Title of Investigations:

20 Billion Shot, 1 kHz, 5 mJ Laser Transmitter for Planetary Mapping, Earth Mapping, and/or High Resolution Target Imaging

Principal Investigator:

D. Barry Coyle (Code 554)

Other External Collaborators:

Gordon Blalock (Swales), Wayne Welch (Welch Mechanical Designs, LLC)

Initiation Year:

FY 2005

Funding Authorized for FY 2005:

$59,000

Actual or Expected Expenditure of FY 2005 Funding:

In-house: $41,000; Contracts: $10, 000 to Swales and $8,000 to Welch Mechanical Designs, LLC

Status of Investigation at End of FY 2005:

To be continued in FY 2006 with funds remaining from FY 2005

Expected Completion Date:

March 2006

Purpose of Investigation:

We had three goals in carrying out this investigation. One, we wanted to use past successes from previous DDF and other R&D programs to build a compact, modular laser. Two, we wanted to demonstrate >6% wall-plug efficiency (fraction of electrical energy in converted to light energy out) with demonstrated flight-electronics performance specifications. This is higher than any laser reported in literature that uses conductive and/or air-cooling. And three, we wanted to perform a 20-plus billion shot life test to demonstrate the design's viability and reliability. Record lifetime reported for this type of system is about 5 billion shots, also performed by us on a previous design.

DDF annual report

Accomplishments to Date:

An accurate mathematical model with verification laboratory data has been completed and a paper submitted to *OSA Optic Letters* for publication. (D. Barry Coyle and Demetrios Poulios, "4-Pass Pumping of Nd^{+3}:YAG Slabs.")

Due to the lack of mechanical engineering manpower and the late delivery of the custom laser crystals and DDF funds, the final system fabrication was begun in mid-December several months late. However, the DDF funds were committed through the appropriate channels to ensure that the project is completed after the FY 2005 DDF timeframe. Delivery of the hardware is expected in mid-January 2006, with final laser-system assembly completion and long-term testing underway by March 1. The long-term performance of this "lessons learned" (LL) laser will commence immediately, with several publications and data sets to be presented during and after the end of this unit's run. This laser is expected to break the current efficiency and life-test records reported for this type of DPSS transmitter.

Goddard is pursuing two patents:

1. "A Solid State Laser Gain Module Based on A Spoiled Hexagon Geometry," which is based on the high-gain, double-pass amplifier design in the LL laser.
2. "A 4-Pass Coupler for Diode Pumped Solid State Lasers," which is used in the LL laser oscillator pump heads.

Planned Future Work:

We hope to build on the success of the ensuing life-test with further IRAD and IIP funding for space-borne planetary and surface imaging altimeter development.

Project Description:

The LL laser is based on knowledge and experience accumulated over the past 10 years in diode-pumped solid-state (DPSS) laser development. The main goal of this DDF was to build a low-cost, high-efficient, DPSS system that featured high pulse repetition frequency (PRF) and demonstrated record lifetimes. The efforts goal was to develop a low cost unit in a very compact package, yet employ available flight-like components. The result is shown in Figure 1, a 3-D rendering of the final design. A photo is not available at the time of this writing since the components have just been delivered. Final cleaning, inspection, and assembly will commence in the next few weeks with the lifetest expected to begin before June 1, 2007.

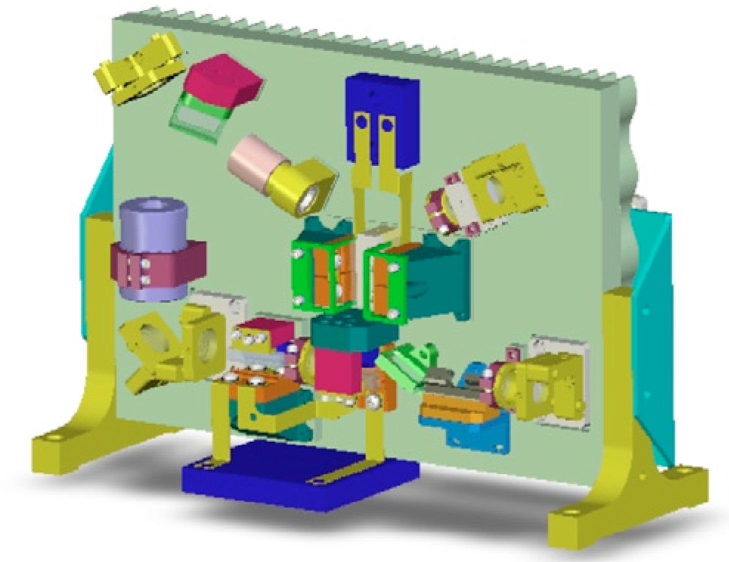

Figure 1. Final assembly of the LL laser transmitter. The MOPA design is mounted vertically to provide better conductive cooling off the incorporated fins, fabricated to the back of the optical bench.

The oscillator cavity has several innovative features developed in-house at GSFC and not found in any other laser system. First is the optimized pump head module (PHM). A PHM incorporates quasi-continuous wave (CW) (QCW) laser-diode arrays, pump light collimating optics or micro-cylinder lenses, a polarization coupling optic, and a Nd:YAG laser slab. The QCW arrays pump the Nd:YAG slab at 809 nm to store the appropriate energy such the surrounding laser cavity optics can produce 1064 nm pulses. The cylinder lenses are mounted to the diode array heat sink at the manufacturer. A complete set of custom-performance parameters in temperature, beam size, beam shape, and diode-array spacing were modeled and then sent to the QCW diode manufacturer for this LL system.

The polarization coupling optics, or 4-pass pump coupler (4PPC), is another unique design undergoing patent application and review. This unit uses a proprietary scheme and optic assembly to produce an absorption path within the Nd:YAG gain media, but it needed half the slab thickness to produce >95% absorption. Without this optic, the slab would have to be twice as thick, which would produce less than half the output energy and far worse beam quality. Intracavity apertures would be required to produce the equivalent TEM_{00} single-mode beam as with the 4PPC, but this would reduce the output energy even more.

Last of the PHM unique features is the optimized Nd:YAG slab design. The slab has been specifically modeled and designed with optimized thickness, tip angle, and the inherent internal path length to match the TEM_{00} mode structure this cavity will produce. This has been used on several other in-house designs, such as the High Efficiency Laser Transmitter (HELT), High Output Maximum Efficiency Resonator (HOMER), and the Vegetation Canopy Lidar (VCL) lasers.[2][3][4] Figure 2 shows a detailed view of the PHM, one of two in our oscillator cavity.

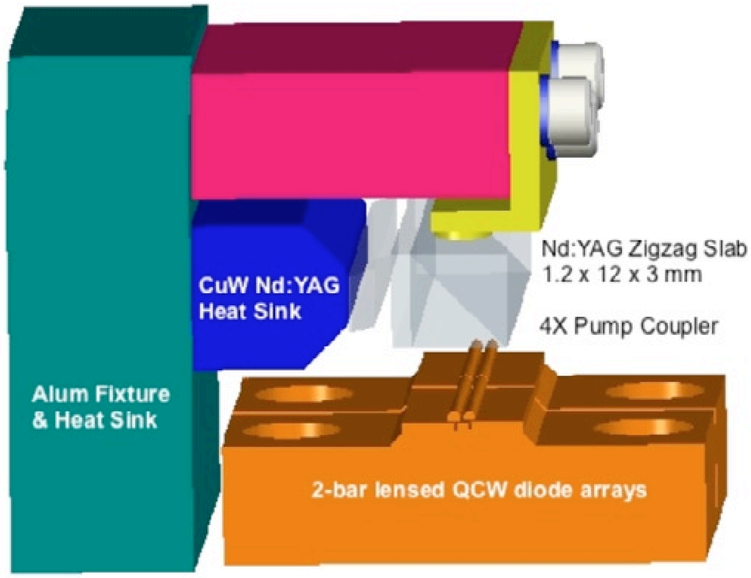

Figure 2. Close up view of the Pump Head Module (PHM). This unit produces equivalent pump absorption efficiencies and much more single-pass gain than that of units with Nd: YAG crystals which are commonly twice as thick.

Finally, the use of zigzag slabs in DPSS laser systems commonly produces asymmetric, or elliptical, beam profiles. This is due to the single axis thermal lens produced by its inherent pumping and optical-path geometry. The magnitude of the slab's thermal lensing effects is usually reduced by the addition of a negative cylindrical lens in the cavity and a small aperture or two. These methods improve the beam quality, but at the cost of reduced total efficiency, added complexity, extra surfaces to keep clean, and often a longer cavity length. Furthermore, the average power band (PRF x Pulse Energy) that a given DPSS laser with a zigzag slab head can be operated in, and still hold the equivalent beam quality, is very narrow due to the sensitivity of this thermal lens. By using two PHMs in series in the LL oscillator, each being almost half the pump power and length as what would be needed with a single PHM for this cavity, these additional beam-improvement methods are not needed. One of the PHMs is oriented at 90° to the other around the cavity optic axis, and their effective cylindrical thermal lenses are produced in each other's non-lensed axis. Thus, an equivalent spherical thermal lens is produced for the two-head system. A spherical thermal lens is easily accounted for in a given laser cavity. By simply changing the design curvature of one of the cavity end mirrors, the result is no asymmetry in the output-beam profile and a broader average power curve for high-beam quality production. A half plate is needed between the PHMs to flip the intracavity polarization for optimum use of each slab, but this is a low maintenance, low-alignment sensitivity optic.

Figure 3 shows a detailed layout of the entire Master Oscillator Power Amplifier (MOPA) system, including the high-gain, two-pass coffin amplifier. The coffin amplifier, also a GSFC in-house design, produces internal-path lengths roughly 10 times the length of the crystal's longest dimension. For example, the crystal developed for the LL laser is approximately 2.5-cm long, but 0.8-cm wide at the "shoulders," yet produces an internal gain path of more than 28 cm. This is far more than what can be produced in a multipass zigzag slab, yet needs no external optics, other than the usual HR mirror, one-quarter waveplate, and thin film polarizer.

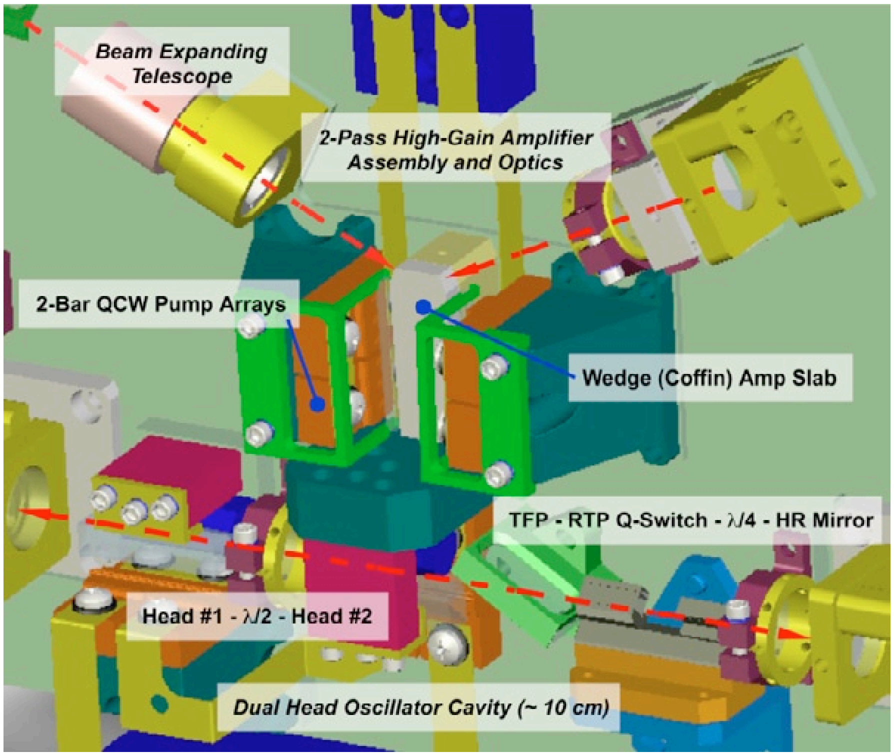

Figure 3. Detail of the total LL MOPA layout. The total optical bench is 8.5 x 6.0 inches, slightly larger than that of MLA's, but capable of the equivalent size reduction if built for flight use.

Our modeling effort was critical to the final design of the LL system as well. Our computer modeling has evolved over the years to include a virtual end-to-end method of DPSS laser transmitter development. This capability only can be acquired through long-term continuous efforts, constantly building on data products in the lab and new technologies. Figure 4 shows a typical modeled Q-switched laser pulse output, with varying output coupler mirror reflectivity for the LL oscillator.

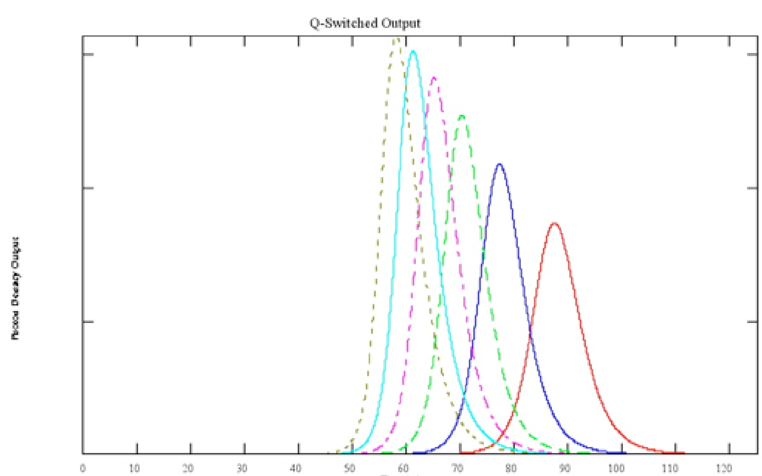

Figure 4. Computed laser pulse output from the 10 cm oscillator of the LL MOPA system. Pulse energies range from 2.4–2.8 mJ over output coupler reflectivities of 30–55%. The amplifier portion should achieve more than 10 mJ per pulse.

Key Points Summary:

Project's innovative features: Innovative features included a record number of laser shots, record efficiency, and an innovative design.

Potential payoff to Goddard/NASA: The amplifier will bring these 2+ mJ pulse energies to over 10 mJ/pulse, while operating at 1000 Hz for an average power of over 10 W. If we achieve optical efficiencies of at least 15% or more, then the heat dissipated will be on the order of 67 W. This is definitely doable with conductive or convective cooling. If the efficiency were less, say 5% or so, which is typical of current flight lasers, then the heat generated would be much higher, or on the order of 200 W. Flight instruments based on DPSS laser instruments will reap huge benefits in overall mission cost, mass, and thermal loads.

The criteria for success: Confidence is high that the laser will perform to within ~10% or better of our model's predictions. We will consider the effort successful when the long-term test passes 10 billion pulses because no other DPSS system of this type has reportedly operated past 5 billion shots. However, from recent laser-diode decay data gathered on our previous efforts, as well as proper de-rating settings, this laser should surpass 20 billion shots with operational margin to spare. At a 1 kHz PRF, the laser will accumulate about 2.7 billion shots/month; thus, a full five months are needed to reach the 10-billion shot milestone. The good news is that long-term tests require very little effort and manpower to perform, if properly automated and interlocked for redundancy and safety. Thus, any additional funds needed for this test can be easily chalked up to general laboratory overhead and maintenance. The DDF program will not be affected.

Technical risk factors: The LL laser design is built on previous. Thus, the individual risk is low for each new technology or component. Confidence is high that the oscillator will perform to specifications; however, the same is not so for the high-gain amplifier. This is simply because our models for the amplifier have not undergone the same level of evolution and iterations with laboratory data over the years. Our biggest worry is that the thermal lensing, discussed earlier with the oscillatory PHMs, will negatively affect us on the amplifier slab. We have the capability to correct for this with our two-pass end mirror and room for a cylindrical lens. Also, since the amplifier does not require a resonant cavity, alignment and thermal effects are not as critical as with an oscillator cavity. If the thermal lensing in the amplifier appears larger than we can calculate, the result will simply be a reduced repetition rate, or average pump power. The final MOPA system should still produce a minimum 10 mJ/pulse, but it may be only achievable at 500 Hz instead of our desired 1000 Hz.