Promoting Robust Design of Diode Lasers for Space: A National Initiative

David M. Tratt[1], Mark A. Stephen[2], Farzin Amzajerdian[3], Nasir B. Kashem[2], Andrew A. Shapiro[4], and Allan T. Mense[5]

[1] The Aerospace Corporation, Pasadena, CA 91101.
[2] NASA Goddard Space Flight Center, Greenbelt, MD 20771.
[3] NASA Langley Research Center, Hampton, VA 23681.
[4] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109.
[5] Raytheon Company, Tucson, AZ 85706.

Background

- **The NASA Earth Science Technology Office sponsored an industry/USG Community Forum on Laser Diode Arrays in Space-Based Applications March 2-3, 2004 in Arlington, Va.**
- **Attendance: 23 industry, 42 USG/contractors, 6 other.**
- **Purpose #1: Brief 2003 ICESat/GLAS on-orbit laser failure to community.**
- **Purpose #2: Intensify dialog between LDA vendor and user communities concerning technology development requirements for robust long-life diode arrays suitable for deployment in space.**
  - Frank debate between USG and industry concerning each others' needs.
- **NASA established the Diode-laser Array Working Group in July of 2004 to continue the dialog.**

Working Group Charter: Purpose

- Provide a national-level consumer/provider forum for discussion of engineering and manufacturing issues which impact the reliability and survivability of high-power broad-area laser diodes and laser diode arrays (LDAs) in space.
- Formulate and validate standardized test protocols and derating recommendations by reference to test data.
- Recommend USG investment and procurement strategies for assuring the quality and availability of space-qualified LDAs.
- Facilitate collaboration between stakeholder USG entities (NASA, DOD, DOE), aerospace system integrators, and laser diode suppliers.
- Provide standardized guidelines for diode laser vendors and programs developing and qualifying parts for space-flight applications.

Working Group Charter: Scope

- Review practices and lessons learned from past, current and planned activities among the Group members.
- Evaluate current and proposed design and engineering practices as they relate to component reliability.
- Synthesize and specify baseline environmental requirements that reflect the minimum qualification standards for laser diodes to be used in space flight applications.
- Recommend standardized testing protocols for the qualification of laser diodes for space flight.
- Develop consensus manufacturing, operational environment control and certification standards for incorporation into contractual vehicles between vendors and the USG.

NASA Test Facilities

- NASA operates LDA test facilities for 808- and 792-nm devices.
- Facilities were established as a key component of the NASA Laser Risk Reduction Program (LRRP) activity.
- Facilities used to characterize performance and conduct lifetest evaluation of products from multiple vendors under consistent set of test conditions.
- Operations will be extended to additional wavelengths.

NASA Test Facilities

- NASA operates LDA test facilities for 808- and 792-nm devices.
- Facilities were established as a key component of the NASA Laser Risk Reduction Program (LRRP) activity.
- Facilities used to characterize performance and conduct lifetest evaluation of products from multiple vendors under consistent set of test conditions.
- Operations will be extended to additional wavelengths.

LOLA† LDA Flight Requirements

Package:	**G2 (two-bar array)**
Operational wavelength:	**808 nm**
Repetition frequency:	**28 Hz**
Pulse current:	**70 A (max 90 A)**
Current pulse width:	**170 μs (max 220 μs)**

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

- LDAs from two vendors were selected as potential candidates for the mission.
- One major difference between vendors: Vendor 1 used indium solder and vendor 2 used gold/tin solder.

†Lunar Orbiter Laser Altimeter (LOLA) is an instrument aboard the Lunar Reconnaissance Orbiter (LRO) scheduled for Launch in December, 2008

LOLA LDA Test Protocol

- LOLA project procured 60 LDA (30 from each vendor)
- Characterized all arrays
- Burned-in all arrays (100M pulses, 90A, 100Hz, 200 μsec, 25°C) and characterized all arrays after burned in
- Based on characterization data – chose arrays to be used in laser assembly and spares (total 10/vendor)
- Randomly chose arrays for vacuum and air tests – a total of 12/vendor set aside for testing
- Started 24/7 vacuum and air automated tests
- Analyze data, correlate characterization and performance data
- Report on findings of tests at time of flight array delivery

LOLA Testing Approach

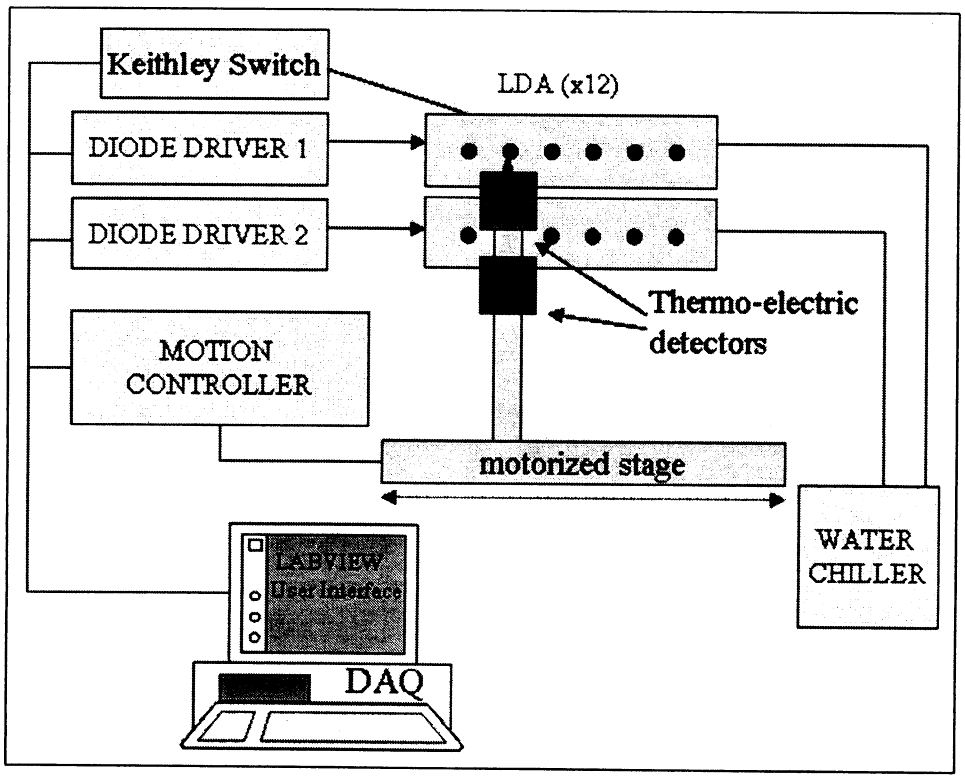
- Use spare vendor to mitigate risks associated with manufacturing problems and defects
- Accelerated tests achieved full mission goal (in pulse count) prior to laser integration
- LDAs tested in flight-like environment and operating conditions
- Continuing performance tests to improve statistics and knowledge base.

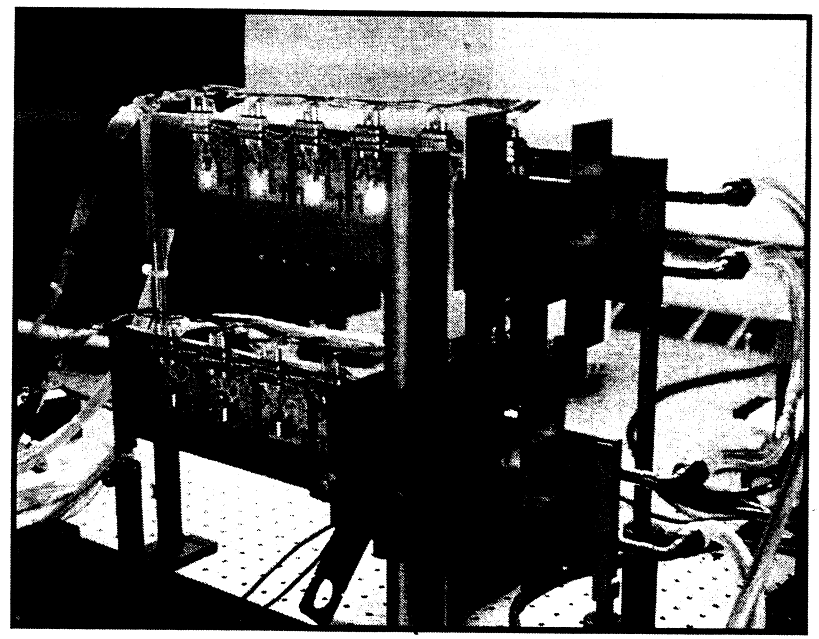
LOLA Performance Test Matrix

Environ-ment	Operating Conditions (pulse width=170us)	Peak Power Rating	Duty Cycle	Vendor 1 (# of LDA)	Vendor 2 (# of LDA)
Vacuum	Nominal 28 Hz, 70 A	70%	0.48%	3	3
	Accelerated 150 Hz, 70 A	70%	2.55%	3	3
Air	Accelerated 210 Hz, 70A	70%	3.57%	3	3
	Full Rating 155 Hz, 100 A	100%	2.64%	3	3

12-LDA Air Long-Term Test Set-Up

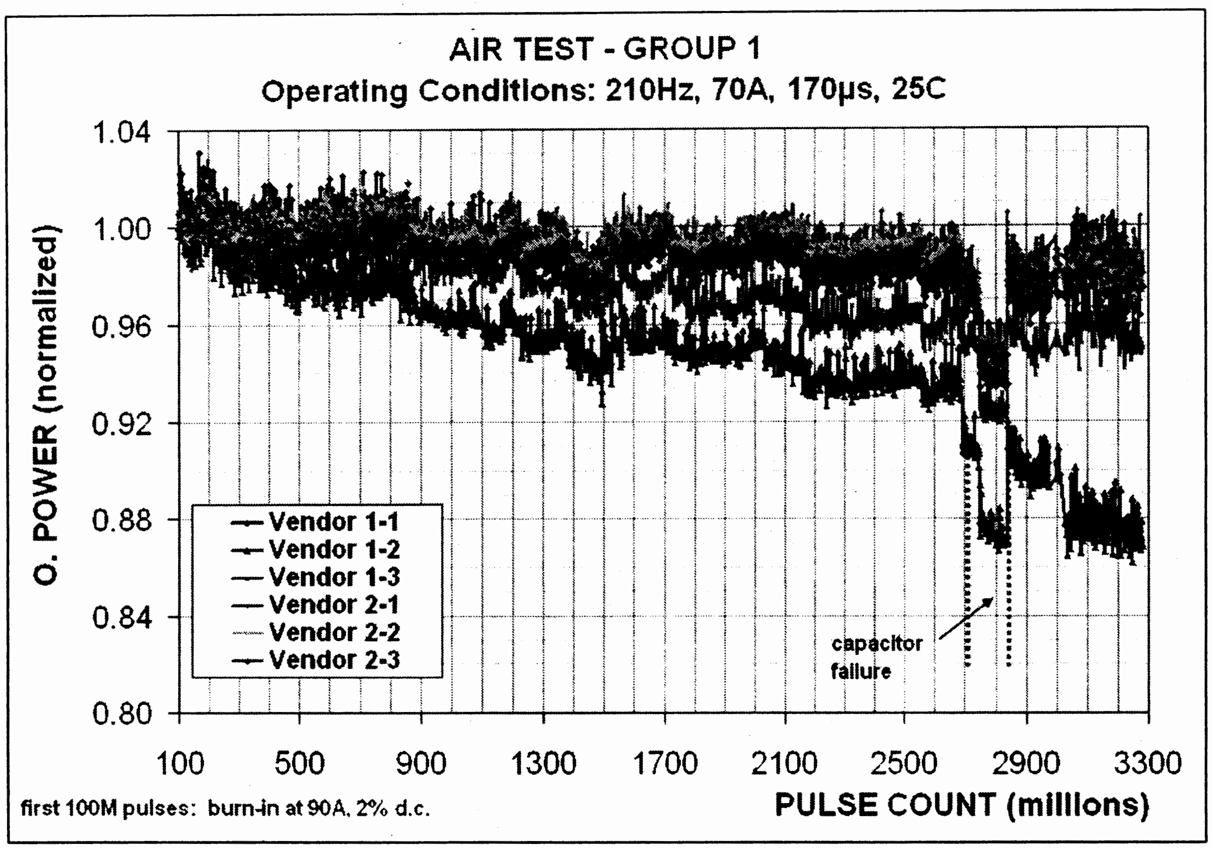
LaRC
JPL
GSFC





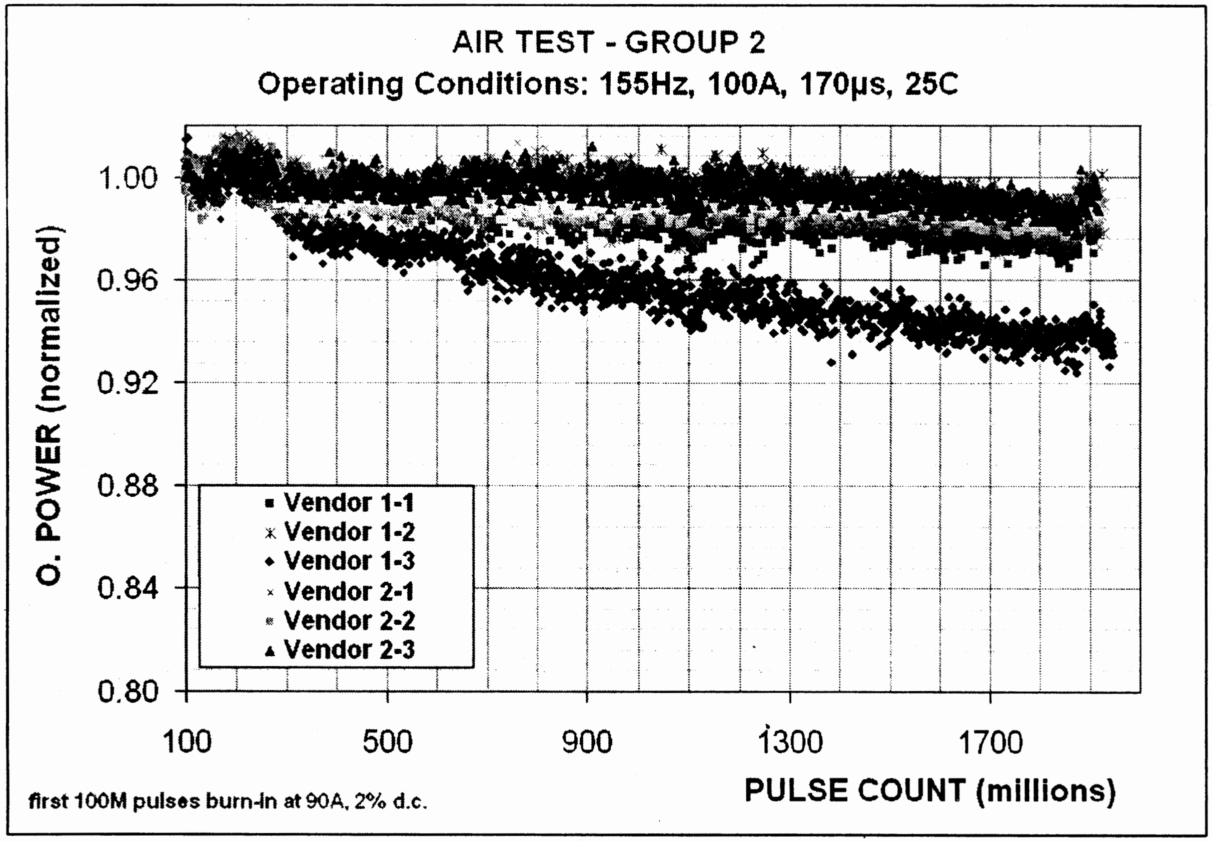
Fully automated custom test station with 12 LDA test positions & continuous power measurement capability

LOLA Flight Spares Test in Air



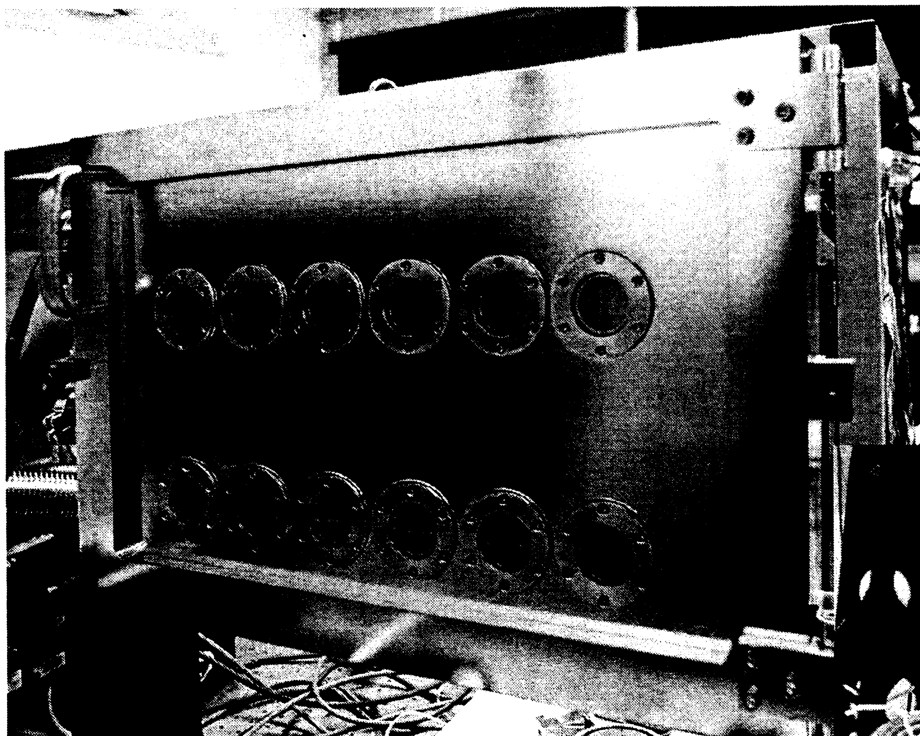
- More than 3.2 billion accumulated pulses.
- No bar failures.
- One LDA (Vendor 1) shows significantly higher (12%) power drop.

LCLA Flight Lot Test in Air

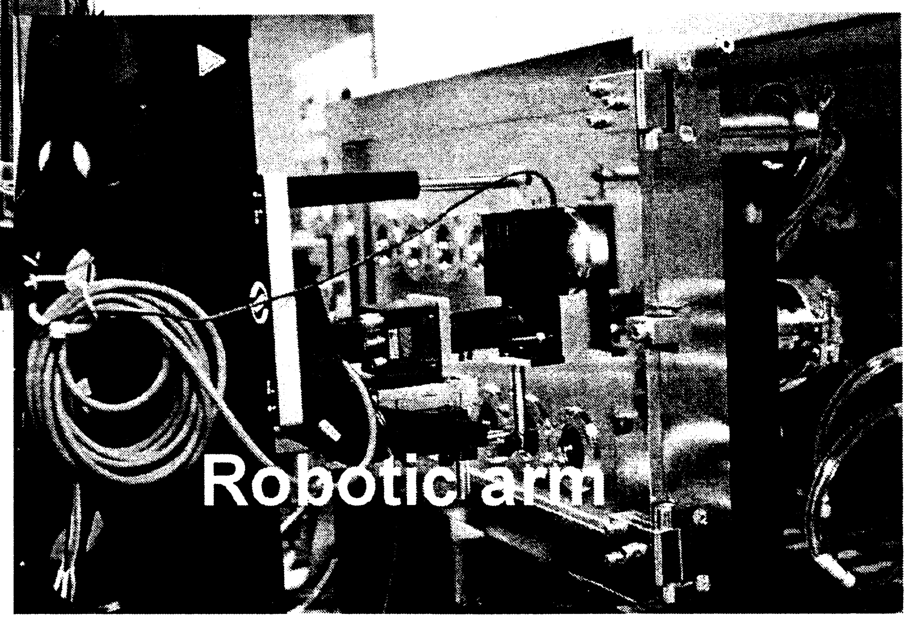


- More than 1.9 billion accumulated pulses.
- No bar failures.
- No significant degradation except for one LDA (Vendor 1).

Vacuum Test Station

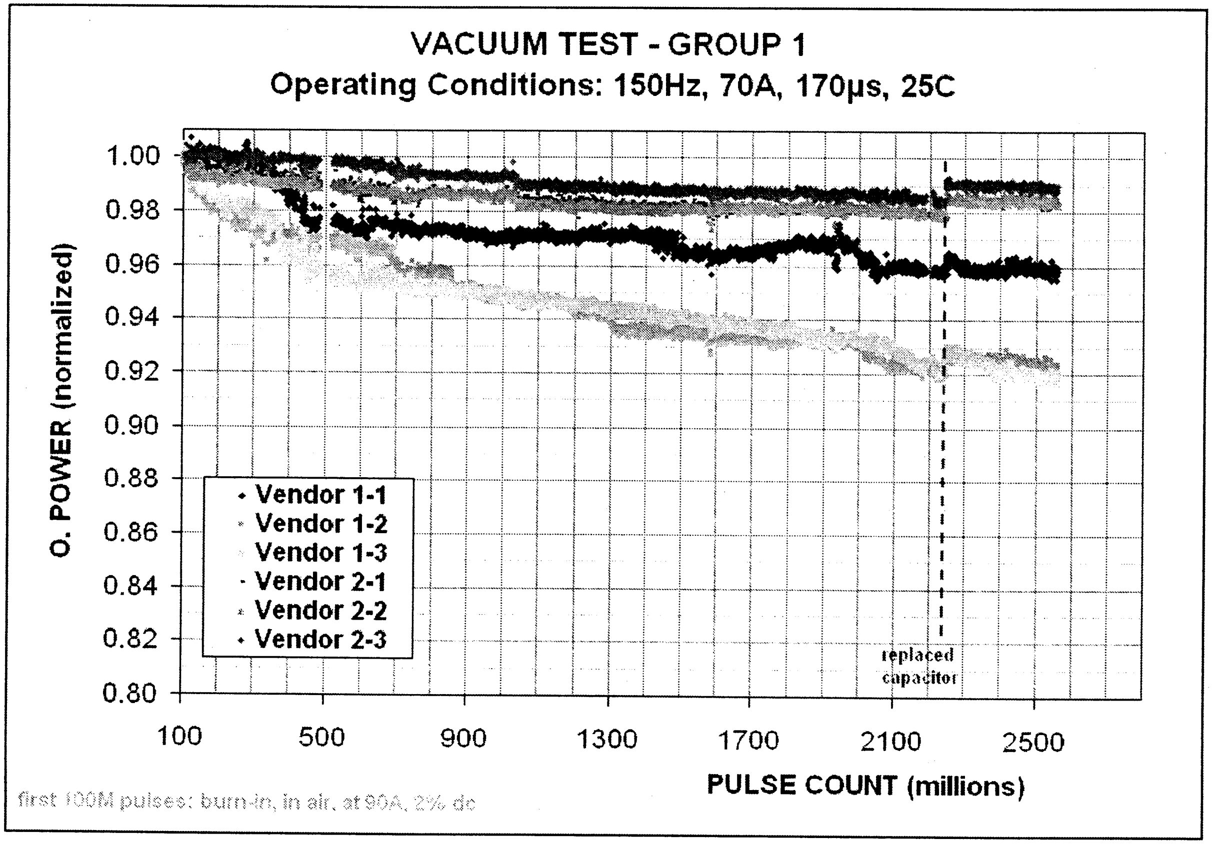


Fully automated custom vacuum chamber with 12 LDA test positions & windows for continuous inspection



LOLA Flight Lot Test in Vacuum

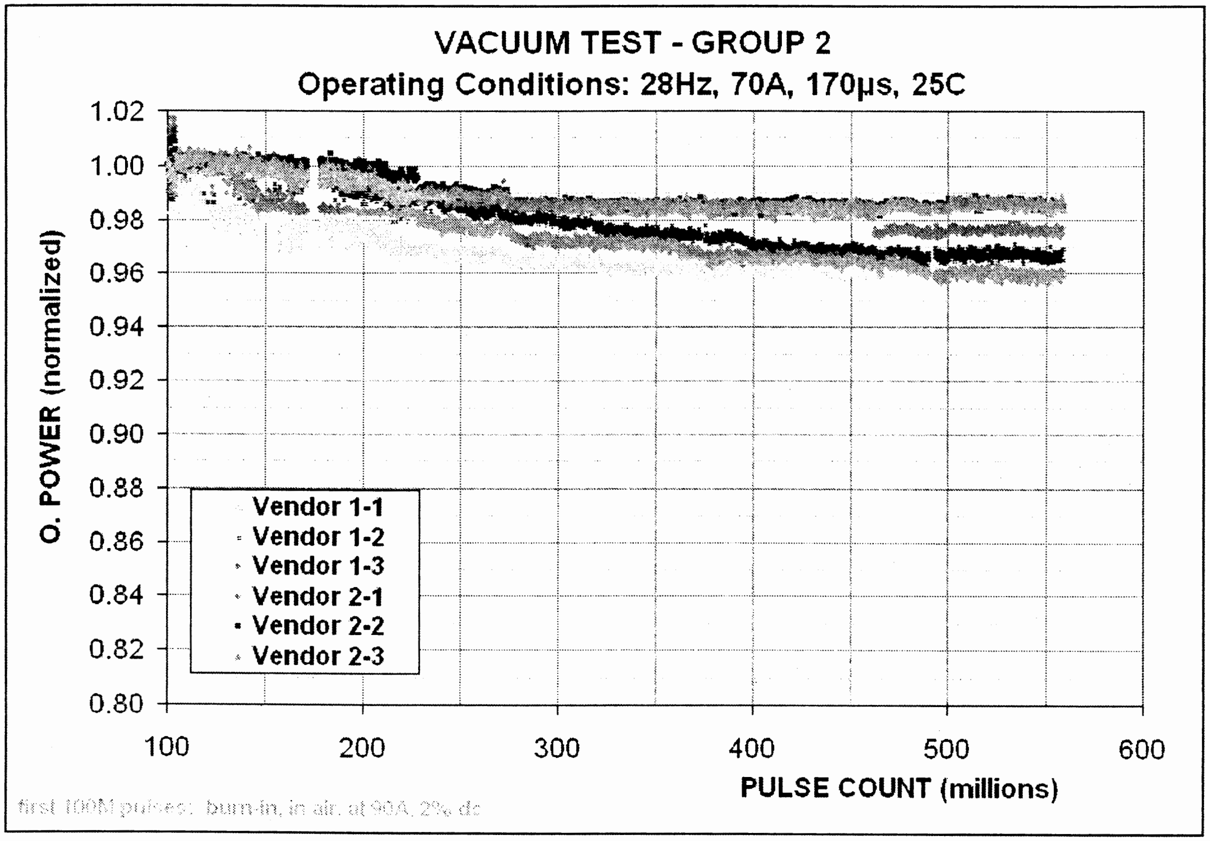
LaRC
JPL
GSFC



- More than 2.4 billion accumulated pulses.
- No bar failures.
- All LDA from Vendor 1 show reduction in optical power.

LOLA Flight Lot Test in Vacuum

LaRC
JPL
GSFC

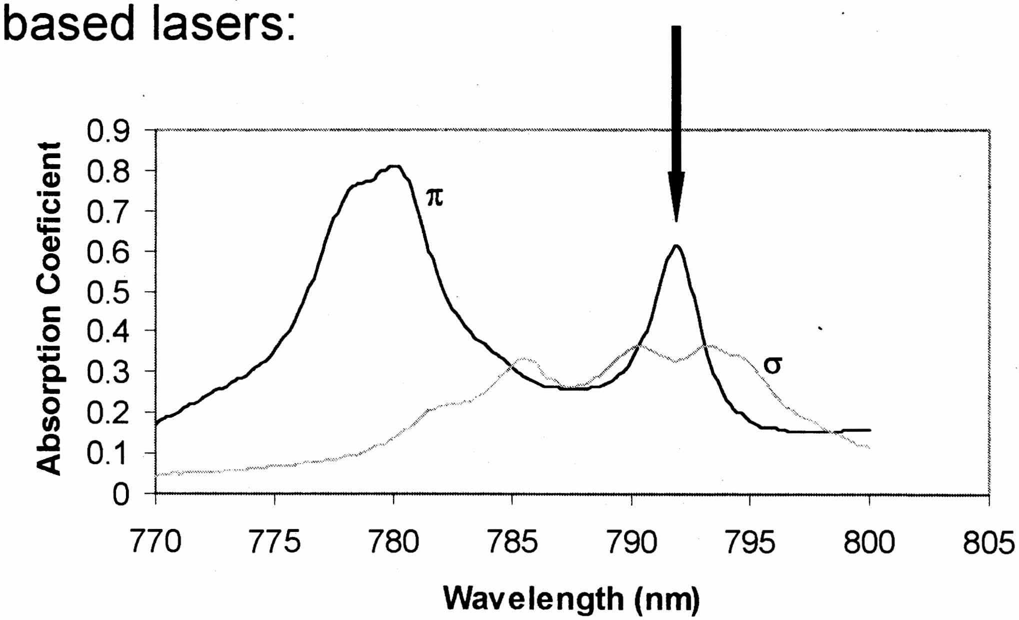


- More than 500 million accumulated pulses.
- No bar failures.
- LDA from Vendor 1 show higher power decay rates.
- Fluctuations in curves up to 200M pulses were due to test electronics.

792-nm Test Program at LaRC

LaRC
JPL
GSFC

Focus is on lifetime and reliability of 792-nm LDAs operating in "***long pulse duration mode***" required for pumping 2-micron Tm- and/or Ho-based lasers:

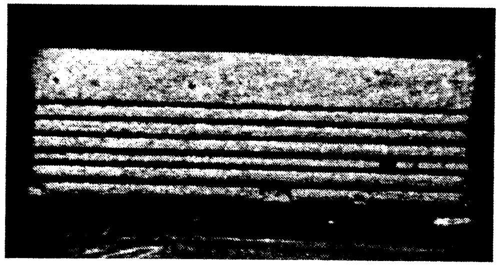


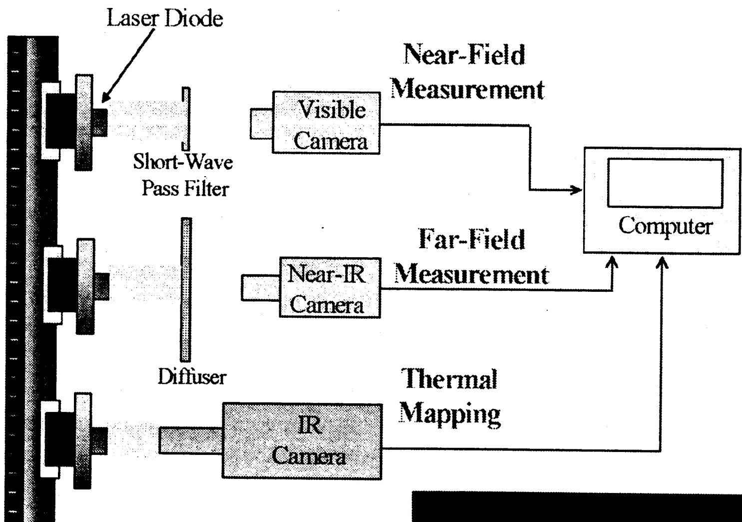
Operating in long pulse duration regime (>1 msec) further limits the lifetime of laser diode arrays due to increased thermal stress.

792-nm Test Program at LaRC

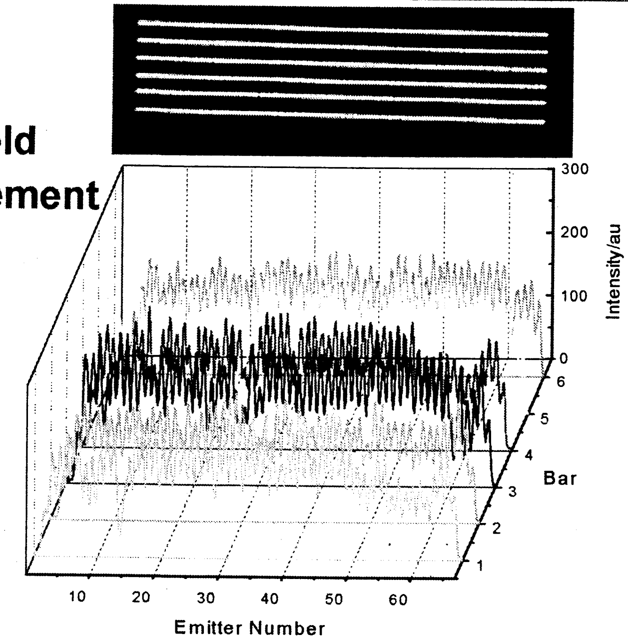
LaRC
JPL
GSFC

Visual Inspection

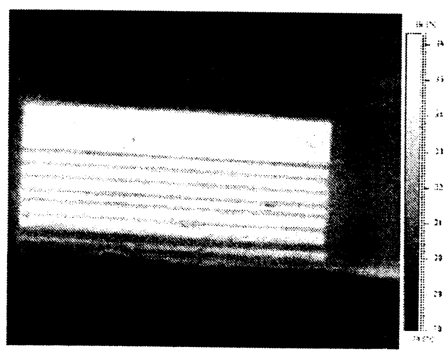




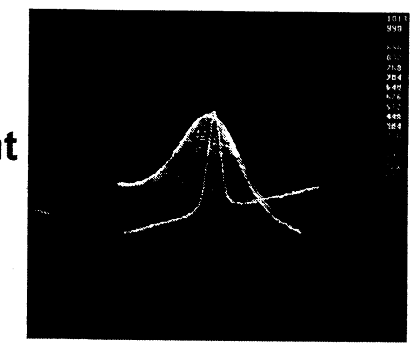
Near-Field Measurement



IR Thermal Imaging

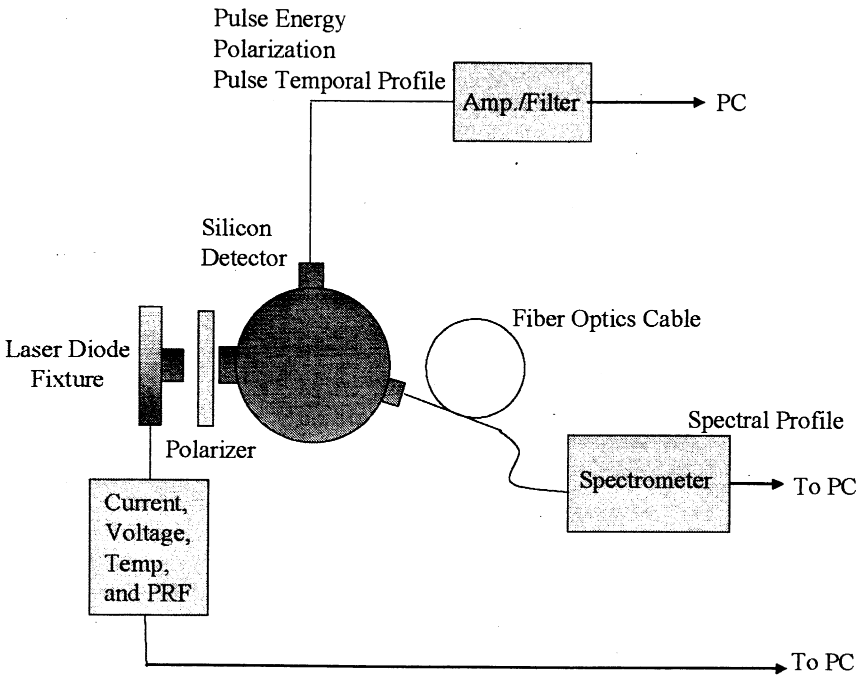


Far-Field Measurement

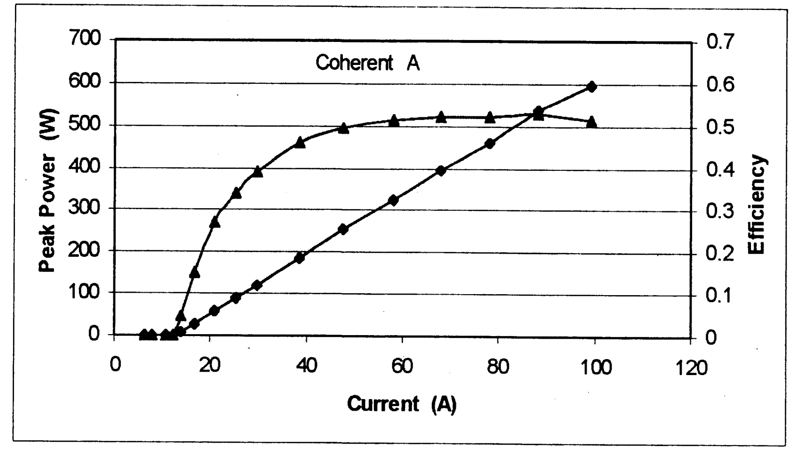


792-nm Test Program at LaRC

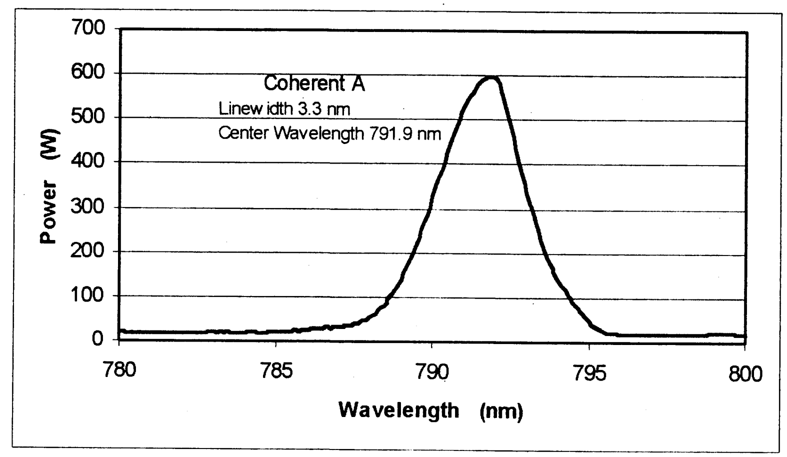
LaRC
JPL
GSFC



P-I and Efficiency



Spectrum



Pulsewidth 1 msec

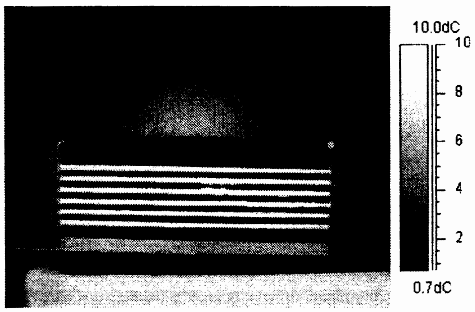
Rep Rate 12 Hz

Op Temp 25 °C

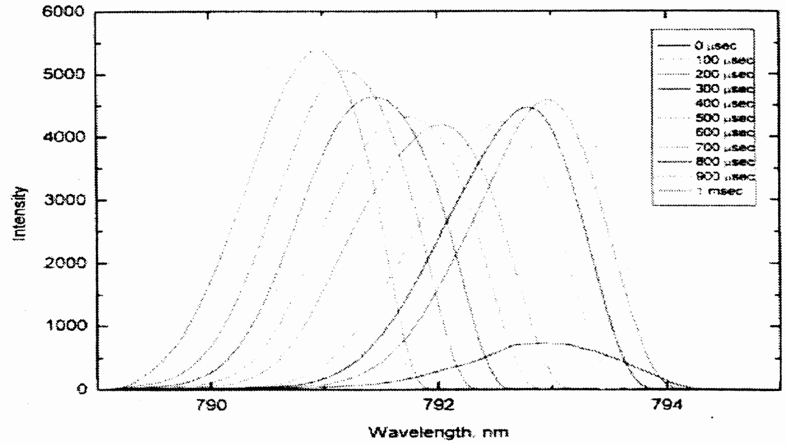
LaRC
JPL
GSFC

In-Depth Thermal Measurements

IR Imaging

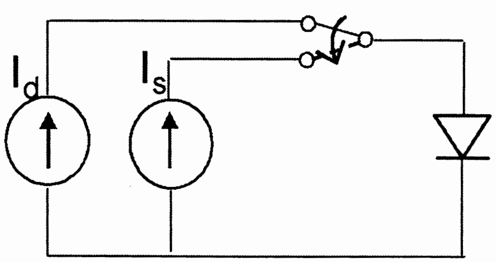


Temporally Resolved Spectral Measurement

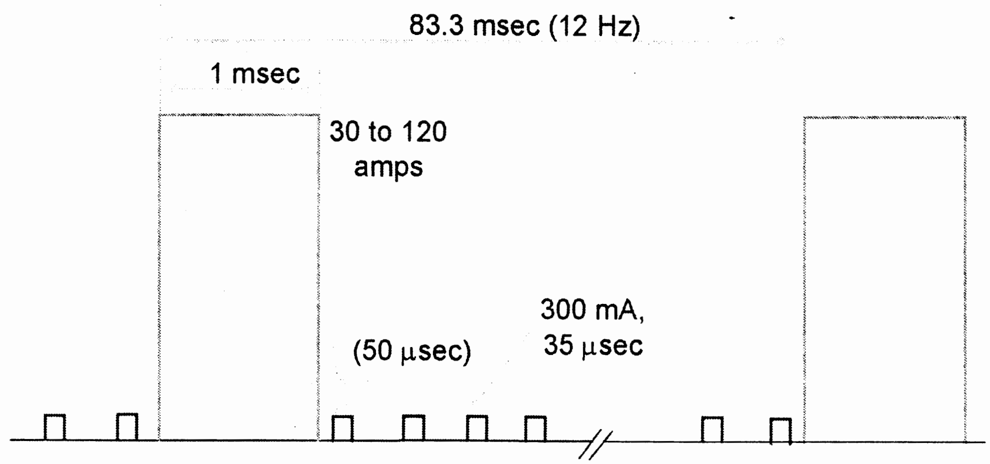


Wavelength shift is a linear function of junction temperature

Forward Voltage-Short Pulse (Junction Temperature) Measurement



Diode Laser

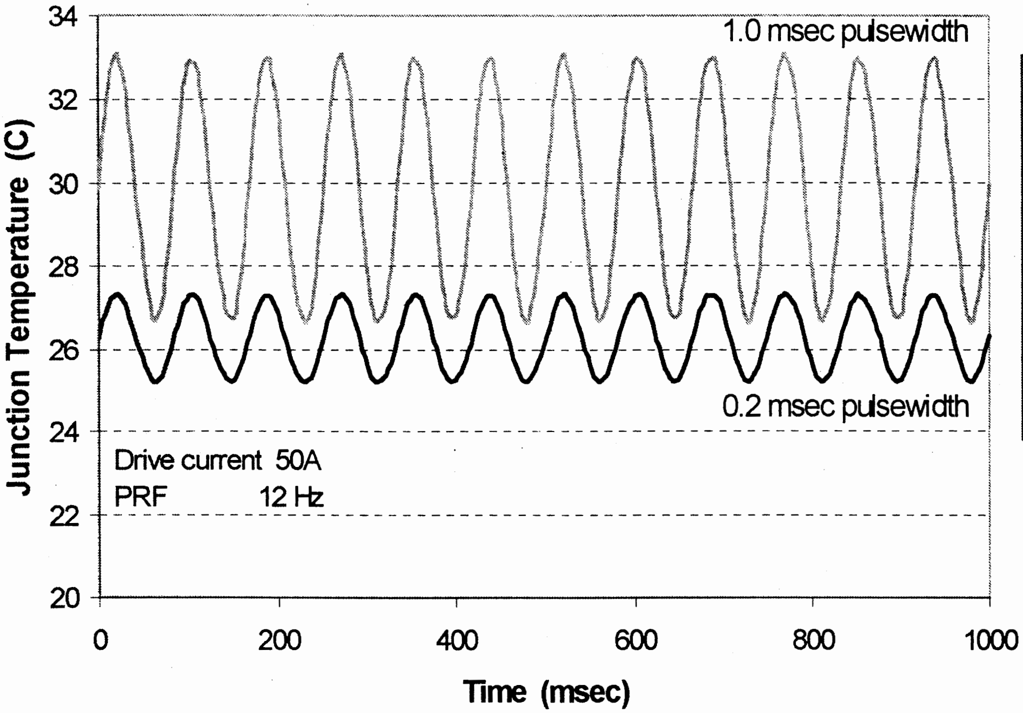


Raytheon

THE AEROSPACE CORPORATION

Thermal Effects of QCW 792-nm LDA

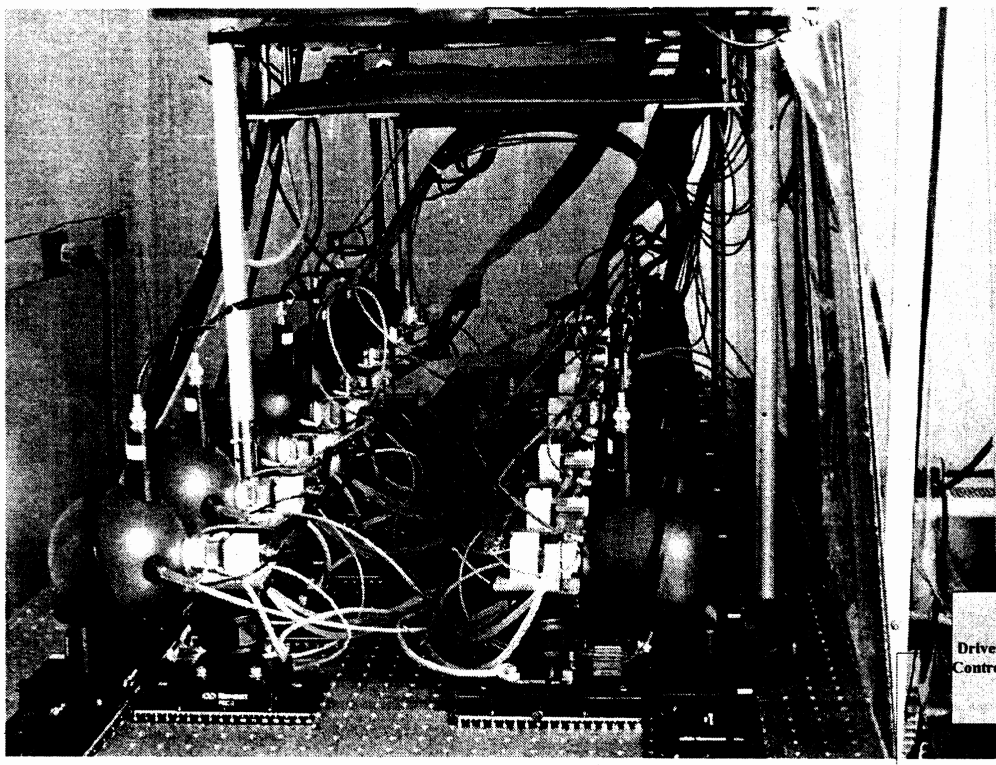
LaRC
JPL
GSFC



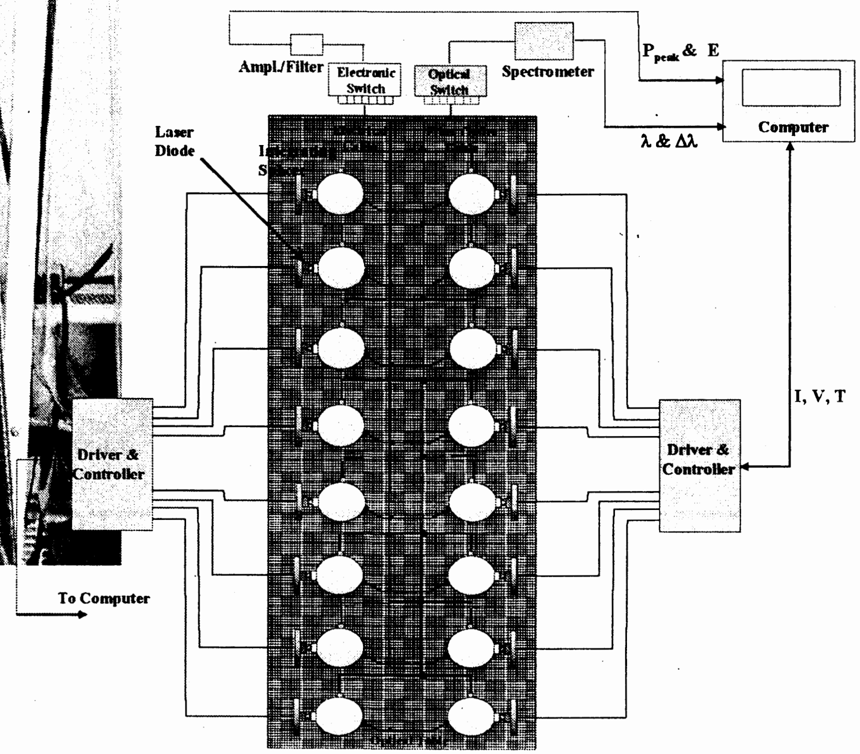
Excessive heating of the active region and drastic pulse-to-pulse thermal cycling limits the lifetime of laser diode arrays when operating in long pulse regime.

Lifetime models predict up to 2 orders of magnitude shorter lifetime when operating in 1 msec pulsewidth regime

792-nm Lifetime Test Facility

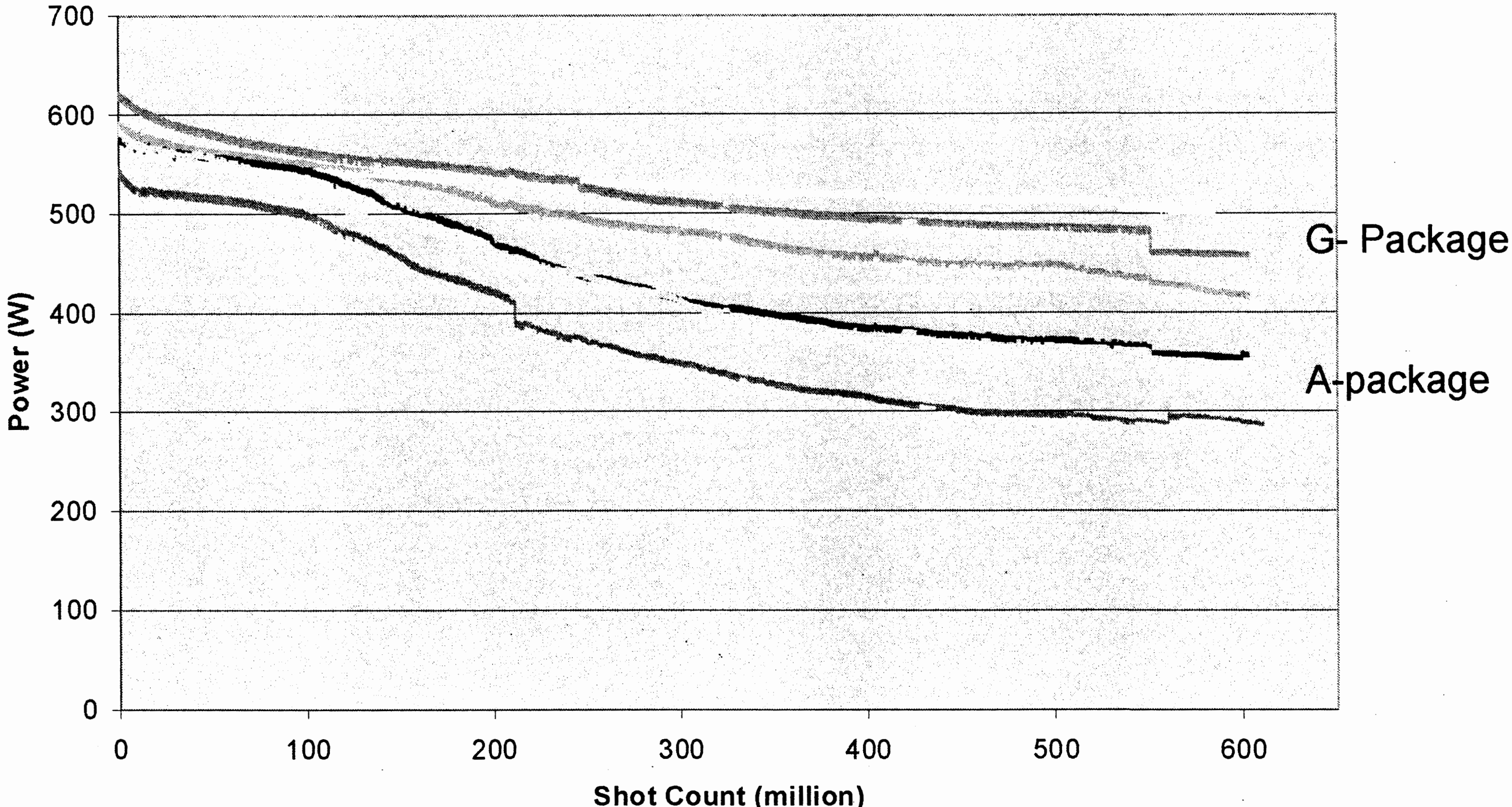


Fully-automated
Running 24/7



Lifetime Testing of 792 nm LDAs Operating in Long Pulse Mode

LaRC
JPL
GSFC



Operated at full rated power (100A)
Pulse repetition rate = 12 Hz
Pulsewidth = 1 msec

Improving Lifetime and Reliability of LDAs

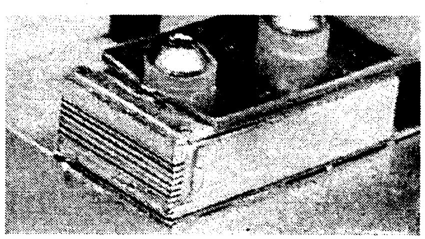
1. Evaluate and selection based on thermal characteristics and tolerance of thermo-mechanical stresses

Package	Geometry	A or G package style
	Architecture	Bars in Groove, Rack & Stack, Stacked Subassemblies
	Heatsink Materials	BeO, Cu, CuW
Bar	Efficiency	Wafer architecture and Epitaxy
	Fill factor	No. of emitters per bar

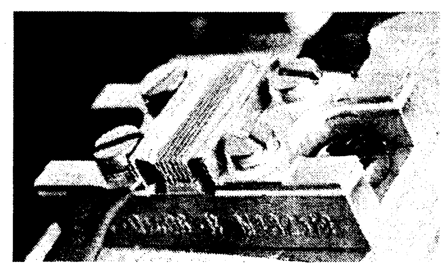
2. Specification based on trades between pump requirements and heat dissipation: number of bars and pitch size

3. Defining optimum operational parameters:
Drive current (de-rating), pulsewidth, pulse repetition rate, sink temperature

A package



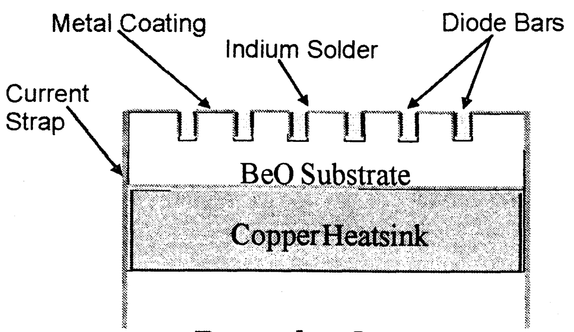
G package



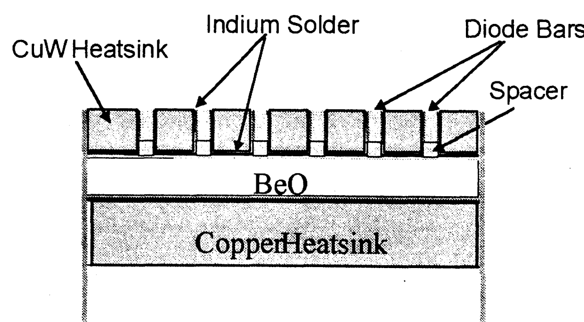
Improving Lifetime and Reliability of LDAs

Advancing Technology

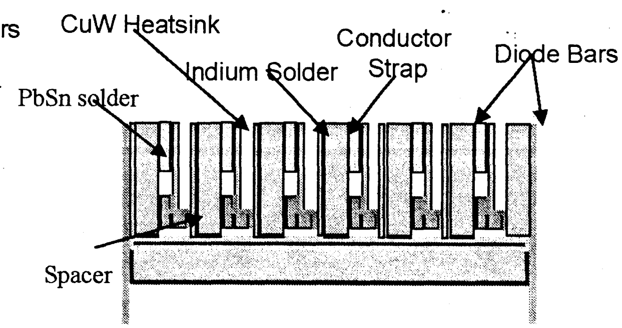
Advanced package materials (Composites, CVD Diamond)	Higher thermal conductivity and lower thermal mismatch
Thin hard solder	Eliminate solder creep
Smart Driver	Prevent *current filamentation*
Integrated fuse	Isolate damaged bars to allow for continued operation of array
Efficiency	Reduce generated heat



Bars in Groves



Rack & Stack



Stacked Subassemblies

Design of Experiments Annotation at JPL

- **Activity led by JPL and Raytheon**
- **Input provided by NASA LaRC and GSFC test programs**
- **Test program extended to JPL with additional contributions:**
  - Design of Experiments (DoE) back annotation for existing experiments
  - Replication of test set-ups for validation
  - Extension to single diode format for a large range of wavelengths corresponding to the diverse nature of laser applications at NASA

Note: this effort is partially funded under the NASA Electronic Parts and Packaging (NEPP) program from the Safety and Mission Assurance office.

DoE Overview

Purpose:

- Establish common test methods
- Establish common procedures
- Review customer requirements to determine commonality
- Create a design of experiment (or a series of designs of experiment) to optimize data collection and minimize cost and overlap

Status:

- Initial potential packaging failure modes identified
- Preliminary parameter list and ranges identified
- Preliminary response list selected
- Sample size and confidence limit trades bounded
- NASA requirements collated
- Common test set-up identified
- Preliminary designs identified
- Data collection for back-annotation started

Laser Packaging Failure Modes

Some of the package failure modes encountered were:

- **Au-In intermetallic formation at W/B**
- **Solder squeeze-out facet contamination**
- **General facet contamination**
- **Sn whisker**
- **Misalignment due to soft solders (In creep)**

Experimental Parameters

- Parameter lists
  - Pulse integrated power (current varied with voltage measured)
  - Pulse frequency: prf 0(cw) - 40kHz
  - Pulse width: cw-30ns
- Responses
  - Lifetime
  - Number of pulses
  - Time to 5, 10, 20 and 50% power loss

Additional Considerations

Items being determined for the experiment:

- Thermal time constant for pulsed vs. CW operation
- Verification of test diode geometry (C-mounted devices initially)
- List of existing suppliers (completed)
- I/P list for supplier needs (completed)
- Accelerated testing
- Test set-up – configuration / distribution
- Test set-up – sampling

Conclusion

- **The National Diode-laser Array Working Group is approaching the end of its fourth year.**
- **Group facilitates focused interaction between the LDA user and provider communities.**
- **Group is authoring standards documents that address the specification and qualification of LDAs for operation in the space environment.**
- **NASA test and evaluation facilities are available to the community:**
  - 808-nm characterization and lifetest:
    Nasir Kashem; 301-286-6360; *nasir.b.kashem@nasa.gov*
  - 792-nm characterization and lifetest:
    Farzin Amzajerdian; 757-864-1533; *f.amzajerdian@nasa.gov*
  - Single diode lifetest (under construction):
    Andrew Shapiro; 818-393-7311; *aashapiro@jpl.nasa.gov*

Working Group Schedule

- **Provisional meeting schedule:**
  - Friday, May 9, 2008; co-locate with CLEO (San Jose, CA), 6-8 May
  - Tuesday, September 23, 2008; Penn. State U. Electro-Optics Center, Northpointe, Penn.
  - Friday, January 30, 2009; Lockheed Martin, Sunnyvale, Calif. (immediately following Photonics West, January 24-29)

- **For more info:**

  - Dave Tratt (The Aerospace Corp.)
    626-395-7743
    dtratt@aero.org
  - Farzin Amzajerdian (NASA LaRC)
    757-864-1533
    f.amzajerdian@nasa.gov