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Numerical Analysis of Tapered Multicore Fibres for Laser System Scaling

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Active multicore fibres (MCFs) enable compact and efficient scaling of laser power and energy, for example in coherent beam combination (CBC) schemes [1]. High-energy amplification was recently demonstrated with a tapered MCF which improved beam quality in large multimode cores, enhancing the scalability of these systems [2]. Tapering MCFs to achieve diffraction-limited beam quality with independent operation of the cores presents unique design challenges in addition to typical constraints of tapered fibres. In this submission, numerical analyses using Beam Propagation Method (BPM) are presented to guide the fabrication of tapered MCFs.

A microscope image of an in-house fabricated Yb-doped 4x4 MCF is shown in Fig. 1a. The cores in these fibres are densely arranged with a core separation of 2.5x the core diameter for high spatial overlap with the surrounding pump cladding and high pump absorption per unit length. The low core NA (0.04) enables nearly-single-mode operation at ~20-micron core diameter, with multimode operation in larger cores. However, the single-mode operating regime can be extended to much larger cores by tapering one end of the MCF to allow only fundamental-mode excitation. In general, tapered fibre amplifiers transition gradually from a single-mode input to a multimode output over several metres [3]. In MCFs, long taper lengths can result in significant inter-core cross-talk, particularly in the single-mode region where the evanescent overlap of the core fields is greatest. However, the minimum taper length is limited by mode-mixing [4] and bend loss due to the non-axiosymmetric nature of MCF tapers. BPM simulations of MCFs tapered from 15- to 25-micron core diameter in Fig. 1 b-c show these effects for a 5 mm taper length (Fig. 1c) which exhibits mode mixing and bend loss, and for a 50 mm taper length (Fig. 1d) which exhibits inter-core cross-talk. For this fibre configuration, a working taper design space can be defined which minimizes mode distortion and/or crosstalk depending on the target application.

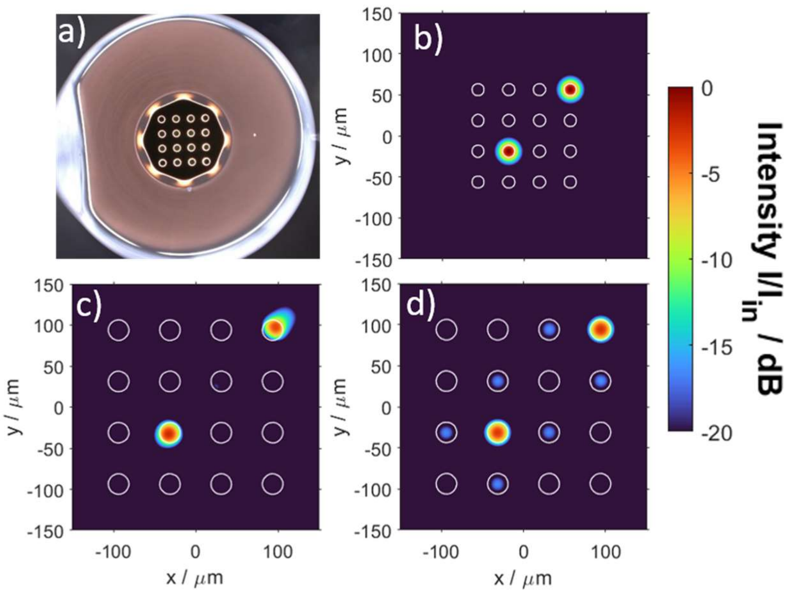

Fig. 1 a) Microscope image of fabricated double-clad Yb-doped MCF. b) BPM simulated input field distribution with 15 micron cores. c) and d) final field distributions of MCF tapered from 15- to 25 micron core diameter over 5 mm and 50 mm, respectively.

Numerical techniques such as BPM can accurately model bend loss, intra-core mode-coupling, and inter-core cross-talk in complex tapered MCF structures. The results of these simulations can guide the tapering of existing high-power compatible MCF designs as a post-processing step as shown here, and further applied for the design of "taper-ready" MCFs. Thus the mode-area scaling property of tapered gain fibres can be utilized in active MCFs to further optimize a new generation of high-power coherently combined laser systems.

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