Power-scaling and frequency-doubling of a diode-bar-pumped Nd:YAG laser at 946nm

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ABSTRACT

A diode-bar-pumped Nd:YAG laser at 946nm, producing 3.5W of linearly-polarised cw output and 2.5W of Q-switched average power, is frequency-doubled in non-critically-phase-matched lithium triborate at ~316°C.

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High-power solid-state sources in the visible spectral region are sought after for numerous applications in important areas such as medicine, display technology and chemistry. Efficient generation of green light via frequency doubling of diode-pumped Nd lasers operating at ~ 1.06μm is now a well established technique [1], with a number of commercial products available. However, for high-power blue light generation there remains a number of difficult obstacles to overcome. One route for blue light generation, which has recently attracted growing interest, is via frequency doubling of 946nm Nd:YAG lasers [2],[3]. This approach offers the prospect of high efficiency, but progress in scaling to the high powers required, whilst maintaining high efficiency has been hindered by strong thermal effects, and also by the lack of a suitable nonlinear crystal.

In this paper we describe a strategy for reducing the effects of thermal loading to allow efficient linearly-polarised operation of a diode-end-pumped Nd:YAG laser at 946nm at the multiwatt power level, and we also discuss the merits of lithium triborate (LBO) for frequency doubling to blue light at 473nm.

Due to the low stimulated emission cross-section ($\sim 4\times10^{-20}\text{cm}^2$) and quasi-three-level nature of the 946nm line in Nd:YAG, efficient end-pumped operation requires the diode-pump beam to be focussed to a relatively small beam size. For high-power diode-bar pump sources this necessitates the use of special beam conditioning optics (e.g. [4]) to equalise the beam propagation factors in orthogonal planes without significantly decreasing the pump brightness. However, one undesirable, but inevitable consequence of a small pump beam size is a high thermal loading density, and hence stress-induced birefringence and strong thermal lensing, which are detrimental to laser performance. To minimise the effect of the highly aberrated thermal lensing we have employed a resonator design which is stable over a wide range of thermal lens powers. The rationale for this is that an aberrated thermal lens can be thought of as a lens with a radially varying focal length. Thus, by choosing a resonator which satisfies this condition, one can minimise cavity loss due to diffraction ensuring efficient operation. The resonator design used in our preliminary experiments (shown in Fig.1) employed a simple folded cavity arrangement with the arm lengths and mirror curvatures specially selected to satisfy the stability condition over a range of thermal lens focal lengths. The 1% Nd-doped YAG rod of length 7mm, mounted in a water-cooled heat-sink maintained at 13°C, was pumped from both ends with the outputs from two fibre-coupled, beam-shaped diode-bars focussed to a relatively small beam radius of 150μm. The maximum pump power (from both diodes) was limited due to non-optimum coupling optics to 17W incident on the laser rod. In the absence of any additional intracavity components, this laser produced a maximum output power of 4.6W at 946nm. When a Brewster-angled TeO_2 Q-switch was inserted into the cavity (with no r.f. power applied) the laser power was reduced to 0.37W (at the maximum pump power) due to the depolarisation loss (~7%) caused by thermally-induced birefringence in the laser rod. This loss was reduced to <0.3% by inserting a quarter-wave plate [5] between the pump incoupling mirror and the laser rod, allowing efficient linearly polarised operation with a cw output power up to 3.5W in a beam with beam quality factors of $M_y^2=1.2$ and $M_x^2=2.2$. A comparison of laser performance with and without the quarter-wave plate is shown in Fig.2. Q-switched operation at a repetition rate of 5kHz resulted in pulses of duration ~100ns and an average output power of ~2.5W.

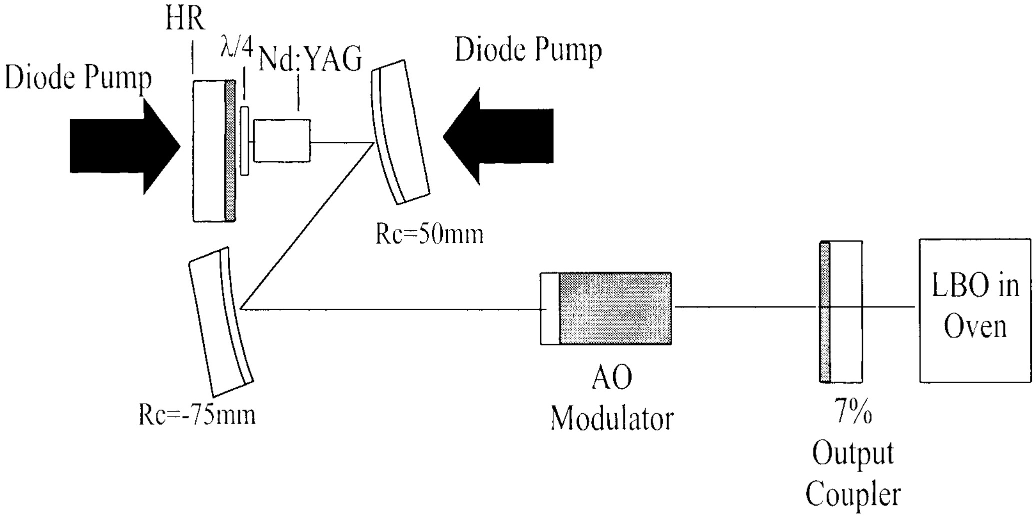

Fig.1. 946nm Nd:YAG Laser with LBO Frequency Doubler

For frequency doubling of the Q-switched 946nm output to the blue we have used a 15mm long LBO crystal cut for type I non-critical phase-matching. LBO is often the preferred choice of nonlinear crystal for frequency doubling of 1.06μm Nd lasers at multiwatt average powers due to its low loss and high damage threshold . In this case the temperature required for non-critical phase-matching is typically in the region of 150°C. LBO can also be used to generate the second harmonic of 946nm, but a much higher temperature (~316°C) is required for phase matching. Operating the LBO at this high temperature we have generated ~300mW of average power at 473nm for 2.5W of average fundamental power. Predictions based on the measured second harmonic efficiency for the laser when operating in the cw regime suggest that much higher second harmonic conversion efficiencies for the Q-switched output should be achievable. We believe that this reduction in efficiency is due to increased thermal loading under Q-switched operation, due to upconversion processes [6], which result in a degradation in beam quality and hence a larger focussed fundamental beam size in the LBO. Thus, with further optimisation of the resonator design, including the use of a Nd:YAG rod with lower Nd concentration to reduce upconversion, it should be possible to achieve average powers at 473nm in excess of 1W.

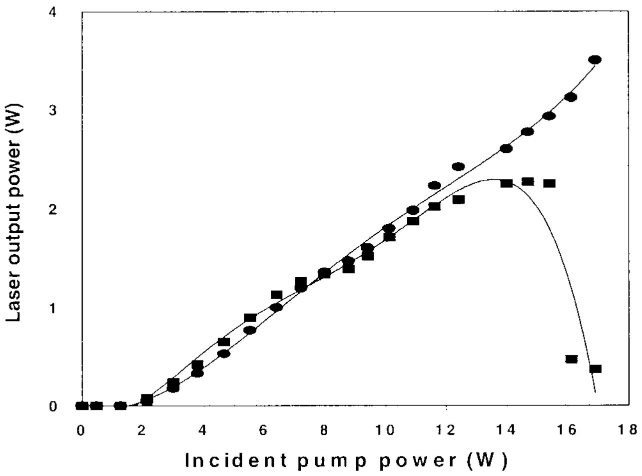

Fig.2. Laser output power against incident pump power

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