Preprint
UCRL-JC-148318

Solid-State Heat-Capacity-Laser Review

M.D. Rotter, C.D. Dane

This article was submitted Solid State and Diode Laser Technology Review, Albuquerque, NM, June 3-6, 2002

May 7, 2002

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

This work was performed under the auspices of the United States Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Solid-State Heat-Capacity-Laser Review

M.D. Rotter and C. Brent Dane

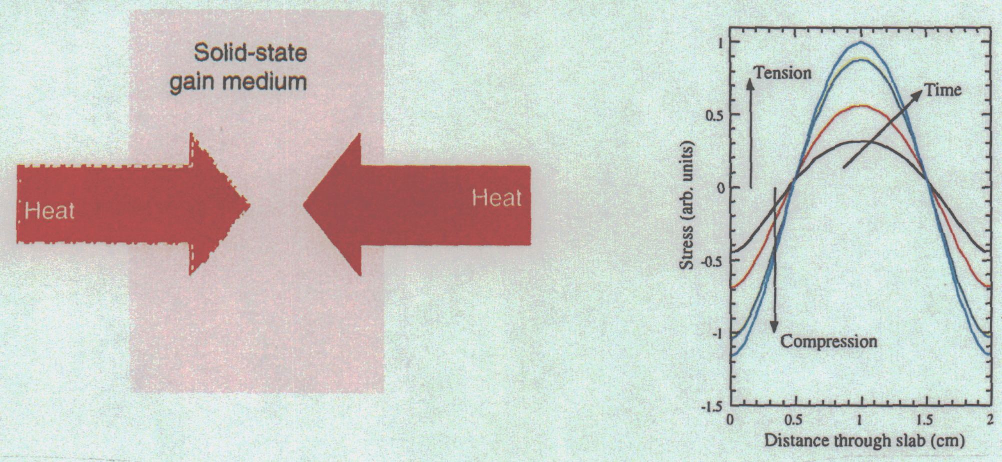
Lawrence Livermore National Laboratory, P.O. Box 5504, L-477, Livermore, California 94551

Abstract
We describe our recent progress in the area of solid-state heat-capacity-lasers (SSHCL). In particular, we examine the physics of heat-capacity operation of a solid state laser and give the present technology status of our 10 kW flashlamp-pumped laser. The current status of work leading to a diode-pumped Nd:GGG HCL is also described.

Introduction
For the purposes of this introduction, we shall consider three modes of laser operation. The first is what is known *as single-shot* operation in which the time between firings is very long. High-power/high-energy lasers such as the OMEGA laser at the Laboratory for Laser Energetics in Rochester, NY, are operated in this mode. Here, thermal effects in the solid-state lasing medium are not considered and ambient cooling of the laser medium occurs after the shot. The prime power source supplies lasing power only and the beam propagates in the absence of thermal cooling gradients.

The second mode of operation is known as *steady-state* operation. This is the typical operating mode for gas ion lasers and certain solid-state lasers such as Nd:YAG or Nd:YLF. To enable operation, the lasing medium is cooled at the same time it is being pumped. As a result, the prime power must supply both lasing *and* cooling power and the beam propagates in the presence of thermal cooling gradients.

The *heat-capacity* mode of operation[1] is intermediate between these two regimes. Here, laser operation rapidly adds single shots and the waste heat is stored in the lasing medium. The prime power supplies first lasing, and then cooling needs. Because the laser is operated in the absence of thermal cooling gradients, there are far less stresses induced on the lasing medium and optical distortions are minimized. In Fig. 1, we show a typical pumping scenario for a HCL. Part (a) shows a solid-state gain medium that is equally pumped on both sides. The stresses resulting from this pump distribution are shown in part (b). As may be seen, this pumping arrangement results in compressive stresses at the surface of the laser medium. This minimizes the possibility of fracture in the medium.



(a) (b)

Figure 1: (a)Pumping geometry for the SSHCL and (b) Stress distribution at various times resulting from this geometry.

This work was done under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

The 10kW Heat-Capacity Laser

As a proof-of-principle of heat-capacity operation, we constructed a 10 kW average power HCL. This laser uses flashlamp-pumped Nd:Glass as its lasing medium. Some of the specifications and measured parameters for this laser are shown in the following table.

Parameter	Objective	Demonstrated
Energy (J/pulse)	500	639 (average)*
Pulse rate (Hz)	20	20
Average power (kW)	10	12.8
Run duration (s)	10	10
Beam divergence (rad)**	<40	<40***

*Initial energy: 700 J/pulse; final energy: 580 J/pulse

**Half-angle for 50% encircled energy

***First pulse

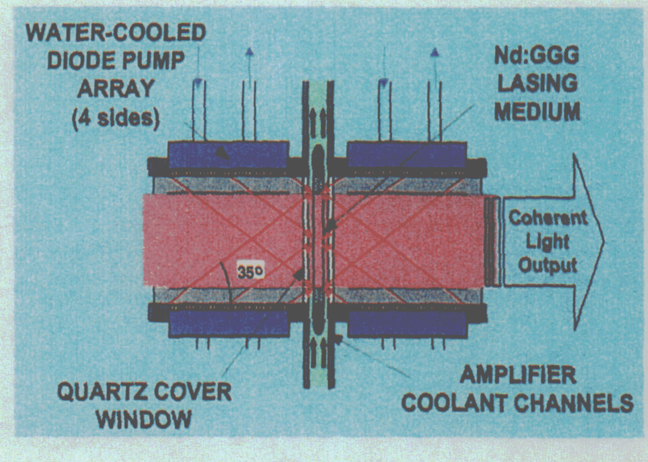
In order to meet the ultimate beam quality goal of < 2x diffraction limit over the ten second burst, we plan on integrating in September of this year an adaptively-corrected unstable resonator (M = 1.4) with a 140-actuator deformable mirror in the cavity. This laser is presently installed at the High-Energy Laser System Test Facility at White Sands Missile Range, NM, where it is being used for laser/target interaction experiments. A picture of the laser as installed at HELSTF is shown in Fig. 2.

Figure 2: Photograph of the 10kW SSHCL as installed at HELSTF

Progress towards a 100 kW Heat-Capacity Laser

A major milestone in the SSHCL program is the construction of a 100 kW SSHCL that can be rapidly cooled between bursts. Such a laser may find utility as a tactical missile defense in battlefield applications. In order to achieve the desired 100 kW output power, several changes need to be made in the design of the laser. The requirement of rapid cooldown forces one to abandon glass as a lasing medium (since thermal diffusivity of glass is relatively low) and replace it with crystalline media. In an HCL, the path to higher power is not through the conventional method of increasing the energy/pulse, but rather by increasing the pulse repetition rate. Thus the 100 kW laser will still operate at 500 J/pulse, but now the pulse repetition rate will be increased from 20 Hz to 200 Hz. This regime requires us to abandon flashlamps as a pump source and replace them with laser diodes..

Both these changes actually result in a laser system that is far more efficient than the flashlamp-pumped system currently employed. We have identified Nd:GGG (Gallium Gadolinium Garnet) as the laser material of choice due to its high thermal diffusivity (roughly 10x greater than glass), greater emission cross-section (5x larger than glass), and greater fracture stress (5x larger than glass). In addition GGG has the advantage that large slabs may be cut from the boule. Another potential laser medium, YAG, has regions of high stress/depolarization in the boule that severely limit the size of the slab that may be extracted. A conceptual diagram of a typical slab in the diode-pumped Nd:GGG laser is shown in Fig. 3(a). We note that in contrast to the existing 10 kW laser, which uses Brewster-angle slabs, here the laser slabs are normal to the beam propagation direction. This results in not only a more compact system, but one in which wavefront distortions due to thermally-induced slab deformations are drastically reduced. In Fig. 3(b), we show a full-size laser diode recently received from Armstrong Laser Technology. The array shown consists of 9 rows of 80 bars/row operating at a wavelength of 808 nm. We are just now beginning to test the characteristics of the array.



(a)

(b)

Figure 3: (a) Pump geometry of diode-pumped Nd:GGG HCL. Each slab is pumped by four diode arrays. (b) Typical laser diode array. Each array produces approximately 75 kW of peak optical power. A six-inch rule lies on top of the array.

As part of our risk-reduction efforts, the path to the 100 kW SSHCL will include the construction of a three-slab sub-module. A drawing showing the layout of the laser system is given in Fig. 4

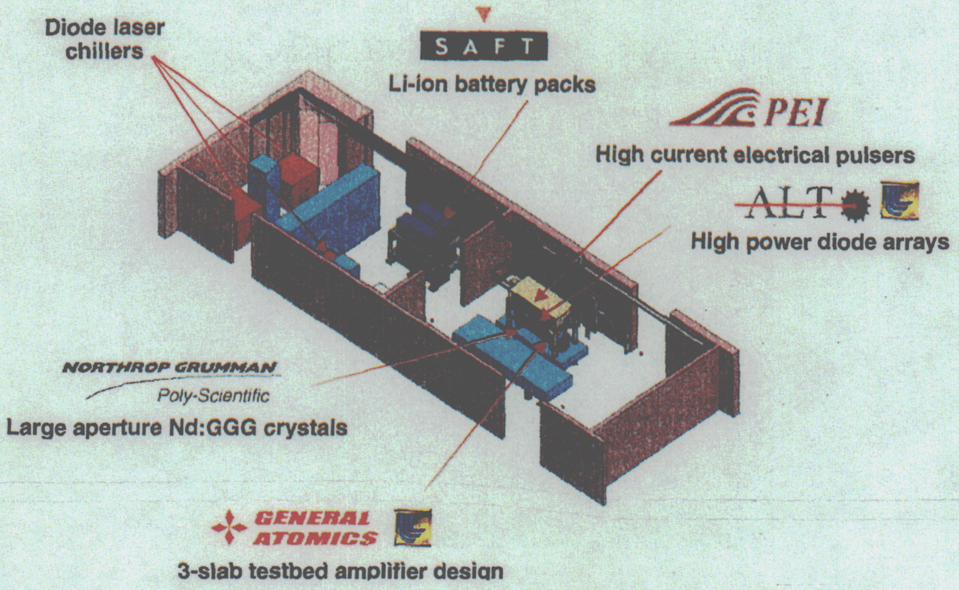


Figure 4: Laboratory layout of the three-slab diode-pumped Nd:GGG testbed. Commercial partners with Lawrence Livermore National Laboratory and their contributions are indicated.

The three-slab laser will be pumped by a total of twelve laser diode arrays, for a peak optical power of roughly one MW. Four diode arrays will share one chiller, shown in the far left of the picture. In order to bring the system closer to the reality of a field environment, we will use Li-ion batteries as the primary power source. These batteries will be connected by means of copper bus bars to the cards comprising the pulse-forming network, which are situated above the laser head as shown. In the immediate future, we plan on using square Nd:GGG slabs which are 8 cm on a side, and retrofit these with 10cm slabs as they become available.

In order to reach the 100 kW milestone, we will require the use of nine Nd:GGG slabs, each approximately 12 cm on a side (and correspondingly larger diode arrays as well). In this case, we will generate approximately 3.5 MW (peak) of optical pump power for an optical-to-optical conversion efficiency of 33% and a wallplug efficiency of approximately 10%.

Summary

The operation of a solid-state laser in the heat-capacity mode is a novel approach to the development of systems which provide high-power, are compact, and most importantly, scalable for directed energy weapon applications. We have demonstrated the heat-capacity proof-of-principle by constructing a 10 kW average power laser that operates in this mode. In FY02, we will continue this endeavor through the use of crystalline laser media and laser-diode pump sources, culminating in the construction of a three-slab diode-pumped, Nd:GGG testbed. Following this effort, we will embark on the construction of a 100 kW average power SSHCL.

Reference:

[1] G. Albrecht, S. Sutton, V. George, W. Sooy, W. Krupke: Solid state heat capacity disk laser , Laser and Particle Beams, Vol. 16, No. 4 (1998)

UCRL JC 148318

Solid-State Heat-Capacity-Laser Review

M.D. Rotter and C. Brent Dane

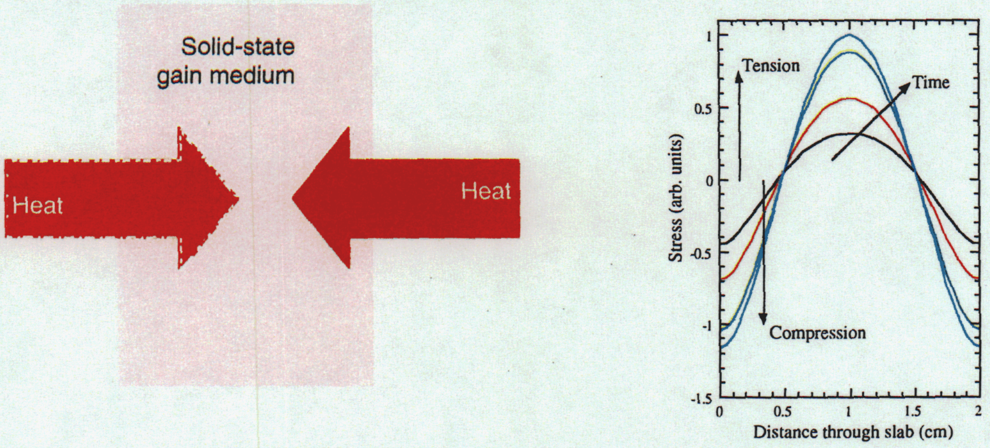
Lawrence Livermore National Laboratory, P.O. Box 5504, L-477, Livermore, California 94551

Abstract
We describe our recent progress in the area of solid-state heat-capacity-lasers (SSHCL). In particular, we examine the physics of heat-capacity operation of a solid state laser and give the present technology status of our 10 kW flashlamp-pumped laser. The current status of work leading to a diode-pumped Nd:GGG HCL is also described.

Introduction
For the purposes of this introduction, we shall consider three modes of laser operation. The first is what is known *as single-shot* operation in which the time between firings is very long. High-power/high-energy lasers such as the OMEGA laser at the Laboratory for Laser Energetics in Rochester, NY, are operated in this mode. Here, thermal effects in the solid-state lasing medium are not considered and ambient cooling of the laser medium occurs after the shot. The prime power source supplies lasing power only and the beam propagates in the absence of thermal cooling gradients.

The second mode of operation is known as *steady-state* operation. This is the typical operating mode for gas ion lasers and certain solid-state lasers such as Nd:YAG or Nd:YLF. To enable operation, the lasing medium is cooled at the same time it is being pumped. As a result, the prime power must supply both lasing *and* cooling power and the beam propagates in the presence of thermal cooling gradients.

The *heat-capacity* mode of operation[1] is intermediate between these two regimes. Here, laser operation rapidly adds single shots and the waste heat is stored in the lasing medium. The prime power supplies first lasing, and then cooling needs. Because the laser is operated in the absence of thermal cooling gradients, there are far less stresses induced on the lasing medium and optical distortions are minimized. In Fig. 1, we show a typical pumping scenario for a HCL. Part (a) shows a solid-state gain medium that is equally pumped on both sides. The stresses resulting from this pump distribution are shown in part (b). As may be seen, this pumping arrangement results in compressive stresses at the surface of the laser medium. This minimizes the possibility of fracture in the medium.



(a) (b)

Figure 1: (a)Pumping geometry for the SSHCL and (b) Stress distribution at various times resulting from this geometry.

This work was done under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

The 10kW Heat-Capacity Laser
As a proof-of-principle of heat-capacity operation, we constructed a 10 kW average power HCL. This laser uses flashlamp-pumped Nd:Glass as its lasing medium. Some of the specifications and measured parameters for this laser are shown in the following table.

Parameter	Objective	Demonstrated
Energy (J/pulse)	500	639 (average)*
Pulse rate (Hz)	20	20
Average power (kW)	10	12.8
Run duration (s)	10	10
Beam divergence (rad)**	<40	<40***

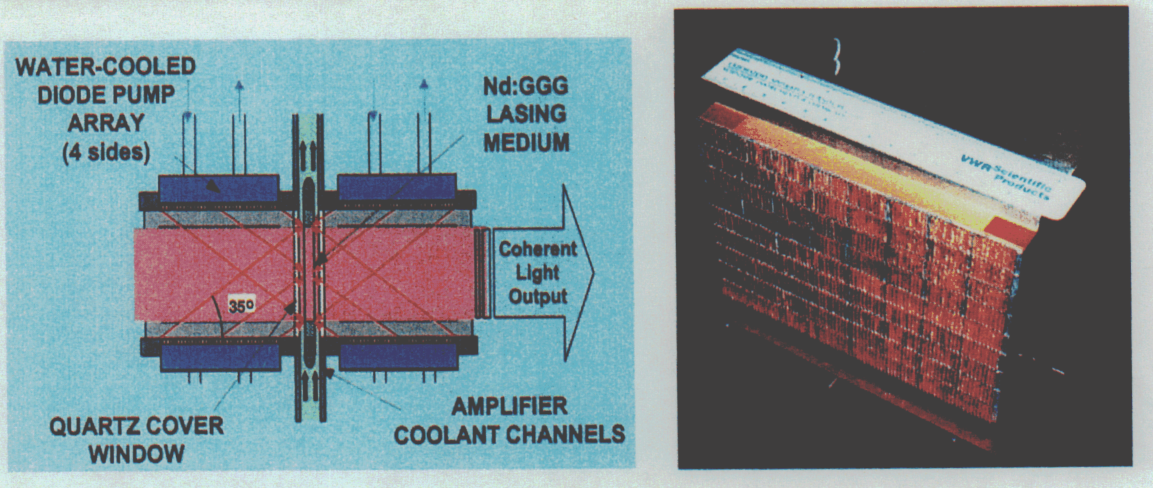
*Initial energy: 700 J/pulse; final energy: 580 J/pulse
**Half-angle for 50% encircled energy
***First pulse

In order to meet the ultimate beam quality goal of < 2x diffraction limit over the ten second burst, we plan on integrating in September of this year an adaptively-corrected unstable resonator (M = 1.4) with a 140-actuator deformable mirror in the cavity. This laser is presently installed at the High-Energy Laser System Test Facility at White Sands Missile Range, NM, where it is being used for laser/target interaction experiments. A picture of the laser as installed at HELSTF is shown in Fig. 2.

Figure 2: Photograph of the 10kW SSHCL as installed at HELSTF

Progress towards a 100 kW Heat-Capacity Laser
A major milestone in the SSHCL program is the construction of a 100 kW SSHCL that can be rapidly cooled between bursts. Such a laser may find utility as a tactical missile defense in battlefield applications. In order to achieve the desired 100 kW output power, several changes need to be made in the design of the laser. The requirement of rapid cooldown forces one to abandon glass as a lasing medium (since thermal diffusivity of glass is relatively low) and replace it with crystalline media. In an HCL, the path to higher power is not through the conventional method of increasing the energy/pulse, but rather by increasing the pulse repetition rate. Thus the 100 kW laser will still operate at 500 J/pulse, but now the pulse repetition rate will be increased from 20 Hz to 200 Hz. This regime requires us to abandon flashlamps as a pump source and replace them with laser diodes..

Both these changes actually result in a laser system that is far more efficient than the flashlamp-pumped system currently employed. We have identified Nd:GGG (Gallium Gadolinium Garnet) as the laser material of choice due to its high thermal diffusivity (roughly 10x greater than glass), greater emission cross-section (5x larger than glass), and greater fracture stress (5x larger than glass). In addition GGG has the advantage that large slabs may be cut from the boule. Another potential laser medium, YAG, has regions of high stress/depolarization in the boule that severely limit the size of the slab that may be extracted. A conceptual diagram of a typical slab in the diode-pumped Nd:GGG laser is shown in Fig. 3(a). We note that in contrast to the existing 10 kW laser, which uses Brewster-angle slabs, here the laser slabs are normal to the beam propagation direction. This results in not only a more compact system, but one in which wavefront distortions due to thermally-induced slab deformations are drastically reduced. In Fig. 3(b), we show a full-size laser diode recently received from Armstrong Laser Technology. The array shown consists of 9 rows of 80 bars/row operating at a wavelength of 808 nm. We are just now beginning to test the characteristics of the array.



(a) (b)

Figure 3: (a) Pump geometry of diode-pumped Nd:GGG HCL. Each slab is pumped by four diode arrays. (b) Typical laser diode array. Each array produces approximately 75 kW of peak optical power. A six-inch rule lies on top of the array.

As part of our risk-reduction efforts, the path to the 100 kW SSHCL will include the construction of a three-slab sub-module. A drawing showing the layout of the laser system is given in Fig. 4

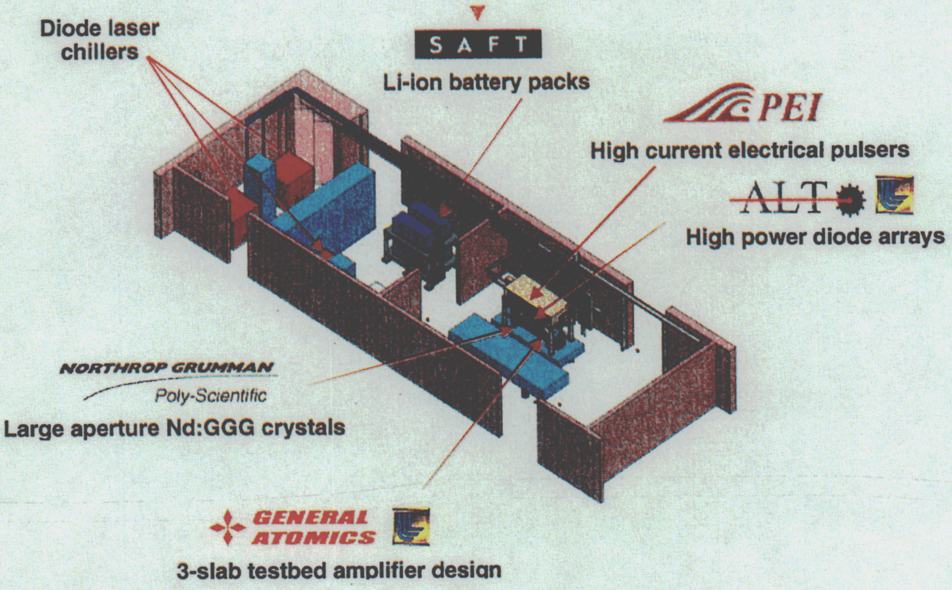


Figure 4: Laboratory layout of the three-slab diode-pumped Nd:GGG testbed. Commercial partners with Lawrence Livermore National Laboratory and their contributions are indicated.

The three-slab laser will be pumped by a total of twelve laser diode arrays, for a peak optical power of roughly one MW. Four diode arrays will share one chiller, shown in the far left of the picture. In order to bring the system closer to the reality of a field environment, we will use Li-ion batteries as the primary power source. These batteries will be connected by means of copper bus bars to the cards comprising the pulse-forming network, which are situated above the laser head as shown. In the immediate future, we plan on using square Nd:GGG slabs which are 8 cm on a side, and retrofit these with 10cm slabs as they become available.

In order to reach the 100 kW milestone, we will require the use of nine Nd:GGG slabs, each approximately 12 cm on a side (and correspondingly larger diode arrays as well). In this case, we will generate approximately 3.5 MW (peak) of optical pump power for an optical-to-optical conversion efficiency of 33% and a wallplug efficiency of approximately 10%.

Summary

The operation of a solid-state laser in the heat-capacity mode is a novel approach to the development of systems which provide high-power, are compact, and most importantly, scalable for directed energy weapon applications. We have demonstrated the heat-capacity proof-of-principle by constructing a 10 kW average power laser that operates in this mode. In FY02, we will continue this endeavor through the use of crystalline laser media and laser-diode pump sources, culminating in the construction of a three-slab diode-pumped, Nd:GGG testbed. Following this effort, we will embark on the construction of a 100 kW average power SSHCL.

Reference:

[1] G. Albrecht, S. Sutton, V. George, W. Sooy, W. Krupke: Solid state heat capacity disk laser , Laser and Particle Beams, Vol. 16, No. 4 (1998)