Virtual Long Term Testing of High-power Fiber Lasers

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Abstract

The remarkable power scaling of high power fiber lasers over the past years has become more and more challenging, because the effects of transverse mode instability (TMI) and photodarkening (PD) of the fiber are limiting the effective output power of typical industrial fiber lasers.
The origin of the TMI is a power transfer from the fundamental mode of the fiber to higher transverse modes via self-induced long period gratings in the fiber due to the thermo-optical effect. The excitation of higher modes can lead to temporal instability of the laser power, and to an increased power transfer from the core to the cladding via bend losses, thus reducing the effective laser power.
Over the lifetime of a fiber laser, the TMI threshold is decreased during operation due to photodarkening of the active fiber core. This leads to a degradation of the laser's performance over several thousand hours typically. Many investigations have been made to understand, model and simulate both effects, but the microscopic mechanisms both of TMI and PD are not yet fully understood. The existing models are usually either comprehensive, but very slow and therefore limited to the simulation of rather short fibers, or reduced models that do not take transverse effects into account. Furthermore, most of these models have been applied only to single-pass fiber amplifiers so far.
We present a hierarchical numerical approach that allows to first pre-calculate the mode shapes and the transverse spatiotemporal distribution of the photodarkening losses over typical lifetimes of fiber lasers using the Wave Optics Module of COMSOL Multiphysics®. The mode coupling strength is calculated by solving the heat equation with locally varying absorption as bulk heat source using the Heat Transfer Module. Then the precalculated data is applied to a scalar coupled-mode model of the full length fiber laser cavity using the ODE interface. The effects of mode competition, laser gain, mode energy transfer and bend losses are considered in this model, as well as the actual refractive index distribution and doping profile of the fiber.
As a result, it is possible to perform virtual long term tests simulating several 10 000 hours of laser operation in a few hours. The transverse distribution of photodarkening losses in the fiber and the mode coupling gain can be analysed at any cross section along the fiber length, which enables the development of advanced mitigation strategies.
The simulation results are compared to experimental data, which also gives rise to a refinement of the established theoretical models.

Figures used in the abstract

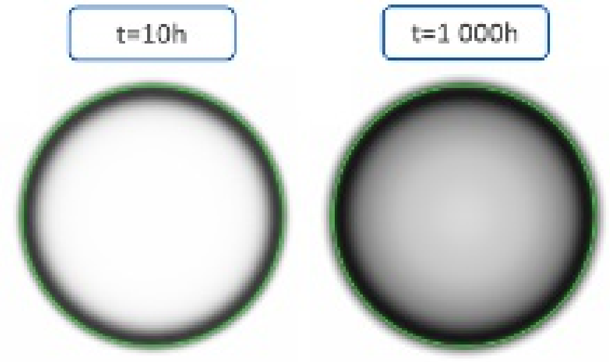

Figure 1: Simulated absorption profiles due to photodarkening after 10h and 1000h