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State of the art of cw fibre lasers

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Summary
Fibre lasers are thin, light-guiding strands of glass only a few times the thickness of a hair which have a tiny core doped with rare-earth materials to absorb the pump radiation and release the stimulated emission at the signal wavelength. Fibre lasers provide unheard of attributes in the laser world – low maintenance, high efficiency, and excellent beam control, and are compact and all-solid-state. Their low cost of ownership will enable industrial laser applications, such as material processing, micro-machining, marking, printing, medicine, etc., which were hitherto thought impractical.

The past few years have seen dramatic increases in the output powers that can be reached by different types of fibre lasers. Conventional single-strand fibres can generate output powers beyond a kilowatt with high beam quality, and are now commercially available. Even more refined fibre lasers operating in a range of regimes are also approaching the kilowatt level. This rapid progress has been stimulated both by the exceptional power-handling ability of fibres and the availability of powerful diode lasers for use as pumps. For example, in case of ytterbium-doped fibres for continuous-wave (cw) generation at 1.1 μm up-to-date achievements within our group are represented by a 1.36 kW broad-linewidth laser; a 0.63 kW plane-polarized laser; a 0.26 kW single-frequency, plane-polarized amplifier. All of these operated with near diffraction-limited beam quality, and the maximum powers were limited by available pump power that we could launch into the fibres [1], [2]. In addition, over hundred-watt output powers from erbium-ytterbium codoped fibres for ~1.5 μm and a similar power level from thulium-doped fibres for ~2 μm have been achieved. Although the overall efficiencies of these fibres are lower than that of ytterbium-doped fibres, these wavelengths are of great interest because of their relative 'eye-safe' operation, which can be a practical issue in many application fields.

The current state of the art-performance has proven that fibre lasers are exceptional for generating cw output up to the kilowatt level, thanks to remarkable improvement in fibre and pump-diode technology. Further power-scaling in the single-mode regime, e.g., to 5 kW, which is demanded for heavy-industrial applications, is presently considered as the next challenge: One might think five times higher pump power would lead to five times higher signal power; however, in practice important design modifications of the fibre and laser would be required. Even more attention should be paid to potential limitation factors, such as material damage threshold, nonlinear scatterings, thermal distortion, etc., which arise at extreme power densities. A ten-meter long, large-core fibre regime with a low-numerical aperture may still be preferable [1], although the management of beam quality should be further a concern with such a highly multi-moded large core. Thus, technological advances in fibre design, pump coupling scheme, mode control, heat dissipation, output coupling, and more, will be the key issues for the successful achievement of multi-kilowatt output power. As well as conventional broad-linewidth fibre lasers, more delicate fibre sources, master-oscillator power amplifiers for high-power single-frequency generation are of great importance. The potential impact of these devices cannot be overstated, because, unlike conventional lasers, the coherent single-frequency output from an individual single-strand fibre can be beam-combined to scale the resultant output power perhaps to as high as a megawatt. In this approach, the suppression of stimulated Brillouin scattering is the key issue on top of the general issues already stated [2].

In conclusion 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 review the current state of the art of cw fibre lasers and discuss the prospect of further power-scaling of a single-strand fibre laser into multi-kilowatt regime, as required for some industrial manufacturing applications.

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References
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