Long-Term Performance Tests on Laser Diode Arrays for the Current and Future Space Missions

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Abstract **- NASA is conducting a series of component-level tests, to better understand the effects of a space-based environment on the operation of diode-pumped, solid state lasers simulating the unique and harsh environment of launch, vacuum and radiation exposure of a typical mission.**

We will report on our continuing work on high-power, laser-diode arrays which are used as an energy source for several diode-pumped solid-state lasers mission We are concentrating on laser diode arrays emitting at 808 nm and operating quasi-cw with peak powers of ~100 W per bar at 100 A. The laser diode arrays are operated with a duty cycle from 0.6% to 2% and current pulses from 50 to 100 A peak. We will discuss our long-term performance tests designed to support current and future space missions. The laser diode arrays have accumulated more then 9 billion pulses during some of these tests and most of them continue to operate within specifications.

I. Introduction

Laser-based satellite remote-sensing instruments enable measurements of atmospheric and geophysical properties with high spatial and temporal resolution. These systems must turn on and operate nominally after the stress of launch, possible long periods of dormancy and continuous exposure to radiation and vacuum. Many of NASA's recent laser based instruments (such as MOLA (Mars Orbiter Laser Altimeter) [1], GLAS (Geoscience Laser Altimeter System) [2], CALIPSO (The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) [3] and MLA (Mercury Laser Altimeter) [4] have employed Nd:YAG lasers with quasi-CW (QCW) diode-pumps. Lifetimes of several billion laser pulses are desired for these space-based LIDAR applications. The reliability of laser diode arrays (LDAs) used in these instruments is of particular interest as the LDA's performance is critical to the operation of the laser system since the arrays are potentially a single point failure for the laser.

LDAs are complex devices with multiple failure mechanisms which are not only dependent on the operational conditions, but also on the design, manufacture and operational history of the device, making reliability models difficult to realize. In addition, different failure mechanisms will have different activation conditions so finding accurate acceleration parameters for testing is not straightforward. Gathering statistics is expensive due to the cost of the arrays. The manufacturer may change the design in an effort to improve device performance or cost that may negate the statistics collected on previous devices.

Our group has an on-going research program to both search for failure predictors and measure the performance of LDAs when operated in conditions simulating a typical mission [5, 6, 7]. In this paper, we present our results from a series of long-term performance tests as well as the procedures which have been used to select and validate performance of the LDA for Lunar Orbiter Laser Altimeter (LOLA). The laser is scheduled to launch in 2008 onboard the Lunar Reconnaissance Orbiter spacecraft.

II. LDA for LOLA

The basic operational requirements for the LOLA laser diode arrays are the following:

TABLE I.
LDA Requirements

Package	G2 (two-bar array)
operational wavelength	808 nm
repetition frequency	28Hz
pulse current	70A (max 90A)
current pulse width	170 μs (max 200 μs)

The laser must operate for one billion pulses in vacuum. The laser has two G2 laser diode arrays. To increase reliability of the system, two units are being built, each with a projected lifetime of one billion pulses.

LDAs from two vendors were selected as potential candidates for the flight mission. One major packaging difference between laser diode arrays from these two vendors was the use of different types of solder. Vendor #1 used indium solder and vendor #2 used gold/tin solder. Indium solder can cause the sudden device failure during long-term operation [8]. We also have observed [6] during our previous long term performance tests that the sudden failure is caused by solder migration and creep at the interfacial bonding layer between the laser bar and the heat sink. Despite some recognized failure modes, LDAs from vendor #1 have performed well in long term testing to one billion pulses [6].

An initial reliability test monitoring the performance of 4 LDAs (two arrays per vendor) was conducted as the first step in long term performance evaluation. All LDAs began testing at 250 Hz frequency with a duty cycle of 4.2% (Fig.1). The 170μs electrical pulses had an amplitude of 70 A. The LDA heat sinks were temperature controlled to 25°C at the beginning of the test. The test was conducted in a laminar flow environment. The arrays operated in quasi-CW mode (i.e. pulsed at 250 Hz) but were not power- cycled (at lower frequencies). The temperature of the laser diode arrays was increased to 40°C after one billion pulses. After 2 billion pulses, the current was increased to 90A, the pulse width to 200μs, and the frequency was reduced to 165Hz. These operating conditions represent the maximum load and temperature the diodes can experience on orbit. After 3.5 billion pulses, the LDAs were placed in a vacuum

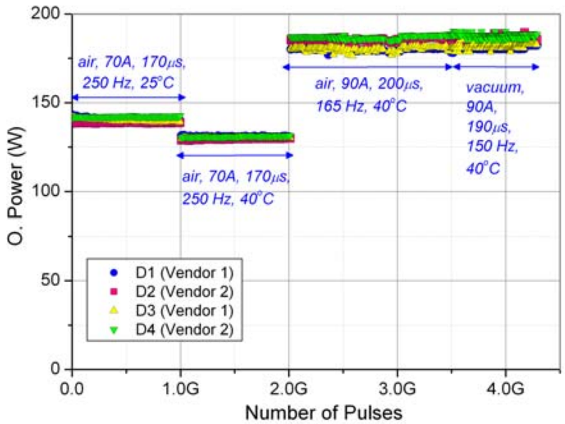

Figure 1. The results of the reliability test for Coherent and Thales LDAs for 2.69billion pulses

chamber. The test was stopped after the LDAs accumulated a total of 4.5 billion pulses. The data shows little or no degradation of the optical power. Thorough performance characterization and microscopic inspections of the front-facets of theses devices were made at regular intervals. The microscopic inspection revealed no changes in the appearance of front facets after 4.5 billion pulses. The LDA near field images and infrared images show minimal changes during testing. Present results of the optical power are shown in Fig. 1. We also did not observe any noticeable solder degradation for the LDAs assembled with indium solder. This may be explained by the fact that vendor #1 had improved their LDA design in order to reduce solder migration and creeping and by the fact that the operating conditions are somewhat different than those refenced earlier [6].

The reliable initial LDA performance lead to the decision to qualify both vendors for the space mission and build one laser using LDA from vendor#1, and the second laser using LDA from vendor#2. Sixty laser diode arrays (30 per vendor) were bought to build the flight lasers and for further evaluation and screening.

The process of selection of the flight arrays included: characterization of all arrays, burn-in all arrays (100Mpulses, 90A, 100Hz, 200μs, 25°C), post burn-in characterization of all arrays and, finally, selection of LDAs for the flight laser assembly and spares (total 10/vendor).

To improve statistics and knowledge base of the laser diode arrays long term performance from these two vendors, we randomly chose arrays for vacuum and air tests (a total of 12/vendor set aside for testing). Performance tests matrix for air and vacuum tests is shown in Table II.

TABLE II.
PERFORMANCE TESTS MATRIX

	Operating conditions	Vendor#1	Vendor#2
Vacuum	28 Hz, 70A	3	3
	150 Hz, 70A	3	3
Air	210 Hz, 70A	3	3
	155 Hz, 100A	3	3

Parameters common to all test groups are: the current pulse width of 170 μs, and the temperature (25 °C). Vacuum testing is performed at 1.2E-6 torr. The air test is conducted under laminar air flow.

During both air and vacuum tests, we continuously monitor optical power, current, current pulse width, compliance voltage, temperature and other performance characteristics. The air test data (Fig. 2 and 3) does not show significant degradation in optical power for both groups and both vendors except for two LDAs from vendor #2.

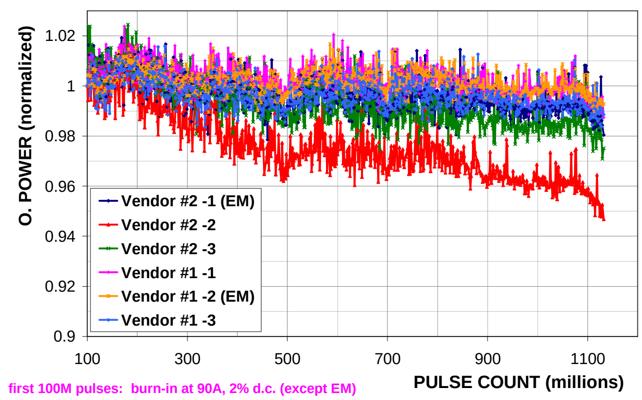

Figure 2. Air test – group 1, operating conditions: 210 Hz, 70A, 170 μs,

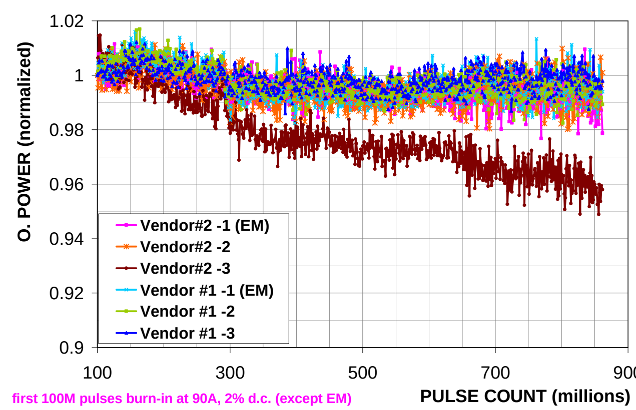

Figure 3. Air test – group 2, operating conditions: 155 Hz, 100A, 170 μs,

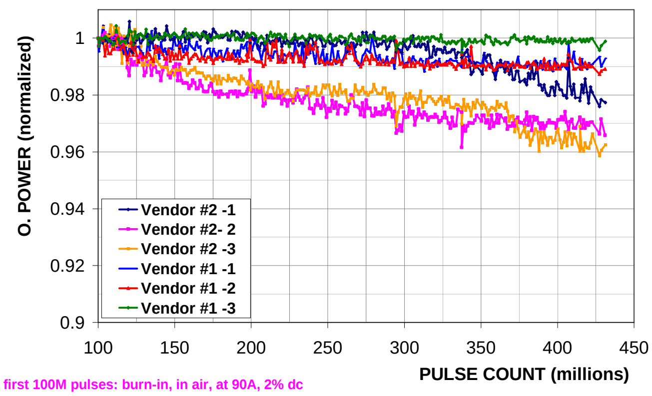

Figure 4. Vacuum test – group 2, operating conditions: 155 Hz, 70A, 170 µs

The picture is similar for the vacuum test. All the LDAs with hard solder (Fig. 4, vendor #2) show reduction in the optical power. The optical output of the devices with indium solder stays constant. Our data from initial long term performance test using 4 arrays as well as burn-in data indicate that devices from vendor #2 are more likely to show a small reduction of the optical power in the first few hundred million pulses than devices from vendor #1. However, devices from both vendors are performing well and meeting our requirements so far.

III. Power-cycling test

The power cycling test was designed to simulate the conditions of a proposed instrument for the Biomass Monitoring Mission (BioMM). This mission is considering turning the laser off while the satellite is over the oceans and on while over land. Since roughly two thirds of the Earth consists of water, this has the potential to increase the laser lifetime by a factor of three if there are no adverse affects from power- cycling the laser. The desired laser lifetime should be on the scale of 10 billion pulses. To achieve this pulse count LDA are expected to operate at highly de-rated conditions: current of 50A and pulse width 80 µs instead of the more common 170 µs. This translates in power de-rating of 50% and reduces the thermal stress during the current pulse approximately in 6 times.

This test is being conducted on 8 4-bar LDAs from a third manufacturer – vendor #3 (also using indium solder). All LDAs operate at 242 Hz frequency with a duty cycle of 2%. The test is conducted in a laminar flow environment. The LDAs are divided into two groups where one group is subjected to power cycling and the other is operated at constant power. All laser diode arrays are maintained at 25°C. The power cycling period is 20 minutes, with the LDAs operating for 18 minutes and powered down for two minutes. Recent test results are shown in Fig. 5. The power-cycled LDAs have accumulated over 8.9 billion pulses in excess of 33,800 power cycles while the constant power devices have accumulated over 10 billion pulses. Two LDAs experienced a single bar failure at around 3 billion pulses. Two different LDAs experienced two bar failures around 8.5 billion pulses. Except for the bar dropouts, the data shows little or no degradation in the output optical power for all eight LDAs. The small fluctuations in LDA optical power for the power cycled group is due to instability in the current supplied by the diode driver.

The cause of the "bar dropout failures" at 3 and 8.5 billion pulses has been determined from microscopic inspection of the LDAs to be due solder creeping and short-circuiting the active region.

III. Conclusions

Our main objective was to quantify the performance of laser diode arrays under the conditions they are likely to encounter during space flight. We saw no effect of power cycling on long-term performance. The use of Indium solder may cause deterioration at the solder interface and lead to the device failure. We conclude that these LDAs are robust enough and can be expected to operate for a billion shots with proper screening and testing and reasonable operating conditions.

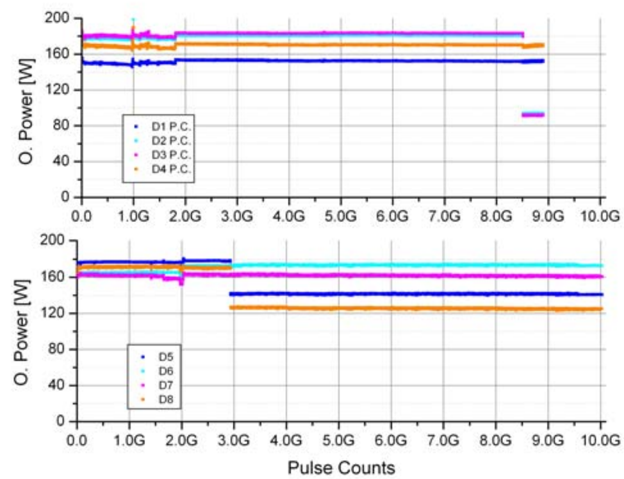

Figure 5. The results of the reliability test for power cycling test

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