Tm:YLF PUMPED Ho:YAG AND Ho:LuAG LASERS

Norman P. Barnes
Donald J. Reichle
Brian M. Walsh

NASA Langley Research Center
Hampton, VA 23681
Phone: (757) 864-1630
Facsimile: (757) 864-8828
n.p.barnes@larc.nasa.gov

Theresa J. Axenson

Science And Technology Corporation
Hampton, VA 23666

Abstract: Room temperature Ho:YAG and Ho:LuAG lasers pumped by a Tm:YLF laser demonstrated a 3.4 mJ threshold and 0.41 slope efficiency, incident optical to laser output energy. Results for numerous rod lengths, Ho concentrations, and output mirror reflectivities are presented.
OCIS Code: (140.3580) Lasers, solid state,

Summary: Ho:YAG and Ho:LuAG lasers pumped by a Tm:YLF laser were evaluated to empirically optimize the Ho concentration, laser rod length, and laser output mirror reflectivity. Ho:YAG, with concentrations of 0.005, 0.010, and 0.020 were evaluated using 4 rod lengths and 5 different output mirrors. A threshold of 3.4 mJ and a slope efficiency of 0.41 were achieved with the Ho:YAG laser at room temperature. Ho:LuAG with 0.01 concentration was also evaluated. Quoted thresholds and slope efficiencies are incident optical to laser output energy. Laser optimization is a compromise of absorption efficiency, Ho:Ho up conversion, mode volume to pumped volume overlap, lower laser level population, and losses. Although performance is calculable, uncertainty in some parameter accuracy, makes empirical optimization useful.

Tm laser pumped Ho lasers are appealing because Ho has a much larger emission cross section than Tm, a complete absence of Ho:Tm up conversion, as well as the ability to store energy and efficiently deliver a single Q-switched pulse. Because the emission cross section of Tm is small, fluences required for an efficient extraction from laser amplifiers often exceed fluences associated with laser induced damage. A much larger emission cross section, makes efficient Ho laser amplifiers practical. Although Ho:Tm lasers demonstrated notable efficiency [1], they often suffer from Ho:Tm up conversion. In this energy transfer process, excited Ho and Tm atoms in close proximity interact in a manner that detracts from laser efficiency. With a Tm laser pumping a Ho laser, any Ho:Tm up conversion is eliminated and Ho:Ho up conversion is much smaller [2]. Furthermore, in Ho:Tm lasers, stored energy is distributed roughly equally between Ho and Tm. In a single Q-switched pulse only the energy stored in the Ho can be extracted because energy transfer time constants are long compared with the Q-switched pulse length. Lasers with Ho only obviate this problem. Energy storage in Ho is abetted by the long Ho:YAG lifetime, 8.5 ms, thus allowing the use of fewer laser diode to pump a long pulse Tm laser.

A folded resonator allowed double pass absorption of the incident pump beam. The experimental arrangement is shown in Figure 1. The incident pump energy from the Tm:YLF laser is

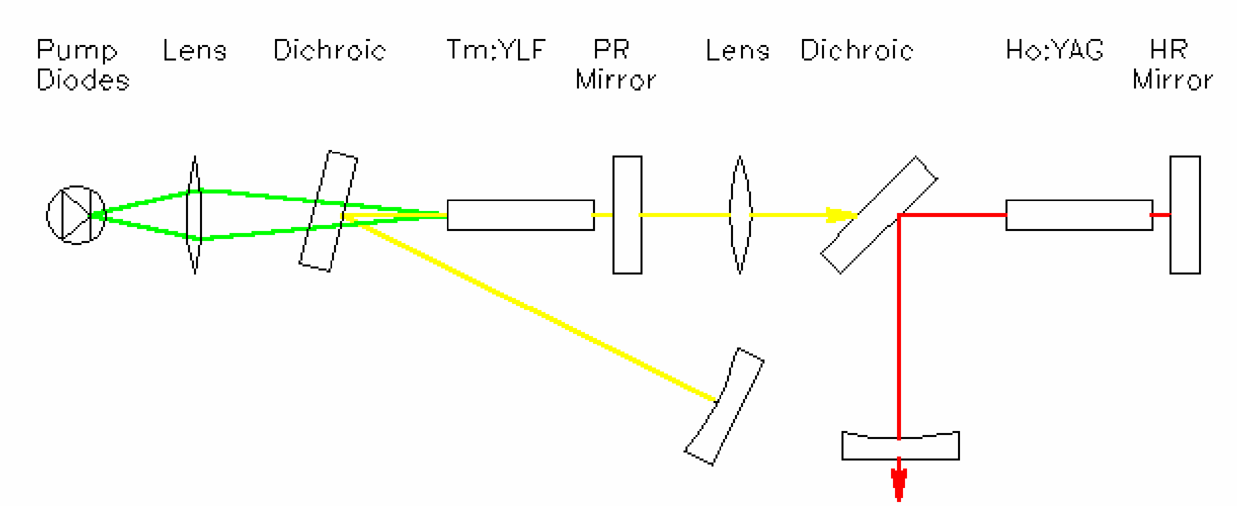

Figure 1. Experimental arrangement of a Tm:YLF laser pumped Ho:YAG laser.

measured before the focusing lens and dichroic mirror. Quoted thresholds and slope efficiencies are corrected for the less than unity transmission of these components. The flat highly reflecting mirror reflects both the pump and laser wavelengths promoting a double pass absorption for the pump. The curved output mirror is adjusted in order to obtain the best overlap of the pumped and mode volumes. Various reflectivity mirrors are used to optimize the performance. The Tm:YLF laser resonator is configured to operate on the 1.911 μm transition. Given the 3 possible wavelengths of Tm:YLF; 1.897, 1.911, and 1.930 μm; this transition has the highest absorption in Ho:YAG. Nevertheless, a slightly shorter pump wavelength is highly desirable.

Laser output energy versus incident pump energy was taken for 3 different concentrations of Ho:YAG and 1 concentration of Ho:LuAG. For each Ho different concentration, 4 different laser rod lengths were evaluated. Lengths were selected based on the calculation of the optimum laser rod length. Both shorter and longer rods were obtained to bracket the optimum length. Low Ho concentrations had long lengths, up to 50 mm where diffraction effects became important. High Ho concentrations had shorter lengths where Ho:Ho up conversion became a concern. 5 different output mirror reflectivities with the same radius of curvature were evaluated. Laser output energy was measured as a function of incident pump energy for a fixed output mirror reflectivity but variable laser rod length and for a fixed laser rod length but variable output mirror reflectivity. Resulting data were fit to obtain a threshold and slope efficiency.

A threshold of 3.4 mJ and a slope efficiency of 0.41 was achieved with a Ho:YAG laser with a Ho concentration of 0.01. In essentially the same experimental arrangement, the Ho:LuAG laser achieved a threshold of 4.5 mJ and a slope efficiency of 0.24. Ho:LuAG has similar absorption and emission parameters to Ho:YAG. Because the Ho:LuAG has both a higher threshold and a lower slope efficiency than Ho:YAG, the losses associated with this material are thought to be higher.

Plots of both the threshold as a function of the laser rod length display a monotonic increase for the range of available laser rod lengths. Conversely, plots of the slope efficiency as a function of the laser rod length display an optimum value. Thus, the optimum length for the laser rod depends on the level of pumping. Laser rods with 0.005 Ho were less efficient than the laser rods with 0.010 Ho. For the lower Ho concentration, diffraction effects began to degrade the inversion density and the pumped volume and mode volume overlap. Laser rods with 0.020 Ho concentration had similar or slightly lower thresholds when compared with the 0.010 Ho laser rods. However, the slope efficiencies were noticeably lower than the slope efficiency of the 0.010 Ho laser rods.

1. J. Yu, M. Petros, U.N. Singh, J.C. Barnes, and N.P. Barnes, “A High Energy Double Pulsed Ho:Tm:YLF 2-μm Laser,” Proceedings Of The Advanced Solid State Laser Conference TOPS 50, 383-387 (2001)

2. N.P. Barnes, B.M. Walsh, and E.D. Filer, "Ho:Ho Up Conversion: Applications To Ho Lasers," J. Opt. Soc. Am. B 20 1212-1219 (2003)