Transverse Mode Instability Mitigation with Multimode excitation in Fiber Amplifiers

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A major limitation to power scaling in high power fiber amplifiers is Transverse Mode Instability (TMI)[1]. We present a novel scheme for mitigating TMI: equally exciting all the modes of a highly multimode fiber. We calculate the TMI threshold for various number of equally excited modes in a 30-mode 2D waveguide, using our newly developed frequency domain theory of TMI[2]. We show that the TMI threshold increases linearly (Fig.1a) with the number of equally excited modes. The theory is validated by time-domain numerical simulations solving the coupled optical and heat equations. A 2D waveguide is chosen for reduced computational complexity but our results are valid for 3D fibers. The linear scaling results from the smearing of thermal grating upon multimode excitation due to optical and thermal length scale mismatch, which leads to weak thermo-optic mode coupling, χ_{mn}, between non-adjacent modes (Fig.1b). We further show numerically that a 5-mode excitation, with increased TMI threshold, can be focused to a diffraction limited spot at the fiber output end by controlling the relative phases of the modes at the input. This allows us to obtain a temporally stable and spatially focused beam (Fig.1c (i)), which can be subsequently collimated using a lens, for output power equal to 300 W. This power is far above the TMI threshold (170 W) for conventional single-mode excitation, which is unstable at this power level (Fig.1c (ii)). Our results demonstrate multimode excitation with wavefront shaping can be an effective pathway to achieve robust TMI suppression, while maintaining high beam quality.

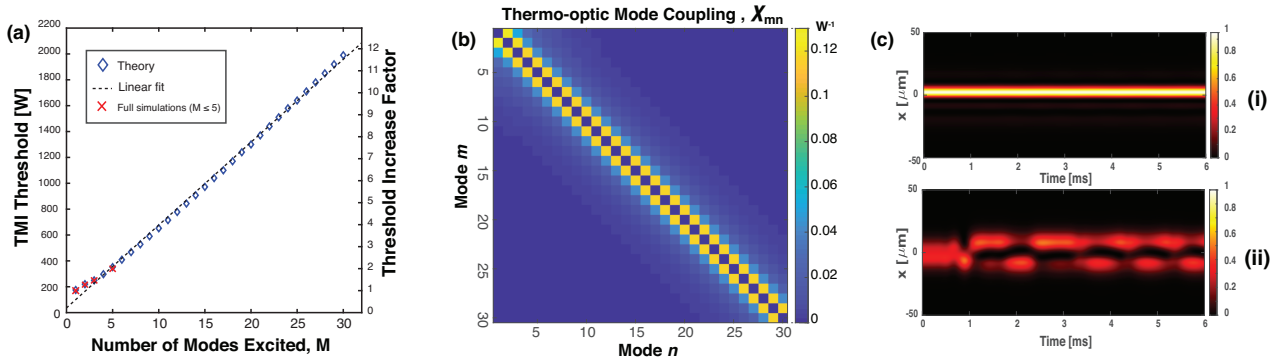

Figure 1: (b) TMI threshold for many-mode excitation increases linearly with the total number of equally excited modes, M. (a) Peak values of thermo-optic mode coupling, $\chi_{mn}(m \neq n)$ for a 30-mode 2D waveguide. (c) Variation of output beam profile with time for (i) 5-mode excitation with a stable, focused output and (ii) fundamental-mode-only excitation with unstable output, for same output power (300 W).

[1] C. Jauregui, C. Stihler, J. Limpert *Adv. Opt. Photon. 12, 429-484 (2020)*

[2] C-W. Chen, K. Wisal, AD Stone, H. Cao *10.48550/ARXIV.2206.15438 (2022)*

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