Available online at www.sciencedirect.com
ScienceDirect
Optics & Laser Technology 40 (2008) 435–440
Optics & Laser Technology
www.elsevier.com/locate/optlastec

Highly efficient dual head 100 mJ TEM_{00} Nd:YAG Oscillator

Paul R. Stysley[a,*], Demetrios Poulios[a], Donald B. Coyle[b], Richard B. Kay[a]

[a]Department of Physics, American University, Washington, DC 20016, USA
[b]NASA/Goddard Space Flight Center, Code 554, Greenbelt, MD 20771, USA

Received 23 April 2007; received in revised form 6 July 2007; accepted 16 July 2007
Available online 7 September 2007

Abstract

A diode-pumped, Q-switched Nd:YAG laser employing a dual-pump zig-zag slab head scheme in an unstable resonator configuration for use in space-based planetary altimetry or atmospheric LIDAR is described. The pump heads are aligned orthogonally to each other, producing a symmetric overall thermal lens that eliminates the need for an intracavity cylindrical lens and aperture. This laser has demonstrated over 100 mJ in Q-switched operation with high optical efficiency (24%), good beam quality, high pointing stability, and large operational margins for multi-billion shot lifetimes.

Keywords: Q-switched; Nd:YAG; LIDAR

1. Introduction

A major goal of Earth sciences at NASA-GSFC is to build flight-quality, 1064 nm, 0.01–1.0 J/pulse, diode-pumped solid-state (DPSS) laser systems for space-based measurements such as atmospheric wind patterns, surface topography, and ice sheet thicknesses on Earth and other planetary bodies. We report on the development of a Q-switched DPSS Nd:YAG oscillator operated at 100 Hz pulse repetition rate (PRF) with over 100 mJ/pulse output; to our knowledge, it is the most efficient DPSS Nd:YAG laser of its type and class. 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 several HOMER lasers, where significant effort was directed at achieving the highest possible optical efficiency consistent 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. All these systems have benefited from an ongoing modeling and experimental verification effort targeting key areas of laser design. Mostly, these iterative methods focus on slab design, conductive heat removal (a must for space flight use), the production of a large TEM_{00} mode, and optimizing the overlap of the laser mode with the gain volume. Big HOMER, however, distinguishes itself further from 10 to 20 mJ cavities by utilizing a pair of orthogonal pump heads, or gain modules, instead of the typical single gain unit. We found that a dual head arrangement dramatically reduced the asymmetric thermal effects in the laser, allowing for a simple spherically symmetric correction for the complete cavity by simply selecting the proper highly reflective (HR) mirror curvature. Additionally, this technique helped to produce a large, aperture-free TEM_{00} mode when combined with refined GRM coating specifications, and a higher range of selective operation points in PRF and pulse energy than what was possible with a single zig-zag head. We have found two previous patents [3,4] regarding the use of dual gain modules with a $\frac{1}{2}$ waveplate in between. Both of these patents were laser rods and the result was to remove astigmatic effects of uneven steady state thermal effects in each rod. Since zig-zag slabs produce longer gain

*Corresponding author. Tel.: +1 301 614 5863.
E-mail address: Paul.R.Stysley@nasa.gov (P.R. Stysley).

0030-3992/$ - see front matter
doi:10.1016/j.optlastec.2007.07.009

lengths than equivalent laser rods, and are more readily employed with conductive, non-liquid based, cooling techniques, this dual head technique is very applicable. Additionally, zig-zag slabs demonstrate generally stronger astigmatic thermal lens products due to the inherent single axis pumping geometry and heat removal paths. However, we believe this is the first application of the orthogonal dual head technique to a high power, Q-switched, zig-zag slab laser cavity. Throughout 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, as well as further exploration in PRF and pulse energy range and lifetime possibilities. Once characterized and proven to have reliable single-frequency operation, it will be mated to a 10 × DPSS Nd:YAG multi-stage amplifier chain to achieve 1 J/pulse output. Other significant advantages of this laser for use in space-based remote sensing, besides its outstanding efficiency, are its low optical component count (~1/3 that of a comparable 100 mJ/pulse master oscillator power amplifier (MOPA)); the inherent high margin available in diode array drive parameters allowing for bar failures, reduced risk, and very long life; the possibility of redundant, albeit reduced, operation should one complete head become inoperable during the mission; and the relatively small hardware footprint with relatively large thermal interface. All of these aspects are improvements over any previous remote sensing flight laser to date.

2. Resonator architecture

An image of the Big HOMER resonator breadboard is shown in Fig. 1. In the initial resonator design, an empty cavity analysis was performed in which the only adjustable parameters were the cavity length, end mirror curvatures, and the GRM reflectivity profile. A Gaussian GRM reflectivity profile was chosen, given by $R(r) = R_o e^{-2(r/\omega_m)}$, 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 $\omega_i = \omega_m(M^2-1)^{1/2}$ for a Gaussian reflectivity profile [5,6]. It was found that a −2.0 m Gaussian GRM with a $1/e^2$ radius of 2.05 mm supported an internal Gaussian mode of ~4 mm diameter for a 40 cm cavity and +3.0 m HR curvature. When the laser was in full operation, a value of $R_{HR} = 8$ m was found experimentally to produce a beam size of ~4 mm diameter on the HR mirror. The difference in HR radius from the modeled empty cavity $R_{HR} = +3$ m ROC to the experimental result of $R_{HR} = +8$ m ROC demonstrates the effective thermal lens compensation. From this change in R_{HR}, we estimate the thermal lens focal length of approximately +4.7 m ROC for 100 mJ/pulse operation at 100 Hz PRF. This HR value is easily changed when a significantly different operating point is desired. Big HOMER has been successfully operated at pulse energies between 40 and 100 mJ and PRFs from 40 to 200 Hz. The full capabilities of this laser are far from being explored experimentally, and plans are to push both the PRF and the pulse energy higher to quantify the limits of conductive cooling and damage free, thermal lens compensation.

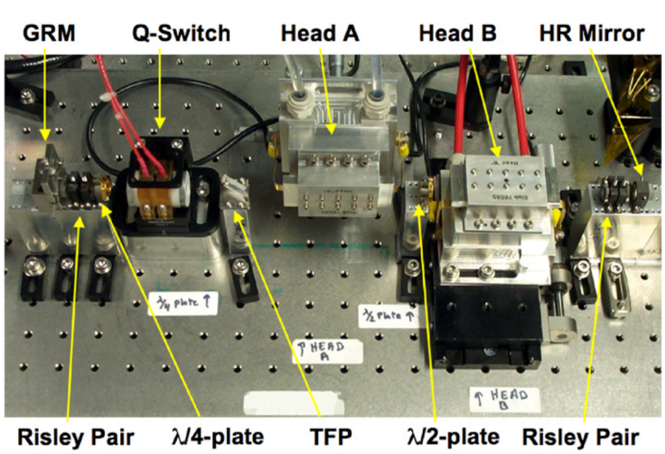

Fig. 1. The 100 mJ oscillator "Big HOMER" configuration.

3. 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 parallelepiped slabs has a tip-to-tip length of 73 mm, a width of 8 mm, and a 6 mm thickness. Uncollimated 808 nm radiation from four 6-bar, quasi-CW (QCW) 100 W/bar laser diode arrays is double-passed through each slab via an AR coating on the exposed pump face and a HR coating on the opposite slab surface, producing 2-pass pump length of 12 mm. This HR coating consists of a standard dielectric high reflectance coating at 808 nm that is over-coated with a thick layer of SiO_2. The thickness of the SiO_2 layer is designed to wholly contain the 1.064 nm evanescent waves at the bounce points in the slab. It can be shown that the evanescent wave depth ζ at a dielectric interface where total internal reflection takes place is [7]:

$$\zeta = \frac{2\pi}{\lambda}\sqrt{\left(\frac{n_2}{n_1}\right)^2 \sin^2(\theta) - 1} \quad (1)$$

where θ is the internal bounce angle measured from the normal (57.74° in this case), λ is 1064 nm which is the wavelength of the reflecting radiation, $n_2 = 1.82$ which is the index of the more dense material (Nd:YAG), and $n_1 \approx 1.5$ which is the index of the less dense material (SiO_2 layer). This calculation yields a $1/e$ wave depth of 0.98 μm, and for 95% extinction, 2.95 μm. The SiO_2 coatings on our slabs are ~3 μm to be sure to satisfy this criterion. The slab is attached to a tungsten copper (W:Cu) heat sink using a