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Beyond 1 kW, the rising power of fibre lasers

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Abstract
We describe recent dramatic advances in the high-power fibre laser technology with particular attention to ytterbium-doped fibre sources in a multitude of regimes and the prospects for further power-scaling into the multi-kilowatt regime.

1 Summary

In the past few years there have been dramatic increases in the output powers that can be reached by different types of fibre lasers. Currently, conventional single-strand cladding-pumped fibre lasers can generate output powers beyond 1 kW with high beam quality, and these are now commercially available [1–4]. Even more refined fibre sources operating in a range of regimes are also approaching the kilowatt level. This fibre circuitry combined with pump-diode technology provides a unique high-gain environment for robust designs, which is also all-solid state, compact, stable, reliable, and reproducible. The low cost of ownership that high-power fibre laser technology promises will enable industrial laser applications which were hitherto thought impractical.

Following the initial demonstration of single-mode fibre lasers and amplifiers in the mid-1980s at the University of Southampton [5], they went on to revolutionize the optical telecommunications industry. Furthermore, in recognition of their potential as versatile tools in the altogether-different industrial manufacturing market, academia and industry have in recent years driven the fibre laser technology to the stage of kilowatt-level output powers. These advances herald a revolution in material processing and micro-machining, as well as in a wide range of science and technology areas, such as medicine, free-space satellite communications, range finding, and guide star (astronomy).

Fibre lasers are thin, light-guiding strands of glass only a few times the thickness of a hair. They have a tiny core doped with rare-earth materials that absorb optical pump power and release it through the process of stimulated emission at the signal wavelength. Fibre lasers adopt technologies from solid-state physics and optical telecoms. Most common types of fibre lasers have a core doped with a rare earth, e.g., neodymium, ytterbium, erbium, or thulium. Typically, the core has a diameter in the range of a few to a few tens of micrometers, preferably small enough to maintain operation on a single transverse mode, whilst large enough to avoid damage and nonlinear scattering and to obtain sufficient pump absorption. Remarkably, it has been proven that such a tiny strand can generate and deliver over 1 kW of output power in a conventional laser configuration based on a single fibre.

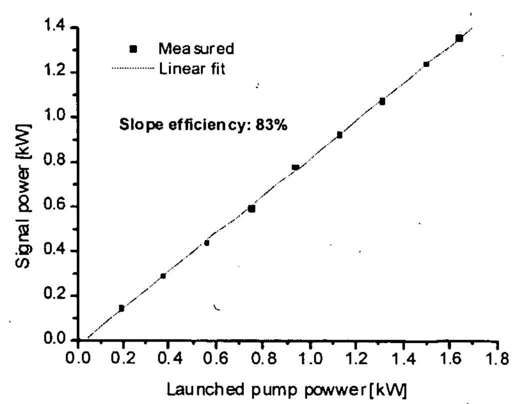

Fig. 1. Laser characteristics of an ytterbium-doped fibre laser with output power beyond 1 kW [3].

An illustration of the power characteristic curve of a kilowatt ytterbium-doped fibre laser is shown in Fig. 1. A maximum output power of 1.36 kW was reached. This power was limited by available pump power. The laser operated with near diffraction-limited beam quality (M^2 = 1.4) despite its relatively large multi-mode core. The excellent slope efficiency of 83% (quantum efficiency close to 95%) leads to a relatively low thermal load, which suggests that significantly higher powers should be possible when higher pump power becomes available.

There is indeed further demand for higher output power. We expect 10 kW of output power is entirely feasible in forthcoming years. Nevertheless, to reach this incredible milestone we must overcome possible constraints on high-power optical fibres, including optical damage, nonlinear scattering, and thermal limits. The fibre design needs to be carefully considered, within the constraints set by material properties and the parameters of realistic pump sources. Additional attention should be paid to issues such as control of modes in a coiled fibre cassette via modal bend loss filtering, thermal properties and heat sinking (fibre coating, water cooling), pump-diode aggregation and launching schemes, etc.

Based on this conceptually rather conventional laser configuration, more refined fibre sources can further be developed for many useful applications: For example, master-oscillator power amplifier configurations can provide highly-controllable single-frequency radiation with opportunities for tunable, frequency-swept, and pulsed operation. Because of the cavity-free travelling-wave nature of the amplifiers, they can maintain the spectral purity of the seed source with a minimum of phase noise added. Furthermore, this configuration allows additional opportunity for beam combination which is a flexible way to further power scaling beyond the limit of an individual fibre source, up to hundreds of kilowatt or even the megawatt level. Several concepts have been proposed: coherent beam combination, spectral beam combination (equivalent to wavelength division multiplexing), multi-core fibres, various self-organizing laser schemes, cladding-pumped Raman conversion, clean-up of combined beams via stimulated Brillouin scattering, etc.

Here we review the current state of the art of kilowatt-level fibre laser sources including fundamental aspects and recent results. We will discuss power-scaling prospects of fibre sources, and present and analyze our up-to-date experimental results, leading to an outlook for the future. The focus will be on sources based on ytterbium-doped silica fibres operating at 1.1 μm, in a multitude of regimes including both continuous-wave and pulsed operation.

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2 References

1. Y. Jeong, J. K. Sahu, D. N. Payne, and J. Nilsson, "Ytterbium-doped large-core fibre laser with 1 kW of continuous-wave output power," Electron. Lett. **40**, 470 (2004).
2. A. Liem, J. Limpert, H. Zellmer, A. Tünnermann, V. Reichel, K. Mörl, S. Jetschke, S. Unger, H.-R. Müller, J. Kirchhof, T. Sandrock, A. Harschak, "1.3 kW Yb-doped fiber laser with excellent beam quality," CLEO 2004, San Francisco, USA, May. 16-21, 2004, postdeadline paper CPDD2.
3. Y. Jeong, J. K. Sahu, D. N. Payne, and J. Nilsson, "Ytterbium-doped large-core fiber laser with 1.36 kW continuous-wave output power," Opt. Express **12**, 6088 (2004).
4. Information available from http://www.ipgphotonics.com, http://www.spioptics.com.
5. R. J. Mears, L. Reekie, S. B. Poole, and D. N. Payne, "Neodymium-doped silica single-mode fibre lasers," Electron. Lett. **21**, 738 (1985).