Power Scaling of Thin Disk laser

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The thin disk laser design is a concept for diode-pumped solid-state lasers which allows the realization of lasers with high output power, highest efficiency and good beam quality, simultaneously. The core idea behind the thin disk design is the use of a thin, disk-shaped active medium that is cooled through one of the flat faces of the disk. This ensures a large surface-to-volume ratio and therefore provides very efficient thermal management. The “classical” approach for power scaling of the thin disk design is the scaling of the active area, keeping power densities and pump source brightness requirements constant.

Numerical modeling is an essential tool for proper engineering of the power scaling of the thin disk. Yb:YAG shows a significant temperature dependent reabsorption of the laser radiation. Consequently, the coupling between the differential equations of pump absorption, laser amplification, inversion and temperature must not be neglected. Besides these laser dynamics, an important question is the stress and deformation behavior of the thin disk. A strong influence of the mechanical properties of the heat sink or a heat spreader can be expected. From numerical calculations concerning temperature, stress and deformation, no scaling limits for the thin disk design can be derived. The remaining challenges would be fabrication and handling of the large disks and proper engineering of the heat sink and the bonding process.

Only the inversion depletion due to amplified spontaneous emission (ASE) inside the disk is the remaining limiting effect for the thin disk design. Different approximations for this influence as a base for estimations of scaling limits can be found in literature. In general, the influence of the ASE can be described as reduction of lifetime of the excited state and expressed by a reduced lifetime τ_{ASE}. One possible approximation would be:

$$\tau_{ASE} \sim \tau \frac{r_p}{h} \exp\left(-\frac{2r_p}{h} g\right) \quad (1)$$

with r_p the radius of the pump spot, h the thickness of the disk, g the single pass gain and τ the spontaneous lifetime.

Based on this expression, estimates for the maximum possible output power for one disk can be derived. For example, with an internal loss of 0.25%, 1 MW laser power should be possible with nearly 50% optical-optical efficiency, requiring only 20 cm pump spot diameter [1].

For “real world” power scaling of thin disk lasers, the method of increasing the active area is not exhaustively used. Due to several technical restrictions (e.g. availability or handling of large disks, challenging resonator design for large mode diameters or limitations of electro-optical switches in the case of pulsed lasers), the disk size is kept moderate; instead the number of disks in one resonator is increased for power scaling. An emerging approach for power scaling (for high repetition rate pulsed lasers or high energy pulsed laser, but also for cw disk lasers) is the use of geometrical multipass amplifiers.

[1] Jochen Speiser, "Scaling of thin-disk lasers-influence of amplified spontaneous emission," J. Opt. Soc. Am. B 26 (1), 26-35 (2009).