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Efficient Er:YAG lased pumped in-band by an Er/Yb fibre laser

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Solid-state lasers operating in the eyesafe wavelength regime around ~1.5-2.1μm regime have numerous applications. In many of these applications the requirement for high-power is also accompanied by the need for high efficiency and good beam quality, which are often difficult to achieve in conventional solid-state lasers due to the detrimental effects of thermal loading. Recently, there has been dramatic progress in scaling output power from cladding-pumped Er/Yb and Tm doped silica fibre lasers operating in the 1.53-1.62μm and 1.85-2.1μm regime respectively. Fibre lasers offer the attraction of relatively simple thermal management and hence a high degree of immunity to thermal effects, but suffer from the drawback that, in pulsed mode, energies are limited by amplified spontaneous emission and by damage to the fibre end facets. An alternative approach which circumvents this problem is to use employ a hybrid laser approach where the cladding-pumped fibre laser is used to 'in-band' pump a bulk solid-state laser. This has the attraction of very low quantum defect heating in the bulk crystal and hence relatively weak thermal effects. In recent work, efficient operation of Er:YAG [1] and Ho:YAG [2] lasers, end-pumped by cladding-pumped Er/Yb and Tm fibre lasers respectively, has been demonstrated.

In this paper we describe an Er:YAG laser with 4W of cw TEM_{00} output at 1646nm pumped by a tunable Er/Yb fibre laser with 11W of output power at 1532nm and discuss the effect of various factors, including Er^{3+} concentration, on laser performance. The Er/Yb fiber pump laser used in our experiments was constructed in-house and utilised a 400μm diameter D-shaped double-clad fibre with an Er,Yb-doped phosphosilicate core of diameter, 24μm, and 0.21NA. A relatively simple cavity configuration was employed with feedback for laser oscillation provided the 3.6% Fresnel reflection from a perpendicularly-cleaved fibre end and by an external cavity at the opposite fibre end comprising a collimating lens and a diffraction grating aligned in the Littrow configuration to provide the means for tuning the lasing wavelength. The fibre end facet nearest the grating was angle-polished to suppress parasitic lasing between the two fibre end facets. Pump light at 940nm from a beam-shaped diode-stack was launched into the perpendicularly-cleaved end of the fibre with the aid of a dichroic mirror with high reflectivity at the pump wavelength at 45° and high transmission at 1.5-1.6μm. A relatively short length of fibre (~2.5m) was selected to reduce the gain for long wavelengths and hence allow tuning to the absorption peak in Er:YAG at 1532nm. The Er/Yb fibre laser yielded 14W of output at 1532nm in a beam with $M^2<6$ and with linewidth ~0.2nm for 33W of absorbed pump power. With relatively simple modifications to the fibre laser design, significantly higher output powers should be readily achievable.

The Er:YAG laser employed a simple three-mirror folded cavity design comprising a plane pump in-coupling mirror with high transmission (>95%) at 1532nm and high reflectivity (>99.9%) at 1625-1800nm, a 100mm radius of curvature fold-mirror with high reflectivity at 1525-1700nm and a plane output coupler. The Er:YAG rod was positioned in close proximity to the pump in-coupling mirror, and mounted in a water-cooled aluminium heat-sink maintained at room temperature (15°C). Pump light from the Er/Yb fibre laser was focussed into the Er:YAG rod with the aid of a simple arrangement of lenses to produce a waist beam radius of 75μm. Five different Er:YAG crystals with Er^{3+}-concentrations in the range 0.25% to 4 at% and with crystal lengths selected for ~95% absorption of the pump light at 1532nm were used in our study, and the laser performance was investigated for a range of output coupler transmissions (2-30%) at 1646nm. In preliminary experiments we have achieved a maximum output power of 4W at 1646nm for 11W of absorbed pump power corresponding to an overall efficiency of 36%, using a crystal with 0.5at% Er^{3+}-concentration and an output coupler transmission of 10%. Our experiments have revealed (quite surprisingly) the cw efficiency decreases quite markedly for higher Er^{3+}-concentrations. The origin this behaviour is currently the subject of further investigation and our findings will be presented. The prospects for further increase in output power and efficiency will also be discussed.

References:

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