A 100 W edge-pumped Nd:YAG conduction-cooled slab laser

W. M. Tulloch, T. S. Rutherford, E. K. Gustafson, and R. L. Byer

Ginzton Laboratory, Stanford University, Stanford CA, 94305

email : tulloch@loki.stanford.edu

Abstract: We have demonstrated a 104 W multimode, laser-diode-pumped zig-zag slab laser based on conduction-cooling and a novel pumping geometry called edge-pumping. The advantages of the edge-pumped design include efficient pump absorption, conductive-cooling, power scalablity, and a simple opto-mechanical laser head design. The multimode laser operates at 104 W with 40% slope efficiency. TEM_{00} mode operation was demonstrated at 39.5 W for 250 W of pump power with a slope efficiency of 21%. Absorption loss due to the thermally populated lower laser level decreases the slope efficiency at high pump powers. This effect is included in laser oscillator performance models to accurately predict the operation of the oscillator.

OCSI Codes: (140.3480) Diode-pumped lasers; (140.3580) Diode-pumped lasers; (140.3530) Nd lasers

Introduction

The zig-zag slab laser allows power scaling to the stress-fracture limit with lower thermal lensing and stress induced birefringence than rod lasers. Zig-zag slab geometries have demonstrated scaling to high average power levels while maintaining good beam quality and polarization contrast.[1,2] The development of commercial slab lasers has been limited by the low efficiencies typically seen in face-pumped slab lasers and by the complexity of the pumping and cooling module. We have developed a zig-zag slab laser head design based on conduction-cooling and a novel pumping geometry called edge-pumping. The edge-pumping geometry decouples the cooling and optical pumping interfaces, simplifying the laser design.

In this paper we describe the design and performance of the edge-pumped zig-zag slab laser. The effect of average temperature dependent loss due to lower laser level absorption on laser performance is described. A simple laser oscillator model including this effect is presented and is confirmed experimentally.

Edge-Pumped Slab Laser Design

Edge-Pumping. The new edge-pumped slab represents a significant departure from conventional zig-zag slab designs. Ideally, a slab should be uniformly pumped and uniformly cooled.[3] The two large faces of the slab are cooled while the other faces are thermally isolated, creating a 1-dimensional thermal gradient between the two cooled faces. Total-internal reflections (TIR) on the cooled faces of the slab create the zig-zag path in the plane of the thermal gradient. This optical path averages out first order thermal lensing effects.[4] Conventional designs have realized the requirement of uniform pumping of the slab volume by pumping the slab through the TIR faces.[1,2] This places significant engineering constraints on the slab laser design, requiring a uniform cooling interface that is transparent to the pump wavelength. In the new edge-pumped slab design, the slab is still uniformly cooled on the large area TIR faces, however, the pump power is incident from the non-TIR faces,

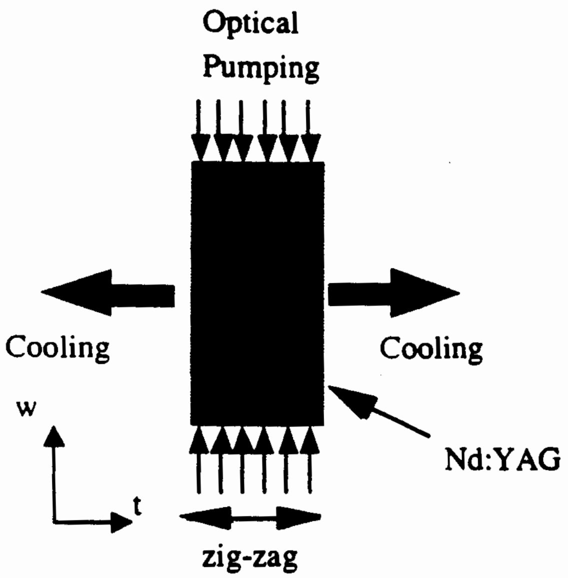

Figure 1: Cross-sectional schematic of the edge-pumped slab laser. Conductive cooling of the slab is provided through the large faces, creating a 1-D thermal gradient across the slab thickness. Uniform optical pumping is incident on smaller edges of the slab ion this 2-sided pump configuration.

along the slab width, transverse to the thermal gradient and the direction of optical propagation. Figure 1 shows a schematic of the pumping and cooling geometry of the edge-pumped slab design.

Power scaling in slab lasers is limited by the slab stress fracture limit. The stress fracture limit is a function of the slab thermal and mechanical properties, and the slab dimensions. The stress fracture limit is proportional to the slab length and the slab aspect ratio, defined as the slab width divided by the thickness. The thermally induced stress is reduced as the slab aspect ratio is increased, resulting in a higher stress fracture limit and lower stress induced birefringence losses.

Pump absorption efficiency is a function of the effective pump absorption length. The effective pump absorption length is a function of the slab thickness in the face-pumped slab geometry, and the slab width in the edge-pumped slab geometry.

Therefore, the edge-pumped geometry has the advantage of improved pump absorption and power scaling characteristics compared to face-pumped slabs. Conventional slabs require a trade-off between reduced thermal stress and pump absorption. Reducing thermal stress requires reducing the slab thickness, however, maximum absorption of the pump power requires increasing the thickness. A key benefit of the edge-pumped slab design is that increasing the pump absorption requires an increased slab width. Efficient pump absorption is no longer achieved at the expense of the slab thermal loading, the two are now complimentary.

In addition to this design advantage, separation of the cooling and optical pumping interface greatly simplifies the mechanical design of the conductively-cooled laser head. The cooling interface no longer requires a material that is transparent to the pump radiation, providing the opportunity to use a simple metal-slab interface design.

<u>The Laser Head</u>. Figure 2 shows a cross sectional schematic and a photograph of the first generation edge-pumped laser head. The Nd:YAG slab is clamped between two water-cooled aluminum blocks. Indium foil is placed between the aluminum and the Nd:YAG slab to improve the thermal contact. The 1.8 mm slab width is approximately 1/2 of an absorption length for the 808 nm pump light, therefore it is critical that the pump light double-pass the slab for efficient pump power absorption. In this geometry one-sided, double-pass pumping is achieved by the use of a diffuse Spectralon reflector on the surface opposite the pumping interface.

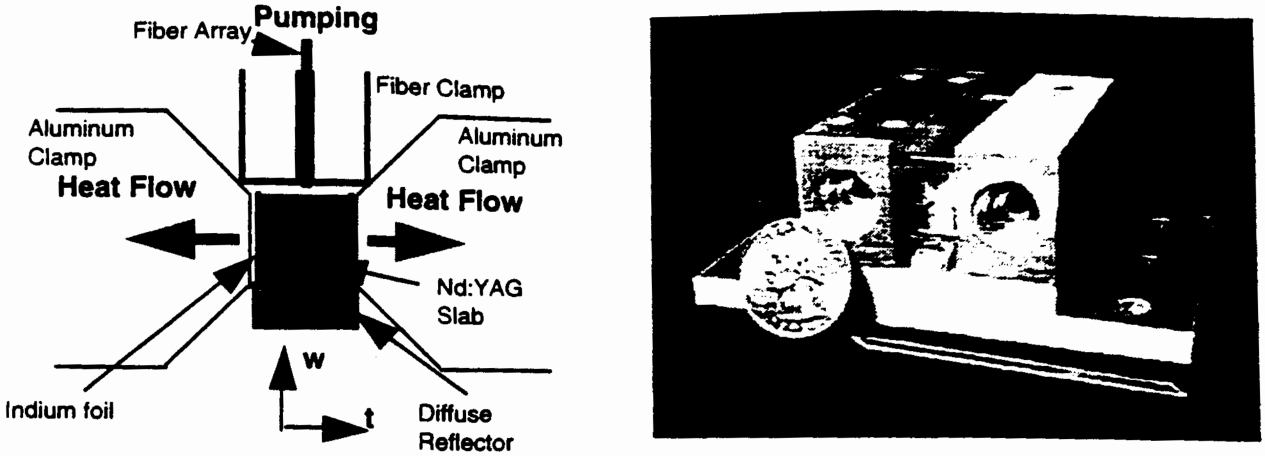

Figure 2: Cross-sectional schematic and photograph of the edge-pumped slab laser geometry. The photograph shows the laser head without the pump power fiber array, in this configuration the pump power fiber array would be mounted above the slab as shown in the schematic. The 1.55 x 1.8 x 58.9 mm Brewster end slab is shown in the photograph foreground.

Fiber-coupled laser diode arrays provide for convenient and robust pump power delivery. An advantage of fiber-coupled laser diode arrays is the ability to replace pump diodes without disturbing the laser head assembly. Additionally, the thermal engineering of the laser head is simplified since the task of cooling the laser slab and temperature control of the laser diodes is separated. The pump module consists of thirty-five Spectra-Diode Laboratories SDL-3450-P5 fiber-coupled laser diode arrays which deliver a maximum power of 10 W each, through a 600 μm diameter, 0.4 N.A. fiber. The bare ends of the fibers are assembled in a linear array mounted 1 mm from the top of the slab.

The Brewster-end face Nd:YAG slab dimensions are 1.55 mm thickness, 1.8 mm width, and 58.9 mm centerline length, which corresponds to a 24 bounce TIR path in the slab. The pump faces of the slab are AR coated at the pump wavelength and the TIR surfaces have a 2.5 μm thick SiO_2 coating to prevent evanescent wave coupling loss. Typical losses in uncoated slabs were measured to be 0.2% per bounce in air. These losses do not change when the SiO_2 coated slab is clamped into the laser head.

Laser Performance Model

Thermal gradients in Nd:YAG lasers are often a limiting factor when scaling lasers to high average powers[5,6] due to thermal lensing effects and thermally induced stress fracture of the slab. However, the average temperature of the slab, and the effect of average temperature on laser performance, is often overlooked in the four-level Nd:YAG laser designs. Absorption due to the thermal population of the lower laser level is an average temperature dependent loss that can seriously degrade laser performance at temperatures above 350 ° K in long laser crystals.