In conclusion we have demonstrated a relatively simple, room-temperature operating, resonant cascaded fibre Raman laser that provides a broad band CW output between 1.56 and 1.95 μm. We believe this is the first report of a CW fibre Raman laser operating in this spectral region. This laser was pumped by an integrated Yb<sup>3+</sup>:Er<sup>3+</sup> fibre laser, which in turn can be pumped either by a compact mini all-solid-state Nd-based laser or laser diodes. Through optimising the fibre lengths employed and output coupling ratios, a considerable increase in the output power levels should be achieved.

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References


Efficient fibre-coupled laser diode end-pumped NYAB laser

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Indexing terms: Fibre lasers, Solid lasers

Under optimum pump conditions, 60mW of green laser output corresponding to a conversion efficiency 6% was obtained from a self-frequency-doubling NYAB crystal when pumped by a 1W fibre-coupled laser diode. The prospect of higher conversion efficiency is also discussed.

Neodymium yttrium aluminium borate (NYAB) has a number of desirable features that make it an attractive material for a diode pumped compact green laser system. The self-frequency-doubling CW NYAB laser end-pumped by a diode laser has been realised in several laboratories [1–4]. However, the conversion efficiency never exceeded 3% in these investigations. In this Letter we demonstrate a highly efficient fibre-coupled diode end-pumped NYAB laser. Under optimum pump conditions, 60mW of green laser output corresponding to a conversion efficiency 6% was obtained from a self-frequency-doubling NYAB crystal when pumped by a 1W fibre-coupled laser diode.

Fig. 1 Fibre-coupled diode pumping experimental setup

The NYAB crystal, dimensions 3mm x 3mm x 2mm, was cut at the type I phase-matching angle for second harmonic generation at 1.063μm (θ<sub>1</sub> = 32.9°). The experimental setup is shown in Fig. 1. The fibre-coupled laser diode used was an SDL-2372-P2 (Spectra Diode Laser Labs), which has a 230μm core fibre with a 36° half width at 1/e<sup>2</sup> of the peak intensity and a maximum CW output power of ~1.2W. The emission wavelength of the diode laser was tuned by controlling the operating temperature control system to match the laser wavelength to the absorption peak of NYAB. The planoconcave configuration of the resonator consisted of one planar crystal surface, high-reflection coated at 1.063μm and 0.532μm and high-transmission coated at 0.808μm for the pump light to enter the rod, and a spherical output mirror. The second surface of the crystal was antireflection coated at 1.063μm and 0.532μm. An output mirror with a curvature of 10cm was used and the reflectivities of the mirror were 99.9% and ~10% for 1.063μm and 0.532μm, respectively. The mirror was mounted approxi-mately 5cm from the planar reflecting facet. This design yields a 0.13mm TEM<sub>00</sub> spot size.

The brightness of a single fibre-coupled laser diode (several tens of kW/cm<sup>2</sup> sr) is two orders of magnitude less than that of the source diode (several MW/cm<sup>2</sup> sr) [5]. Therefore, the characteristic of the pump-beam quality should be taken into account in determining the optimum pump condition of the fibre-coupled laser-diode pumped lasers. Including the effect of the pump-beam quality, the normalised spatial distribution of the pump energy can be described by [6, 7]

\[
r_{p}(x, y, z) = \frac{2\alpha}{\pi a_0^2(z)[1 - \exp(-\alpha z)]} \exp\left(-\frac{2r^2 + z^2}{a_0^2(z)} - \alpha z\right)
\]

(1)

On the basis of the paraxial approximation, \(\alpha(z) = \omega_0^{-2} \theta_0^{-1} (z - z_0)\). Here \(\omega_0\) is the radius at the waist, \(\theta_0\), and \(z_0\) are the far-field half-angle and focal plane of the pump beam in the active medium. The brightness theorem gives a relationship of \(\Theta_{in}\) = C, where C is a constant that is a characteristic of the beam quality and \(\Theta\) is the refractive index for the pump beam. For a fibre-coupled diode, the...
The fibre-coupled diode end-pumped NYAB laser was operated using the pumping configuration discussed above. Experimental and theoretical results for output power against optical pump power are shown in Fig. 3. A CW green output power of ~60mW was obtained at a pumping power 1 W corresponding to a conversion efficiency of ~6%. To our knowledge, the present conversion efficiency is the highest reported so far for a self-frequency-doubling CW NYAB laser. Also, it can be seen that the predictions of the analysis agree very well with experimental data. With NYAB crystals of good optical quality the efficiency and output power can be improved considerably. The dependence of green output power on the length of the NYAB crystal is shown in Fig. 4. It can be seen that the conversion efficiency can be higher than 10% for an NYAB with internal loss less than 1.4%/cm. It can be seen that the optimum crystal length is ~1.5-2.0 mm, with almost total insensitivity to internal losses.

References