60-W cryogenically-cooled Nd:YAG 946nm laser

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Cryogenic-cooling has proved to be an efficient way of power-scaling solid-state lasers, thanks to the enhancement of spectroscopic and thermo-optical properties of the gain media [1].

We have investigated the dependence of the Nd:YAG $^2H_{9/2} +^4 F_{5/2}$ absorption cross section at cryogenic temperatures, enabling the measurement of the analogous dependence of the Energy Transfer Upconversion (ETU) macroparameter. These results were key to establishing that, although at Room Temperature (RT) the quasi-four-level transition of Nd:YAG at 946 nm is essentially limited by low gain and detrimental thermal effects exacerbated by ETU, cryogenic-cooling results in an overall improvement in laser performance, despite an increase in the ETU coefficient. In-band-pumped by a novel source at 869 nm, a simple linear cavity produced 60W of output in preliminary measurements.

We have executed small signal absorption measurements, the details of which are described in [2], characterising the Nd:YAG absorption cross section around 808 nm in the temperature range from RT to 77K. The peak absorption cross section increases from (7.0 ± 0.4) pm^2 to (41.0 ± 4.0) pm^2, narrowing from (0.93 ± 0.01) nm to (0.21 ± 0.01) nm, while blue-shifting by (0.16 ± 0.01) nm, from RT to 77K. Using these results, we measured the ETU coefficient in 0.3at.% and 0.6at.% Nd:YAG over a similar temperature range, via a simple and automated z-scan technique coupled to a spatially-dependent two-level rate-equation model [2]. The ETU macroparameter is found to increase from $(21.5 \pm 2.3) \cdot 10^{-18}$ cm^3/s and $(36.0 \pm 2.8) \cdot 10^{-18}$ cm^3/s at RT to $(52.6 \pm 2.5) \cdot 10^{-18}$ cm^3/s and $(65.7 \pm 1.9) \cdot 10^{-18}$ cm^3/s at 73K, for respectively 0.3 at.% and 0.6 at.% Nd:YAG samples. Results are shown in fig. 1(a) and 1(b).

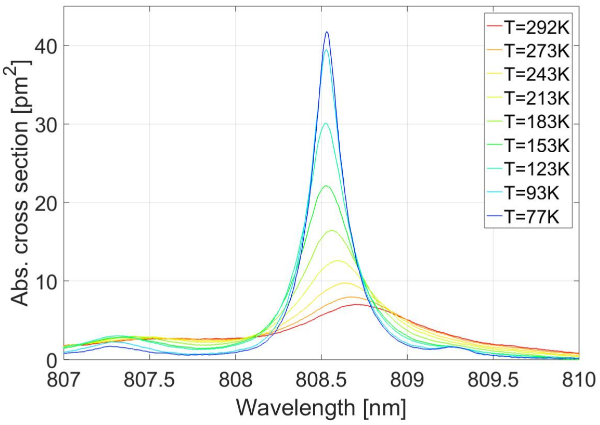

Fig. 1(a). 808 nm absorption cross section.

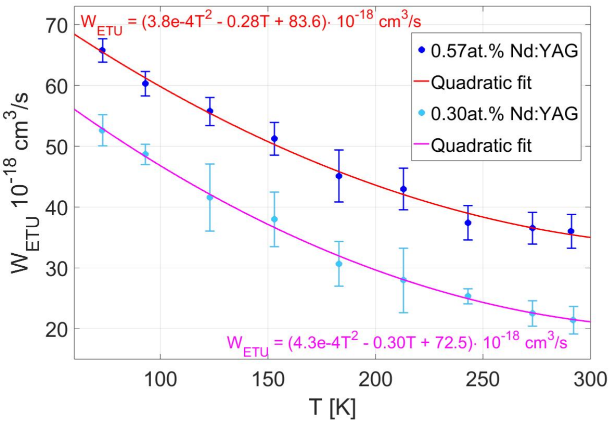

Fig. 1(b). ETU coefficient.

Using the model reported in [3], we have estimated that whilst the ETU coefficient increases, its contribution to the laser threshold is below 1%, and therefore, thanks to the enhancement of the spectroscopic properties, reduced pump saturation, higher gain, and a truly 4-level energy scheme, better performance with respect to RT is achieved.

Furthermore, in order to minimise the quantum defect, we have developed a 869 nm Volume-Bragg-Grating-locked high-brightness diode-laser source, which we have employed to pump a simple linear flat-curved (ROC= 200 mm, T= 10%) cavity encompassing a cryogenically-cooled, 0.3 at.% doped, Nd:YAG crystal. As a preliminary result we have obtained the first 60-W cryogenically-cooled, in-band end-pumped, Nd:YAG 946 nm laser with an optical to optical, and, slope efficiency (versus absorbed power) of $(52 \pm 1)\%$. We expect to exceed 100W of output power after optimisation.

References

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