# Space Laser Transmitter Development for ICESat-2 Mission

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## ABSTRACT

The first NASA Ice, Cloud and land Elevation Satellite (ICESat) was launched in January 2003 and placed into a near-polar orbit whose primary mission was the global monitoring of the Earth's ice sheet mass balance. ICESat has accumulated over 1.8 B shots in space and provided a valuable dataset in the study of ice sheet dynamics over the past few years. NASA is planning a follow-on mission ICESat-2 to be launched tentatively in 2015. In this paper we will discuss the development effort of the laser transmitters for the ICESat-2 mission.

**Keywords:** LIDAR, Remote Sensing, Space Laser Systems, Laser Altimeter, Space-Qualified Lasers, Micropulse Lidar

## 1. INTRODUCTION

The NASA Goddard Space Flight Center (GSFC) has been engaged in producing space-borne laser transmitters for missions such as Mars Orbiter Laser Altimeter (MOLA) for the Mars Global Surveyor (MGS) [1], Geoscience Laser Altimeter (GLAS) for the Ice, Cloud and land Elevation Satellite (ICESat) [2], Mercury Laser Altimeter (MLA) for MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) Mission [3], and Lunar Orbiter Laser Altimeter (LOLA) for the Lunar Reconnaissance Orbiter (LRO) [4]. All of these were diode-pumped solid-state lasers (DPSSL) with low repetition rates (< 100's Hz) and pulse energies ranging from 3 to 100 milliJoules. With ICESat-2, we are transitioning to a new generation of space-based laser remote sensing instruments. Table 1 summarizes the various programs that were led by GSFC in the past decade. In this paper we will discuss several candidate laser architectures that are under investigation at GSFC to meet the ICESat-2 mission schedule.

Table 1. Summary of past and current GSFC spaceborne laser instruments.

| Laser Parameters | MOLA | GLAS | MLA | LOLA |
|---|---|---|---|---|
| Mission | Mars Global Surveyor | ICESat | MESSENGER | LRO |
| Laser Architecture | Cross Porro Power Oscillator, Atively Q-Switched | Porro-Mirror Resonator passively Q-switched with two stage amplifiers | Cross-Porro Resonator passively Q-switched with single stage amplifiers | Cross-Porro Resonator passively Q-switched |
| Launch Date | 7 November 1996 at 17:00:50 UTC | 13 January 2003, at 00:00:45 UTC | 3 August 2004 at 6:15:56 UTC | 18 June, at 21:32:00 UTC |
| Center Wavelength (vacuum) | 1064 nm | λ1 1064.5 nm ± 100 pm<br>λ2 532.2 nm ± 50 pm<br>(≤ 15 pm single shot) | 1064.5 nm ± 0.1 nm | 1064.3 ± 0.1 nm |
| Energy output | 48 mJ pulse | λ1 = 75 mJ<br>λ2 = 35 mJ | 20 ± 2 mJ over operational run | 2.7 ± 0.3 mJ |
| Pulse Repetition Rate | 10 Hz | 40 ± 0.1 Hz | 8 Hz | 28.0 ± 0.1 Hz |
| Pulsewidth | 7 – 6 ns | ≤ 6 ns | 4 – 8 ns | 6.0 ± 2.0 ns |
| Divergence (86.5% encircled energy) | 80 μrad | 110 μrad (+23, -10) | 50 ± 10 μrad | 100 μrad<br>(= 5 m footprint) |
| Number of Beams | 1 | 1 | 1 | 5 |
| Radiation | 20 krad | 30 krad | 50 krad | |
| In-Space Shot Counts | 670 Million Shots | 1.98 Billion shots to date | >1 Mshots to date | > 400 Mshots to date |
| Operation without damage | 33 °C ± 7.5 °C | 10 °C – 30 °C | 5 °C – 35 °C | 5 °C – 35 °C |

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ICESat was launched in January 2003 and placed into a near-polar orbit whose primary mission was the global monitoring of the Earth's ice sheet mass balance. The GLAS instrument on ICESat was the sole instrument on the satellite, and provided unprecedented science data on global surface elevation of ice and land, sea ice freeboard heights, vertical cloud height distributions, and vegetation canopy heights, despite issues with laser lifetime. GLAS has accumulated over 1.8 billion data points and has exceeded the designed range accuracy of 10 cm with in-space accuracies <3 cm over a 70 meter footprint and 170 m along track separation. The follow-on mission, ICESat-2, is being planned for continued monitoring of the Earth's ice sheet mass balance with a tentative launch date of 2015 and is expected to be a five-year mission. In late 2008, mission-planning activities were aimed at refining the instrument architecture with the laser transmitter baselined on the GLAS master oscillator power amplifier (MOPA) configuration. The MOPA architecture was a low repetition rate (~50 Hz), high energy (~50 mJ per pulse) with lineage tracing back to the MOLA instrument in the late 1990's. In mid-2009, updated science requirements precipitated an instrument redesign calling for a micropulse, multi-beam architecture. The new laser being developed is therefore, a high repetition rate (10's kHz), low energy laser transmitter (ranging from 25 to 100 μJ per pulse per beam).

Due to the change in laser architecture, we altered our strategy from an in-house build of the flight hardware to an external procurement. There has been substantial development in industry in these high repetition rate, low energy lasers and GSFC has not previously focused its resources in this area. Therefore we decided to leverage the substantial external investment to meet our current mission requirements. We are currently investigating several vendors with differing laser architectures. In order to make a well-informed decision about the relative strengths, weaknesses and risks associated with potential laser architectures, GSFC has initiated an in-house research program to investigate different oscillator and amplifier designs and key components. In this paper, we will present internal development projects at GSFC, which are designed to increase our understanding, inform our decision-making and help us determine suitable success criteria.

### 1.1 Instrument Requirements

The original design of the Advanced Topographic Laser Altimeter System (ATLAS) instrument for ICESat-2 evolved as a modified version of the ICESat GLAS instrument concept. More specifically, for ICESat-2, the original ATLAS design was a single-beam altimetry system with the laser transmitter operating at a slightly higher repetition rate (50 Hz), lower energy per pulse (50 mJ) and similar 6-7 ns pulse width at the near-infrared (NIR) wavelength of 1064 nm when compared to GLAS. These changes would have provided higher derating on the lasers and potentially longer mission life.

In mid-2009, the ICESat-2 instrument architecture had a major re-design during the pre-Phase A activities to accommodate more science objectives and incorporate recommendations from the ICESat-2 science workshop [5]. For ice sheets, improved pointing will reduce the uncertainty in the ice sheet elevations introduced by the cross-track surface slope. In addition, for land topography and vegetation, improved pointing will provide observations along exact repeat ground tracks, and sampling along uniformly spaced ground tracks will provide well-sampled grids of topography and biomass. Based on this and other recommendations [5], a new instrument concept was proposed and accepted by the ICESat-2 program. The new baseline is a micropulse laser altimetry approach. In this case, a high repetition rate (10's kHz), lower energy (100's μJ), shorter pulse width (~1 ns), multi-beam laser altimeter system will be used. A single laser transmitter having sufficient laser energy will be split into multiple beams using a diffractive optical element (DOE) similar to the one used on LOLA [6]. The current instrument architecture consists of a 9-beam system arranged in a 3x3 configuration. Figure 1 shows the ground spot configuration and the coverage with this beam pattern. The repetition rate is determined to minimize the number of pulses in each beam that will be propagating in the atmosphere at any one time, thus minimizing the ambiguity of multiple returns due to high clouds while the satellite is orbiting the Earth.

A link budget analysis has been developed for ICESat-2, and Table 2 shows the nominal performance characteristics of the laser transmitter for the micropulse laser altimeter system. Although Table 2 shows the IR energy and wavelength requirements, both visible and NIR detector options are still being considered which could necessitate frequency doubling the output of the transmitter described. A doubling crystal will be used to frequency double the fundamental IR wavelength to generate the necessary visible wavelength. Assuming a conversion efficiency of 60%, the energy of the visible beam before the DOE will be about 1.2 mJ. From Figure 1, the total green energy from the 9 beams is about 0.4 mJ, so there is a derating of about 67% to provide necessary margin to meet mission life of 5 years. A DOE is necessary to split the laser beam into a 3x3 pattern with energies distributed as shown in Figure 1.



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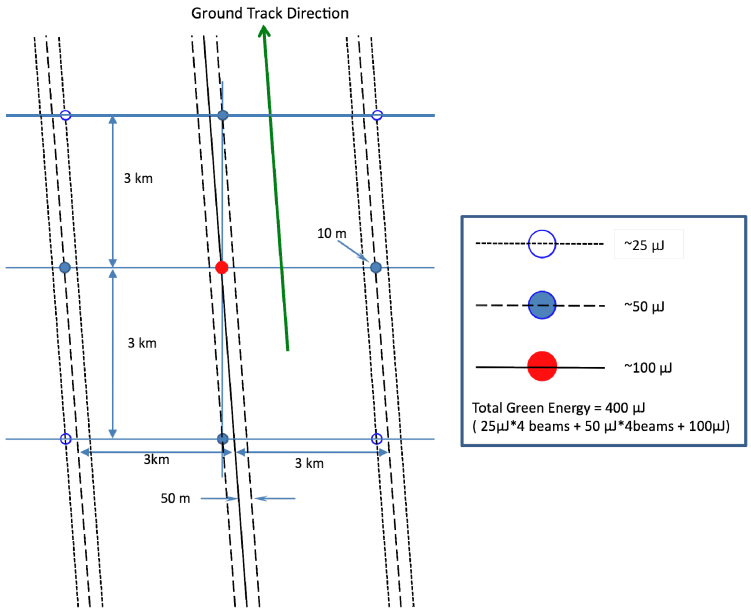


Figure 1. This figure shows a snapshot of the 3x3 laser spot pattern currently conceived for ICESat-2. The energy per spot is indicated by the different spot colors and line styles showing the ground track orientation from an orbiting ICESat-2 satellite. The 3x3 pattern consists of 9 spots in a 6 km grid pattern. Each beam has a 10-meter diameter spot on the ground. The ground track is slightly off the vertical axis of the constellation so the spots sweep out three sets of three tracks from orbit, each set of tracks consists of three 10 m wide ground tracks separated by 50 m, the sets are separated by ~ 3km.

Table 2. Current laser transmitter performance requirements for the ICESat-2 micropulse laser altimeter system.

| **Requirements:** | |
|---|---|
| **Parameter** | **Specification** |
| Pulse Energy (IR) | 2 mJ |
| Pulse Width | < 1.5 ns |
| Repetition Rate | 10 kHz (± 0.2 kHz) |
| Center Wavelength (IR) | 1020 - 1080 nm |
| Wavelength Stability/Linewidth | < 60 pm |
| Polarization Extinction Ratio (PER) | > 100:1 |
| Polarization orientation | ± 1 ° |
| Spatial Mode | $M^2 < 1.6$ |
| Pointing Stability (shot-to-shot) | < 10% of divergence |
| Pointing Stability (long-term) | < 20% of divergence |
| Lifetime | > 5 years |
| Operating Temperature | ± 1 °C of design wavelength |
| Operating Survival Temperature | 10 – 40 °C |
| Non-Operating Survival Temperature | 0 – 50 °C |
| **Design Goals:** | |
| Mass | < 10 kg |
| Volume | < 40 x 25 x 15 $cm^3$ |
| Efficiency (Wall plug) | > 15% |



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# 2. GSFC LASER DEVELOPMENT EFFORT FOR ATLAS

## 2.1 Master Oscillator Power Amplifier (MOPA)

The micropulse laser altimeter system for ATLAS represents a new space-based altimeter architecture for NASA GSFC. All previous laser altimeters for space have been quasi-continuous wave (QCW) laser diode array (LDA) pumped solid-state oscillator/amplifier systems with low repetition rate and high energy with a single-beam system (except for LOLA). The LOLA instrument is the first multi-beam altimeter system in space. It used a diffractive optical element to divide a single beam into five for mapping of the lunar surface. For ATLAS, continuous wave (CW) diode pumping is anticipated.

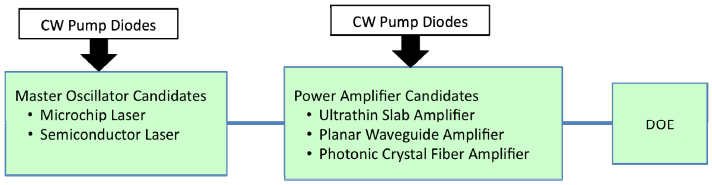


Figure 2. MOPA laser architectures under in-house development for ATLAS.

The laser requirements shown in **Table 2** drive the laser architecture for ATLAS to a MOPA design (see **Figure 2**). The short pulse width (~1.5 ns) and high beam quality ($M^2 < 1.6$) can be met with a lower energy, short cavity master oscillator such as a microchip or semiconductor laser. A power amplifier following the MO can then bring the energy to the required millijoule level. Power amplifier architectures such as planar waveguide, photonic crystal fiber and thin slab amplifiers are all potential candidates for the ATLAS instrument. In the following sections, we will describe our in-house development effort in MO and PA as well as risk mitigation programs on critical components. We will also describe development of the laser test station for environmental testing of these lasers at appropriate times during the development program.

### 2.1.1 Master Oscillator

The ATLAS laser specifications place a tight requirement on the master oscillator. In order to reduce the sunlit background counts on the detectors in the ATLAS instrument, a very narrow bandwidth optical filter is necessary. The bandwidth of the optical filter currently being considered is ~60 pm. Thus the MO needs to have minimal center wavelength jitter and narrow linewidth for the return signal to be received by the detector. Over the last two decades there has been significant advancement in the area of miniature solid-state lasers. Microchip lasers are small lasers [7-10] whose performance is comparable to larger conventional lasers systems. In many cases they are manufactured by the diffusion bonding of multiple optical materials, creating a monolithic system that is extremely compact and can be mass produced and does not require any optical alignment. The most widely used mode of operation of microchip lasers is passively Q-switched, which generate ultrashort laser pulses at multi-kHz repetition rates.

Even though microchip lasers are widely used in the industry, there has been no report of using microchip lasers for space applications. The goal of the research carried out at GSFC is to demonstrate their suitability for use in the ATLAS instrument, further mature the technologies for miniature lasers, and adapt them to space applications. The two areas of interest include passively Q-switched microchip lasers and passively Q-switched non-planar ring oscillator (NPRO) designs [11-13]. The primary laser material being investigated is crystalline Nd:YAG co-doped with $Cr^{3+}$ for radiation hardening. Other materials of interest include Yb:YAG, Nd:YVO4, and ceramics such as Nd:YAG to enable higher doping densities.

We are also investigating the use of semiconductor lasers as the MO. Here, we will use a similar approach in using a semiconductor laser, which provides the flexibility of any data modulation formats such as the pseudorandom number (PN) code laser ranging scheme.[14] Indeed, a similar system had been developed for free space laser communication at GSFC [15]. We will leverage the strengths of semiconductor lasers such as small size, high efficiency, spectral and spatial quality and reliability. Associated mature technologies in direct or external modulation, optomechanical



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packaging and frequency stabilization can also be instrumental in meeting the ATLAS laser transmitter requirements. Semiconductor lasers typically operate at low optical power and have wavelength chirp while under direct modulation. To overcome these weaknesses, we will increase the MO output power using a semiconductor optical amplifier (SOA) and will also design experiments to evaluate the use of using semiconductor optical amplifier (SOA) as an external modulator. We will also evaluate the extent of wavelength chirp under direct modulation, typical semiconductor laser linewidth is on order of 10's MHz and it be possible to directly modulate these lasers and still meet the ATLAS requirement. The goal is to improve our understanding of the range of viable, space worthy laser technologies and to better understand the strengths and weaknesses of various approaches.

### 2.1.2 Power Amplifier

Three main laser amplifier architectures are under investigation: bulk crystal, planar waveguide and photonic crystal fiber. These technologies represent the current state-of-the-art for very high efficiency, short pulse and high power laser architectures. Slab lasers and amplifiers are mature technologies that have been used for most space-based laser systems (MOLA, GLAS, MLA, CALIPSO and LOLA). They are potentially very simple and robust systems. The biggest technical challenge for this type of amplifier is achieving high optical efficiency due to poor mode overlap between pump and seed mode. In addition, thermal management can be difficult in bulk crystals in high power lasers that can lead to poor spatial mode performance.

Fiber amplifier technologies offer a promising approach to meet the demanding efficiency requirement of ATLAS.[16] Optical-to-optical efficiencies of better than 60% have been demonstrated with large core fiber and photonic crystal fiber amplifier.[17] Compared to bulk media, the main limitations for achieving high peak power inside optical fibers are due to small mode field size and large propagation length. Nonlinear effects caused by high optical energy densities in the fiber are observed even in the large core fiber and PCF amplifiers. The required narrow linewidth single mode performance is the main challenge for fiber-based amplifier technology and so the non-linear thresholds and achievable performance will be investigated.

The MOPA architectures utilizing Yb-doped fibers as gain media have proven an effective means of generating short laser pulses (1-10 ns) with high repetition rates, excellent beam quality and high optical efficiency. However, the small core sizes and long interaction lengths inherent to fiber geometry lead to a number of nonlinear effects resulting from intensity-dependent refractive index shifts (four-wave mixing, self- and cross-phase modulation) and also from various inelastic stimulated scattering mechanisms (stimulated Brillouin and Raman scattering). One means of ameliorating these nonlinear effects is to reduce the peak intensity in the core by increasing the effective mode area, while the numerical aperture (NA) of the fiber core is concomitantly reduced to maintain good beam quality. The so-called large mode area (LMA) step-index fibers that employ this strategy are, unfortunately, limited to ~30 μm core size in practice, restricting peak output power to <100 kW.[18]

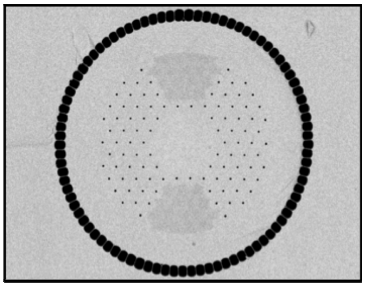

Figure 3. Polarization-maintaining large mode photonic crystal fiber.

One strategy for boosting the peak power available from fiber systems to the MWatt level is to use rod-type photonic crystal fiber (PCF) as a gain medium. Air-hole microstructuring of the fiber allows for precise control of the effective index difference between the core and cladding, affording signal NA values (<0.02) much lower than what may be achieved in conventional step-index fibers.[19] Thus far, Yb-doped PCFs with core diameters as large as 100 μm



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demonstrating robustly single-mode behavior have been successfully fabricated [20] (see Figure 3). The low core NA of these fibers renders them especially susceptible to coiling losses, and so a thick silica glass jacket (~1 mm radius) is utilized to keep the fiber straight and rigid. In addition, the high NA of the microstructured pump waveguide (~0.6) allows for efficient coupling of pump light into the PCF, and the high core-to-cladding size ratio yields substantial pump absorption per unit length, further mitigating nonlinear effects.

To evaluate this technology as a possibility for the ATLAS laser system, we will construct and assay tabletop laser amplifiers utilizing photonic crystal fibers (PCF) as the active media. Different PCF fibers will be separately evaluated as gain media while maintaining overall system operation at or above the ATLAS laser specifications. The PCFs will be counter-pumped with a 70 W fiber-coupled multi-mode 976 nm diode pump, and seeded with either an Nd:YAG microchip laser or a multi-stage Yb fiber amplifier. The PCFs used in the ATLAS testbed (see Figure 4) will be outfitted with expansion endcaps to reduce signal fluence at the air-glass interface and reduce the likelihood of optical damage. [21]

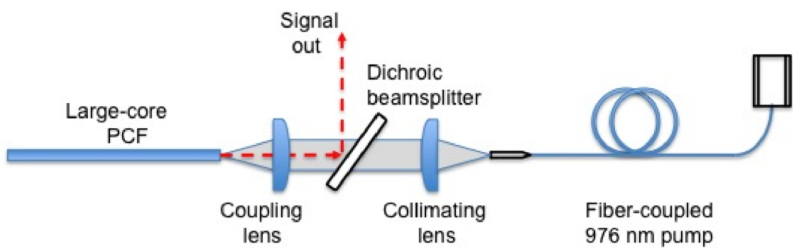


Figure 4. Simple schematic of proposed PCF testbed for ATLAS laser.

Construction and performance testing of these PCF amplifier stages will address a number of significant known issues with optical fiber amplifiers. For example, the threshold and severity of the aforementioned nonlinear effects will be investigated experimentally to determine if PCF technology can effectively meet the required system specifications. Furthermore, since state-of-the-art large mode area PCF fibers cannot be fusion spliced with currently available technology, free-space coupling of the signal and pump light into the PCF stage is required. The small core and cladding sizes inherent to all optical fiber designs necessarily entail a relatively high sensitivity to mechanical misalignment of coupling optics. The effects of small optical misalignments on overall amplifier performance will be quantified by placing all relevant optics and laser sources on precision translation stages, whereupon the effects of small adjustments in the positions of each component on optical output can be assessed in a controlled environment. In this manner, it can be readily determined which optics are most critical to amplifier performance and what tolerances are required for a viable space-worthy packaging effort.

Planar waveguide amplifier (PWA) geometry is essentially a one-dimensional optical fiber.[22] It has the advantage of waveguiding effects in one dimension and a large gain width in the unguided dimension. The short propagation length also reduces potential nonlinear effects even for very high peak intensity. The PWA architecture is also compatible with a wide range of materials, waveguide architectures and fabrication techniques. A great deal of research has been centered on the development of planar waveguide lasers for the past decade.[23] However, few works have been published on the planar waveguide amplifier. Planar waveguide lasers and amplifiers have the potential to achieve multi-kW output power with good beam quality and high efficiency. Compared with PCF amplifiers, PWAs offer another dimension to optimize the design for single frequency, high peak power, high repetition rate and moderate average output power.

We will consider and evaluate several design approaches for achieving the demanding optical-to-optical efficiency. In order to obtain very high efficiency, an end-pumped geometry is preferred. End-pumped PWAs have much higher gain than the side-pumped geometry, and the higher gain is necessary for high-energy extraction. A typical double-clad planar waveguide design is shown in Figure 5. Several novel planar waveguides are currently under development to improve system performance.



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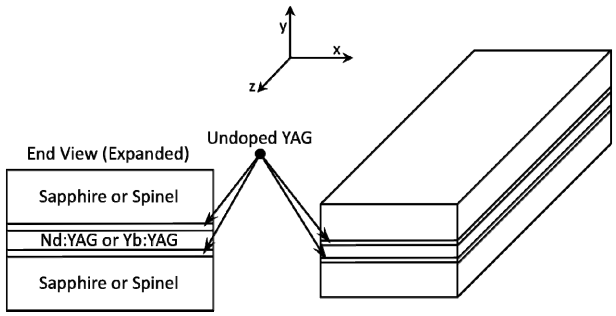


Figure 5. Double-clad planar waveguide amplifier concept.

### 2.2 CW Pump Diodes

The reliability of the laser diode pumps used in the ICESat-2 instrument is of particular interest as their performance is critical to the operation of the ATLAS laser system. The diodes are potentially a single point of failure for the laser. If the diodes fail to operate properly, the performance of the laser will degrade and potentially jeopardize the ICESat-2 mission. The laser diodes have a unique set of challenges that must be understood and addressed in order to improve their functionality in continuously operable lasers in space. In view of the fact that the diodes are the power source for the laser, their correct and reliable operation is critical to the performance of the entire instrument.

Table 3. Summary of tests being performed and the risks the tests will address for the laser diode components.

| PERFORMED TEST | RISK ADDRESSED |
|---|---|
| **I. Characterization of Laser Diodes** | |
| A. Mounting diode on test plate and storing in its individual conductive box. | ESD event |
| B. Low and high-magnification microscope inspections: | Contamination<br>Mechanical Damage<br>Design changes |
| a. IR facet thermography | Presence of thermal stress (reduces lifetime and/or affects long-term performance) |
| b. P-I curves, spectrum, NF imaging | Do not meet specifications and/or performance requirements |
| c. Spatially resolved spectrum (per bar)<br>d. Polarization-resolved NF measurements | Presence of thermal or mechanical stress (affects lifetime and /or long-term performance) |
| C. Photocurrent measurements (for fiber-coupled diodes) | Presence of defects or mechanical stress (affects lifetime and/or long-term performance) |
| **II. Aging (Long-Term Performance) Testing of Laser Diodes** | |
| A. Burn-in.<br>B. Long-term performance and accelerated tests. | Do not meet lifetime or performance requirements |
| **III. Environmental Testing of Laser Diodes** | |
| A. Radiation Testing | Do not meet lifetime or performance requirements in space |
| B. Vibration Testing | |
| C. Temperature Cycling | |
| D. Long-term performance test in vacuum | |

At NASA's GSFC we have developed a state-of-the art facility to characterize and test QCW LDAs.[24] We have performed long-duration tests to evaluate the performance of LDAs under various operating conditions, both in air and in vacuum. This information has already enabled NASA to improve its selection of LDAs and has been widely shared with LDA suppliers. We are working to expand our diode characterization and testing capabilities to satisfy the qualification requirements for potential ATLAS laser diode pumps such as fiber-coupled diode modules and open heatsink single-emitter laser diodes that operate under continuous wave (CW) conditions. The failure and aging



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behavior of CW laser diodes are vastly different than that of QCW LDAs, and under this task we will characterize and quantify CW lasers with the overall objectives being:

a. to develop a comprehensive set of tests and characterization procedures which can be used for early detection of the potentially 'bad' laser diodes; and
b. to measure the reliability of the laser diodes in conditions replicating launch and space environments.

A set of tests has been developed under the QCW LDA program for qualifying and characterizing diodes. Similar tests and procedures will be used for the CW case. Table 3 summarizes various tests that we will implement and the associated risks these tests will address.

### 2.3 Optical Damage

One major risk that is associated with the ATLAS laser system involves failure of the system due to optical damage of critical components within the laser transmitter. Our emphasis in the past had been on laser damage threshold tests that used low number of shots (<100) with high-energy fluence to determine the damage threshold of certain optical components. In these tests, a number of sites within a clear aperture of a test sample are tested with increasing laser fluence on each site until damage occurs.

For high repetition rate, micropulse lasers, the emphasis is shifted to large number of accumulated, low energy fluence on laser optics. The impact of fatigue on optical coatings and optical components are of concern.[25] Here the fluence is relatively low but the accumulated number of shots far exceeds what we have experienced previously on spaceborne lasers such as MOLA, GLAS, etc. For a 5-year mission, the accumulated number of shots is on order of 1.5 Tshots. Long duration testing involving multi-billion number of laser shots on a test sample with low energy fluence is rarely done due to the need of dedicated test stations and equipment.

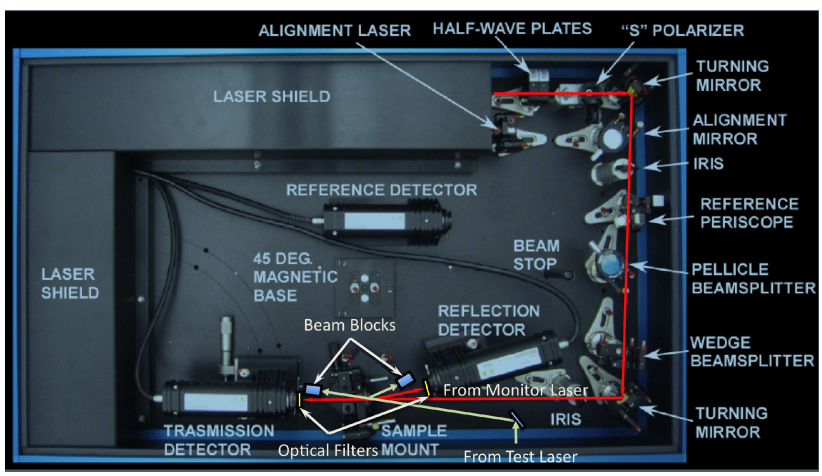


Figure 6. Long duration test station for ATLAS laser optics.

We are planning on setting up a dedicated test station to examine the impact of fatigue on critical components as shown in Figure 6. We plan to modify an existing laser spectrophotmeter to very sensitively monitor the transmission of an optic while it is irradiated by a test laser. The spectrophotometer has a CW, single frequency, tunable fiber laser located inside the laser shield (in Figure 6) used as a monitor laser. A sample under test (SUT) will be placed in the sample mount. A commercial-off-the-shelf (COTS) short pulse Q-switched diode pumped solid-state (DPSS) laser having similar energy (2 mJ) and pulse width (~1nS) to the ATLAS laser will be used to test the durability of the optical component under long exposure of laser irradiation. The monitor laser will be aligned to same area of the SUT that is being irradiated. The transmitted and reflected beams of the monitor laser will be measured using two corresponding detectors as shown in Figure 6. The monitor laser is tunable from 1020 to 1080 nm and will be tuned to at least 20 nm from the test laser so appropriate optical filters can be used in front of the detectors to block out any scattering into these detectors by the Test Laser. It is expected that the optical sample could gradually deteriorate and the transmission of the



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monitor beam will diminish. We will therefore monitor the optic's transmission with great precision to look for very small changes in its performance.

### 2.4 Laser Testing

We are also developing a laser test system to verify and quantify the performance of candidate lasers for the ATLAS instrument. Our plan is to: 1) identify, procure and assemble the necessary test equipment, 2) develop software to control and monitor the testing, as well as acquire and analyze the data, 3) subject all laser candidates to identical testing using the developed test systems, 4) report the test results.

Each laser test station will be designed around the block diagram shown in Figure 7. Since the designed ATLAS laser repetition rate is to be in the 10 kHz regime, we do not expect to characterize and archive every laser shot. However, we do intend to characterize laser parameters for successive laser shots for limited periods of time, and report and archive relevant statistics based on analyses of the "burst mode testing". This style of parameter trending has been successfully used before in the monitoring and reporting of laser parameters associated with the GLAS and the LOLA laser systems in both ground testing and in support mission/orbital operations. [26-28]

Within the test system itself, it is expected that the laser power measurement will be directly compared to the combined laser pulse energy and repetition rate measurements as cross-checks on each other and verification that the laser can fulfill the science requirements associated with radiometric, two-way ranging from orbit to the Earth. A high speed detector and high bandwidth oscilloscope will be used to evaluate candidate laser designs for the temporal pulse width as well as evaluate for potential mode-beating behavior, both of which can impact the science requirements tied to ranging accuracy and laser lifetime requirements. The laser wavelength and line width need to be monitored closely and be well characterized, as the long-term wavelength stability of the laser is directly coupled to the design requirements for the ATLAS receiver optical design, particularly regarding the etalon filter design. The laser beam profile must also be well characterized and confidence in the stability of pointing, spatial mode, and divergence must be demonstrated as these parameters have a direct impact on the ability of the ATLAS instrument to fulfill its science requirements of consistently placing well characterized footprints of a known size and location on the Earth.

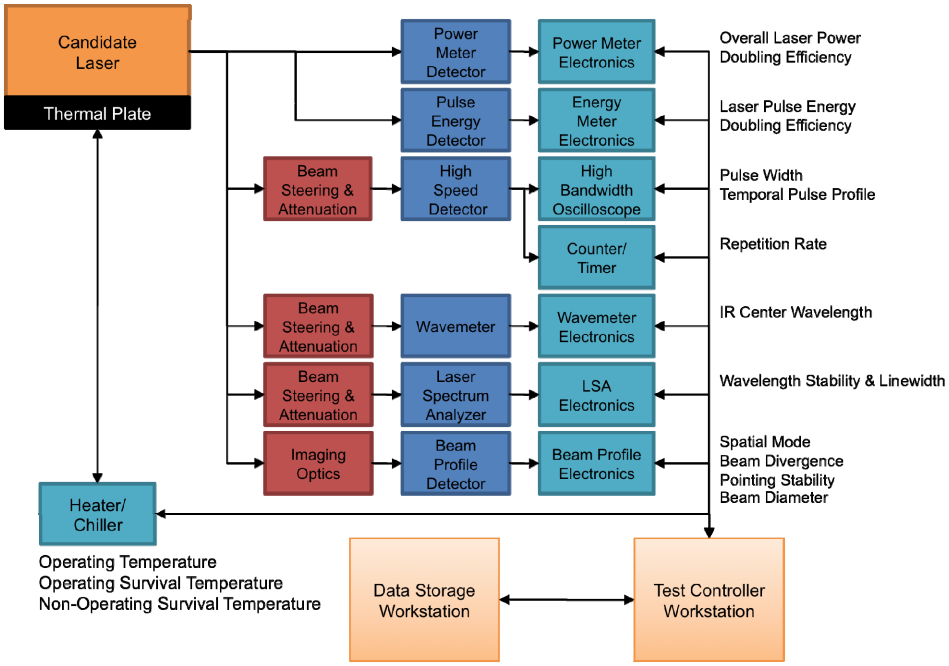


Figure 7. Block diagram of laser test station for ATLAS.



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Most of the measurements for the ATLAS laser are virtually identical in scope to measurements made on previous space flight laser altimeters (GLAS, LOLA). However, the one most significant outlier is the repetition rate of the laser. In the regime of 10 kHz, it is typically not desirable to keep and report each individual laser shot, but to instead perform a number of statistical methods to trend laser performance over time. Some methods involve tracking parameters such as pulse energy, repetition rate, and laser system current draw as Maximum, Minimum, Standard Deviation, and Mean values over specific and discrete binned time intervals, usually on the order of several minutes or more. Other measurements will likely be periodic in nature to spot check that parameters tied to optical alignment (e.g. laser pointing and beam quality) remain stable with temperature fluctuations and long term mechanical settling. Still other measurements such as mode beating characterization may be setup to "trigger" when the characteristics of a running measurement fall outside of an established nominal "envelope". Then the period between these "out-of-family" events would be trended.

## 3. CONCLUSIONS

The ATLAS instrument on ICESat-2 underwent a complete redesign in 2009. The now baselined instrument is a high repetition rate, micropulse laser altimeter system. GSFC has begun an in-house program to investigate various potential laser technologies to meet the laser requirements for the ATLAS instrument. We are leveraging the development efforts from many areas such as the DoD and telecommunication industries. We are working to gain a better understanding of the strengths, weaknesses and risks associated with these technologies to inform our decision on which technology to pursue for flight and also to assist in the instrument system engineering trades. The next major milestone in the ATLAS project is the pre-design review (PDR), which is currently scheduled for the summer of 2011. Many of the trades that we are studying will be down-selected by the first quarter of 2011 so that a finalized design will be carried forward to meet the PDR milestone.


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