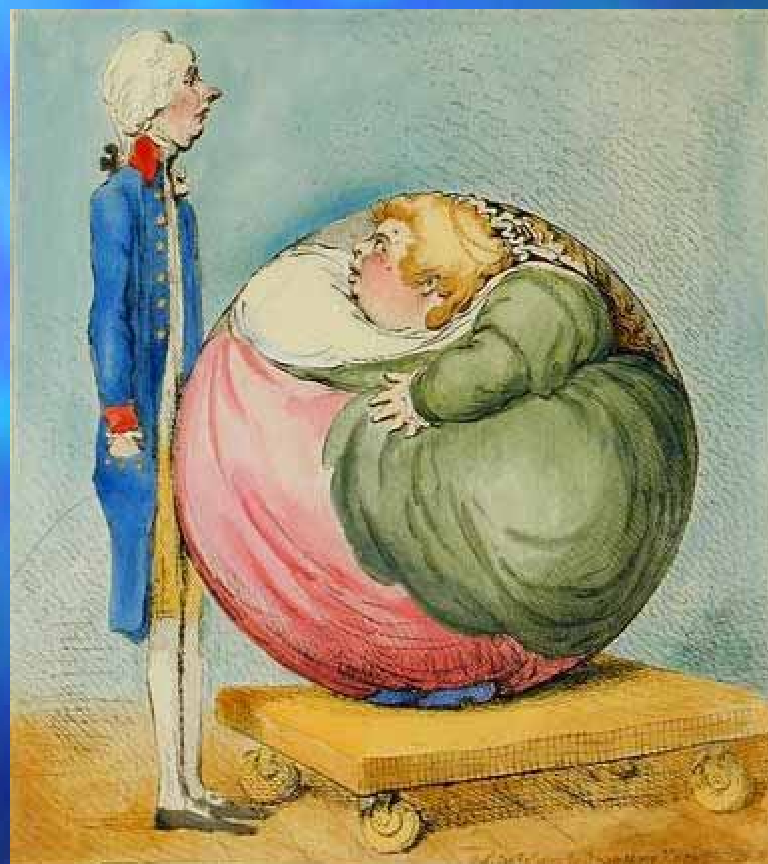
Approaches to heat resistance
Fibre Laser or Disk Laser?
The two newcomers

Long and thin?



Or short and fat?

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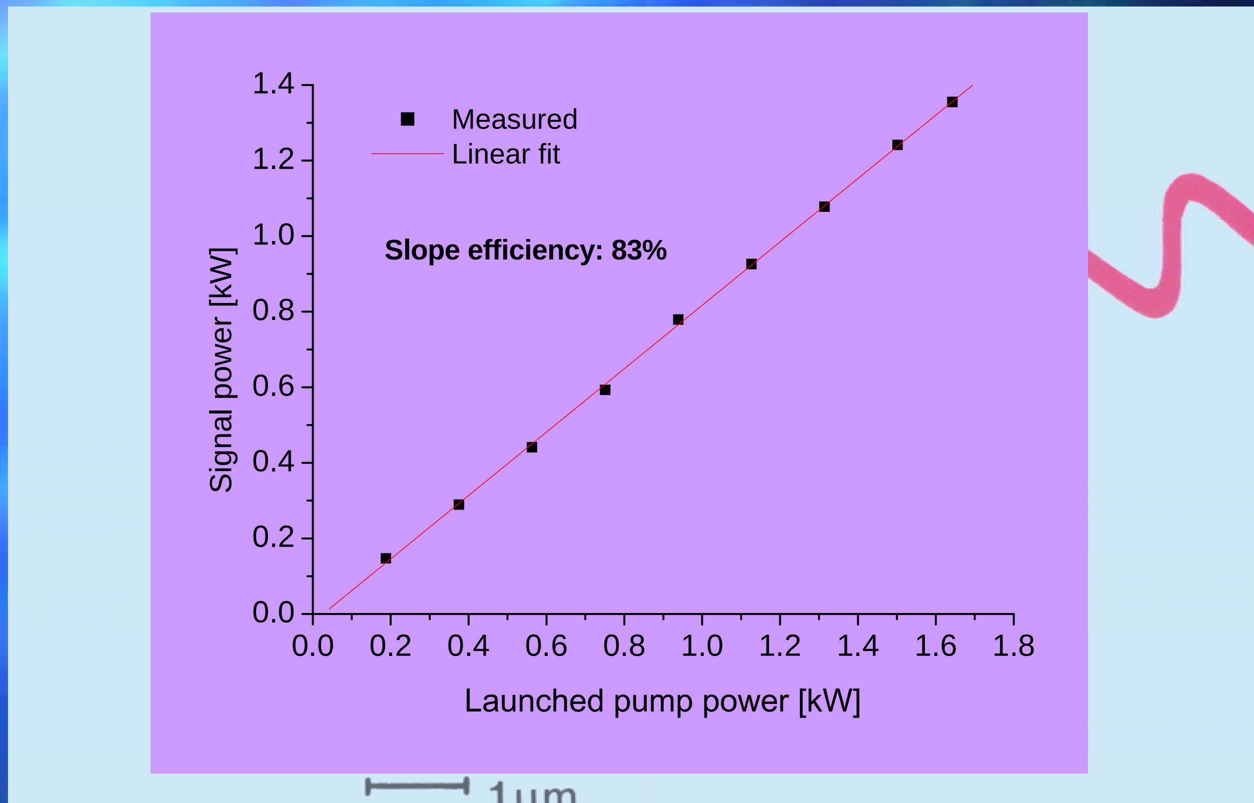
Why can a fiber take so much power?
Scaling the core size for high power handling

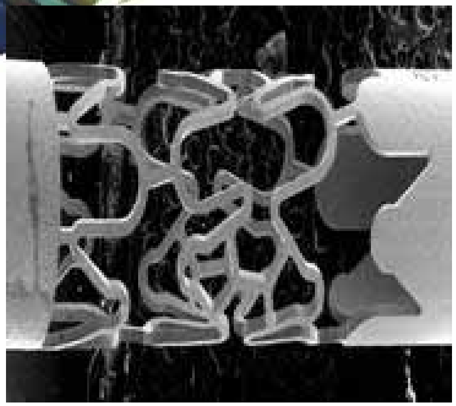


Max power: 1.36 kW @1090 nm
Slope efficiency: 83%
Beam quality M^2: 1.4

- Core ar … telecoms
- Non linear effects and damage scale with core area

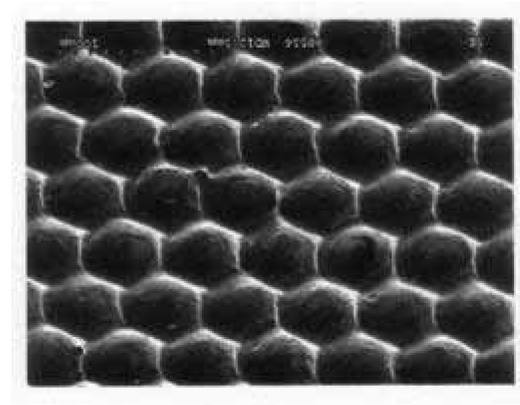
10 kW should be possible!

Unique advantages of fibre lasers



Stent manufacture

Welding



Printing/gravure

Superb beam quality and pointing accuracy at kW's

Excellent pulse stability

High gain permits MOPA's

High efficiency (>30% wall plug)

Ease of thermal management

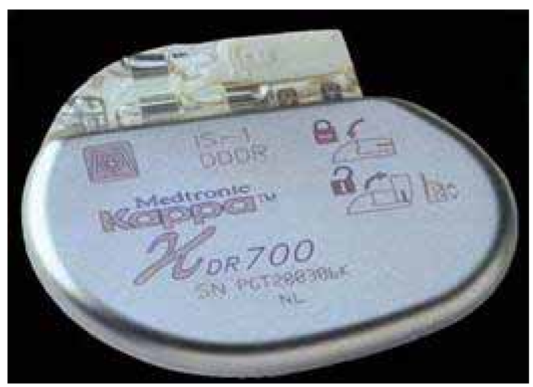
Low-cost medium

Monolithic robust structure

Small footprint

Can be mobile/airborne

Marking

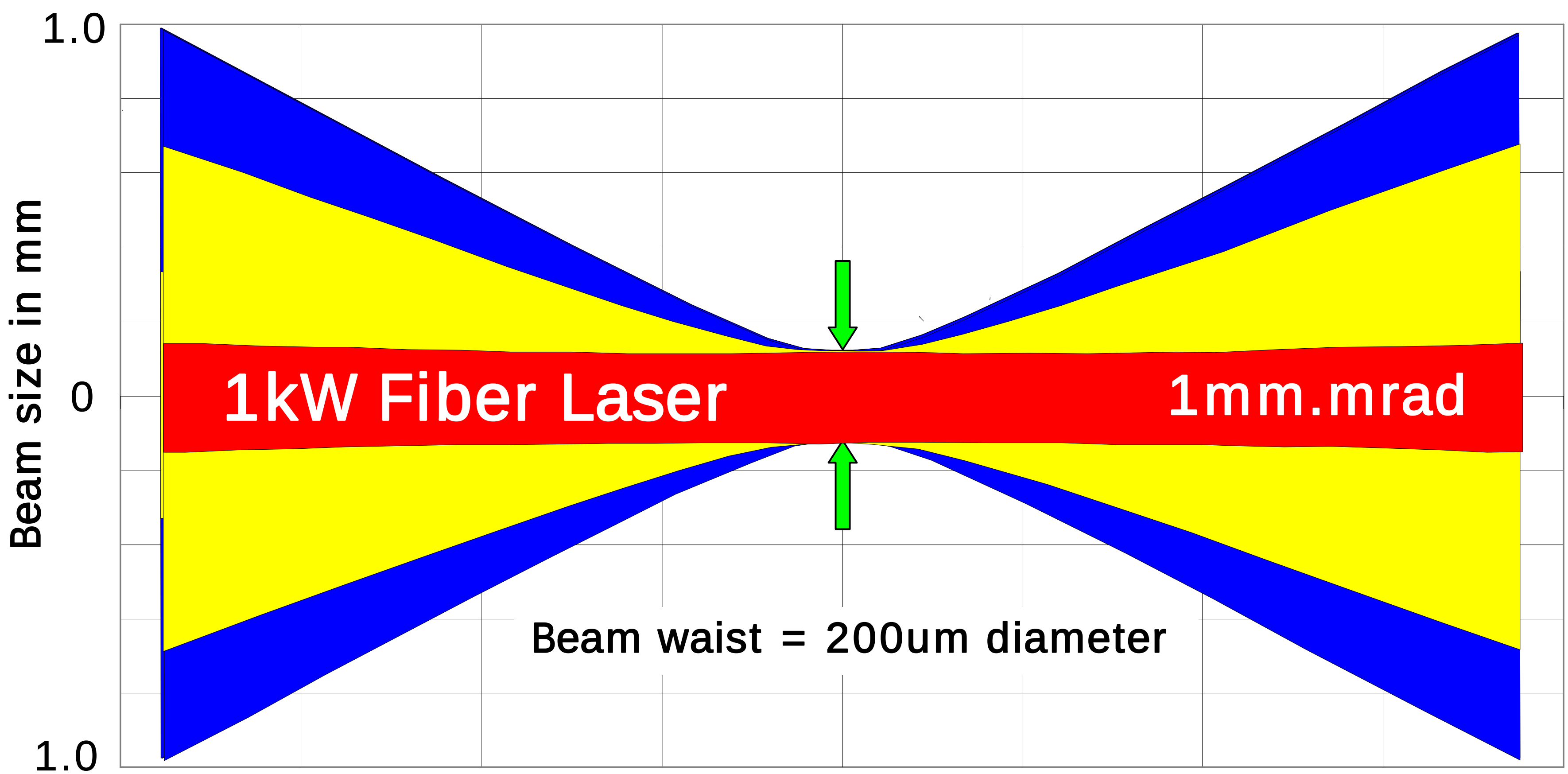


Pacemakers

Cutting

Perfect Beam Quality:

Smaller spot, greater target intensity or larger working distance



Users have never before had a tool
with such beam precision at high power

The advantages of beam quality
Welding at a distance

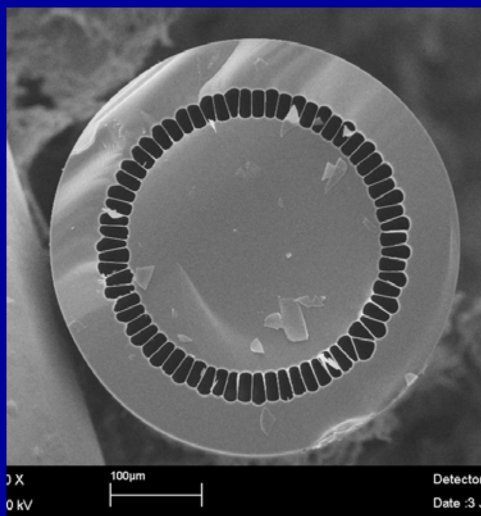
Disadvantages of Fiber Lasers

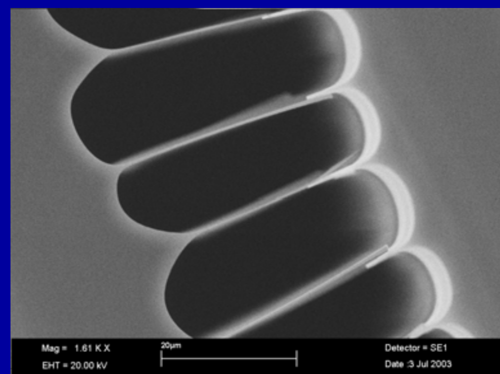
Long and thin gives:

- Very high core intensity – damage, nonlinear limitations for pulsed applications (Brillouin, Kerr and Raman)
- Small active volume – low pulse energy (~10mJ)
- Very high gain – can be difficult to stop spurious lasing
- Photodarkening (if you are not careful!)
- And - are they scalable to very high powers?

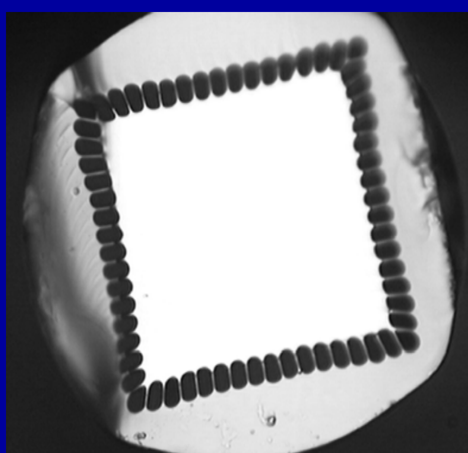
But – we can use all the low cost fiber telecom tricks
Special fibers, filters, compression, couplers, etc

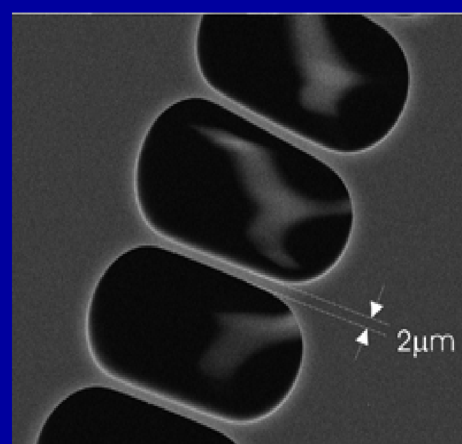
Some fibre tricks:
All silica double-clad fibres for high power





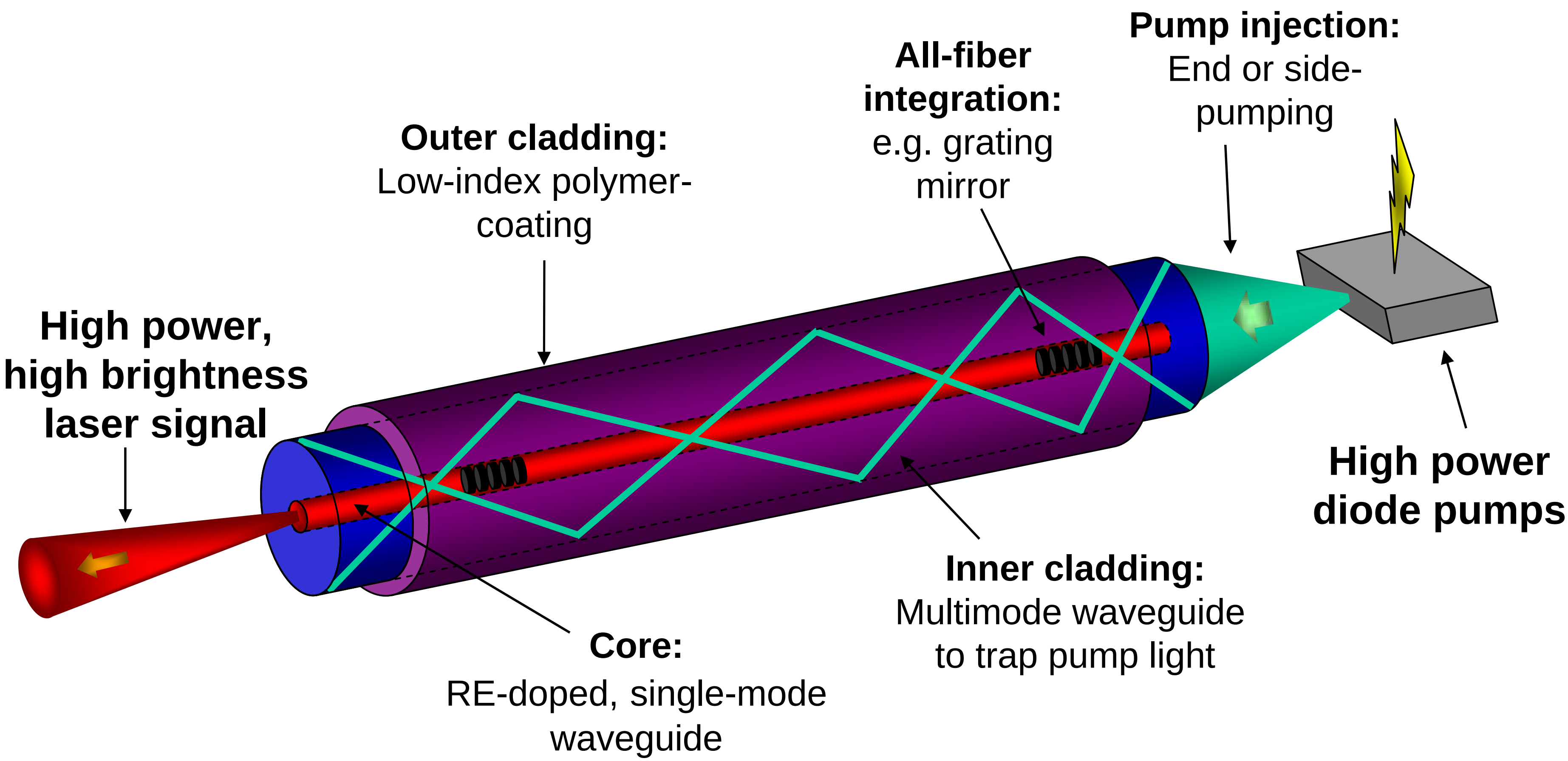
Circular geometry
100nm struts give NA>0.6





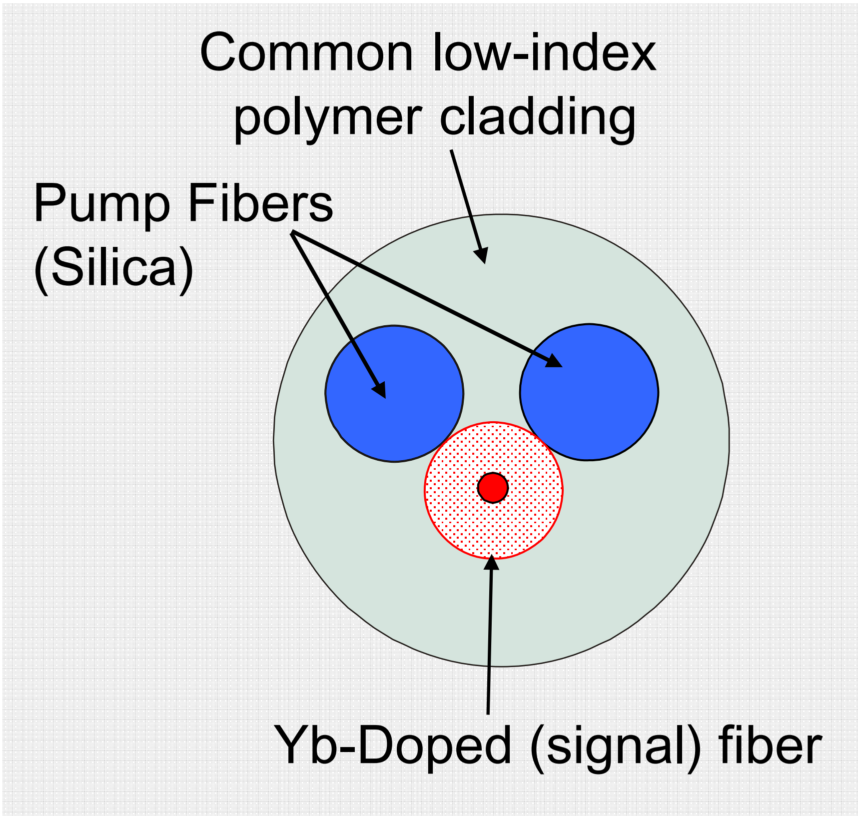
Square geometry
2µm struts give NA=0.1

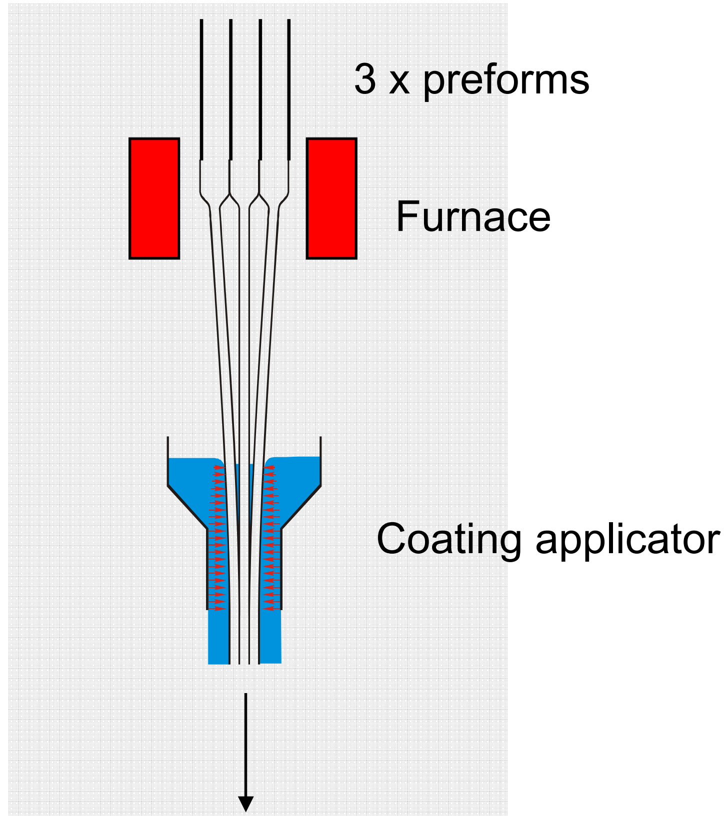
What is a Cladding-Pumped Fiber Laser?

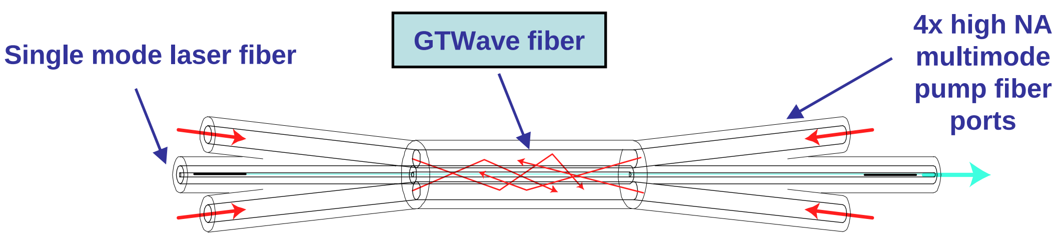


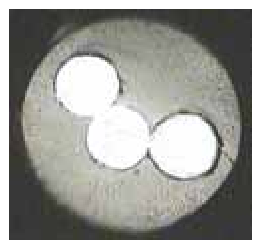
Rare-earth-doped core converts multimode pump energy to high brightness, *diffraction-limited*, signal beam

An elegant solution to pump injection: GTWave^{TM} Double-Clad Fiber



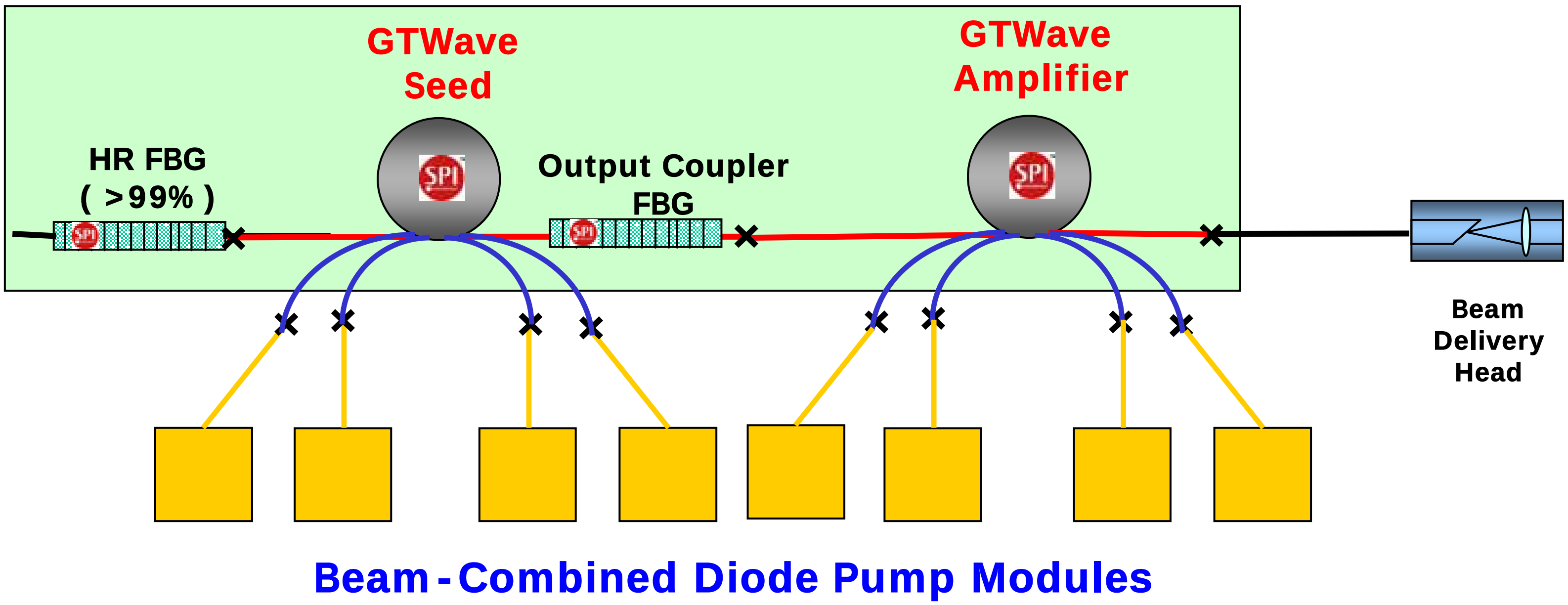






Diam ~1mm

Power Scaling using a MOPA Chain

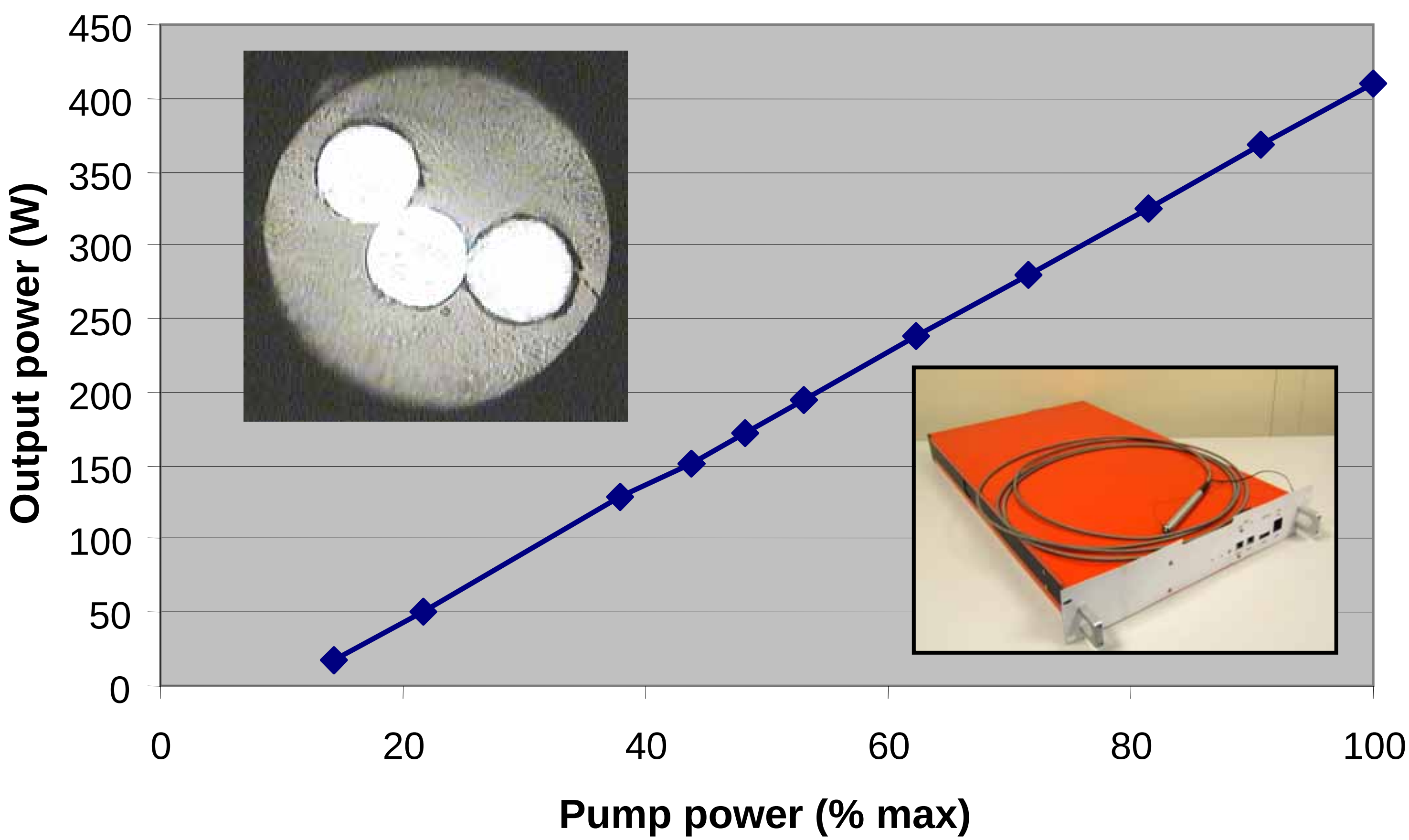


- Add one or more amplifiers
- Retain all-fibre approach
- Scalable to >1000W

Further power scaling currently requires spatial beam combination and loss of beam quality

400W GTWave module

What is the optimum module power before beam combining?



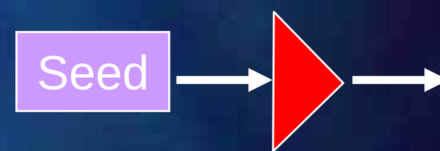
Recent results at Southampton

CW laser Configuration

- 1.36 kW Yb-doped fibre laser (M^2=1.4)
- 633 W PM Yb-doped fibre laser
- 188 W 1550 nm Er/Yb co-doped fibre laser ("eye safe")
- 75 W 2 µm Yb-sensitized Tm-doped fibre laser

CW MOPA Configuration

- 402 W / 511 (PM / Non-PM) single-frequency Yb-doped fibre MOPA
- 151 W 1562 nm single-frequency Er/Yb co-doped fibre MOPA



Pulsed

- 120 W Q-switched Yb-doped fibre laser (0.6/8.4 mJ/pulse)
- 60 W 4 ps 10 GHz Er/Yb codoped fibre MOPA (1550 nm)
- 321 W 20 ps 1 GHz Yb-doped fibre MOPA (1060 nm)

All pumped with 915 - 980nm laser diodes

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More wavelengths:

'Eye-safe' wavelengths > 1.5µm are important

Technology alert

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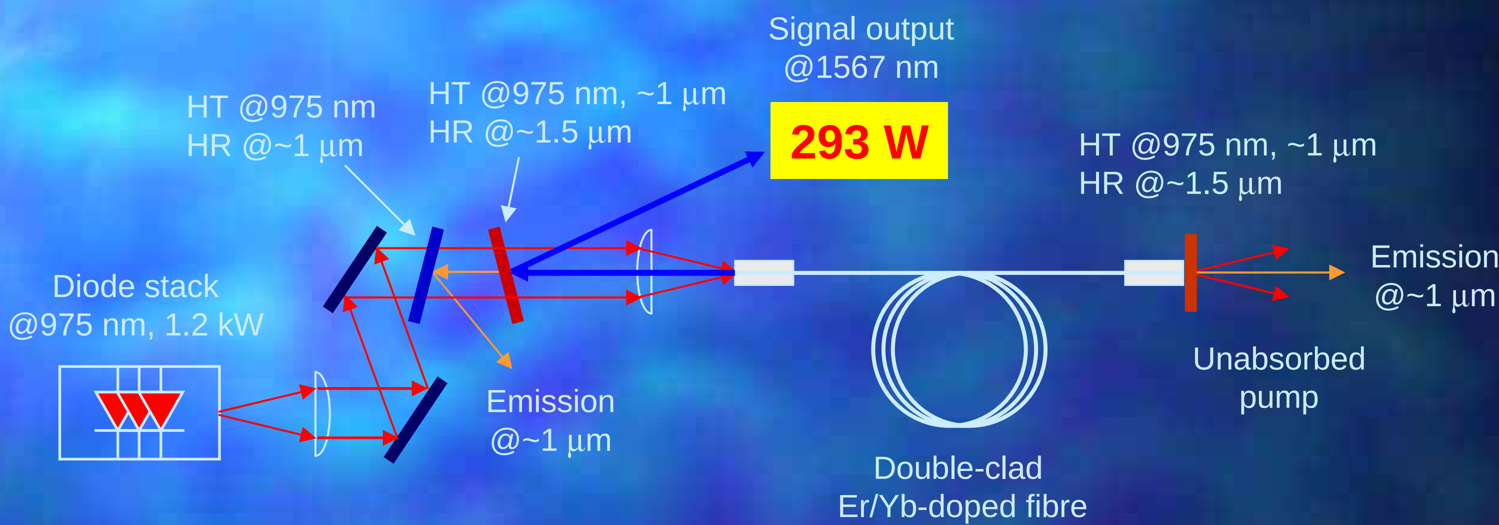
Latest 293W 'Eye-safe' Er/Yb co-doped fibre laser



Er/Yb co-doped core ~30 µm
Fiber OD 600 µm
Length 6 m

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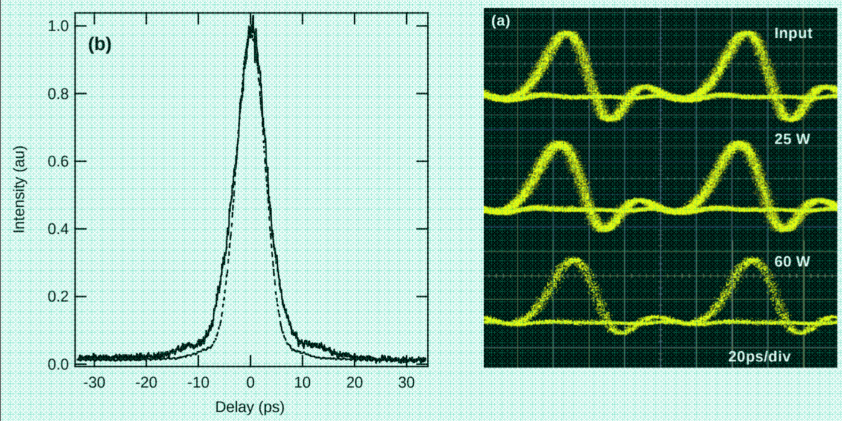
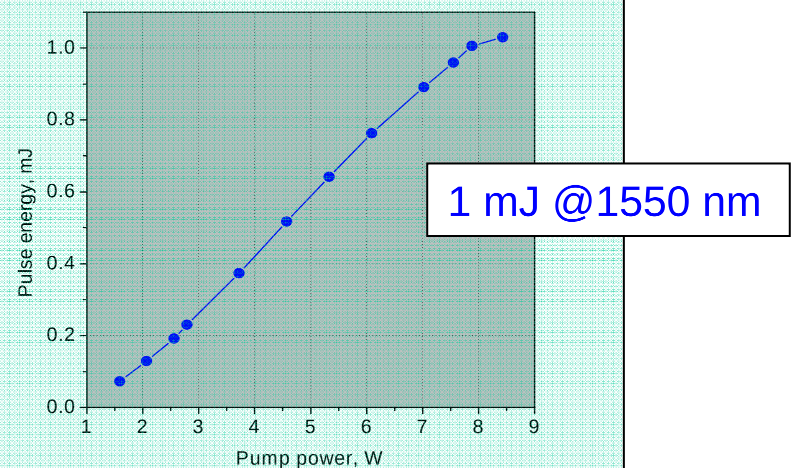
High-power pulsed operation

- Fiber lasers typically limited to a few mJ and ~10kW peak power
- A very large core volume increases stored energy
- Leads to questions over packaging and mode control
- Beam combination may be the answer
- What can we do?

Pulsed 1550nm EYDF MOPA's





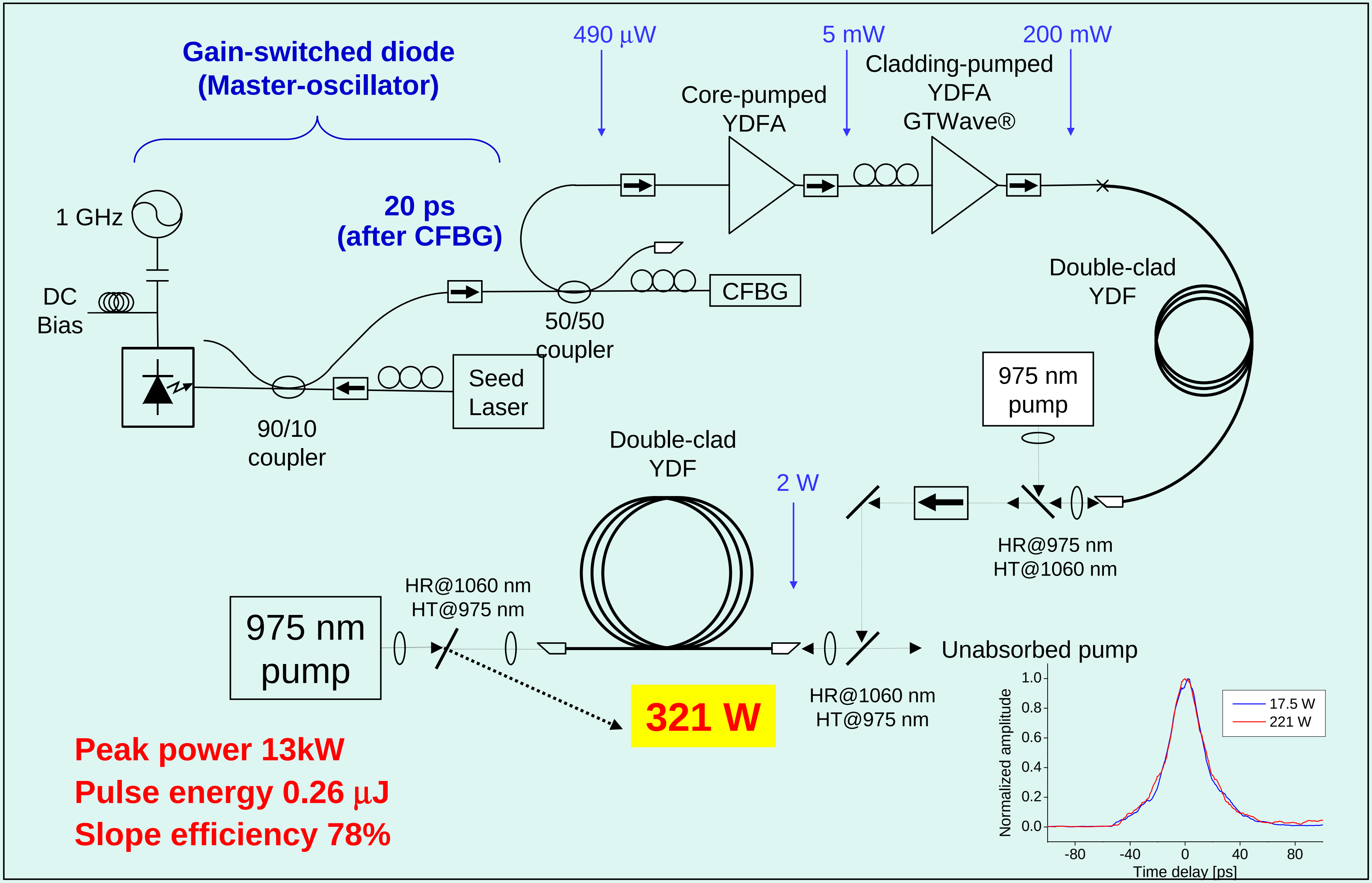
4 ps 60W 10GHz
Amplified gain-switched diode

100ns High-energy
Amplified Q-switched fibre laser

Latest results: 321W (1060nm) 20ps 1GHz and now 300fs

J. Nilsson et al.
Southampton University / Southampton Photonics
July 2004

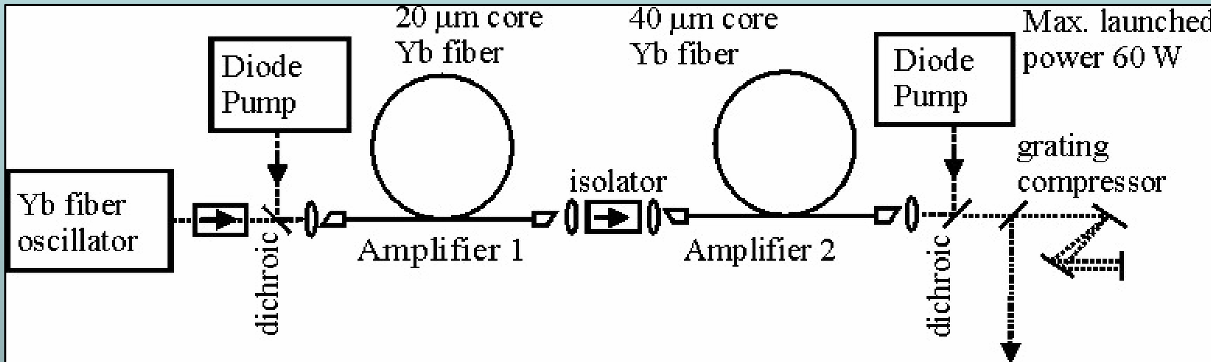
321 W average power, 1 GHz, 20 ps, 1060 nm pulsed fibre MOPA source

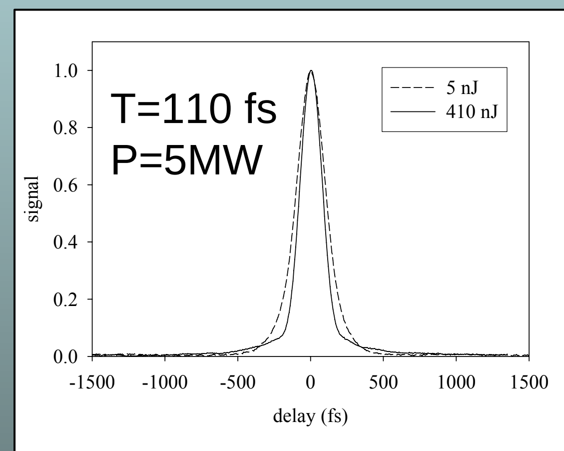


Peak power 13kW
Pulse energy 0.26 µJ
Slope efficiency 78%

For higher peak power we can use pulse compression tricks

Parabolic pulse amplification (fs)





- **Broad gain bandwidth of Yb allows amplification of ultrashort (~100fs) pulses**
- **Parabolic pulse formation exploits fiber gain/nonlinearity to give high-power linearly-chirped pulses that can be compressed**

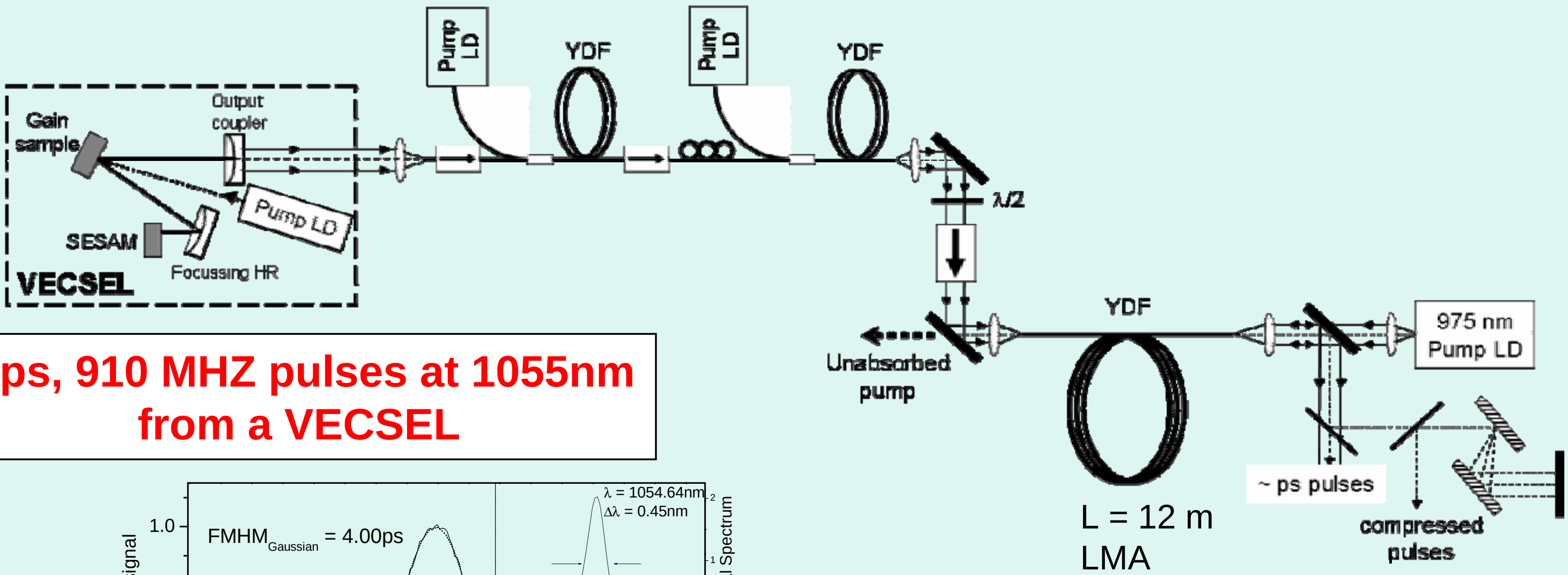
>5MW peak power ~100fs pulses at 25W average power

Pulsed: Higher average power

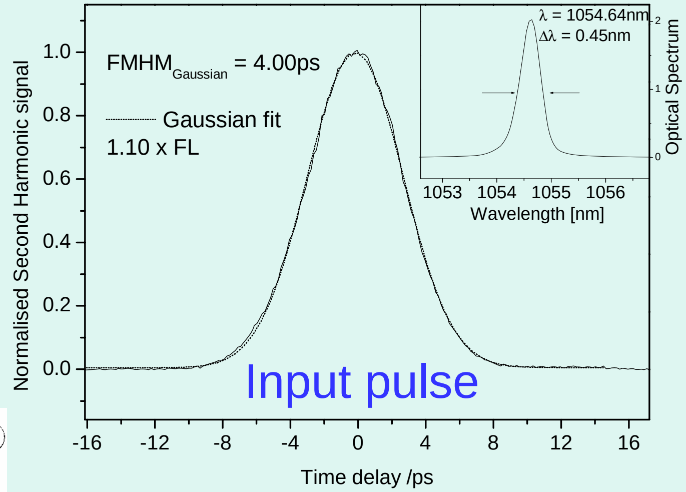
160W 300fs MOPA

Passively mode-locked 1055-nm VECSEL
and Yb-fiber power amplifier

Amplified VECSL 160W fs source



4 ps, 910 MHZ pulses at 1055nm from a VECSEL

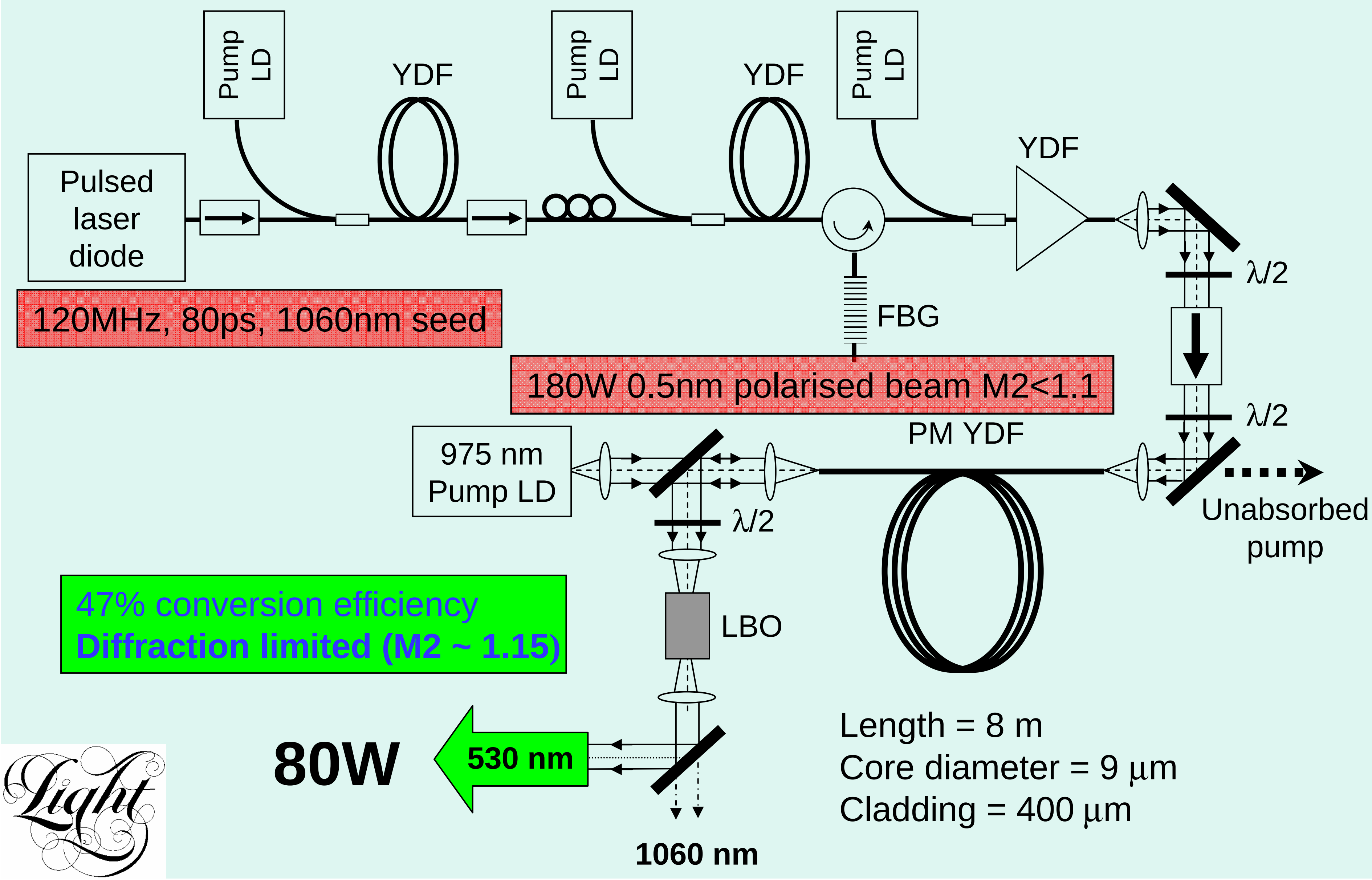


Fiber amplification up to 160 W plus temporal compression to 330 fs

More colours

80 W average power green from a frequency-doubled picosecond Yb-doped fiber MOPA source

80W Green laser



The $300 laser lamp for projection displays?

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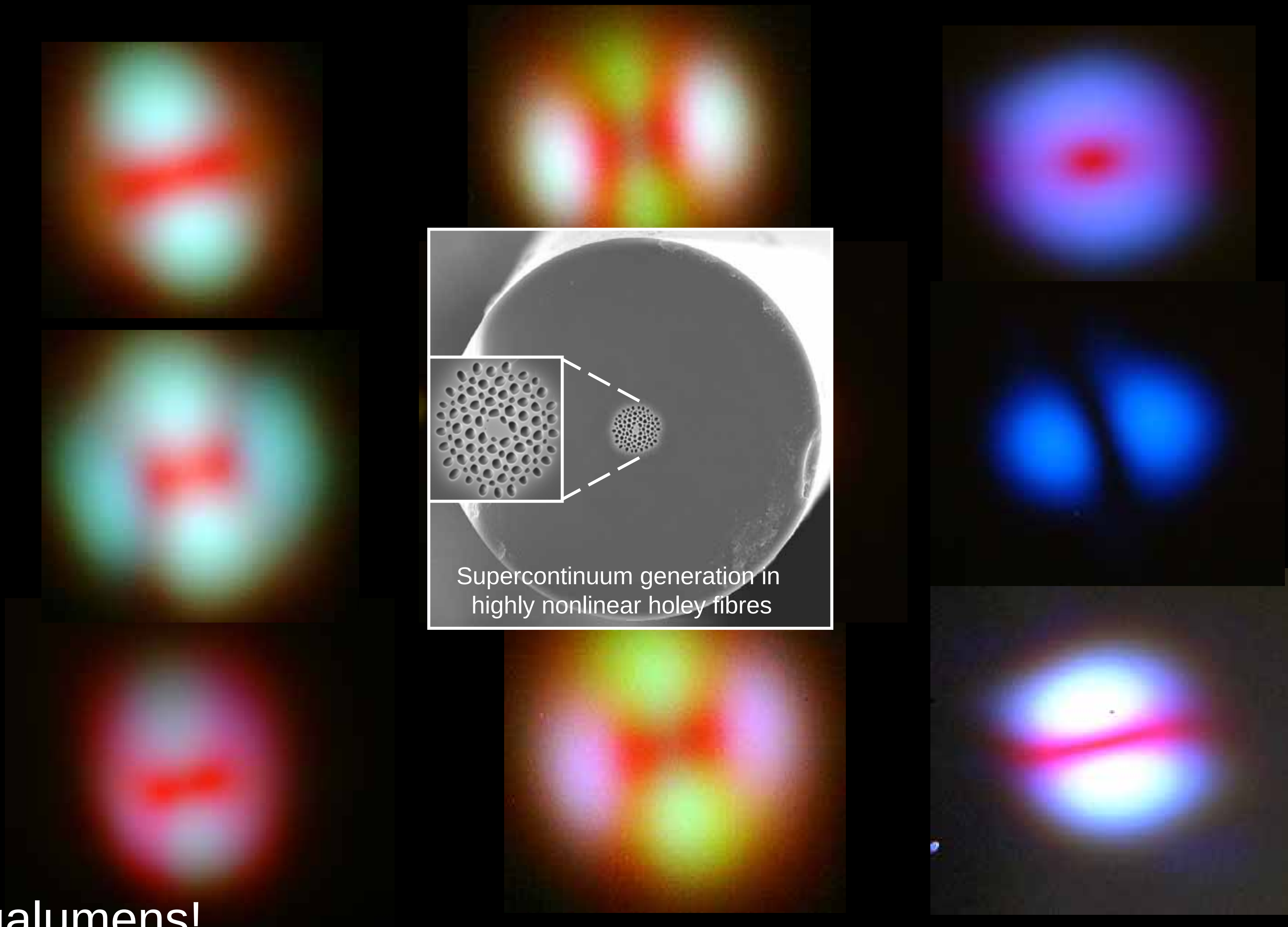

Supercontinuum generation in highly nonlinear holey fibres

Megalumens!

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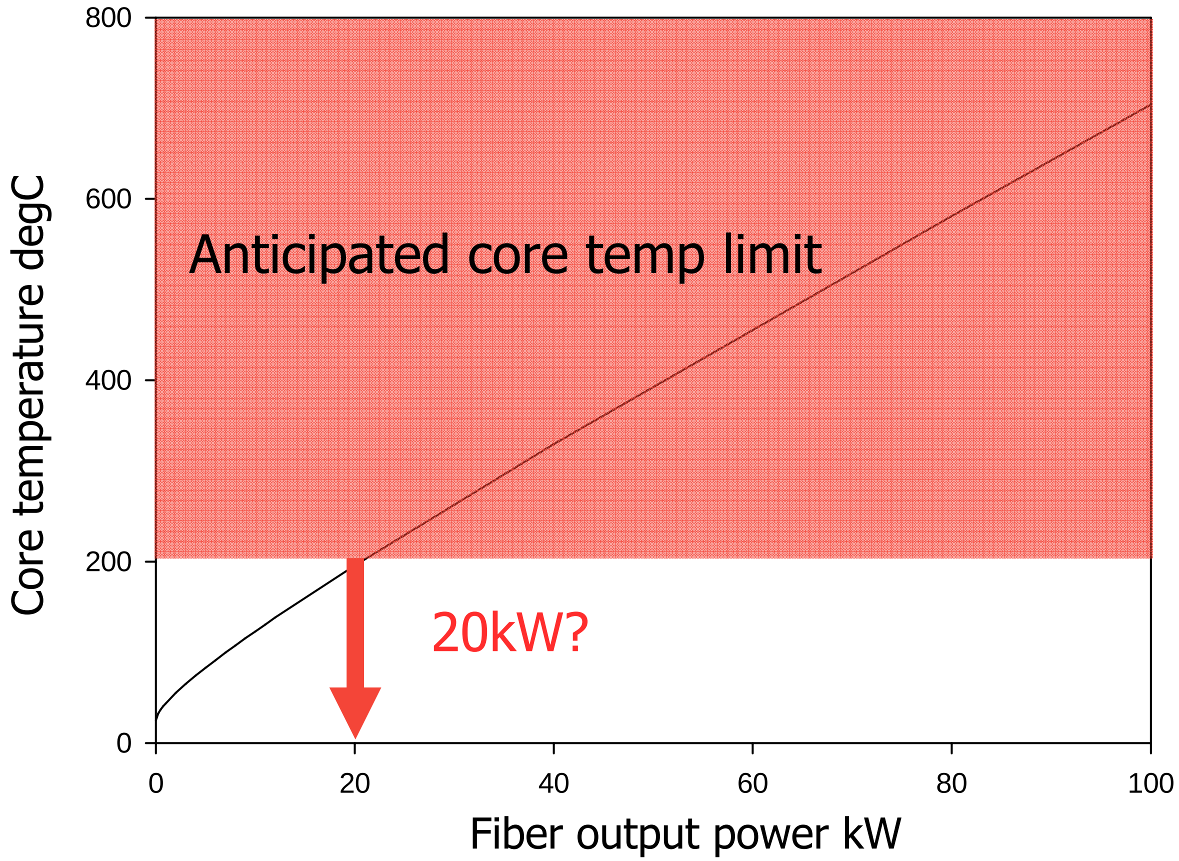
The Power Limits

How High Can We Go?

Thermal limits of single fiber lasers

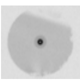


Assumptions:

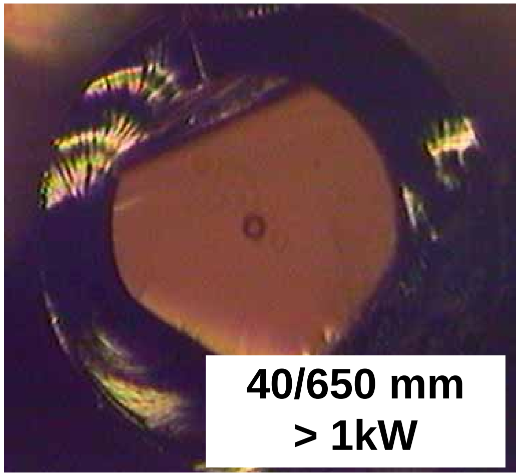
- JAC fiber, NA~0.44, 20μm air-gap.
- Surface temperature maintained at 25C by cooling
- Uniform heat dissipation along 10m device length
- Core and Inner Cladding dimensions scaled to maintain pump and signal intensities at a known safe level

Further Power Scaling: Fiber Design Is The Key

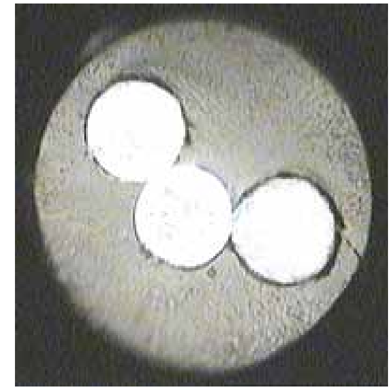
Size matters!

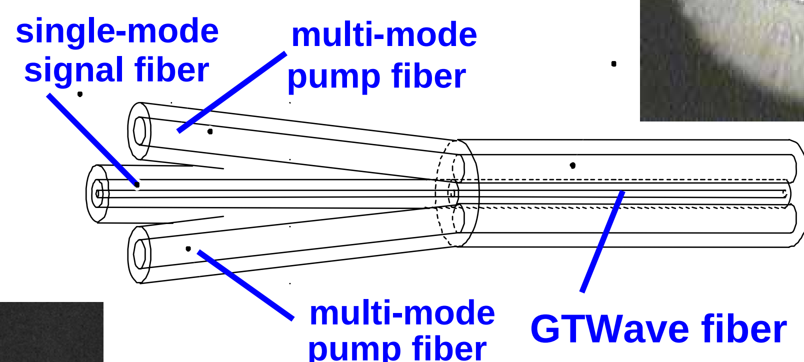


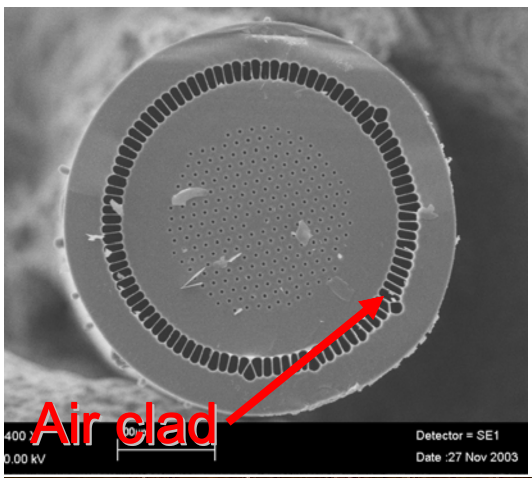
9/125 mm
100W

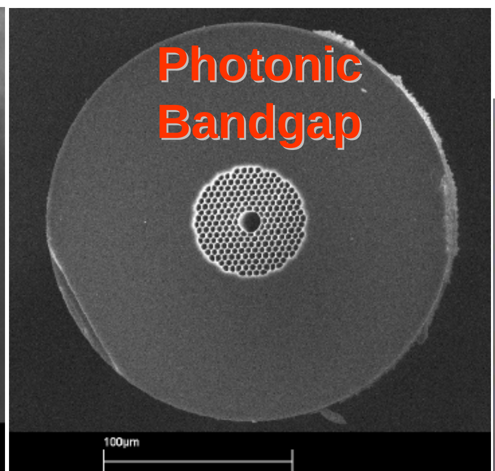


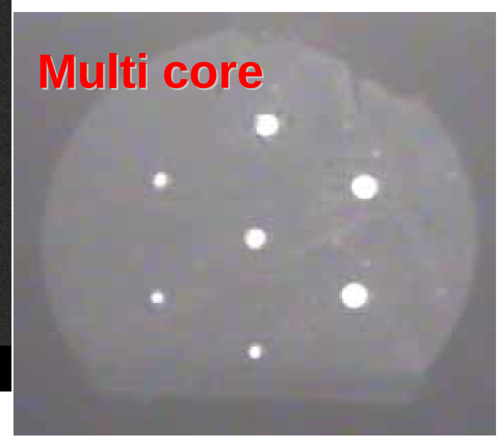
GTWave multi-port fiber

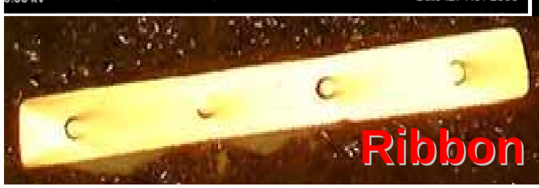












Towards a Megawatt CW?

- Fiber lasers are ideal for power scaling by beam combination because of their near-perfect beam profiles and coherence
- Important to maintain beam quality (M^2~1)
- Wavelength beam combination for industrial?
- Coherent beam combination looks attractive for military (Requires single-frequency and polarised beams)

Where have we got to?

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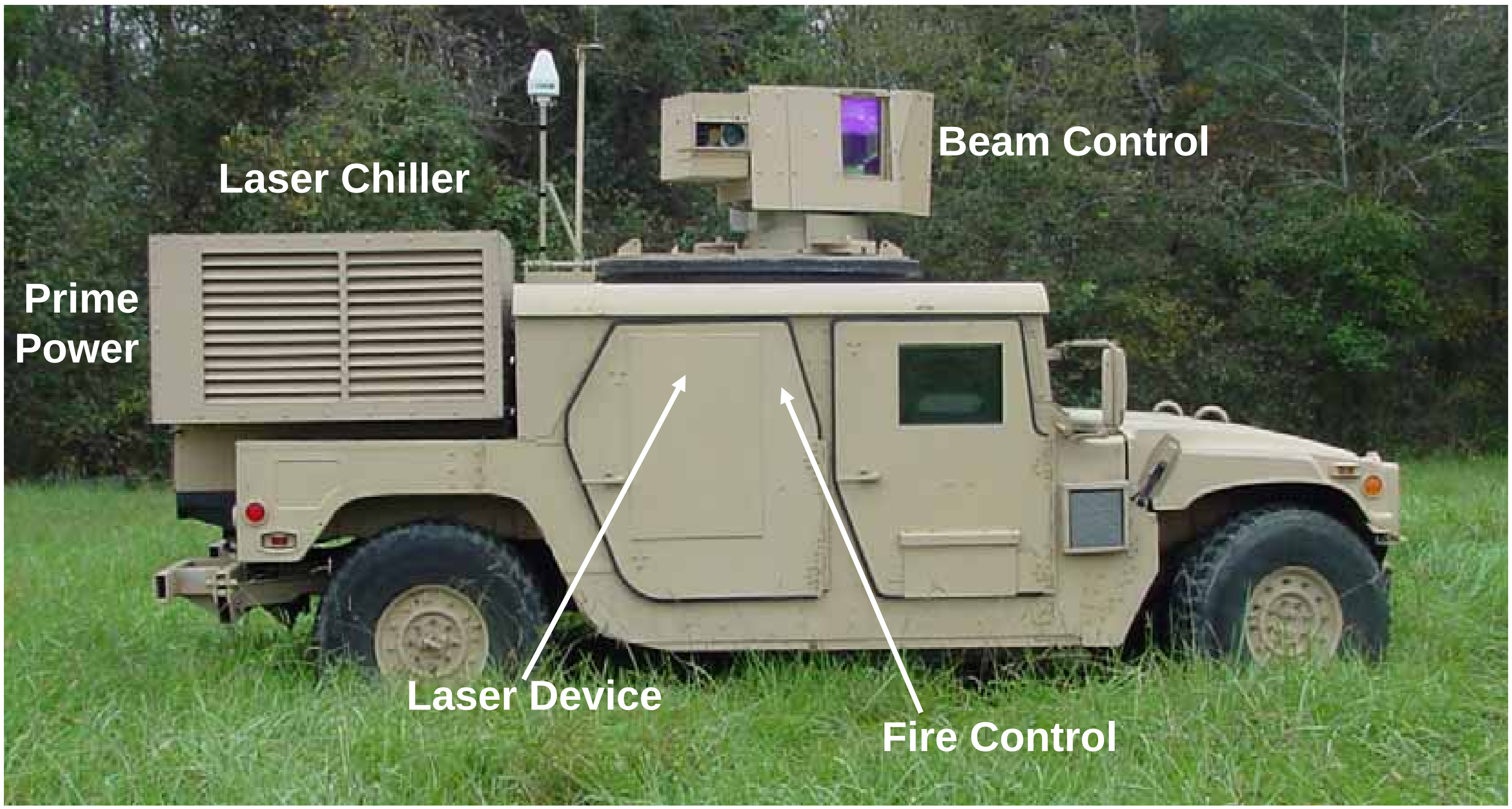
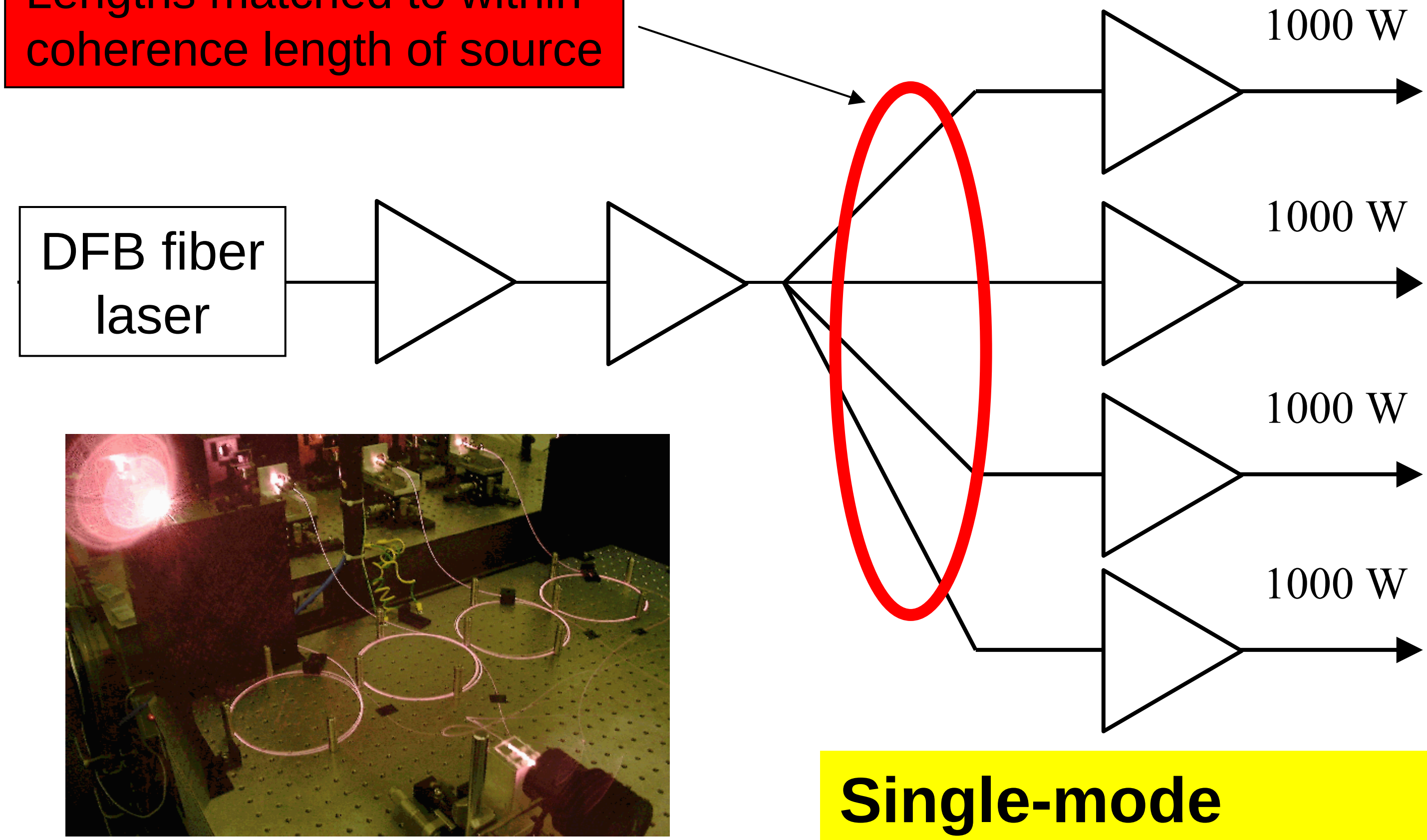
Who is interested?



Future Steerable 1 MW Design?

Multi-path MOPA

Lengths matched to within coherence length of source

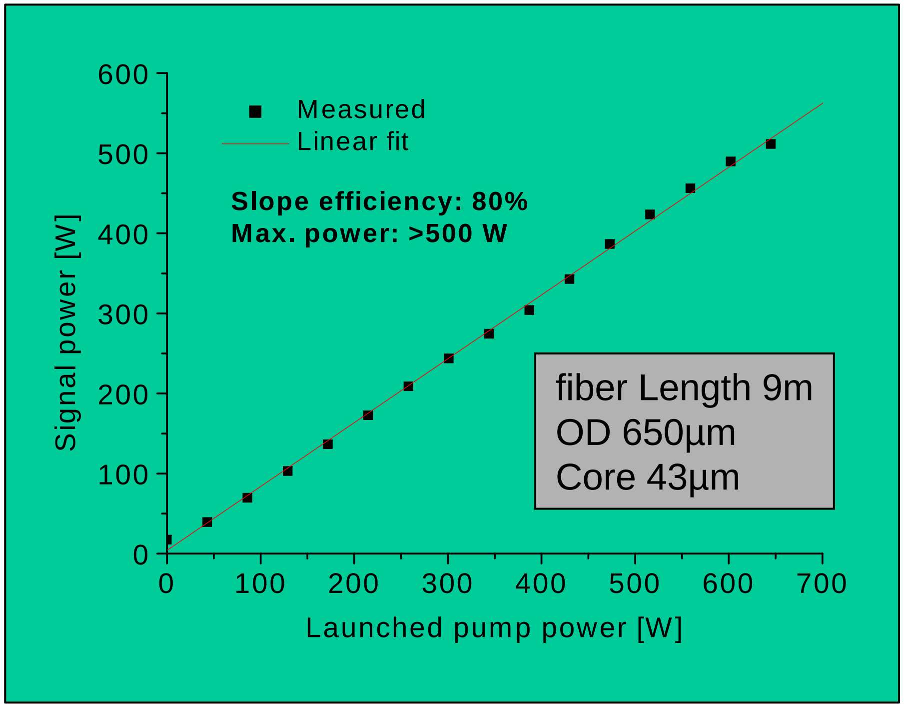


Phase-coherent output for synthetic-aperture source

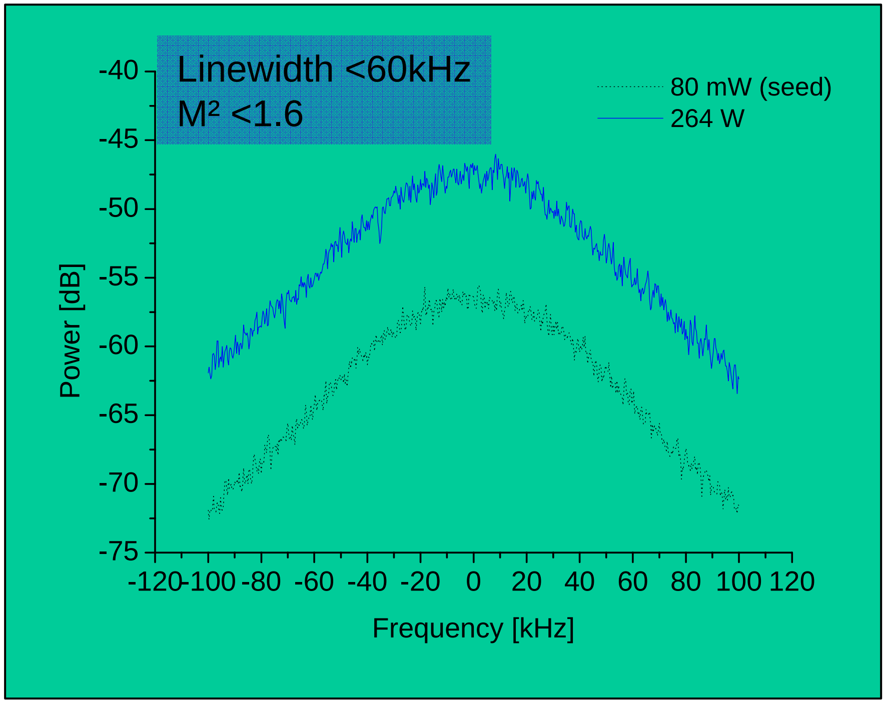
Single-mode
Single-frequency
Single-polarization

511W Single-Frequency MOPA

Output Power

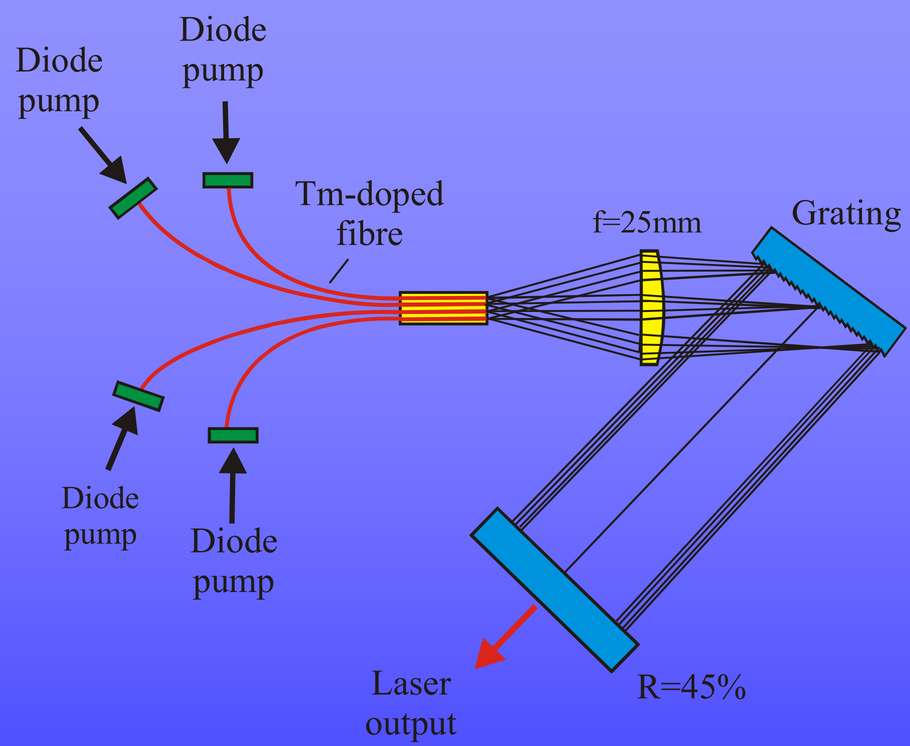


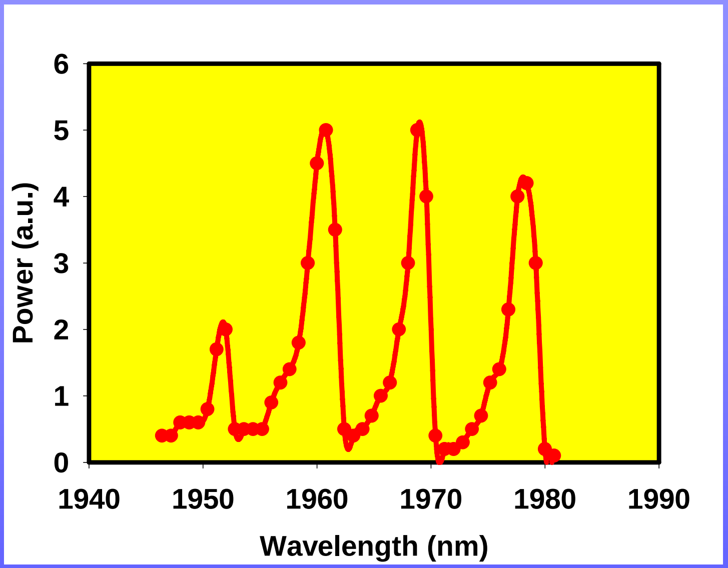
Backward Signal Power



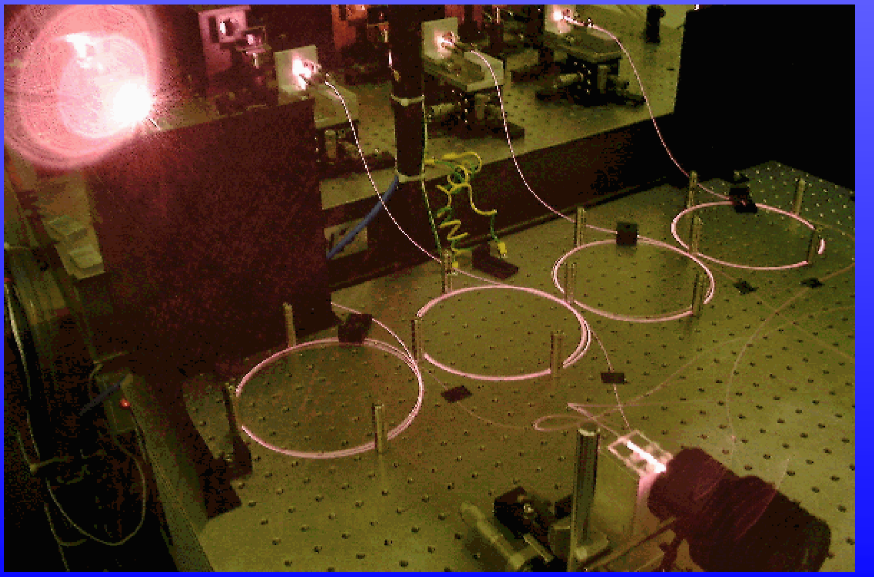
But why was the Brillouin limit so high?

Wavelength-combining for high power industrial lasers?





- Could combine tens of fiber lasers as in telecom DWDM
- Retains beam quality
- An advantage to have numerous pump diode injection points



Conclusions: A view from the cutting edge

- Fibre lasers are challenging conventional laser technology and continue to gain market share
- Fiber circuitry provides a unique high-gain environment for robust designs. Stable, reliable and reproducible
- The single-fiber laser will reach 10kW sooner than you think!
- MOPA configuration allows highly-controllable pulse and single-frequency operation
- With beam combination, the ideal laser for both industrial and defence applications

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