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Performance of a Diode-End-Pumped Yb:YAG Laser*

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Abstract

Using an end-pumped technology developed at LLNL we have demonstrated a Yb:YAG laser capable of delivering up to 434 W of CW power and 280 W of Q-switched power. In addition, we have frequency doubled the output to 515 nm using a dual crystal scheme to produce 76 W at 10 kHz in a 30 ns pulse length.

Introduction

Many potential applications motivate the development of efficient, compact 1 μm laser systems with operational lifetimes capable of exceeding thousands of hours. Yb-doped laser hosts offer spectroscopic and laser properties that make them promising candidates for high power 1 μm laser systems. In particular, Yb:YAG has a long storage lifetime (951 us) and a very low quantum defect (8.6%) resulting in less heat generation during lasing than comparable Nd-based laser systems[1]. In addition, the broad pump line at 940 nm makes this material highly suitable for diode pumping using InGaAs diodes which are more robust than AlGaAs diodes which are used to excite Nd:YAG at approximately 808 nm. Another advantage of using Yb:YAG occurs because the 940 nm absorption feature is approximately 10 times broader than the 808 nm absorption feature in Nd:YAG and therefore, the Yb:YAG system is less sensitive to the diode wavelength specifications.

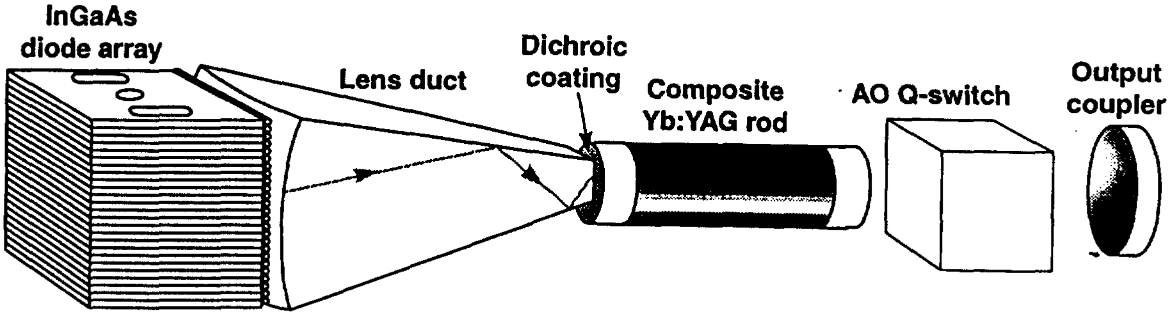

Fig. 1. Schematic of the Yb:YAG laser system.

Fig. 1 is a sketch of our end-pumped Yb:YAG laser. The pump source consisted of a 47 bar stack of 1.5 cm long InGaAs laser diode bars with large spot optical cavities[2] packaged on microchannel coolers. The 47 bar array produced up to 1733 W of cw power at 60 amps. The diode light is first conditioned by a uniquely shaped microlens directly mounted on each diode package. The microlens allows the diode light to emerge with a divergence of 50 mrad and 150 mrad in the fast and slow axis directions respectively (85% "energy in the bucket" measurement). The pump light is then homogenized and concentrated down with a fused silica lens duct to allow for end-pumping of the laser rod. The laser rod is a composite of doped and undoped YAG. The undoped YAG pieces or endcaps are diffusion bonded to both ends of the doped rod. The endcaps help reduce the thermal loading and stresses on the input and output faces of the rod and therefore help prevent damage. The Yb:YAG composite rod was coated at the pump end of the rod with a multilayered, dichroic coating for high reflectance at 1030 nm and high transmission at 940 nm, thus allowing one end of the rod to perform as a flat high reflector for the laser cavity. A simple broad band anti-reflection coating was placed on the opposite or output end of the rod.

Laser performance

We have demonstrated the Yb:YAG laser in both CW and Q-switched operation. The doping concentration was 0.5% and the rod diameter was 2 mm with an overall composite length of 60 mm. The rod was housed in a simple aluminum cooling jacket designed to flow coolant along the barrel of the rod. The rod temperature was kept close to zero degrees by using a mixture of water and propanol. Approximately 87% of the pump light was transmitted through the microlenses and lens duct. Through internal reflections down the barrel of the rod, the pump light becomes well homogenized with approximately 75-80% of the pump light being absorbed on the first pass. In cw operation we produced up to 434 W cw power with an intrinsic optical to optical efficiency of 27%. The data is shown in Fig. 2. The cavity length was approximately 15 cm. An 80% reflective output coupler with a 1 meter positive radius of curvature was used.

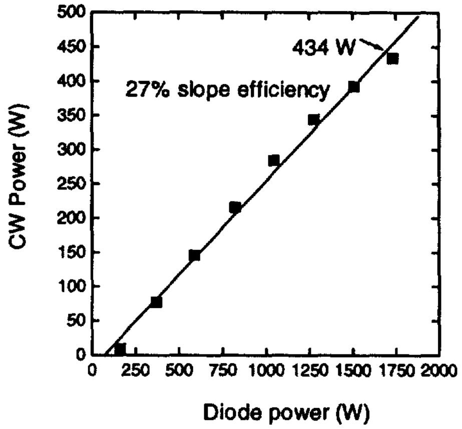

Fig. 2. Up to 434 W of cw power was produced with the large spot diodes as the pump source

We also Q-switched output of the laser using an acousto-optic Q-switch. The insertion loss from the Q-switch was only 2%. We were able to produce up to 277 W at a repetition rate of 10 kHz with a pulse length of 31 ns. The output coupler had a reflectivity of 50% and a 1 meter positive radius of curvature. Beam quality measurements were made at the 150 W level for both cw and Q-switched operation and yielded values of $M^2 = 5$ and 6.75 respectively.

Frequency conversion results

External frequency conversion experiments were conducted using Type II phase matching at room temperature with KTP. The phase matching angles were $\varphi = 49.8$ deg. and $\theta = 90$ deg. The crystal sizes were both 6x6x8mm. To reduce the possibility of damage due to gray tracking mechanisms, the frequency converted light generated from the first crystal was split out of the 1.03 μm path with a dichroic beam splitter. Using two KTP crystals and a dichroic beam splitter (Fig. 3) we achieved up to 40% conversion. With 217 W of 1.03 μm input power up to 76 W of cw power at 515 nm was produced in a 30 ns pulse length.

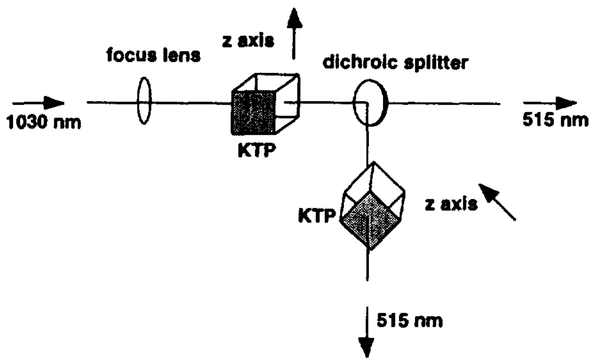

Fig. 3 A dual crystal conversion scheme was employed using KTP.

Scaling Diode End-Pumped Solid-State Lasers to kW Power Regimes

The development of high-average-power radiance-conditioned laser diode arrays and lens ducts allow for the possibility of scaling systems, like that described in this paper, to average powers approaching the kW level. Because the excitation geometry is capable of generating pump intensities on the order of 10's of kW/cm^2, kW laser systems utilizing quasi-three-level schemes are also possible. The design of such systems generally involves a judicious balancing of the contradictory requirements needed to optimize thermal management and gain-to-loss so as to achieve overall optimum system performance. Also required, is the ability to model the delivery of the pump radiation into the laser rod or slab in order to design optimized pump transport systems. Using LLNL demonstrated high-average-power diode-pumped solid-state lasers, we will describe the modeling and design rationale of scaling these systems to higher power levels.

Summary

We have produced up to 434 W of cw power at 1030 nm with an end-pumped Yb:YAG laser. At 10 kHz repetition rates we produced up to 280 W of Q-switched power in a 31 ns pulse length. The M^2 values at 150 W cw and Q-switched were 5 and 6.75 respectively. Using a dual KTP crystal frequency conversion scheme, we produced up to 76 W of 515 nm light in a 30 ns pulse length. The use of large spot diodes in our system enabled us to reach diode pump powers of up to 1733 kW at 941 nm.

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References

1. H. Bruesselbach and D. Sumida, "69-W-average-power Yb:YAG laser," Opt. Lett. 21, 480 (1996).
2. M. A. Emanuel, N. W. Carlson, and J. A. Skidmore, "High-efficiency AlGaAs-based laser diode at 808 nm with large transverse spot size," IEEE Photonics Tech. Let. Vol. 8 No. 10 1291-1293 (1996).

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