Efficient Dual Head Nd:YAG 100mJ Oscillator for Remote Sensing

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Abstract

A diode pumped, Nd:YAG laser producing 100 mJ Q-switched pulses and employing a dual-pump head scheme in an unstable resonator configuration is described. Each head contains a side pumped zig-zag slab and four 6-bar QCW 808 nm diodes arrays which are de-rated 23%. Denoting 'z' as the lasing axis, the pump directions were along the x-axis in one head and the y-axis in the other, producing a circularized thermal lens, more typical in laser rod-based cavities. The dual head design's effective thermal lens is now corrected with a proper HR mirror curvature selection. This laser has demonstrated over 100 mJ output with high optical efficiency (24%), good TEM_{00} beam quality, and high pointing stability.

OCIS codes: 280.3640, 140.3540, 140.3580, 140.6810, 140.3480.

Introduction

A major goal of Earth sciences at NASA-GSFC is to build a flight-quality, 1064 nm, 1 J/pulse, diode-pumped solid-state (DPSS) laser system for making atmospheric wind LIDAR measurements from space. We report on the development of a Q-switched Nd:YAG master oscillator capable of operating at a 100 Hz repetition rate with over 100 mJ/pulse output. This laser is referred to as "Big HOMER", since its design was derived from the 20 mJ/pulse High Output Maximum Efficiency Resonator (HOMER), developed for earth and planetary laser altimetry, and its predecessor, the High Energy Laser Transmitter (HELT).[1] The success of the Big HOMER design is founded on lessons learned from constructing the HOMER laser, where significant effort was directed at achieving high optical efficiency commensurate with reliable, multi-billion shot lifetime.[2] Like HOMER and HELT, Big HOMER features a positive branch confocal unstable resonator (PBUR) with a graded reflectivity mirror (GRM) output coupler that achieves a large intracavity TEM_{00} mode, high optical efficiency, with low intracavity fluence. Big HOMER, however, distinguishes itself as unique by utilizing a pair of orthogonal zigzag slab pump heads, or gain modules, in its cavity instead of a single gain unit. We found that this arrangement dramatically reduced the asymmetric thermal effects in the laser, allowing for a simple spherically-symmetric correction for the whole cavity by simply selecting the proper highly reflective (HR) mirror curvature. Through the Big HOMER effort, we have implemented improved techniques in laser modeling, slab design optimization, detection and prevention of laser-induced optical damage, and state of the art opto-mechanical design. Future plans for this laser include active frequency stabilization and injection seeding with a single-frequency 1064 nm

source. Once characterized and shown to have reliable single-frequency operation, it will be mated to a 10X DPSS Nd:YAG multistage amplifier chain to achieve 1 J/pulse output.

Resonator Architecture

A picture of the Big HOMER resonator layout is shown in Figure 1. In its initial design, an "empty resonator" analysis was performed. This consisted of the GRM output coupler and an HR mirror separated by a fixed distance of air. A 2.0 m radius of curvature (ROC) convex GRM and a 3.0 m ROC concave HR placed 40 cm apart creates a PBUR cavity with a magnification M = 1.41. The GRM reflectivity profile is selected to support an internal Gaussian mode of ~4 mm $1/e^2$ diameter. A Gaussian GRM reflectivity profile was chosen, given by $R(r) = R_o\, e^{-2(r/\omega m)2}$, where R_o is the peak reflectivity and ω_m is the $1/e^2$ radius of the profile. It can be shown that the relationship of the beam waist at the output coupler (ω_i), the magnification M, and ω_m is $\omega_i = \omega_m \cdot (M^2 - 1)^{1/2}$ for a Gaussian reflectivity profile.[3,4] For ω_i = 2.0 mm, a value of ω_m = 2.05 mm is calculated. A value of R_{HR} = 8 m was found experimentally to produce a beam size of ~ 4 mm diameter on the HR mirror. The reduction in strength of the HR radius from R_{HR} = 3 m ROC in the empty resonator analysis to 8 m ROC in the experimental laser represents the effective thermal lens compensation. From this change in R_{HR}, we estimate the thermal lens focal length of approximately +4.7 m ROC.

Pump Head Design

Big HOMER utilizes a pair of 8-bounce, 1.1%-doped Nd:YAG zig-zag slabs with near-Brewster (~29°) end faces. Each of the two parallelepiped slabs has a tip-to-tip length of 73 mm, a width of 8 mm, and a 6 mm thickness along the pump axis. Pump radiation of

808 nm from four 6-bar quasi-CW (QCW) diode arrays is double-passed through each slab through use of an AR coating on the pump face and a HR coating on the opposite slab surface. The pump diodes are mounted on an aluminum block, which is attached to a water-cooled surface for conductive heat removal. This simulates an instrument's radiator surface for and holds the diode array assemblies at their optimum operating temperature of 25°C. This thermally controlled assembly holds an aluminum "bridge" that houses the Nd:YAG slab and its CuW heat sink, as seen in Figure 2. The copper-tungsten alloy has thermal expansion properties, as well as thickness/length dimensions quite similar to the Nd:YAG slab, and therefore is able to reduce any thermo-mechanical stress that may be induced while the laser is in operation. The slab is bonded to the CuW heat sink along it's HR face using a thermally conductive adhesive that has passed all the flight qualification and materials properties testing required by NASA. Use of this adhesive greatly reduces the time and effort required to bond and debond a slab over a typical potting operation.

Preliminary analysis showed it was possible to construct a 100 mJ laser with a single slab of about 10 cm of gain length, giving a single-pass small signal gain value of about 51. Unfortunately, such high gain can reduce the efficiency of the laser due to parasitic losses from amplified spontaneous emission (ASE). Furthermore, from our experience with the 20 mJ HOMER laser, it was expected that using a single zigzag slab would produce near- and far-field beams with slightly elliptic profiles due to the asymmetric thermal lens produced in the slab. Despite considerable efforts to compensate these astigmatic lensing effects using various end mirror curvatures and intracavity negative cylindrical lenses in the HOMER laser, we found we were unable to

reduce the difference between the X and Y beam divergences to less than 15%. To ameliorate these difficulties, we chose a more innovative design of using a pair of zig-zag slabs aligned so that their respective pump axes were orthogonal. In this configuration, the intracavity mode experiences near-symmetric thermal lensing effects after each round-trip pass through the PBUR resonator. Inserting a half-wave plate between the slabs minimizes polarization-induced optical losses from the near-Brewster faces and a larger effective laser head is produced with a spherical thermal lens, similar to that of a commercial laser rod-based system.

Diode Power Distribution

In past efforts, we found it wise to fully model the pump beam shape as it travels through the slab for a complete double pass. We opted for a directly coupled pump configuration as opposed to using a coupling lens as in the HOMER system. Using the array specifications provided by the diode manufacturer, the average pump energy distribution inside the gain medium was calculated using commercial non-sequential raytracing software. It was found that a 6-bar array with a 0.5 mm pitch placed 0.7 mm from the slab gave a smooth super-Gaussian distribution with a radius of 2 mm. The expected heat load in the slab was modeled to approximate the thermal lens strength in each slab under a variety of pumping conditions. The effective focal lengths of each thermal len was projected as $f_{strong} = +4.0$ m and $f_{weak} = +16$ m, respectively. The expected maximum temperature excursion is 3°C above the diode array base temperature of 30°C. After completing this analysis, we decided on a final diode bar-bar pitch of 500 um and a diode-slab distance of 700 um to produce the optimum pump volume to insure effective pump beam thicknesses ~ 4 mm. The transverse gain distribution was then used to

calculate pumping parameters necessary to generate 100 mJ pulses. The results indicate that a 100 mJ output pulse with an ~8 ns width would be achieved when the diodes, capable of 100 W/bar operation, were run at ~ 70 W/bar with a 125 μs pump pulse duration.

Experimental Results

The Big HOMER laser was first characterized while operating in long-pulse mode with the Q-switch absent from the cavity. These early tests were typically performed with a pump diode pulse width of 200 μs and frequency of 100 Hz. A data system was constructed that allowed real-time tracking and monitoring of the far-field beam profile, intracavity beam size on the HR mirror, beam pointing, laser head temperature, and output pulse energies, during our configuration experiments.[5] An initial long pulse P-I curve shows that we can easily achieve 160 mJ, well over our design parameters, with a slope efficiency of 37%. The output of the laser versus pump pulse widths, cavity lengths, slab locations, GRM types, and HR mirror curvatures measured.

After settling on a final configuration using a 2 mcx GRM, 8mcc HR mirror and a cavity length of 40 cm, several pointing stability experiments were carried out due to its importance in wind lidar applications. Prior to aforementioned adjustments to the heat sink, under identical Q-switched operating conditions, the output beam drifted on average ~ 0.11 mrad from optic center, versus ~ 0.035 mrad from optic center, with the improved heat sink over a period of 1 hour; a factor of 3 improvement. The pointing stability is much better than many comparable commercial lasers of similar pulse energies. During these tests we discovered that by reducing the pump pulsewidth and increasing the current to maintain 100 mJ operation, we could control thermal lens production such that

a somewhat larger and more symmetric laser mode is produced as well as improved pointing stability. The pump parameters were set to 80 A, 120 us, and 100 Hz which is a de-rating of 23%, to ~75 W/bar. Typical beam sizes out of the GRM, made as round as possible to prevent damage in the ensuing amplifiers, were 3.0 mm X 3.0 mm. The beam profile imaged just inside of the HR mirror, characteristically measuring at 3.9 mm by 4.1 mm, is particularly important for measuring intracavity fluences since the laser slabs are very near the HR. Fluences normally stay around 2.5 J/cm^2, which is well below our self-imposed limit of 3.0 J/cm^2, above which we have found damage may occur. We are particularly pleased with the roundness of the intracavity beams showing excellent compensation for the slabs' thermal lensing. The far-field beam divergences were 0.7 mrad and 0.6 mrad in the x-axis and y-axis, giving M^2 values of 1.55 and 1.33, respectively. The oscillator's beam images can be seen in Figure 3. The resultant pulse energy is 107 mJ, with a pulse width of 13-14 ns, an average power of 10.7 W, and an optical efficiency of approximately 24%.

Conclusions

The 100 mJ laser described herein has been operating flawlessly as the pump source for the 1J @ 1μm Testbed of the NASA LRRP (Laser Risk Reduction Program) at NASA-GSFC, Greenbelt MD. The Big HOMER oscillator easily meets the LRRP amplifier requirements in beam quality and power output. Furthermore, its 24% optical efficiency is the highest reported value, to our knowledge, for a laser of this type and class. When coupled to well designed amplifier stages, a space worthy 1J/pulse system with a wall plug efficiency of >10% is achievable. Work continues to further improve the laser performance and robustness, with a "brass-board" version currently under construction.

References

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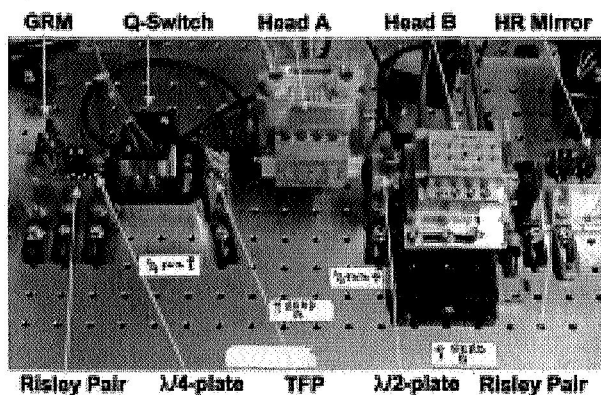# Figure Captions

Figure 1.   The 100 mJ Oscillator "Big HOMER" configuration.
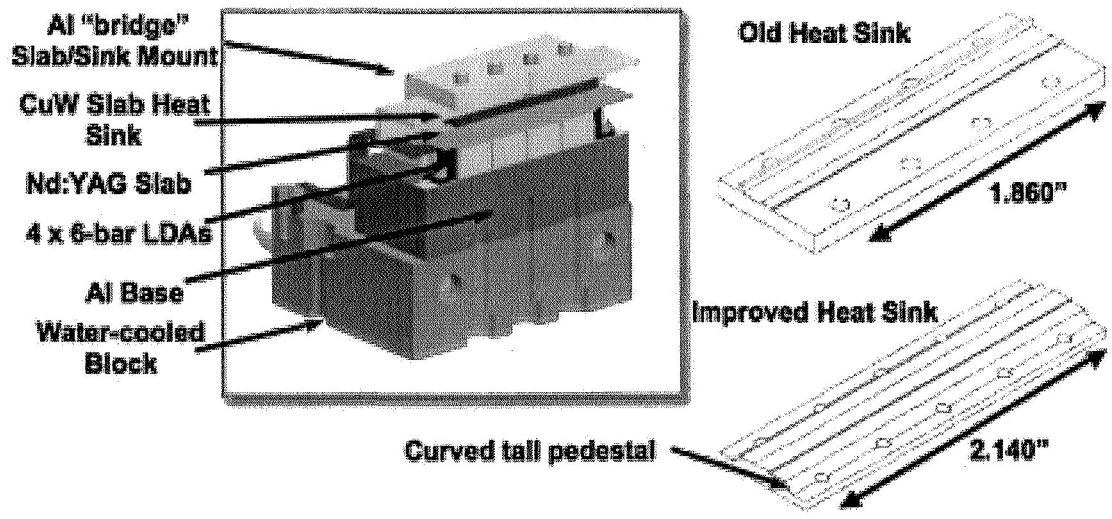
Figure 2.   The "Big HOMER" laser head. Note the improvements in the CuW slab

heat sink mount of matching the slab pump face length and curved pedestal to better
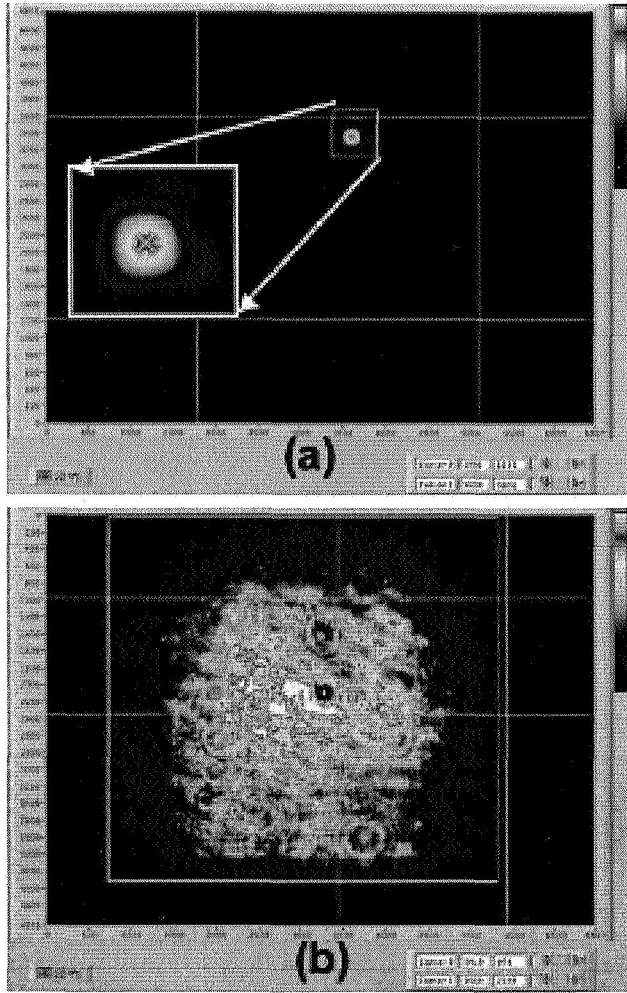
control thermal lensing

Figure 3.   Typical beam images of the (a) far-field (b) and on the HR mirror.