Ultra-efficient Er:YAG laser with 60 W output power at 1645 nm end-pumped by an Er-Yb co-doped fibre laser

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High-power solid-state lasers operating in the eyesafe wavelength regime around ~1.5-1.6 µm have numerous applications and provide an ideal platform for nonlinear frequency conversion to the mid-infrared. The traditional approach for producing laser output in this wavelength region is via direct diode pumping of erbium-ytterbium co-doped bulk glass or crystal lasers. Power scaling of such lasers has proved rather difficult due to the high thermal loading density which results from a large quantum defect, the need for a relatively high active ion concentrations and additional heat loading due to energy-transfer-upconversion. Another approach for generating laser emission in the 1.5-1.6 µm wavelength regime is via cladding-pumping of erbium-ytterbium co-doped fibre lasers. Fibre lasers are becoming increasingly attractive for high power generation due to their high efficiency and immunity from thermal effects. However, due to their small core sizes and long device length, fibre laser suffer from detrimental nonlinear effects and are susceptible to core damage, especially when operating in the high peak power pulsed regime. In-band pumping of bulk solid-state lasers with high-brightness fibre sources is an attractive alternative approach which combines the advantages of efficient cw high-power generation in cladding-pumped fibre lasers with the energy storage and high pulse energy capabilities of bulk solid-state laser crystals. A key attraction of this fibre-bulk hybrid laser scheme is that most of the heat generated via quantum defect heating is deposited in the fibre, and thermal effects in the bulk laser are dramatically reduced leading to the prospect of much improved efficiency, beam quality and higher average output power. This approach has already been successfully applied to Er:YAG [1] and Er:LuAG [2] lasers pumped (in-band) by an erbium fibre laser, with multi-watt average powers up to ~7W and slope efficiencies with respect to incident pump power up to 54% and 40% respectively. In this paper we report an Er:YAG laser with much higher output power and higher efficiency end-pumped by a tunable cladding-pumped Er,Yb fibre laser. The laser yielded 60 W of output at 1645.3 nm for 82 W of incident pump power from the Er,Yb fibre laser at 1532 nm. The corresponding slope efficiency was 80.7% with respect to incident pump power.

The Er,Yb-doped fibre laser used in our experiments was constructed in-house and comprised ~ 2m of double-clad fibre with a 30µm diameter (0.22 NA) Er,Yb-doped phospho-silicate core surrounded by a 400µm diameter pure silica inner-cladding with a calculated NA of 0.49. The fibre laser was pumped through opposite fibre end facets by spatially-combined diode-stacks at 975nm delivering a maximum combined pump power of up to 700W. The fibre absorption coefficient at 975nm was measured to be ~ 6.9dB/m. Selection of the Er,Yb fibre laser operating wavelength at the absorption peak in Er:YAG at 1532nm was achieved by employing an external cavity comprising a simple diffraction grating (600 lines/mm) in the Littrow configuration to provide the required wavelength discrimination. At an incident pump power of 420 W (corresponding to ~ 336 W launched), the lasing wavelength could be tuned over 36 nm from ~ 1532 to 1568 nm with output power >100 W and with a linewidth of ~1nm by simple adjustment of the grating angle.

A simple four-mirror folded-resonator configuration was used for the Er:YAG laser comprising a plane input mirror with high reflectivity (>99.8%) at the lasing wavelength (1600-1700nm) and high transmission (~ 94%) at the fibre pump wavelength (1532nm), two concave mirrors with high reflectivity (>99.8%) at both the lasing and the pump wavelengths and with radius of curvature, 100mm, and a plane output coupler with a transmission of 10% at the lasing wavelength. An Er:YAG rod with 0.5(at.)% Er^{3+} concentration and length, 29mm, with both end faces antireflection coated in the 1.5-1.7µm wavelength regime, was used as the gain medium and positioned at the centre of the resonator arm defined by the concave mirrors. The physical length between the two curved cavity mirrors was 124mm and the total physical length of the resonator was ~367mm, resulting a calculated TEM_{00} beam waist radius of ~80ìm in the Er:YAG rod under unpumped conditions. Pump light at 1532.4nm from the Er,Yb fibre laser with an M^2 factor of 1.9 was focussed to a beam radius of ~ 98 µm in the centre of the Er:YAG crystal with the aid of one of the concave cavity mirrors. The Er:YAG rod was mounted in a water-cooled copper heat-sink maintained close to room temperature at 16□C. Under these operating conditions the laser reached threshold at a pump power of ~0.6W and generated 60.3W output at 1645.3nm at the maximum incident pump power of 82W, corresponding to an optical conversion efficiency of 73.5%. The slope efficiency with respect to incident pump power was 80.7%. The beam quality was determined to be M^2□1.2 at 20 W output and ~3.2 at the maximum output of 60W. To the best of our knowledge, this represents the highest cw power and highest efficiency so far achieved for an Er:YAG operating at 1645nm. The prospects for further increase in output average power and improved beam quality in cw and pulsed modes of operation will be discussed.

1. Y. E. Young, S. D. Setzler, K. J. Snell, P. A. Budni, T. M. Pollak and E. P. Chicklis, "Efficient 1645nm Er:YAG laser," Opt. Lett., **29**, pp.1075-1077, 2004.
2. S. D. Setzler, K. J. Snell, T. M. Pollak, P. A. Budni, Y. E. Young and E. P. Chicklis, "5W repetitively Q-switched Er:LuAG laser resonantly pumped by an erbium fiber laser," Opt. Lett., **28**, pp.1787-1789, 2003. p.1787.