COHERENT COMBINATION OF HIGH-POWER ULTRAFAST LASER SYSTEMS

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We present the latest results of coherent combination of ultrafast fiber lasers. This technology allows for the first time to arbitrarily scale both average power and peak power of state-of-the-art femtosecond laser systems. Finally, a compact and robust 6-channel system ideally suited for materials processing is presented.

Today, ultrafast laser systems capable of emitting energetic pulses with durations ranging from a few hundred femtoseconds up to picoseconds have become a versatile tool for a plethora of applications. However, the requirements that these applications impose on the laser systems are demanding. Typically, both the pulse energies and the peak powers should be as large as possible in order to generate fields strong enough to initiate the physical processes of interest. Additionally, the pulse-repetition frequencies and, therewith, the average powers should be maximized to allow for short integration times or for an increase in processing speed. Simultaneously, an excellent beam quality is typically desired to achieve and maintain the necessary intensities over long distances. The combination of all these requirements is a challenging task for any laser architecture.

Although there has been tremendous progress during the recent years, even today's most successful solid-state-laser geometries (thin-disk, slab and fiber), approach more and more some fundamental power-scaling limitations. A solution to such a dilemma, i.e. the scaling of a physical system beyond its fundamental limitations, is parallelization. In terms of ultrafast laser systems this can be achieved via spatially separated amplification and subsequent coherent combination [1].

Here we present the latest results of applying this technology to ultrafast fiber lasers. By maturing coherent combination from laboratory setups to turn-key laser systems, unprecedented power levels become accessible for the first time.

The basic idea is to employ a state-of-the-art chirped-pulse-amplification system, i.e. to start from a femtosecond oscillator, stretch the pulses in time, amplify them and finally compress the pulses back to femtosecond duration. However, the final amplifier now consists of N parallel diode-pumped fiber amplifiers (see Fig. 1). Therefore, the (stretched) pulses to be amplified are split into N spatially separated replicas that are amplified and, subsequently, coherently recombined to one intense pulse. Hence, in the ideal case the achievable average output power and pulse energy can be scaled by a factor of N. All other parameters such as beam quality, spectral or temporal pulse shape and the stability remain unaltered or even improve due to an averaging effect. Finally, the coherent combination approach is especially suited to fiber amplifiers due to their compact design, high single-pass gain and, therefore, straightforward spatial multiplexing.

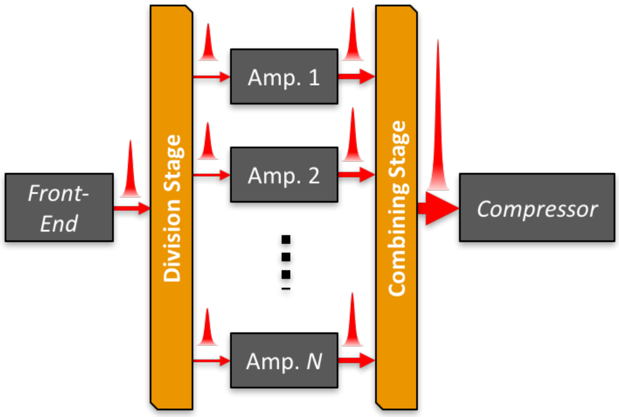

Fig. 1: Schematic drawing of an ultrafast laser system employing an N-channel coherently combined main amplifier.

There are several possibilities to stabilize such an active interferometer. The most successful so far is polarization combining and control the path-length difference via measuring the state of polarization with Hänsch-Couillaud detectors [2]. The stabilization can be easily achieved by generating a feedback signal and using piezo-mounted mirrors in N-1 interferometer arms.

We report further on scaling properties and the integration of coherent combination in a state-of-the-art high-power ultrafast fiber laser used for materials processing (Fig. 1).

Fig. 1: kW-class ultrafast fiber laser employing 8 parallel amplification channels.

References

[1] Limpert, J., Klenke, A., Kienel, M., Breitkopf, S., Eidam, T., Hädrich, S., Jauregui, C, & Tünnermann, A. (2014). Performance scaling of ultrafast laser systems by coherent addition of femtosecond pulses, *IEEE Journal of Selected Topics in Quantum Electronics*, *20*(5), 268-277.

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