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Detailed study of thermal lensing in Nd: YVO_4 under intense diode end-pumping

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Thermal lensing in diode-end-pumped Nd: YVO_4 has been measured for different cooling arrangements and different neodymium concentrations under lasing and non-lasing conditions. The significant effect of energy-transfer-upconversion on lens aberration and beam quality is examined.

With its natural birefringence and high $\sigma\tau_f$ product, Nd:YVO_4 is becoming an increasingly popular choice as a lasing material for diode pumped solid-state lasers. The short absorption length for pump light at ~809nm relaxes the constraints on diode beam quality allowing tight focusing of the pump beam and hence the use of relatively small laser mode sizes. However, in comparison to Nd:YAG it has poorer thermal properties, resulting in strong thermal-lensing, a knowledge of which is essential for optimum laser design. Whilst there has been some published work on certain aspects of the thermal lensing behaviour in Nd:YVO_4 (e.g. [1,2]), a detailed study has yet to be reported. Here, we present the results of such a study, which considers the effect on thermal lensing of neodymium concentration, heat-sinking arrangement and laser configuration on thermal lensing. We have also examined the effect of energy-transfer-upconversion (ETU), between neighbouring excited ions on thermally-induced lens aberration and degradation in beam quality.

The thermal lens power and higher-order aberration terms in end-pumped Nd:YVO_4 were determined by measuring the induced phase difference as a function of transverse position using a Mach-Zehnder interferometer. The Nd:YVO_4 crystal was located in one arm of the interferometer close to a 45° high reflector at ~1μm which had a high transmission for pump light at ~809nm. The crystal was pumped by a fibre-coupled diode-bar, the output of which was focused to a spot radius, w_p, of 120μm with a maximum power of 5.3W incident on the crystal. The probe beam for the interferometer was provided by a single-frequency Nd:YLF laser operating at 1.053μm, and aligned collinear to the pump beam. The square cross-section Nd:YVO_4 crystal was mounted in a heat-sink which allowed cooling from either of two faces (perpendicular to the a or c axis). The interferometer was also equipped with a set of mirrors to form a stable non-collinear resonator for the Nd:YVO_4 crystal to allow thermal-lensing to be investigated under lasing and non-lasing conditions.

Figure 1 shows an example of the results obtained for 1% and 0.3% Nd-doped YVO_4 crystals with cooled faces perpendicular to the c-axis and probe beam polarization parallel to the c-axis. The thermal lens power is ~5 times greater under non-lasing than for the lasing conditions for the 1% doped crystal, which we attribute mainly to additional heating from ETU, this being greater under non-lasing conditions where the excited ion density is greater. This is further compounded by reduction of thermal conductivity at higher temperature. The much smaller corresponding value for the 0.3% doped crystal indicates the potential benefits to (~2) be achieved with lower Nd concentrations. The results for the perpendicular heat-sinking direction and the orthogonal probe beam polarization, which suggest that thermally-induced stresses play a role in thermal lensing behaviour will also be presented.

To illustrate the problems associated with the aberrated nature of the thermal lens we have calculated the degradation in the beam quality factor M^2 caused by the quartic phase aberration terms [3]. Figures 2 and 3 show calculated M^2 values as a function of pump power for the above example of thermal lensing for two different probe beam sizes. The benefits of using a lower Nd concentration and smaller laser mode than the pump beam size are evident, with a dramatic reduction in M^2 for the same pumping power. The results provided by this study allow formulation of a design strategy for further power-scaling of Nd:YVO_4 lasers and amplifiers while maintaining good output beam quality.

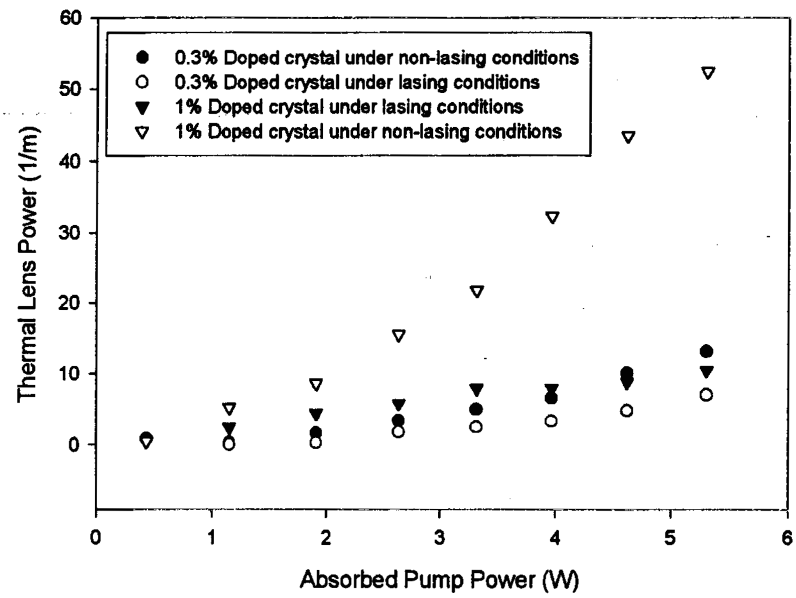

Fig. 1. Variation of thermal lens power with absorbed pump power.

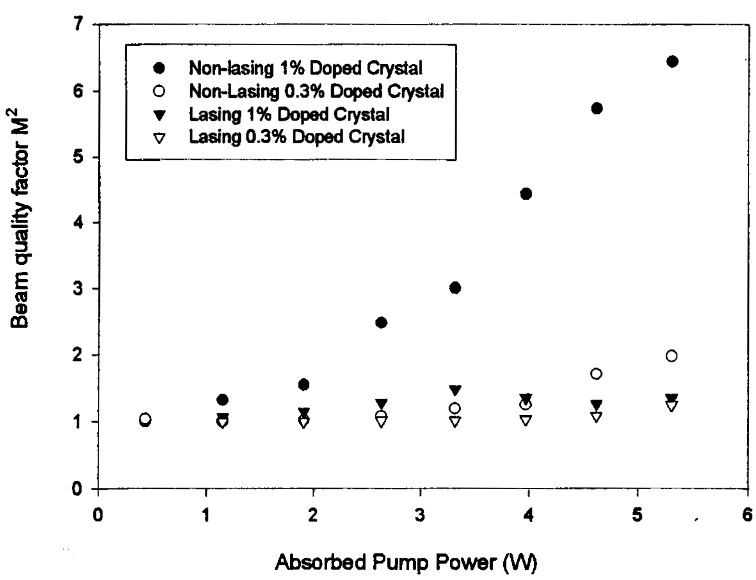

Fig. 2. Single-pass degradation in beam quality for $w_{probe}=w_p$,

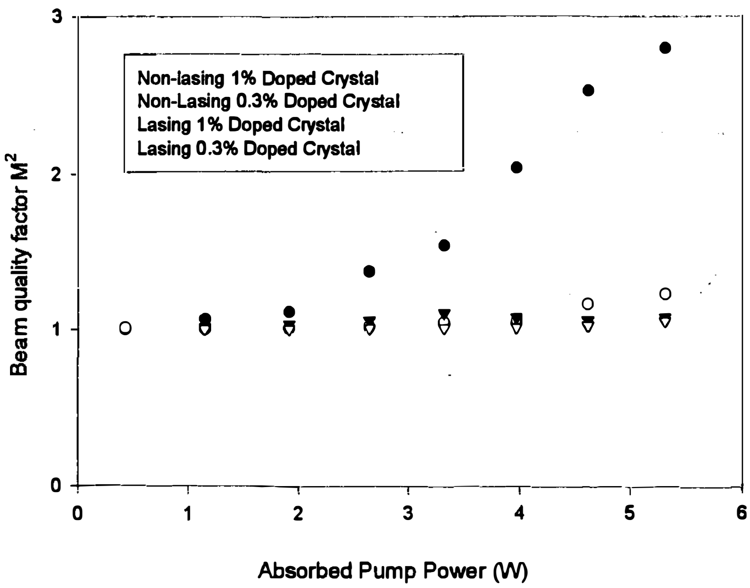

Fig. 3. Single-pass degradation in beam quality for $w_{probe}=0.8w_p$,

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