60-W CRYOGENICALLY-COOLED ND:YAG 946nm LASER

S. Cante, J. I. Mackenzie

Optoelectronics Research Centre, University of Southampton SO17 1BJ, UK

s.cante@soton.ac.uk

http://www.orc.soton.ac.uk/planar-waveguide-and-slab-lasers

Abstract: 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. We have investigated the absorption cross section of Nd:YAG at cryogenic temperatures via a small-signal measurement method, enabling the determination of the analogous dependence of the Energy Transfer Upconversion (ETU) macroparameter, via a z-scan technique. These results were key to establishing that, while at Room Temperature (RT) the 946 nm quasi-four-level transition of Nd:YAG is essentially limited by low gain and detrimental thermal effects exacerbated by ETU, for cryogenic cooling of the gain crystal, an overall improvement in laser performance, despite an increase in the ETU coefficient, is obtained. In-band-pumped by a diode-laser, locked to 869 nm via a volume-Bragg-grating, we demonstrate a 60-W 946 nm laser with a 50% conversion efficiency.

1. Motivation — Why 946nm?

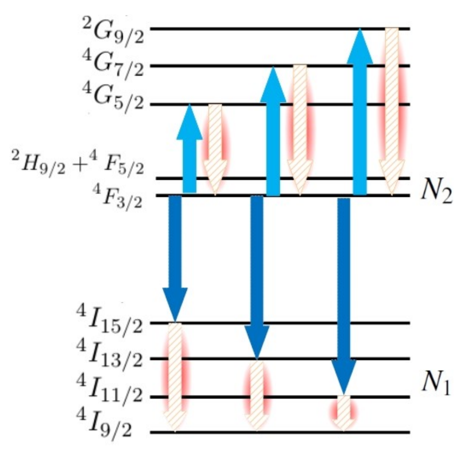
- Applications
  - Material processing, LIDAR systems (in IR spectrum)
  - Underwater communication, medical, environmental, technological (in blue-green spectra, with second-harmonic-generation)
  - Industrial micro-precision cutting and drilling, micro-lithography — need for short wavelengths (in UV spectrum, with fourth-harmonic-generation)

Why cryogenic cooling?

- Enhancement of spectroscopic and thermo-optical properties
  - Thermal expansion coefficient decreases from 6ppm/K to 1ppm/K, dn/dT decreases from 8ppm/K to 1ppm/K and thermal conductivity increases from 11W/m*K to 75W/m*K (undoped YAG) over the range from Room Temperature to 77K
  - Emission cross section increases from $4pm^2$ to $8.5pm^2$

2. ETU

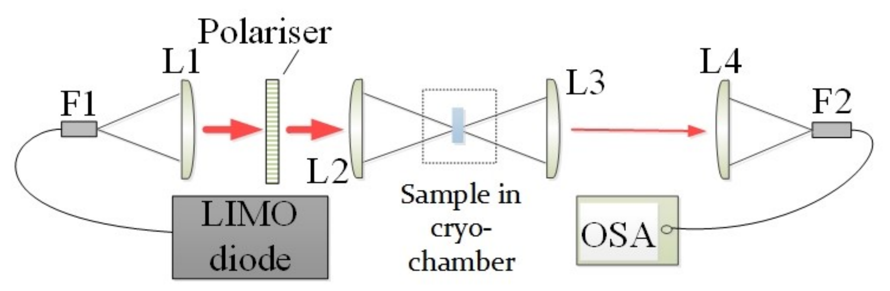
- Energy Transfer Upconversion (ETU) is detrimental to the performance of the low-gain 946nm transition
- Depopulates the upper laser level by exciting ions from the $^4F_{3/2}$ level to higher energy levels
- These excited ions produce additional heat via non-radiative decay



ETU dynamics

3. Methodology

Absorption cross section measurements (model in [1])



Experimental setup

LIMO diode: sub-threshold fibre-coupled laser diode

L1 and L4 = 30mm

L2 and L3 = 150mm

OSA: fibre-coupled optical spectrum analyser

ETU coefficient measurements (model in [1])

After L3:

M^2=1.06

w_{ox}=19.7 µm

w_{oy}=19.9 µm

P_{in}=200 mW

L1 = 50 mm

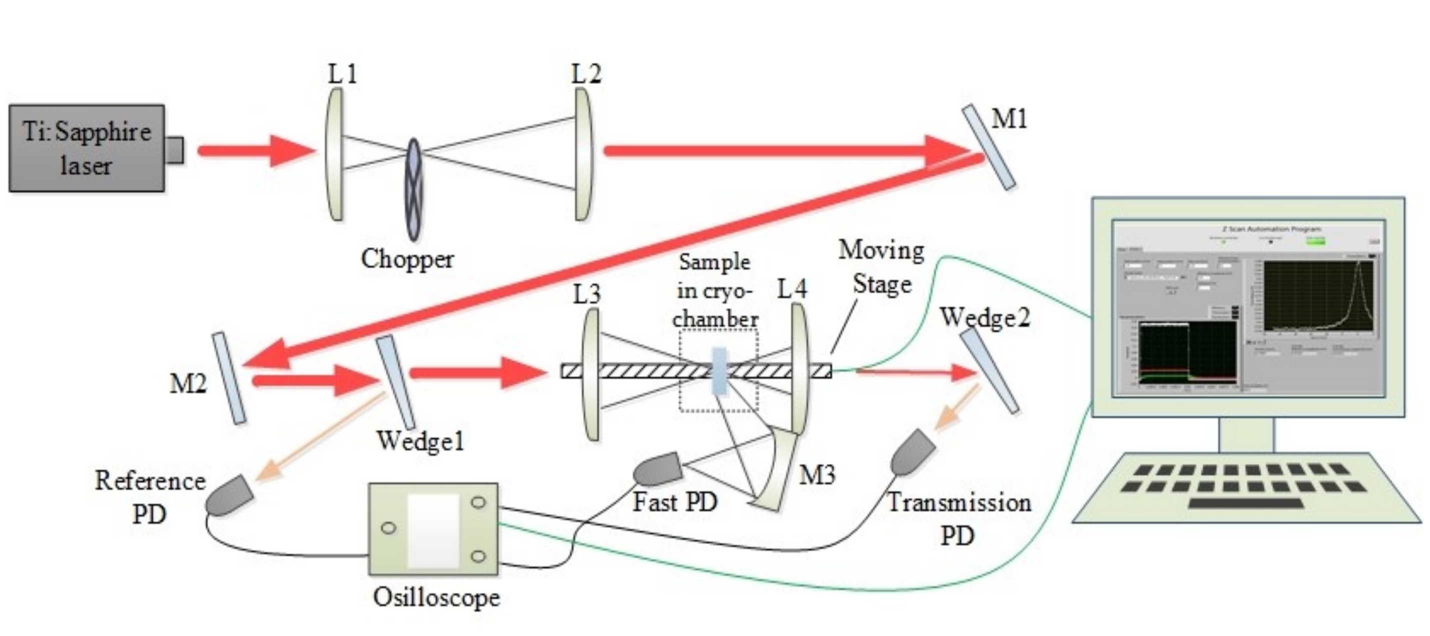
L2 = 300 mm

L3 = 200 mm

L4 = 75 mm

1 ms pulse

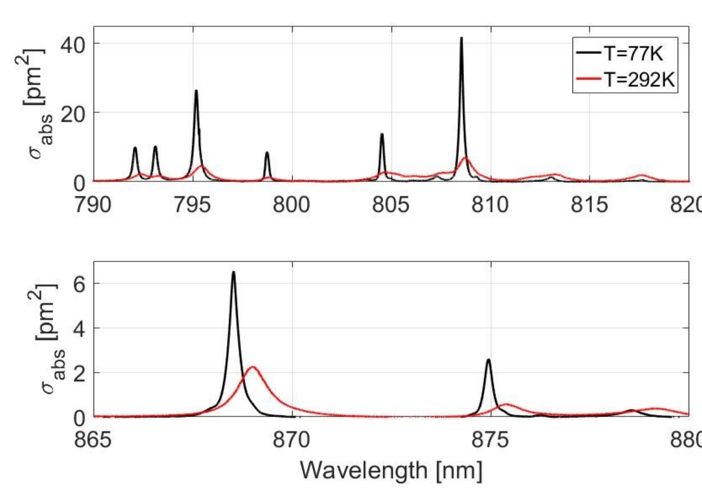
10% duty cycle



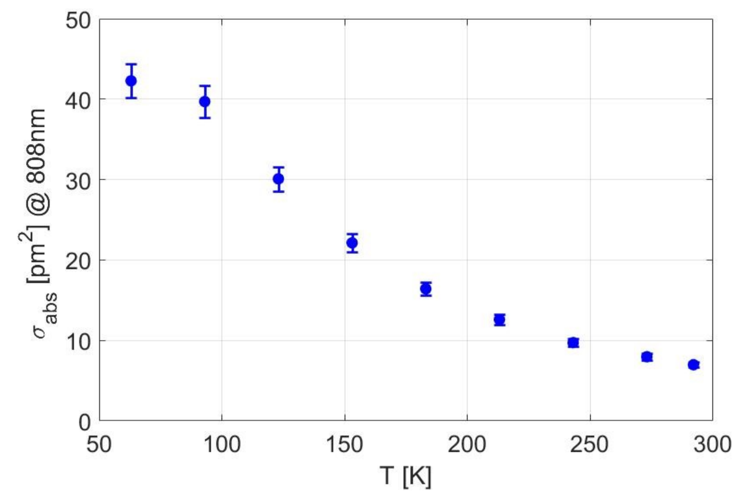
LabView-interface-driven automated z-scan setup

4. Absorption cross sections results

- Absorption cross section for Nd:YAG increases with decreasing temperature



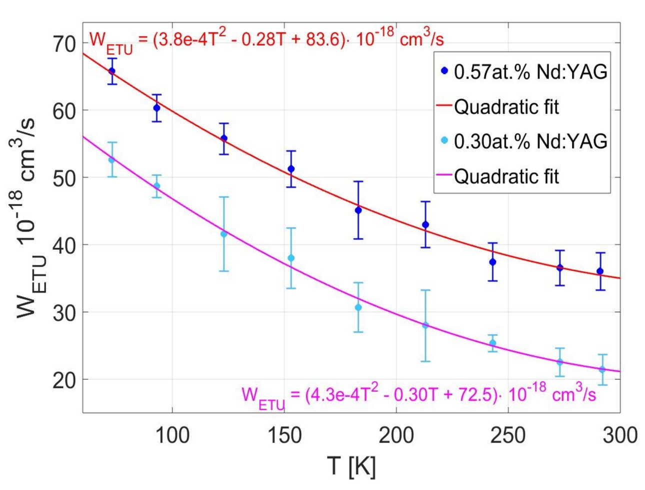
Abs. cross section spectra in the 808nm and 869nm [2] bands for T=77K and RT



Abs. cross section peaks @ 808nm vs T

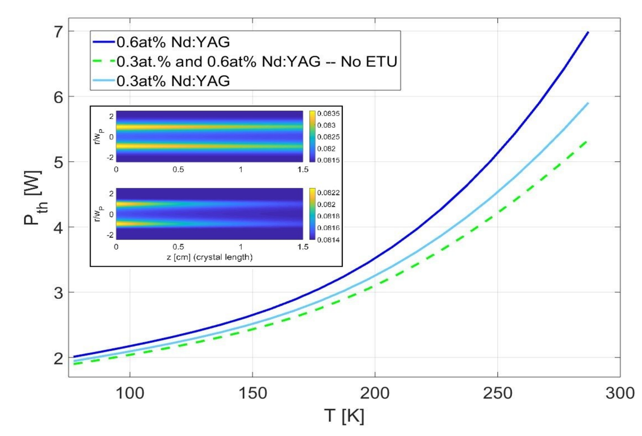
5. ETU results

- ETU coefficient increases with decreasing temperature



ETU vs cryo-T for 0.3at.% and 0.6at.% Nd:YAG

However, in cryogenic regime, ETU effects are less detrimental than at RT: thermal load distribution [3] (inset: 0.3at.% Nd:YAG, RT top, 77K bottom) and threshold pump power (main plot) are lower.



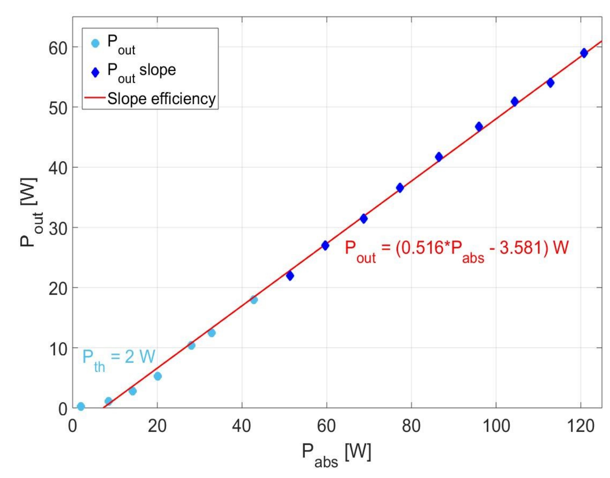
Threshold pump power with and without considering ETU [3] vs Temperature for 0.3at.% and 0.6at.% doped Nd:YAG. Pumping respectively 15mm and 0.75mm long crystals, at 869nm, lasing at 946nm, 350µm pump and 200µm mode waists, 2% cavity loss, 10% output coupling.

6. 60-W 946nm laser

- Pump: λ_c=869nm, $\Delta\lambda$=0.2nm, 130W max power, M^2_x<35, M^2_y<25, w_x=310µm, w_y=360µm
- 0.3at.% Nd:YAG, 15mm, cooled at 77K
- Simple linear cavity comprising a flat input mirror, a ROC=200mm, 10% transmission, output coupler

Preliminary result

- 60 W of 946nm output power
- 50% slope and optical-to-optical efficiency



7. Conclusions

- We have investigated the 808nm absorption cross section dependence on cryogenic temperatures, which led to the characterisation of the ETU over the same temperature range
- We have determined that the effects of ETU are less detrimental in the cryogenic regime, despite the increase in the ETU macroparameter with respect to the RT case
- Using these results, we have developed a simple linear cavity, for which we have employed a VBG-locked 869nm pump and a, 15mm long, 0.3at.% Nd:YAG crystal, to further reduce the thermal load
- Preliminary results produced 60W of output power at 946nm with a 50% conversion efficiency

References

[1] S. Cante, S. J. Beecher, and J. I. Mackenzie, "Characterising energy transfer upconversion in Nd-doped vanadates at elevated temperatures," Opt. Express **26(6)**, 6478-6489 (2018)

[2] S. J. Yoon, "Cryogenically-Cooled Neodymium-Doped Solid-State Lasers," Dissertation, University of Southampton, ORC (2016)

[3] S. Bjurshagen and R. Koch, "Modeling of Energy-Transfer Upconversion and Thermal Effects in End-Pumped Quasi-Three-Level Lasers," Appl. Opt. 43(24), 4753—4767 (2004)