Power scaling of continuous-wave and Q-switched hybrid fiber-bulk erbium lasers at 1645 nm

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Abstract: We report recent progress in the development of high-power Er,Yb fiber-laser-pumped Er:YAG lasers at 1645 nm operating in continous-wave and Q-switched regimes. Strategies for further scaling of output power and pulse energy are considered.

Summary: Solid-state laser sources operating in the eyesafe wavelength regime around ~1.5-1.6 μm have numerous applications and provide a good starting point for mid-infrared generation via nonlinear frequency conversion. The standard approach for producing laser output in this wavelength region is via direct diode pumping of erbium-ytterbium co-doped bulk glass or crystal lasers. Scaling of the output power from such lasers is rather challenging due to the high thermal loading density which results from a large quantum defect and the need for relatively high active ion concentrations. In contrast, cladding-pumped Er,Yb fiber lasers are becoming increasingly attractive for generating high power in this wavelength regime due to their high efficiency and relative immunity from thermal effects. However, due to their small core size, long device lengths and high gains, they offer limited energy storage and are susceptible to damage, so pulse energies are limited. An alternative approach is to use a hybrid laser configuration in which an Er fiber source is used to 'in-band' pump the Er bulk solid-state laser. This scheme combines the advantages of efficient cw high-power generation in cladding-pumped fiber lasers with the energy storage and high pulse energy capabilities of bulk solid-state laser crystals. One of the main advantages of the fiber-bulk hybrid laser scheme is that most of the heat generated via quantum defect heating is deposited in the fiber, and thermal effects in the bulk laser are dramatically reduced leading to the prospect of much improved efficiency, beam quality and higher average power. Another important attraction of the scheme is that a bulk gain medium with very low Er ion concentrations can be used. As a result, the loss due to energy-transfer-upconversion is dramatically reduced opening up the prospect of much higher Q-switched pulse energies.

The fiber-bulk hybrid scheme has already been successfully applied to Er:YAG [1] and Er:LuAG lasers pumped by an erbium fiber laser at 1532nm, yielding multi-watt average powers up to ~7 W and slope efficiencies with respect to incident pump power up to 54% and 40% respectively. More recently, we have demonstrated an Er:YAG hybrid laser with >60W of output at 1645nm (limited by available pump power) and with a slope efficiency with respect to incident pump power of ~81% and with an optical conversion efficiency with respect to Er fiber laser pump power of 73.5% [2]. In addition, a Q-switched version of the laser, incorporating an RTP electro-optic Q-switch, has been demontrated. In preliminary experiments, Q-switched pulses of energy up to 15mJ and with duration ~67ns (FWHM), corresponding to a peak power of ~220kW were generated in a diffraction-limited TEM_{oo} output beam (limited by poor quality mirror dielectric coatings). Further details of these lasers, their performance characteristics and factors limiting their performance will be presented.

Scaling hybrid erbium lasers to higher power levels requires careful consideration of heat generation in the laser medium and its detrimental impact on efficiency and beam quality. Even though quantum defect heating is very low (i.e. ~7%) in this system, the net power converted to heat starts to become significant at high pump powers and thus further power scaling requires special measures to be adopted to alleviate thermal effects. We have theoretically analysed this problem taking into account quantum defeat heating and energy transfer upconversion to determine the pump power levels at which thermal effects (i.e. thermal lensing, stress-induced birefringence, stress-fracture) start to have a significant impact. In addition, we describe a range of simple measures to alleviate or compensate thermal effects to extend operation to even higher power levels. We also discuss the prospects for scaling Q-switched pulse energy.

References

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