High-power fiber-bulk hybrid lasers

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Fiber-bulk hybrid lasers combine the advantages of both high-power, cladding-pumped fiber and conventional bulk-crystal lasers, opening up prospects of high average power and high pulse energies.

In the search for high power generation, conventional ‘bulk’ solid-state lasers (those with crystal rods) offer the possibility of high pulse energies, but suffer from detrimental thermal effects that degrade beam quality and efficiency. On the other hand, cladding-pumped fiber lasers have high efficiency and effective passive cooling, but their small core size and long device length limit pulse energies.

An alternative avenue for enhancing output power and pulse energy marries the strengths of both fiber and solid-state lasers. This hybrid approach uses a fiber laser as a high-brightness source that in-band pumps a bulk solid-state laser. The hybrid design’s strong advantage is that most of the quantum defect heating—generated by unproductive electron energy transitions—is dissipated in the fiber, dramatically reducing the bulk laser’s thermal problems. This leads to the prospects of higher average power and large improvements in efficiency and beam quality. In addition, output losses from energy-transfer upconversion can be dramatically reduced by using bulk gain media with very low doping concentrations, facilitating much higher Q-switched pulse energies.

We have demonstrated the efficient operation of hybrid fiber-bulk lasers using Er:YAG and Ho:YAG for bulk laser materials, and high-power fiber sources doped with Er or Tm to pump directly into the upper manifolds (see Figure 1). These bulk materials show promise for high-power continuous-wave operation, and for the production of high Q-switched pulse energies near wavelengths of ~1.6 and 2.1μm owing to robust thermo-mechanical properties and a long fluorescence lifetime. The heat loading in the bulk crystals should be very low with this pumping due to the small quantum defect (~7% in Er:YAG, and 9% in Ho:YAG), promoting high lasing efficiencies.

To in-band pump the Er:YAG and Ho:YAG crystal lasers, we developed high power, tunable fiber lasers that are cladding-pumped by beam-shaped diode sources. One of the tunable lasers—pumped by a 975nm diode source and Er-Yb-doped—can be tuned over a 36nm interval, from ~1532 to 1568nm. Its output power levels can exceed 100W with a line-width (full-width at half-maximum, FWHM) of ~1nm and a beam quality factor ($M^2$) of 1.9. It was used to pump the Er:YAG laser at 1532nm.

The other tunable laser—pumped by a 790nm diode source and Tm-doped—has a core composition optimized for efficient ‘two-for-one’ cross-relaxation. It has generated 66W of continuous-wave output at ~2μm, producing 117W of launched pump power with a corresponding pump quantum efficiency that exceeds 1.7. It was used to pump the Ho:YAG laser at 1907nm.

When operated in continuous-wave mode, the Er:YAG and Ho:YAG hybrid lasers had slope efficiencies with respect to incident pump power of ~80%. The Er:YAG laser produced ~60W of continuous-wave output at 1645.3nm for 82W of incident pump power (as shown in Figure 2). In Q-switched mode, this hybrid laser produced ~5.5mJ energy pulses that lasted ~81ns (FWHM). This corresponds to a peak power of ~67kW at a rep-
Figure 2. Shown is the output power versus incident pump power of the hybrid Er:YAG laser.

etition rate of 500Hz for an incident pump power limited by the onset damage to 16.8W.

The fiber-bulk hybrid laser scheme combines the thermal advantages and high-power operation of fiber lasers with the energy-storage capabilities and larger mode sizes of bulk lasers. Our preliminary results suggest that it should be possible to increase the average power and pulse energy of the hybrid laser while maintaining high efficiency and good beam quality. These increases would require increasing the power of the fiber pump sources at 1.5 and 1.9μm. In addition, the heat generation in the laser medium and its detrimental impact on efficiency and beam quality should be carefully considered. Even though quantum-defect heating is very low (∼7% – 9% for Er:YAG and Ho:YAG systems), the net power converted to heat becomes significant at high pump powers, and would mandate special measures to alleviate thermal effects.

References

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