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Resonator design considerations for power-scaling TEM_{00} operation of end-pumped solid-state lasers

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ABSTRACT

A novel resonator design approach which reduces the degradation in beam quality due to thermally-induced aberrations in high-power end-pumped solid-state lasers is described.

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Efficient power-scaling of solid-state lasers end-pumped by high-power diode arrays is an area which has attracted increasing interest over the last few years. This has been driven by the relatively low cost and wide availability of diode-bars, and by the recent development of novel beam shaping techniques (e.g. [1]), which have allowed their output beams to be focused to the small beam sizes required for efficient end-pumping. However, progress in scaling TEM_{00} operation to high powers has been hindered by strong thermal effects which occur due to the high thermal loading density in end-pumped lasers. The principal problem is the degradation in beam quality due to the highly aberrated nature of the thermal lens - a problem which is particularly pronounced in low gain and quasi-three-level lasers where intense pumping is required [2].

Various approaches aimed at solving this problem have been reported including the use of aspheric lenses to compensate for the phase aberration [3], and face-cooling to reduce thermal lensing [4]. Both of these approaches have successfully demonstrated TEM_{00} operation at high powers, but at the expense of increased complexity.

In this paper we report a simple, alternative resonator design strategy to reduce the beam distortion resulting from strong thermally-induced aberrations without using compensating components. The basis of this approach is that the aberrations which result from a Gaussian-like pump beam are most pronounced in the wings of the inversion distribution. Hence by using a resonator with a TEM_{00} mode which is smaller than the pump beam it is possible to achieve a near-diffraction-limited output. However, a consequence of the smaller mode size is that it is more difficult to achieve efficient extraction of the gain stored in the wings of the inversion distribution. In addition, appropriate measures must be taken to prevent this unused inversion from providing sufficient gain for simultaneous oscillation on higher-order transverse modes. Our results indicate that this suppression of higher-order transverse modes can be achieved by applying a second condition to the resonator design, namely that the TEM_{00} beam size in the laser rod should decrease with decreasing power (increasing focal length) of the thermal lens. The rationale for this can be explained by considering the aberrated thermal lens as a lens whose focal length varies radially. Thus, higher-order transverse modes, which tend to experience a weaker thermal lens (due to their larger size) compared with the TEM_{00} mode, have less access to undepleted inversion by virtue of their close spatial overlap with the fundamental mode. In this way it is possible to operate the laser on the TEM_{00} mode and suppress higher-order transverse modes without the need of apertures.

We have verified this resonator design approach for a diode-bar end-pumped Nd:YAG laser operating at 1.064μm using the experimental arrangement shown in fig. 1. In our experiment the 20W diode-bar pump was re-formatted using a two-mirror beam shaper [1] and focused to a nearly circular beam of beam radius ~225μm inside the Nd:YAG rod. After the focusing optics the maximum pump power incident on the laser rod was ~14.2W, which resulted in a thermal lens of focal length ~60mm at the centre of the pumped region. The resonator design employed was a simple three-mirror folded cavity with its arm lengths; d_1 and d_2, carefully selected to satisfy the resonator design criteria for good beam quality. The requirement for a decrease in mode size in the laser rod with increasing focal length of the thermal lens was be achieved by simply setting the effective optical path length d_1 to be just less than the sum of the focal lengths of the curved mirror and the thermal lens (see fig. 2). The required TEM_{00} beam size in the Nd:YAG rod was obtained by simply adjusting the arm length d_2. Without a polariser present in the cavity and at the maximum pump power it was found that diffraction-limited TEM_{00} operation ($M^2 \leq 1.1$) could be achieved with a laser mode radius ~165μm, which was significantly smaller than the pump beam radius. Under these operating conditions we obtained a maximum output power ~6.2W (unpolarised). Inserting a Brewster-angled plate into the cavity resulted in a linearly polarised TEM_{00} output of slightly lower power ~5.5W. This reduction in power was caused by an additional cavity loss of ~1% due to thermally-induced stress-birefringence. However, the increased depolarisation loss for the higher-order transverse modes further helps to suppress their oscillation allowing for more robust TEM_{00} operation.

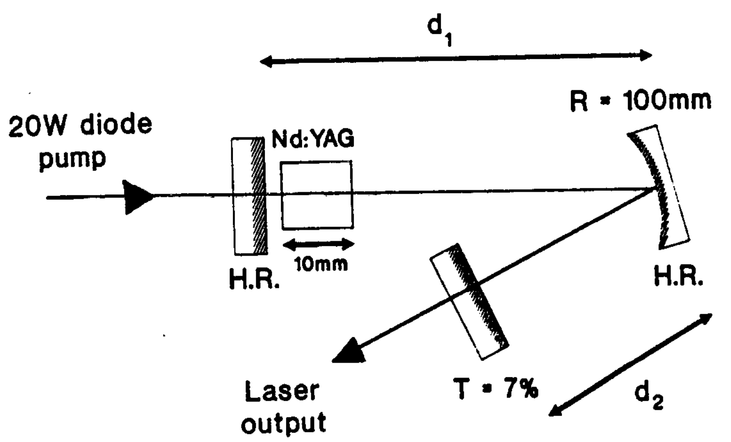

Fig. 1 Nd:YAG laser design

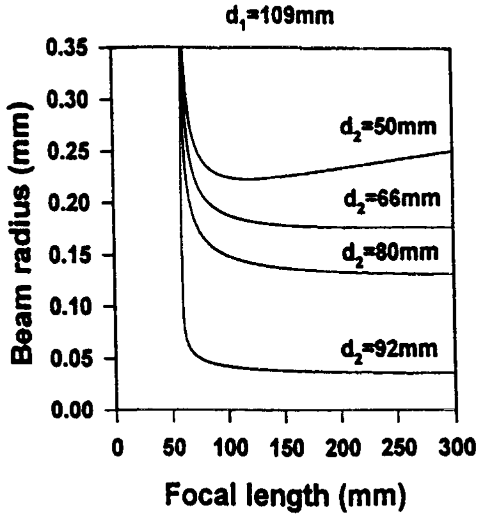

Fig. 2 TEM_{00} radius in laser rod versus thermal lens focal length

This resonator design strategy has also been successfully applied to diode-bar-pumped Nd:YAG lasers operating on low gain transitions to obtain multiwatt TEM_{00} output at 946nm and 1.3μm.

The scope for further increasing TEM_{00} power from end-pumped lasers via this resonator design approach will be discussed.

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