Exploiting the natural doping gradient of Nd:YLF crystals for high-power end-pumped lasers

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Of the various Neodymium-doped materials, Nd:YLF is particularly attractive for use in high-power diode end-pumped solid-state lasers due to its weak thermal lens, especially on the σ-polarisation, and it's long upper laser level lifetime that enables efficient energy storage for *Q*-switching. However, due to the low thermal fracture limit in Nd:YLF, power scaling has proven to be difficult.

In our previous work, we addressed several issues relating to Nd:YLF in a novel fashion and were subsequently able to demonstrate the highest published power for an end-pumped Nd:YLF laser [1]. The laser delivered a total output power of 60.3 W CW and an average power of 52 W when *Q*-switched between 5 and 30 kHz, with good beam quality and no sign of lifetime quenching. However, we experienced fracture at 5 kHz.

In order to address the fracture problem we decided to use crystals of a doping concentration below the 0.5% previously used. In addition, we decided to exploit the natural doping gradient along the length of the boule, which is especially pronounced at low concentrations but commonly ignored. In a collaboration, VLOC estimated the doping gradient of a specially manufactured boule (Fig. 2) and maintained the crystal orientation information during the manufacturing process of the 45 mm long, 6 mm diameter crystals. Initial thermal calculations indicate that for these crystals, the lower-doping end can be pumped 58% harder than the higher-doping end before the thermal fracture limit is reached.

To be able to pump each crystal rod from its low-doping end, we implemented a folded resonator (Fig. 1). In addition to using relatively low doping concentrations, we pumped at a wavelength of 805 nm, where the absorption of Nd:YLF is ~5 times lower than the conventionally used 792 or 797 nm. The combination of these techniques resulted in a more even distribution of the heat load along the length of the crystals. As in our previous work, we compensated for the strong astigmatism of the crystals by using two crystals with the c-axis vertical and two with the c-axis horizontal with a λ/2-plate in-between [1].

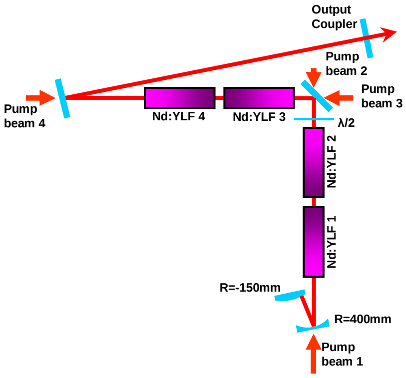

Fig. 1 Laser resonator

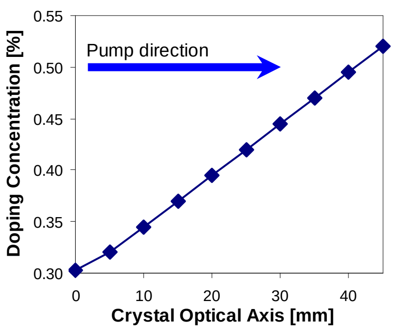

Fig. 2 Crystal doping gradient as estimated by VLOC

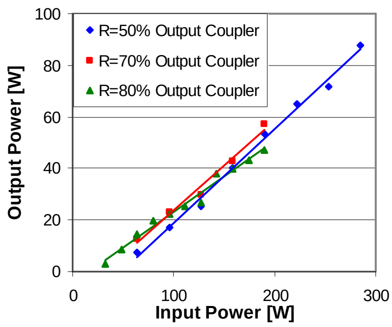

Fig. 3 Power under CW operation

With this configuration, no crystal damage occurred, even with all four fibre-coupled 75 W diode laser modules at full power. A total output power of up to 87 W CW was achieved, which is the highest reported so far but still less than expected (Fig. 3). Using Findlay-Clay and Caird analysis, the resonator loss was estimated to be 10% and 15% respectively. The crystals' total scatter loss was subsequently measured but was found to be only 1.64% round-trip loss at the laser wavelength.

We observed significant fluctuations in the output power and beam pointing. These could be because the laser operates in Zone II of the thermal stability diagram [2], which makes the laser very sensitive to misalignment and to small fluctuations in the pump overlap and variations in diffraction in the air. We believe that the lower than expected output power is due to this as well, rather than to actual resonator losses.

By redesigning the laser to operate in zone I, efficient and stable operation in excess of 100 W should be achievable. In the next step, *Q*-switched operation will be investigated, which has the potential to yield high average powers even at repetition rates below 5 kHz.

References

[1] C. Bollig, C. Jacobs, H. M. von Bergmann, and M. J. Esser, "High-power end-pumped Nd:YLF laser without lifetime quenching" CLEO/Europe 2005

[2] V. Magni, "Resonators for solid-state lasers with large-volume fundamental mode and high alignment stability," Appl. Opt. **25**, 107 (1986)