Thulium Laser Design and Experimental Verification for NIR and MIR Nonlinear Applications in Specialty Optical Fibers

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Abstract : Nonlinear phenomena in the near- and mid-infrared region are attracting scientific attention mainly due to the supercontinuum generation possibilities and subsequent utilizations for ultra-wideband applications like e.g. absorption spectroscopy or optical coherence tomography. Thulium-based fiber lasers provide access to high-power ultrashort pump pulses in the vicinity of 2000 nm, which can be easily exploited for various nonlinear applications. The paper presents a simulation and experimental study of a pulsed thulium laser based for near-infrared (NIR) and mid-infrared (MIR) nonlinear applications in specialty optical fibers. In the first part of the paper the thulium laser is discussed. The thulium laser is based on a gain-switched seed-laser and a series of amplification stages for obtaining output peak powers in the order of kilowatts for pulses shorter than 200 ps in full-width at half-maximum. The pulsed thulium laser is first studied in a simulation software, focusing on seed-laser properties. Afterward, a pre-amplification thulium-based stage is discussed, with the focus of low-noise signal amplification, high signal gain and eliminating pulse distortions during pulse propagation in the gain medium. Following the pre-amplification stage a second gain stage is evaluated with incorporating a thulium-fiber of shorter length with increased rare-earth dopant ratio. Last a power-booster stage is analyzed, where the peak power of kilowatts should be achieved. Examples of analytical study are further validated by the experimental campaign. The simulation model is further corrected based on real components – parameters such as real insertion-losses, cross-talks, polarization dependencies, etc. are included. The second part of the paper evaluates the utilization of nonlinear phenomena, their specific features at the vicinity of 2000 nm, compared to e.g. 1550 nm, and presents supercontinuum modelling, based on the thulium laser pulsed output. Supercontinuum generation simulation is performed and provides reasonably accurate results, once fiber dispersion profile is precisely defined and fiber nonlinearity is known, furthermore input pulse shape and peak power must be known, which is assured thanks to the experimental measurement of the studied thulium pulsed laser. The supercontinuum simulation model is put in relation to designed and characterized specialty optical fibers, which are discussed in the third part of the paper. The focus is placed on silica and mainly on non-silica fibers (fluoride, chalcogenide, lead-silicate) in their conventional, microstructured or tapered variants. Parameters such as dispersion profile and nonlinearity of exploited fibers were characterized either with an accurate model, developed in COMSOL software or by direct experimental measurement to achieve even higher precision. The paper then combines all three studied topics and presents a possible application of such a thulium pulsed laser system working with specialty optical fibers.

Keywords : nonlinear phenomena, specialty optical fibers, supercontinuum generation, thulium laser
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