The impact of heat-load modulation on transverse mode instability in high-power, quasi-continuous wave fibre amplifiers

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Nowadays, transverse mode instability (TMI) constitutes the main limitation for a further power scaling of fibre laser systems with diffraction-limited beam quality [1]. TMI is observed when a certain average output power level (i.e., the TMI threshold) is reached. Above this level a dynamic deterioration of the beam profile suddenly occurs [2]. The root cause of this effect is that the modal interference pattern (MIP) in the fibre core- between the fundamental mode (FM) and at least one higher-order mode (HOM)- induces a phase-matched refractive-index grating (RIG) through the thermo-optic effect. This RIG allows for a modal energy transfer between the fibre modes if there is a phase-shift between the MIP and the RIG. This is because the sign of this phase shift determines the direction of the modal energy transfer. In a previous theoretical study, it has been revealed that a permanent energy transfer from the HOMs to the FM can be induced above the TMI threshold when pulsing the input seed with some specific modulation parameters [3]. In this way, the heat load is modulated, which allows controlling the sign of the phase shift.

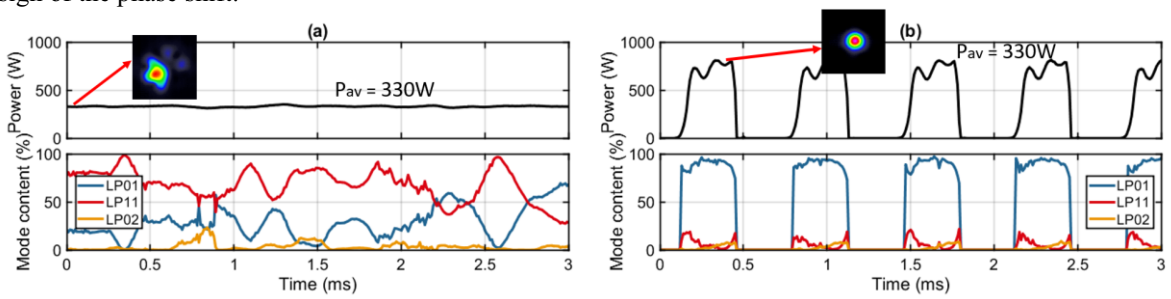

Fig. 1 Modal analysis at an average output power of 330 W for **a)** free-running system and **b)** heat load modulation technique by pulsing the seed and pump with a modulation frequency of 1.5 kHz, a duty cycle of 45 %, 65 % TMI increase, and dominant FM time-window of 300 µs. The insets are intensity frames measured by HSC with 10 µs temporal resolution.

In this work, we experimentally demonstrate dominant FM operation at an average output power significantly higher than the TMI threshold via heat load modulation [4]. The heat-load modulation can be achieved by pulsing the seed, the pump or both simultaneously. With this technique it is possible to obtain a beam which energy is predominantly contained in the FM at all times even at an average output power of 370 W, which is 75% higher than the TMI threshold of the free-running system. This result is even more impressive considering that the instantaneous output power of the pulsed signal is higher than 850 W (i.e., over 4.1 times higher than the TMI threshold). Figure 1 shows an example of this measurement to compare between the modal content analysis [5], at the same average output power of 330 W, for a free-running system (figure 1a) and the heat-load modulation (figure 1b) at a modulation frequency of 1.5 kHz, a duty cycle of 45 % and a modulation depth of 100 %. The upper frames describe the temporal evolution of the instantaneous output signal power, whereas the lower frames describe the temporal evolution of the relative FM/HOMs modal content. As can be seen, the FM is dominant in the on-time interval of the modulated period (i.e., 300 µs). This result is beneficial in improving quasi-continuous wave (QCW) fibre laser systems which are vital for a variety of applications [6].

References

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