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Highly efficient Ho:YLF and Ho:YAG lasers pumped by Tm-doped silica fibre laser

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Abstract : Efficient operation Ho:YLF and Ho:YAG lasers end-pumped by a tunable cladding-pumped Tm-doped silica fibre laser is reported. Output powers of 4.8W at 2066nm and 6.4W at 2097nm were obtained from the Ho:YLF and Ho:YAG lasers for < 9.6W of incident pump at 1940nm and 1905nm respectively.

The Ho^{3+} emission in the 2μm spectral region is of great interest for applications in a number of important areas, including medicine, remote sensing and mid-infrared generation via pumping of optical parametric oscillators. Unfortunately, direct pumping of holmium lasers by near-infrared diodes lasers requires that the crystal is co-doped with Tm, leading to high upconversion losses and reduced efficiency, particularly when operating in the Q-switched regime. One solution to this problem is to pump in-band with a diode-pumped Tm-doped bulk laser or double-clad Tm-doped fibre laser [1]. This approach has the advantage of very low quantum defect heating in the laser crystal with the result that very high lasing efficiencies are attainable. The use of a cladding-pumped Tm-doped fibre laser as the pump source is a particularly promising route for further power scaling, since the generated heat can be dissipated over a relatively long length of fibre reducing the risk of damage. Moreover, the output beam quality is determined by the waveguiding properties of the core, which can be tailored, if required, to produce a single-mode output with relative immunity from thermal lensing. An additional attraction of this approach is that the Tm fibre laser operating wavelength can be tuned over a wide range spanning the absorption lines of interest in Ho:YLF, Ho:YAG and many other Ho-doped crystals. In recent work [2], we reported a Ho:YAG laser, pumped by a cladding-pumped Tm-doped silica fibre laser, with ~5W of TEM_{oo} output and a slope efficiency with respect to incident pump power of ~80%. In this paper we report preliminary results for a Ho:YLF laser pumped by the Tm fibre laser and recent results for a Ho:YAG laser with improved performance.

The Tm-doped fibre laser used in our experiments was constructed in-house and comprised ~ 4.7m of double-clad fibre with a 20μm diameter (0.12 NA) Tm-doped alumino-silicate core surrounded by a 200μm diameter pure silica inner-cladding with a nominal NA of 0.49. The fibre laser was pumped through opposite ends by two beam-shaped diode-bars at ~790nm delivering a total combined maximum pump power of 54W (corresponding to 43W launched). Wavelength tuning was achieved by employing an external cavity comprising a simple diffraction grating (600 lines/mm) in the Littrow configuration to provide wavelength selective feedback. The lasing wavelength could be tuned over 215 nm from 1855 to 2070 nm at multi-watt power levels, and over 150 nm from ~ 1860 to 2010 nm at output power levels in excess of 9 W with an output linewidth of < 0.5nm.

A simple, low loss, two-mirror resonator configuration was used for the Ho:YLF laser comprising a plane input mirror with high reflectivity (>99.8%) at the lasing wavelength (2050-2250nm) and high transmission (>95%) at the fibre pump wavelength (1940nm), and a concave output coupler with a transmission of 2% at the lasing wavelength and radius of curvature, 25mm. The latter also had high reflectivity at the pump wavelength to improve the pump absorption efficiency by allowing a second pass of the laser rod for unabsorbed pump light. A 15mm long Ho:YLF rod with 1.5(at.)% Ho^{3+} concentration, and with both end faces antireflection coated in the 1.8-2.1μm wavelength regime, was used as the gain medium and positioned ~ 1mm from the pump input mirror. The Ho:YLF rod was mounted in a water-cooled copper heat-sink maintained at 15°C. The physical length of the resonator was ~18mm, resulting a TEM_{oo} beam radius of ~90ìm in the Ho:YLF rod. The single-pass absorption for the crystal at 1940nm was ~78% at low pump intensity and reduced to ~51% at an incident pump power of 9.4W due to the ground state depletion. The laser had a threshold pump power of ~1.5W and generated 4.8W output at 2065nm at the maximum incident pump power of 9.4W, corresponding to an optical conversion efficiency of 51%. The slope efficiency with respect to incident pump power was 59%. A similar resonator configuration was employed for the Ho:YAG laser but with the output coupler replaced by one with a transmission of 10% at the lasing wavelength and radius of curvature, 100mm. At the maximum incident pump power of 9.6W, we obtained ~6.4W of TEM_{oo} output (M^2<1.1) at 2097nm corresponding to an optical-to-optical efficiency of 67%, and the slope efficiency with respect to incident pump power was 80%. In both cases, the laser output power increased linearly with pump power with the maximum output power limited by the available pump power, and with no evidence of any detrimental effects due to thermal loading. These results suggest that there is a considerable scope for further power scaling by simply increasing the pump power.

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2. A.Abdolvand, D.Y.Shen, L.Cooper, R.Williams, W.A. Clarkson, "Ultra-efficient Ho:YAG laser end-pumped by a cladding-pumped Tm-doped silica fibre laser", in 2003 Advanced Solid-State Photonics, San Antonio, Texas, 2-5 Feb. 2003, paper MA7.