THE INFLUENCE OF ENERGY-TRANSFER UPCONVERSION ON THERMAL LENSING IN END-PUMPED ND:YLF AND ND:YAG LASERS

P. J. Hardman, M. Pollnau, W. A. Clarkson, and D. C. Hanna
Optoelectronics Research Centre, University of Southampton,
Highfield, Southampton SO17 1BJ, United Kingdom
Tel. +44-1703-593136, Fax +44-1703-593142, email pjh@orc.soton.ac.uk

Nd:YLF and Nd:YAG are two of the most commonly used solid state laser crystals because of their qualities both spectroscopically and thermo-mechanically. However, scaling these lasers to higher powers has been hindered by thermal lensing problems. We have found that under different schemes of operation, e.g. CW versus Q-switched, the heat load and consequent thermal lensing may vary significantly. The mechanisms underlying this difference must be thoroughly understood and controlled if optimum design for efficient operation is to be achieved.

The thermal lensing for both crystals was measured under CW lasing conditions as well as under non-lasing conditions, for which the excitation density was set at a level appropriate for operation as an amplifier, as a low-repetition-rate Q-switched laser or on a low-gain transition. A 20-W diode-bar pump was beam-shaped and focussed to ~250μm, a spot-size typically used in our lasers. Measurements were taken by using both probe and interferometric techniques. The results showed a significant difference in the thermal lens under lasing and non-lasing conditions. Under non-lasing conditions a much stronger thermal lens was measured, whose power increased non-linearly with pump power. With 11W of pump power incident on the Nd:YLF crystal, a factor of ~6 difference between lasing and non-lasing values of focal length was determined (π-polarisation, plane perpendicular to c-axis). For Nd:YAG a factor of ~2 stronger thermal lens was observed.

These measurements demonstrate that significant additional heat is generated in the non-lasing case. Utilising a simple analytical approach, the fraction of absorbed pump power converted to heat under non-lasing conditions was calculated as ~56% for Nd:YLF and ~35% for Nd:YAG as opposed to ~24% under lasing conditions. The explanation for this additional heat generation is based on the strong increase in energy-transfer upconversion, with the higher excitation density under non-lasing conditions, thus increasing the heat input into the laser crystal via subsequent multi-phonon relaxation.

In addition to this increased heat input, the lens is further worsened by the temperature dependancies of heat conductivity and thermo-optical parameters. So Nd:YLF displays a larger increase in thermal lens than Nd:YAG not only because the extra heat input is larger but also because it has a smaller thermal conductivity, resulting in a higher temperature profile. However, thermal lensing is generally stronger in Nd:YAG, resulting in stronger thermal lens aberrations. These observations were reproduced, with good agreement, using a finite-element calculation which considered the relevant processes, including upconversion and the temperature dependancies of heat conductivity and thermo-optical parameters.

These results are particularly pronounced when the system is operated under conditions of higher excitation density, e.g. in a Q-switched regime, as an amplifier or on a low-gain transition. However, a reduction of these detrimental effects can be achieved by decreasing the dopant concentration and using a longer crystal or by increasing the pump spot size. Controlling the underlying mechanisms has enabled us to design efficient, high power Nd:YLF amplifiers and Q-switched lasers.