LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

UCRL-CONF-235413

The Use of Large Transparent Ceramics in a High Powered, Diode Pumped Solid State Laser

R.M. Yamamoto, B.S. Bhachu, K.P. Cutter, S.N. Fochs,
S.A. Letts, C.W. Parks, M.D. Rotter, T.F. Soules

October 9, 2007

ASSP 2008
Nara, Japan
January 27, 2008 through January 30, 2008

The Use of Large Transparent Ceramics in a High Powered, Diode Pumped Solid State Laser

Robert M. Yamamoto[1], Balbir S. Bhachu, Kurt P. Cutter, Scott N. Fochs, Steven A. Letts, Charles W. Parks, Mark D. Rotter and Thomas F. Soules
Lawrence Livermore National Laboratory
Lawrence Livermore National Security, LLC
Livermore, CA 94551
[1]Yamamoto1@llnl.gov

The advent of large transparent ceramics is one of the key enabling technological advances that have shown that the development of very high average power compact solid state lasers is achievable. Large ceramic neodymium doped yttrium aluminum garnet (Nd:YAG) amplifier slabs are used in Lawrence Livermore National Laboratory's (LLNL) Solid State Heat Capacity Laser (SSHCL), which has achieved world record average output powers in excess of 67 kilowatts. We will describe the attributes of using large transparent ceramics, our present system architecture and corresponding performance; as well as describe our near term future plans.

Over the past several years, the Solid State Heat Capacity Laser has utilized large transparent ceramics as the laser gain media. Their high optical quality, robust mechanical strength and ability to be made into large aperture sizes makes them perfect for use in our high average power laser system.

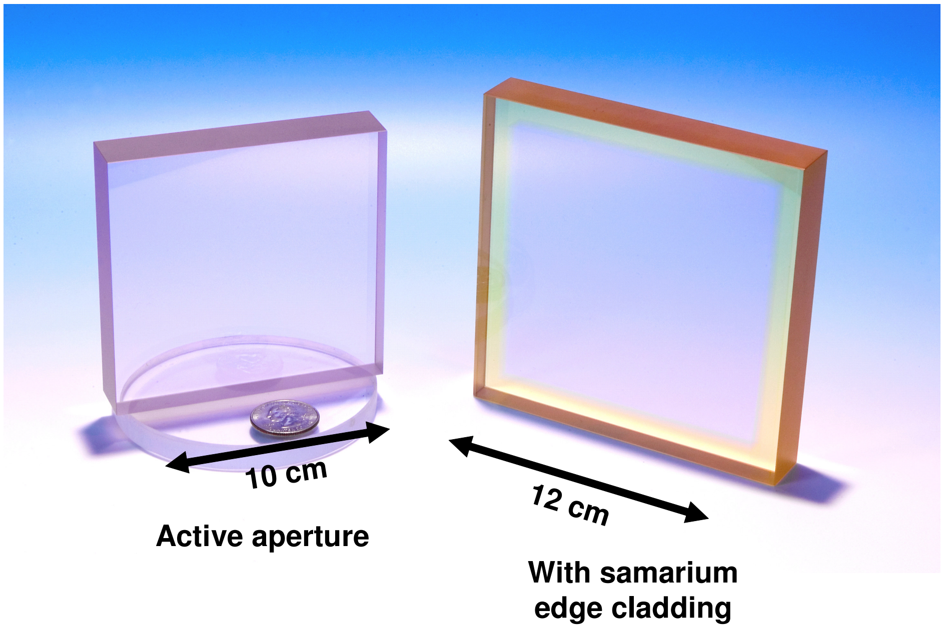

Figure 1: The photo on the left shows a 10 by 10 by 2 centimeter ceramic neodymium-doped yttrium aluminum garnet (Nd:YAG) amplifier slab designed for use in the SSHCL. On the right is a ceramic Nd:YAG slab integrally framed with transparent ceramic samarium doped YAG (Sm:YAG) to suppress amplified spontaneous emission (ASE) that was also demonstrated in the SSHCL.

Both transparent ceramics were produced by Konoshima Chemical Co. and Baikowski International Ltd.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

In addition to size, ceramics have several other advantages over traditional single crystal laser gain media. Although forming a ceramic slab requires careful process control, it takes on the order of only several days of firings. Whereas, in comparison, growing single crystals often requires weeks to months, and then the crystal may crack during cooling. Ceramic slabs have much higher fracture toughness than single crystals, and they are much less likely to shatter or undergo catastrophic breakage when thermally shocked compared to single crystals. Crack growth is inhibited by the numerous grain boundaries, and little or no residual stress exists in the ceramic slabs from the manufacturing process. Higher dopant concentrations are possible, and doping is very uniform. When growing single crystals dopant ions tend to be refined out so that significant gradients occur.

Benefits of ceramics versus single crystals for laser gain media include:

- Much larger apertures–limited only by size of furnace hot zone.
- Complete fabrication in several days versus weeks growing single crystal boules.
- Different shapes can be made to optimize performance parameters.
- Higher concentrations of optically active ions are possible.
- Uniform distribution of optically active ions.
- Low or no residual stress birefringence.
- Much higher fracture toughness and shatter resistance.
- More than one component can be included in a single slab.
- Tailored distribution of optically active ion(s) is possible.

The basic building block of the SSHCL is the laser gain module, which consists of a ceramic YAG:Nd^{3+} slab with Cobalt/GGG (Gadolinium Gallium Garnet) edge-cladding, and two diode arrays on each side of the slab that pump the slab's face at a defined angle. Up to five gain modules interlock to form a compact cavity from which energy is extracted as a free running resonator (see Figure 2). An intra-cavity adaptive optics (A/O) system maintains wavefront phase uniformity. This AO system consists of a wave front sensor, deformable mirror, tip/tilt mirror and controller. The output beam wavelength is 1064 nm and the pump wavelength is 808 nm.

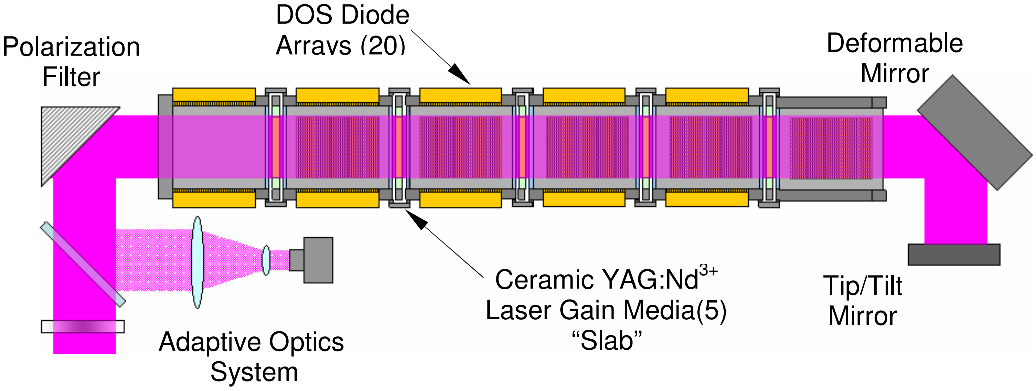

Figure 2: Diode-pumped SSHCL System Architecture

In January 2006, the SSHCL achieved 67 kW of average output laser power for short fire durations, which equates to 335 joules/pulse at our 200 Hz pulse repetition rate. Our pulsed laser has a 500-microsecond pulse width and utilizes up to a 20% duty cycle from the high-powered diode arrays. This power level was accomplished by pumping five ceramic YAG:Nd^{3+} slabs (laser gain media), each 10 cm by 10 cm by 2 cm thick in size. Recent experiments on the SSHCL have demonstrated 2X diffraction limit beam quality for up to 5 seconds of run time, roughly a 20 times improvement from our earlier performance.

The SSHCL has shown that solid-state laser technology can produce significant amounts of laser output power in a very small volumetric footprint, via an extremely simple and straightforward architecture. Power scales linearly in each of three ways: by adding more laser gain media, by increasing the cross-sectional area (and correspondingly increasing diode pump light) of the laser gain media, and by increasing the duty cycle of the high powered diode arrays.

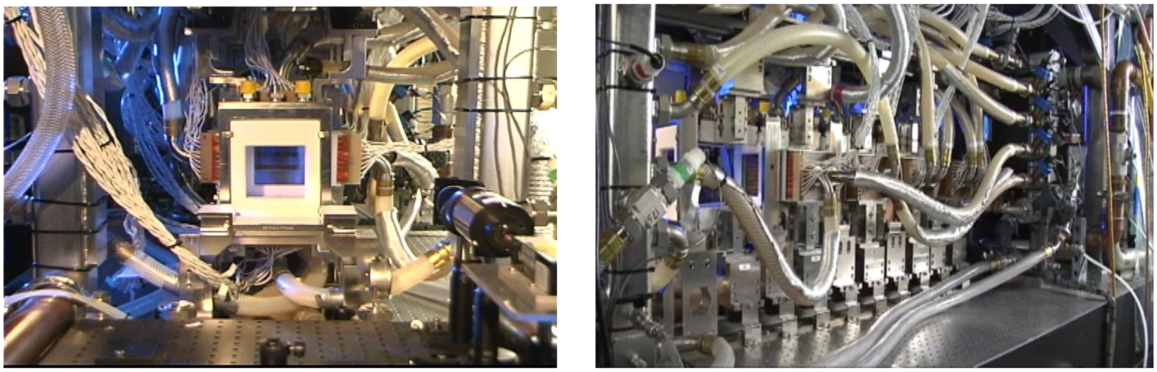

Figure 3: Current configuration of the SSHCL at Lawrence Livermore National Laboratory

In a new method for suppressing amplified spontaneous emission (ASE) that would otherwise degrade the efficiency of the laser, an ASE absorber is built into the slab. This new method for suppressing ASE is to partially sinter separate ceramic pieces of YAG doped with samarium (Sm:YAG), and then co-sinter them to the ceramic Nd:YAG (right hand photo of Figure 1).

The ceramic Sm:YAG edge-cladded slab has been installed in the SSHCL and has been shown to be effective in reducing ASE (Figure 4). What's more, the edge cladding does not absorb any diode-pump light, which helps limit wave-front distortion by minimizing heating. Making ASE suppression an integral part of the slab and having it be transparent to the pump light had not been done before. Our near term development will concentrate on utilizing this type of laser gain media in the laser cavity, to promote good beam quality for extended periods of run time.

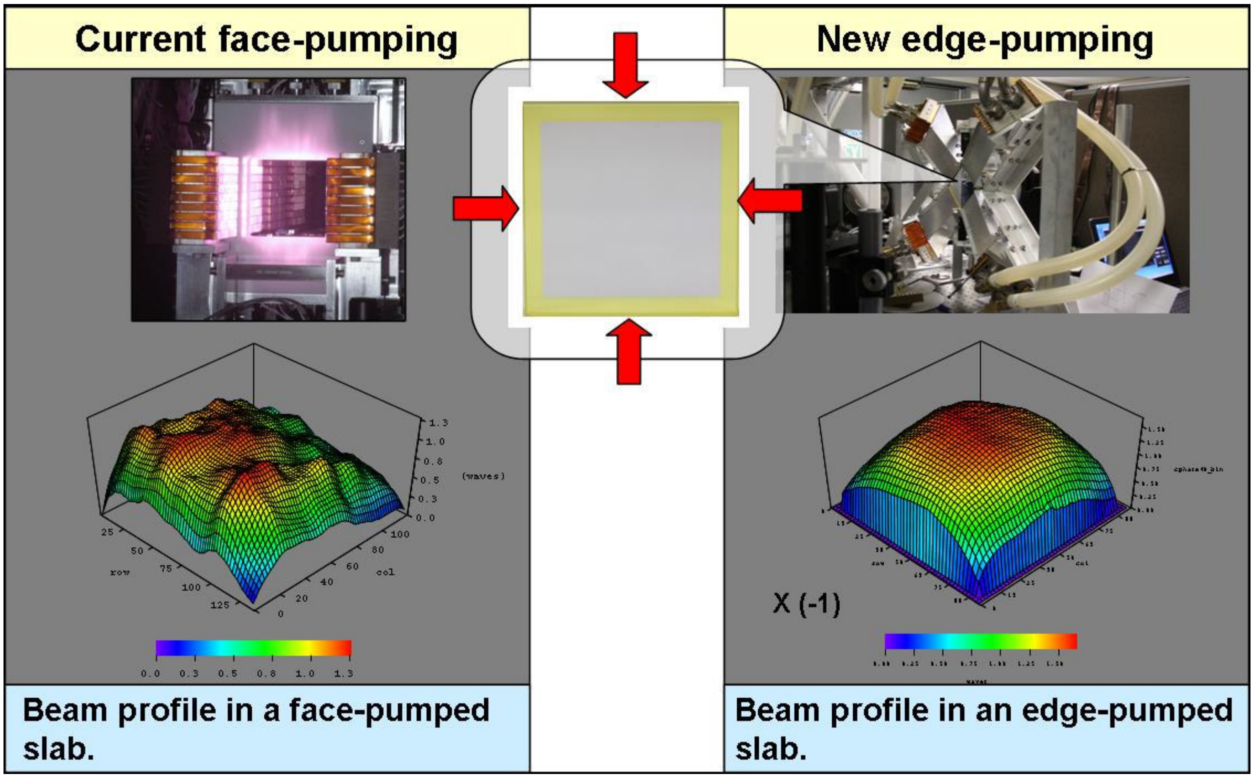

Figure 4: Comparative results of face pumping vs. edge pumping;
Note significant improvement of beam profile utilizing the edged pumped geometry

We believe that we are just at the "tip of the iceberg" with regards to the application of large transparent ceramics for use in high powered solid state lasers. Their attributes are many, and because of their flexibility in fabrication, provide a large range of design parameters to explore. Special thanks to Dr. Takakimi Yanagitani and his technical staff in working with us to develop these state of the art large transparent ceramics needed for successful operation and performance enhancement of our laser.