High-power narrow-linewidth all-fibre amplifiers for power scaling applications

Adrian Carter, Francis Corbin, David Machewirth, Bryce Samson, Kanishka Tankala and Michael O'Connor
Nufern, 7 Airport Park Road, East Granby, CT 06026, USA
Phone: +1-860-408-5000, Fax: +1-860-408-5080
Email: acarter@nufern.com

Introduction:

Recent advances in diode technology and the development of ytterbium-doped Large Mode Area (LMA) fibres have facilitated the demonstration of kilowatt-level fibre lasers [1,2,3]. Scaling to higher powers whilst maintaining beam quality, using beam combining schemes, requires linearly polarized narrow-linewidth lasing outputs. Typically however these experiments have been characterized by broadband (typically greater than 10nm) linewidths. At the same time however, the higher stimulated Brillouin (SBS) threshold in these LMA fibres has enabled greater than 200W of single frequency output power based on master oscillator fibre amplifier configurations [4,5] and beam combining schemes have been demonstrated with the intention of taking these building blocks to the level of 10's of kWs [6,7]. Building reliable field-deployable systems requires all-fibre, high-power, single-frequency LMA amplifiers. In this paper we discuss the recent progress on standardising LMA fibres, pump sources, pump combiners and high-power end-caps required for such amplifiers. Furthermore, we present results for a 220W LMA single-frequency all-fibre amplifier based on an LMA 20/400 fibre geometry.

Experimental Results:

LMA fibres with core diameters of 20-30µm and NAs of around 0.06 have become the industry standard for high-power laser and amplifier devices because of their ability to deliver good beam quality through preferential modal excitation [8] or coiling induced higher-order mode losses [9]. The addition of PANDA-type stress elements to make PM-LMA fibres has added to the application space for the fibre technology and enabled high power linearly polarised fibre amplifiers both in the cw [10] and pulsed regimes [11]. The availability of fibres with large claddings (400µm) and high NAs (0.46) in conjunction with high brightness pump sources have featured in many of the high power results. More particularly, they have facilitated the amplification of single frequency sources into the high power regime (hundreds of Watts) and as such are potential building blocks for coherent beam-combining [6], and fibre array phase-locking [7] experiments.

An indicator of maturity in the LMA fibre technology is the availability of standard support components with LMA compatible fibre pigtails; including the multimode pump combiners which also serve as signal multiplexers. These components are available with input fibres compatible with industry standard pigtail fibres on commercial high power diodes. For example, the (6+1) to 1 design consisting of LMA compatible 20/400 double-clad fibre on the output of the combiner with six 200/220 0.22 NA pump delivery fibres on the input side are commercially available. Furthermore high-brightness, fibre-coupled, pump diodes compatible with pump combiners are now commercially available with industrial-grade reliability. These advancements in high-brightness pumps and high-power pump combiners have enabled the high-power, all-fibre design shown in Figure 1 below.

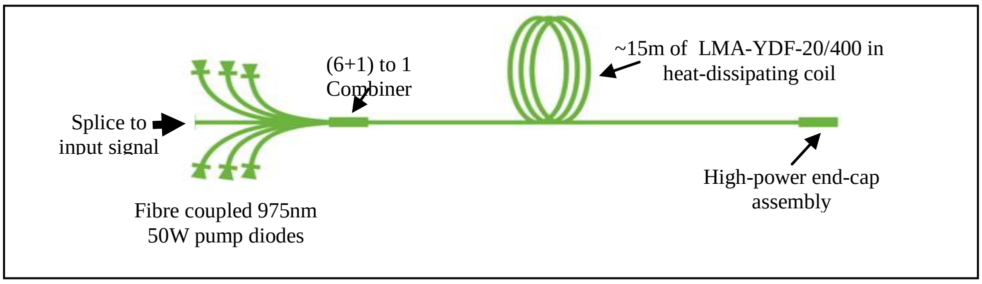

Figure 1: Schematic of the all-fibre 200W LMA amplifier.

In our experiment we employed six 50W fibre-coupled pump diodes (200/220 0.22NA delivery fibre) to provide approximately 300W of 975nm pump power without the need of any free-space optics. The diodes were water-cooled to ensure good pump wavelength stability. We used around 15m of a commercially available LMA-

YDF-20/400 ytterbium-doped double clad fibre as the amplifying medium. The heat-dissipating aluminum coil had a diameter of 10cm to ensure near-diffraction limited beam quality, through the preferential loss of higher-order transverse modes, and was mounted in intimate contact with the solid aluminum box, the base of which was water-cooled. At the output of the fibre device an angled end-cap was employed to both minimize back-reflection into the amplifier and to expand the mode sufficiently to ensure that the signal intensity was well below the surface damage threshold for the air-glass interface. Experimental results for the system are presented in Figure 2, and demonstrate the applicability of these high-power LMA all-fibre amplifiers to output powers greater than 200W cw. Although the power level is well below that demonstrated with broad linewidth fibre lasers and amplifiers [1-3], these LMA devices are applicable to amplifying single-frequency input signals with coherence lengths suitable for further beam combining into the multi-kW regime [6].

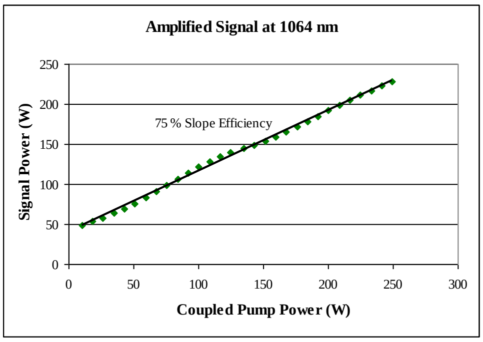

Figure 2: Amplified signal power as a function of coupled pump power (left) from the 19" rack mounted LMA all-fibre amplifier (right).

Conclusion:

LMA fibre technology has become an established means of power scaling fibre lasers and amplifiers. As the basic fibre design has become standardised, this has encouraged component manufacturers to design and build high power LMA compatible devices. We have demonstrated an example of this, by constructing a pump-power limited high-power (220W) all-fibre amplifier based on LMA fibres and components. Such amplifiers are suitable for amplifying single frequency input signals into the 200W regime and then potentially beam combining into the multi-kW regime. Furthermore, as higher brightness fibre-coupled pumps continue to become available this should enable further power scaling.

References:

[1] C-H Liu *et al*, "810W continuous-wave and single transverse mode fibre laser using 20um core Yb-doped double-clad fibre", Electronics Letters., **40**, pp.1471-1472, 2004.
[2] Y. Jeong *et al*, "Ytterbium doped large-core fibre laser with 1.36kW continuous-wave output power", Optics Express, 12, **25**, pp.6088-6092, 2004.
[3] D. Gopentsev *et al*, in "Fibre Lasers II: Technology and Applications", Ed: by L.N. Devarsala, A. Brown and J. Nilsson, Proc. SPIE, **5709** (SPIE, Bellingham, WA), 2005, see also www.ipgphotonics.com.
[4] A. Liem *et al*, "100W single-frequency master-oscillator fibre power amplifier", Optics Letters, **28**, pp.1537-1539, 2003.
[5] Y. Jeong *et al*, "Single-frequency single-mode plane-polarized ytterbium-doped fibre master-oscillator power amplifier source with 264W output power", Optics Letters, **30**, pp.459-461, 2005.
[6] M. Wickham *et al*, "High Power Fibre Array Coherent Combination Demonstration", Proc 16th SSDLTR, paper HPFib-5, 2003.
[7] M. Minden *et al*, "Self organized coherence in fibre laser arrays", Proc. SPIE, **5335**, pp.89-97, Fibre lasers; Technology Systems and Applications, 2004.
[8] M. Fermann, "Single-mode excitation of multimode fibres with ultra-short pulses", Optics Letters, **23**, pp.52-54, (1998). See also IMRA Patent No 5,818,630.
[9] F. Teodoro *et al*, "Diffraction limited, 300kW peak power pulses from a coiled multimode fibre amplifier", Optics Letters, **27**, pp.518-520, 2002.
[10] V. Khitrov *et al*, "Linearly polarized high power fibre laser with monolithic PM-LMA fibre and LMA-based grating cavities", Photonics West, **5709-10**, San Jose, USA, January 2005.
[11] A. Liu *et al*, "60-W green output by frequency doubling of a polarized Yb-doped fibre laser", Optics Letters, **30**, pp.67-69, 2005.
[12] 12. F. Gonthier *et al*, "High power all-fibre components: the missing link for high power fibre lasers", Proc SPIE 5335, **5335-48**, 2004.