Modal instabilities in very large mode area rod fiber amplifiers

Jørgensen, Mette Marie; Hansen, Kristian Rymann; Laurila, Marko; Noordegraaf, Danny; Alkeskjold, Thomas Tanggaard; Lægsgaard, Jesper

Publication date:
2012

Modal instabilities in very large mode area rod fiber amplifiers

Mette M. Jørgensen[1], Kristian R. Hansen[1], Marko Laurila[1], D. Noordegraaf[2], Thomas T. Alkeskjold[2], Jesper Lægsgaard[1]

[1]DTU Fotonik, Ørsteds Plads, building 343, 2800 Kgs. Lyngby, Denmark, mmajo@fotonik.dtu.dk
[2]NKT Photonics A/S, Blokken 84, 3460 Birkerød, Denmark

Optical fiber amplifiers have gained increased scientific and commercial interest due to high output powers with easy operation and maintenance. The main advantages of fiber amplifiers are good thermal properties, due to a large surface/volume ratio, excellent beam quality and stability [1]. Very large core fiber areas are highly desirable to mitigate various nonlinear processes, such as Kerr, four-wave mixing, Raman, and Brillouin effects. It is difficult to scale up the core area without going into a multi-moded regime. Microstructured fiber technology has allowed core diameters of 60-100 microns, by reducing all index contrasts to very low values, and possibly utilizing advanced photonic-band gap cladding designs to filter out higher-order modes [2], see Fig. 1. The guided modes of such cores are very sensitive to perturbations. An unavoidable perturbation at large average power is the formation of thermal gradients across the core, which induces a power dependent transverse index modification due to the thermo-optic effect. A phase shift between the thermally induced index grating and the signal intensity causes power transfer from the fundamental mode to a higher order mode leading to modal instability [3-5], represented in Fig. 2 as the growth of the higher order mode content. This is a fundamental obstacle for power scaling in fiber amplifiers that significantly reduces beam quality and stability.

We combine analytic considerations for thermally induced mode coupling with the finite element method to allow complex micro structured fibers to be considered. Thereby the modal instability threshold is estimated for very large mode area fiber amplifiers of various photonic crystal fiber designs. Experimentally the modal instability threshold for very large mode area fiber amplifiers is determined repeatedly and a decrease in the modal instability threshold level is observed as the threshold is reached multiple times.

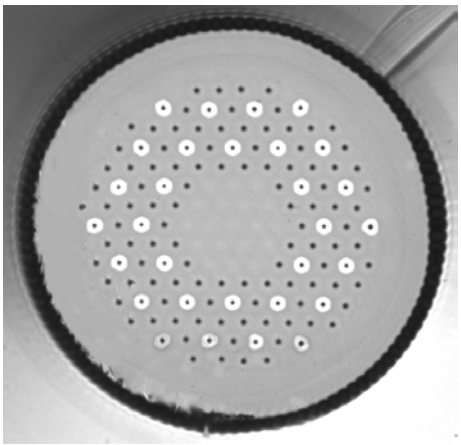

Fig. 1: Microscope picture of a complex micro-structured photonic crystal rod fiber [2].

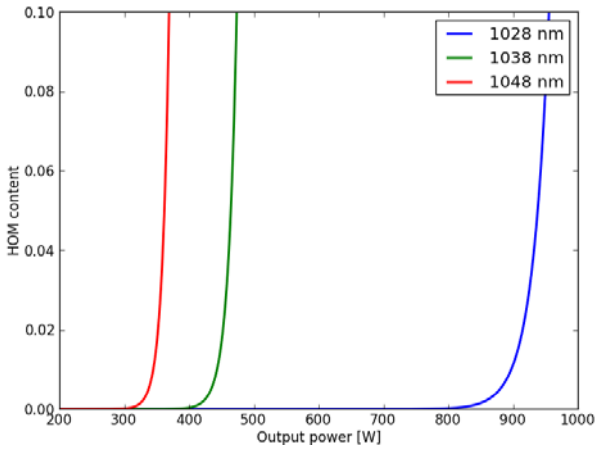

Fig. 2: Threshold like increase of higher order mode (HOM) content as a function of output power yielding modal instability.

[1] J. Nilsson and D. N. Payne, “High-power fiber lasers,” Science 332, 921-2 (2011).
[2] M. M. Jørgensen, S. R. Petersen, M. Laurila, J. Lægsgaard, and T. T. Alkeskjold, “Optimizing single mode robustness of the distributed modal filtering rod fiber amplifier,” Opt. Express 20, 7263-7273 (2012).
[3] A. V. Smith and J. J. Smith, "Mode instability in high power fiber amplifiers," Opt. Express 19, 10180-10192 (2011).
[4] T. Eidam, C. Wirth, C. Jauregui, F. Stutzki, F. Jansen, H.-J. Otto, O. Schmidt, T. Schreiber, J. Limpert, and A. Tünnermann, "Experimental observations of the threshold-like onset of mode instabilities in high power fiber amplifiers," Opt. Express 19, 13218-13224 (2011).
[5] K. R. Hansen, T. T. Alkeskjold, J. Broeng, and J. Lægsgaard, "Thermally induced mode coupling in rare-earth doped fiber amplifiers," Opt. Lett. 37, 2382-2384 (2012).