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The Rising Power of Fibre Lasers

Y. Jeong, J. K. Sahu, S. Baek, C. Alegria, C. A. Codemard, D. B. S. Soh, V. Philippov, R. B. Williams, K. Furusawa, D. J. Richardson, D. N. Payne, and J. Nilsson
Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, United Kingdom
Tel: +44 23 8059 3141, Fax: +44 23 8059 3142, Email: yoj@orc.soton.ac.uk

Abstract
We review the recent rapid progress in the area of high-power fibre lasers and amplifiers in 1.1 and 1.5 μm spectral ranges. This progress is represented by a 610 W Yb-doped fibre laser, for example.

Summary
The output powers of fibre laser systems have grown rapidly over recent years thanks mainly to improvements in fibre design and fabrication and in the performance of pump diode sources (including multi-emitter lasers diodes, diode bars and diode stacks). Fibre lasers benefit from a geometry that allows simple thermal management and a high beam quality. By applying the technique of cladding-pumping, fibre lasers with high-brightness, even diffraction-limited, output can be realized, even when low-brightness diode lasers are used as pump sources.

To date most work has focused on Yb-doped fibre lasers operating at wavelengths around 1.1 μm, largely because the efficiency that can be achieved is extremely high (>80%). There is now also increasing interest in fibre lasers operating at so-called eye-safe wavelengths in the range 1.5~2.0 μm with a high-power level. High output powers at these wavelengths are required for many applications such as free space and satellite optical communications and LIDAR.

Output powers exceeding 100 W have already been reported both at 1.1 μm and 1.5~1.6 μm from Yb-doped fibre lasers and Er/Yb-doped fibre lasers, respectively [1-3]. For cw operation of lasers, an output power of 485 W with an M^2 value of 1.5 from a 35-m long Yb/Nd-doped fibre, and of 400-W with an M^2 value of 1.05 from a 24-m long Yb-doped fibre have been achieved [4, 5]. At 1.5 – 1.6 μm, operation of Er/Yb co-doped fibres from a few tens watt up to ~100 W have been reported [6, 7]. In addition, amplification of single-frequency beams in Yb-doped fibre amplifiers to the 100 W level has also been demonstrated [4, 7, 8]. This is a significant result in view of the strong nonlinear effects in optical fibres: High-power single-frequency amplification in cladding-pumped optical fibres is troublesome because the narrow linewidth, relatively long fibres, and tight confinement lead to a low threshold for stimulated Brillouin scattering (SBS), which is detrimental to performance. Nevertheless, 118 W of output power with a linewidth of 2-3 kHz has been achieved experimentally in a nearly diffraction-limited beam, from a 9.4 m fibre with a 28 μm diameter core [4].

While kW power levels have already been demonstrated from multiplexed fibre devices with poor beam quality, the drive is now towards such high powers from single fibre devices with high beam quality. To get there, optical damage and stimulated Raman scattering (SRS) must be controlled, with stimulated Brillouin scattering (SBS) being the most serious challenge for narrow linewidth beams.

With a long fibre length (~60 m) and a small core (~9 μm diameter), stimulated Raman scattering (SRS) limits the maximum achievable output power with traditional cladding-pumped fibre designs [2]. To avoid such undesirable effects it is necessary to increase the threshold of the nonlinear scattering processes. Therefore, a larger core is used to realize further power scaling (preferably while maintaining a good spatial beam quality), because the effects of nonlinear scattering can be reduced via the corresponding reduction in the power density. Use of as short a fibre as possible also helps to increase the SRS and SBS thresholds. Thus, maximising the pump absorption by fibre design, doping concentration (whilst maintaining good efficiency), and the choice of pump wavelength becomes an important issue when developing fibre lasers of high power and high-brightness. Additional advantages to be derived from the use of short fibres are less mode-coupling (with multimode fibres), lower total propagation losses for pump and signal, and, obviously, less fibre material usage. However, the shorter the device the greater the heat generated per unit length, which further emphasizes the issue of thermal management [9].

To date, we have realized several highly efficient Yb-doped and Er/Yb-doped fibre lasers and amplifiers in different configurations and with different performance: for example, a single-ended output power of 610 W at 1.09 μm with a slope efficiency of 82% (see Fig. 1), 103 W at the eye-safe wavelength of 1.56 μm with a slope efficiency of 30%, and 87 W of a single-frequency output at 1.56 μm from an Er/Yb-doped master-oscillator amplifier. These powers were limited by available pump power. Our results highlight the impressive power capacity of Yb- and Er/Yb-doped fibres even in relatively short lengths (<10 m), with relatively high nonlinear threshold. We have been improving the beam quality as well as the maximum output powers, and thus, we will be able to show better results in due course.

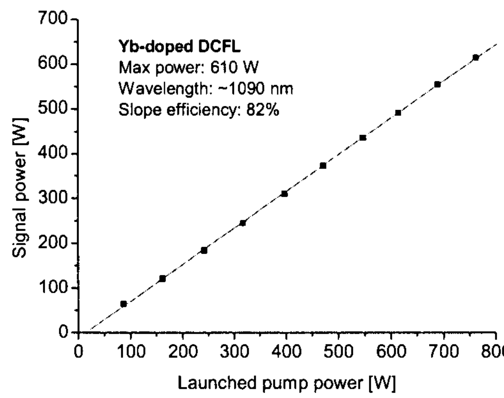

Fig. 1. Power characteristics of a Yb-doped fibre laser.

To conclude, we emphasize that despite the recent rapid increase of output power from different fibre sources, the power is still limited by available pump sources rather than by fibre properties. We believe that in due course an optimised single-mode fibre can have an output in excess of a kilowatt with sufficient pump power. Up-to-date results on high-performing, high-power, fibre lasers and amplifiers will be presented at the conference.

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