An Initiative Toward Reliable Long-Duration Operation of Diode Lasers in Space

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Background

- **NASA 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

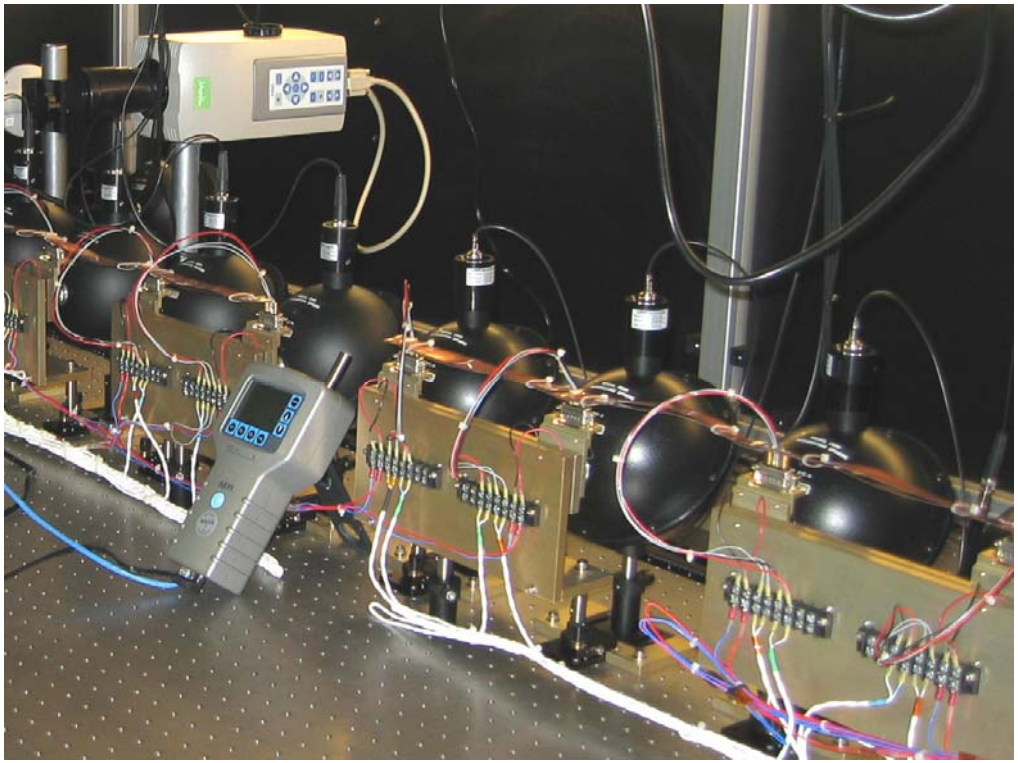
- Review practices and lessons learned from past, current and planned activities among the Group members.
- Evaluate current and proposed design and engineering practices as they relate to component reliability.
- Synthesize and specify baseline environmental requirements that reflect the minimum qualification 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.

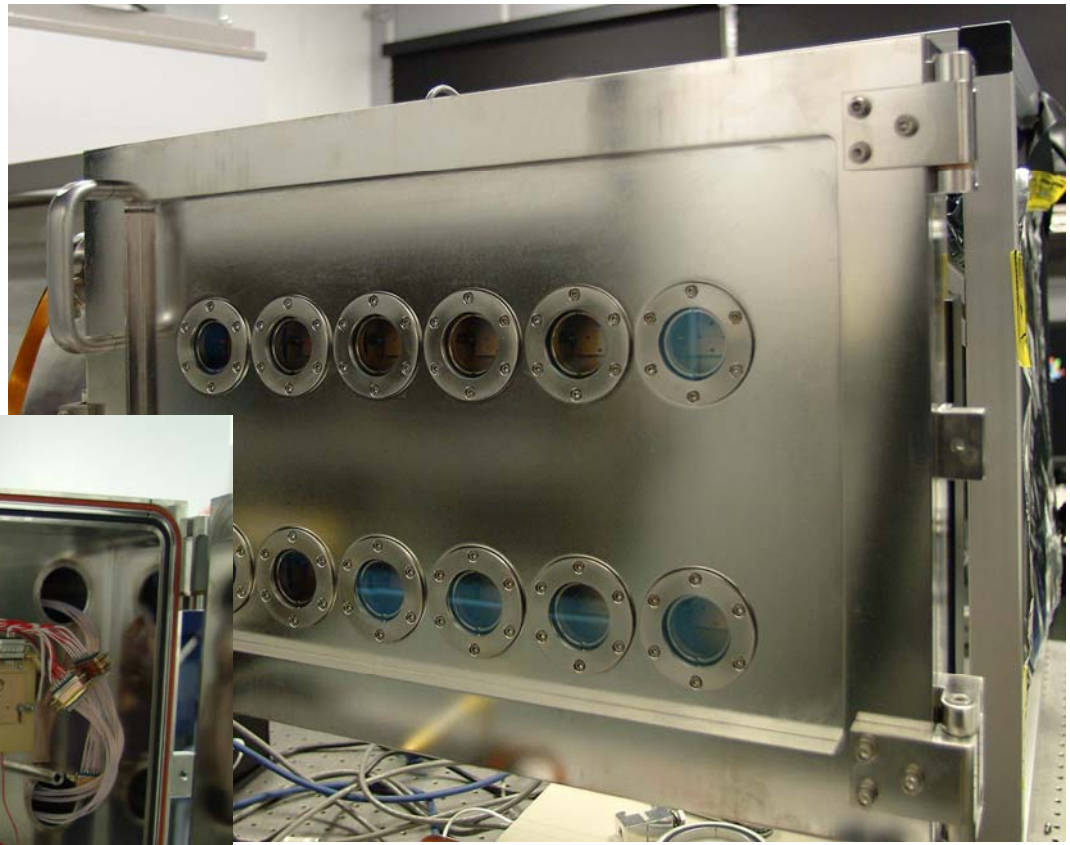
808-nm Test Program at GSFC

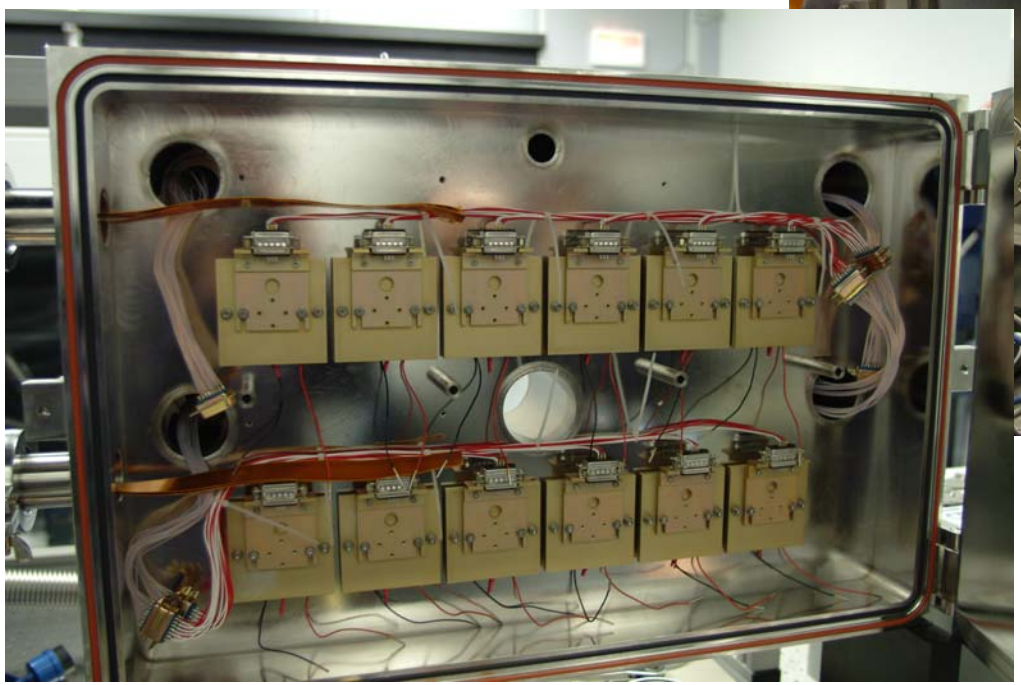
- Microscopic inspection
  - Facet inspections - BF 50x, 200x, DF 50x, EFI as needed
  - Side views - BF 50x, 200x
- IR imagery
  - Averaged
- Spectral measurement
  - Spatially and temporally averaged
  - Spatially resolved
  - Temporally resolved
- Optical power
  - Average, peak, power/ emitter, time-resolved
- Near field
  - Normal, polarization-resolved
- Electronic parameters
  - Current pulse width, amplitude, efficiency, voltage, threshold current



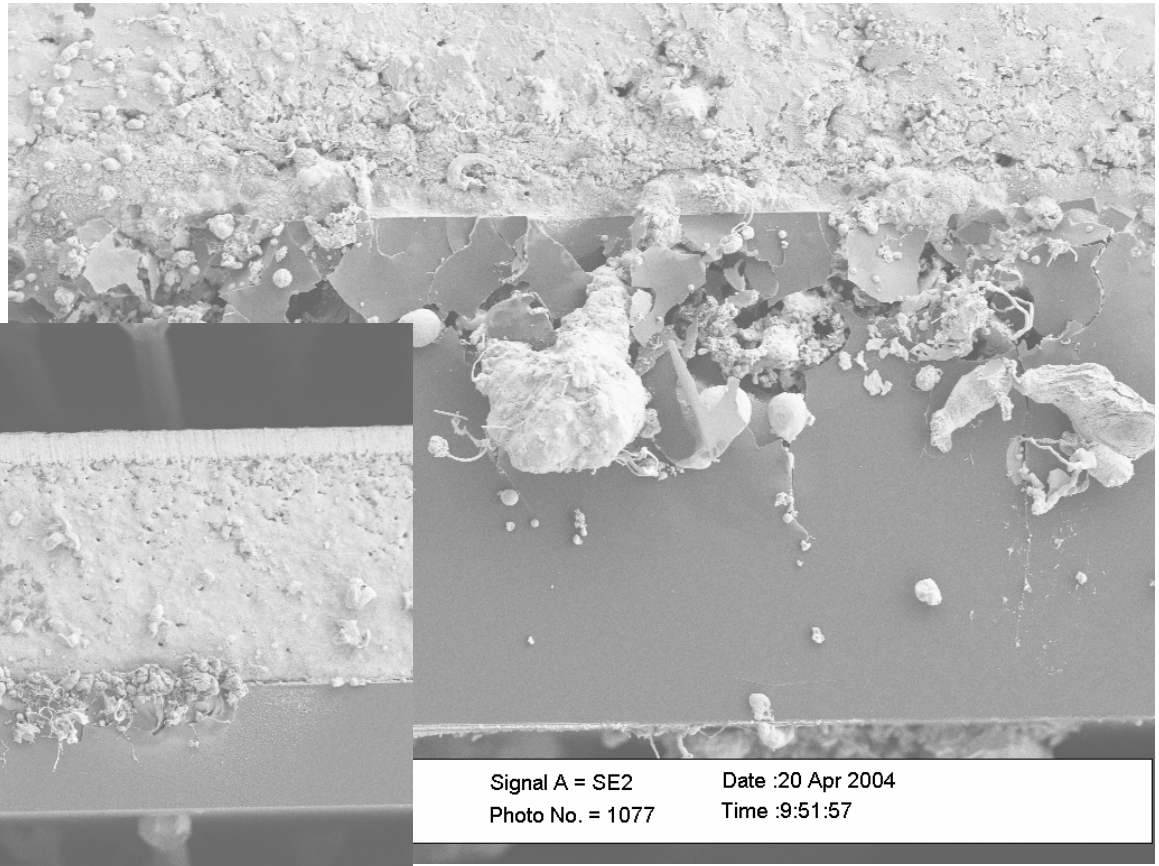
Vacuum Test Facility

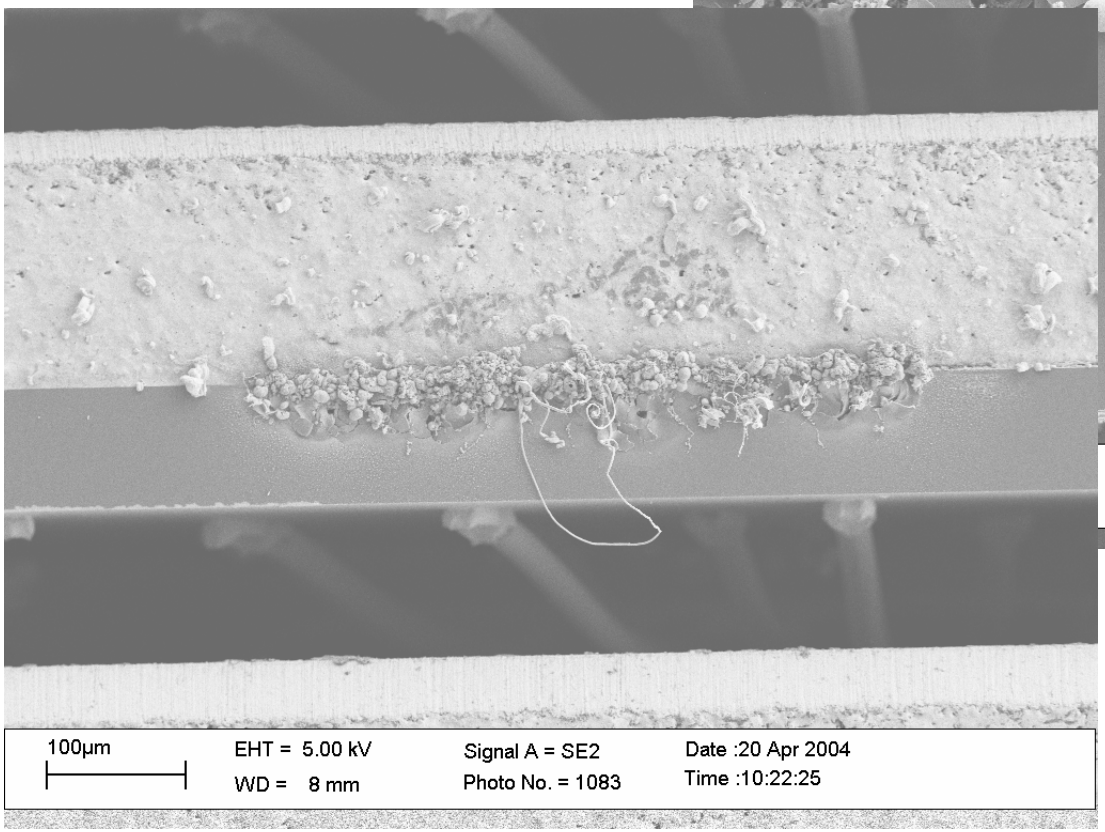
Custom vacuum chamber with 12 LDA test positions and viewports for continuous inspection



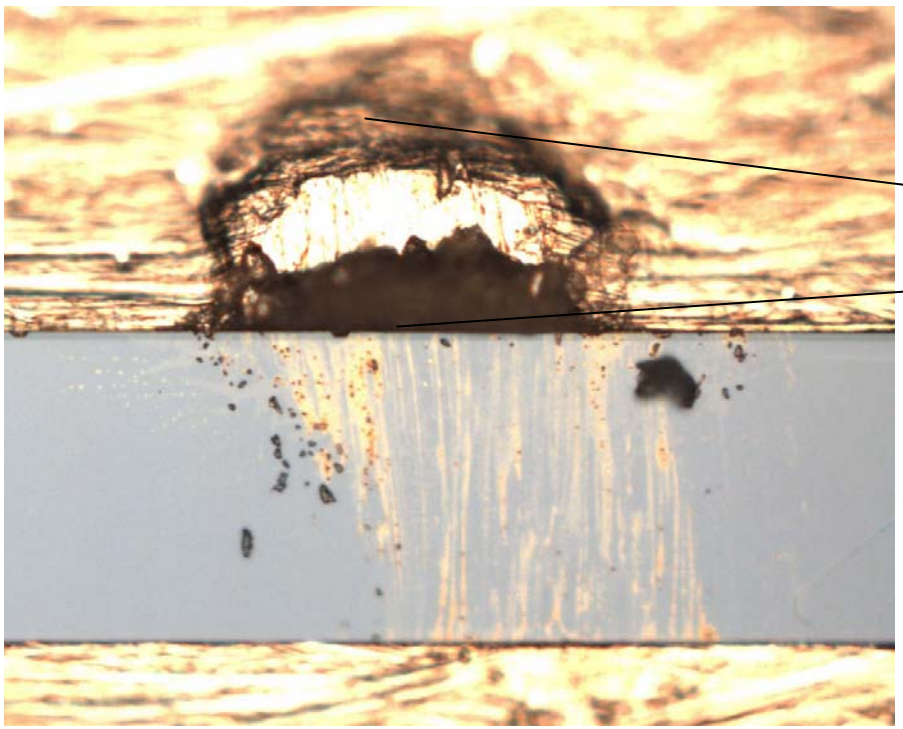


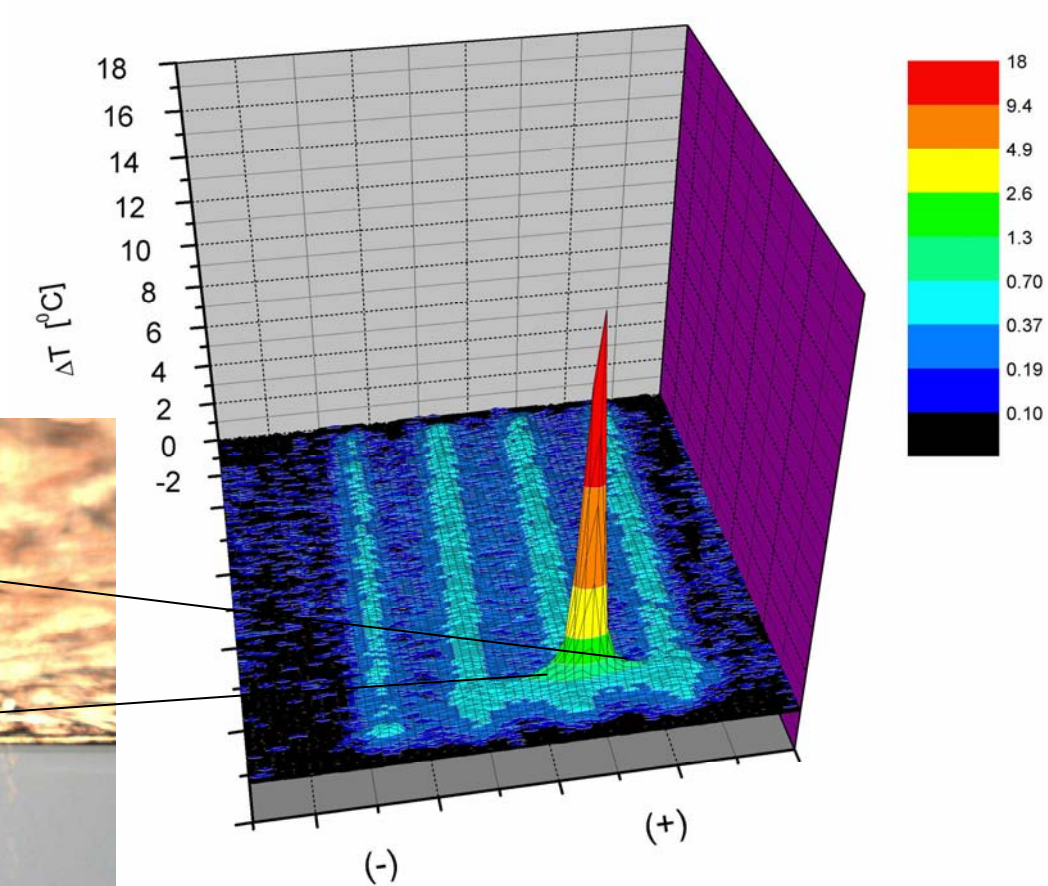
SEM of Solder and Facet Damage



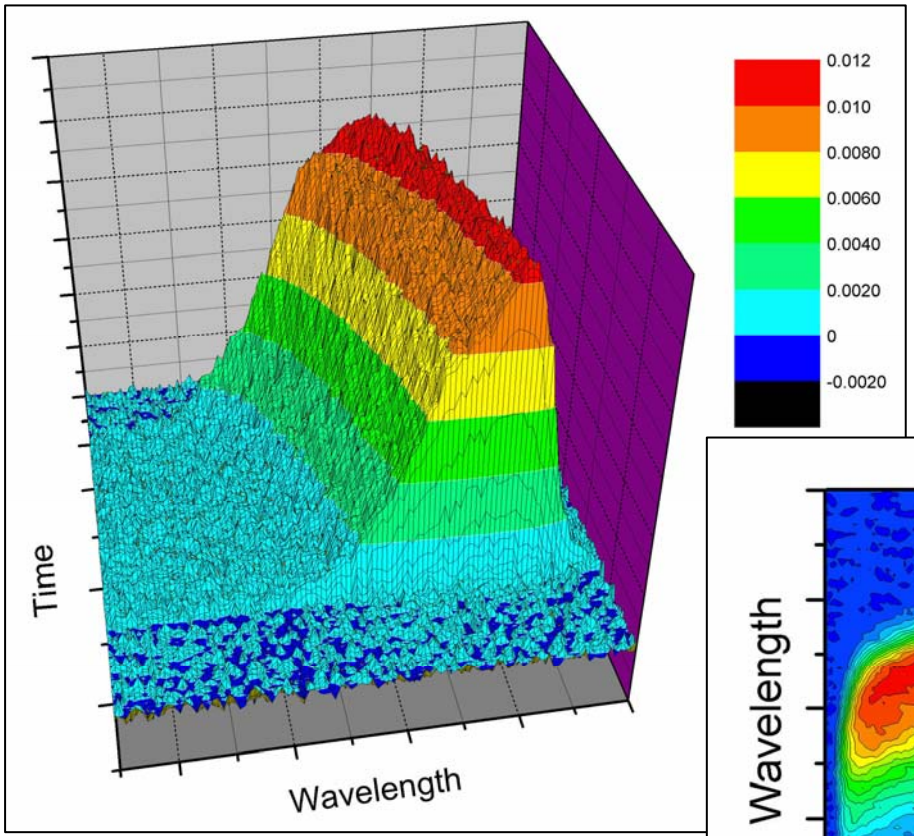


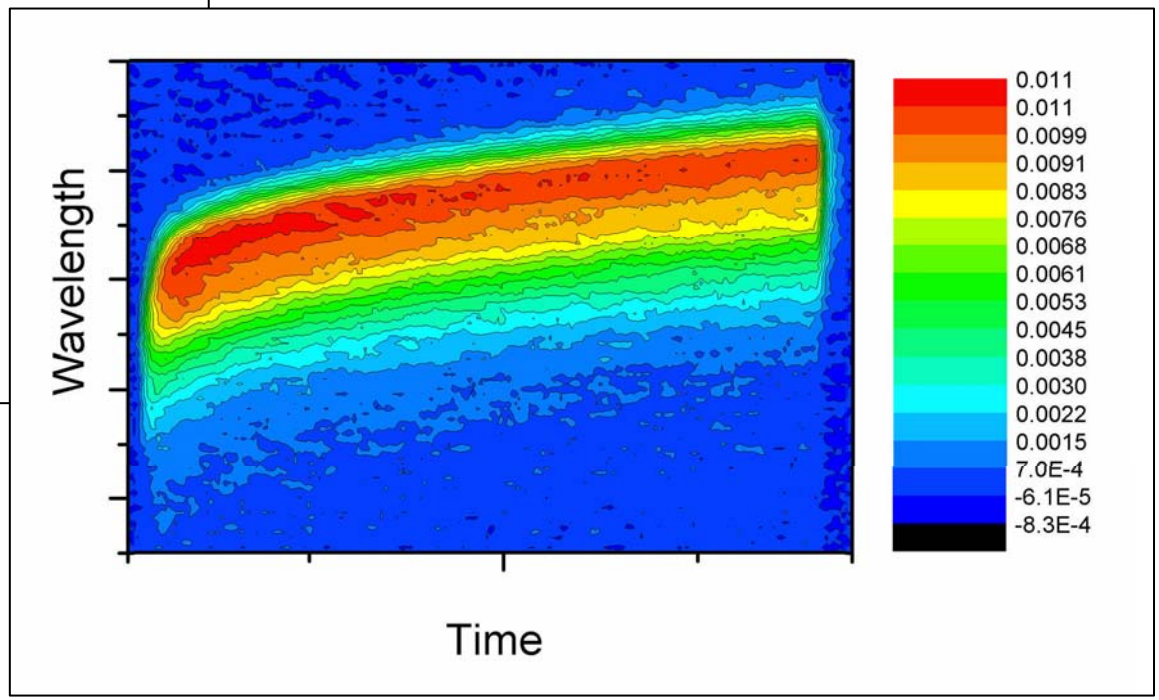
Thermal Characterization of 808-nm LDAs



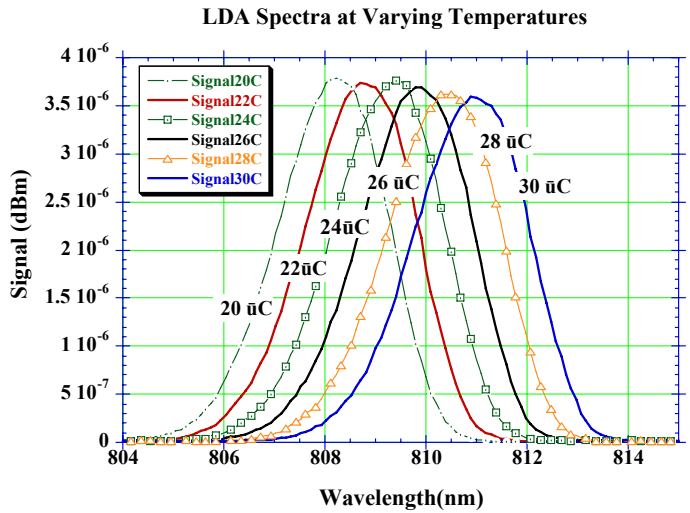


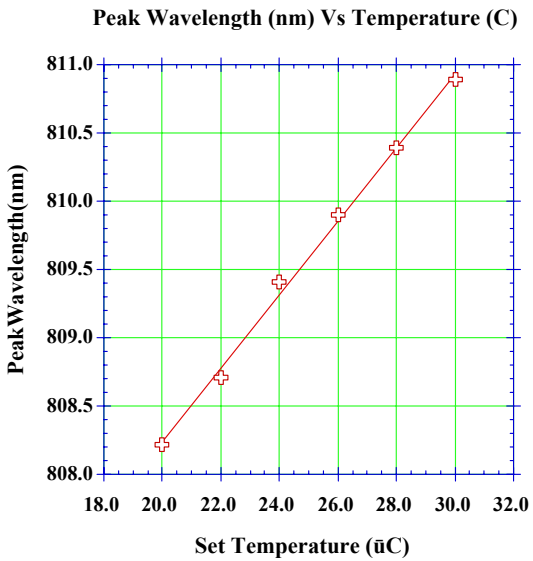
Temporally and Spectrally Resolved Power

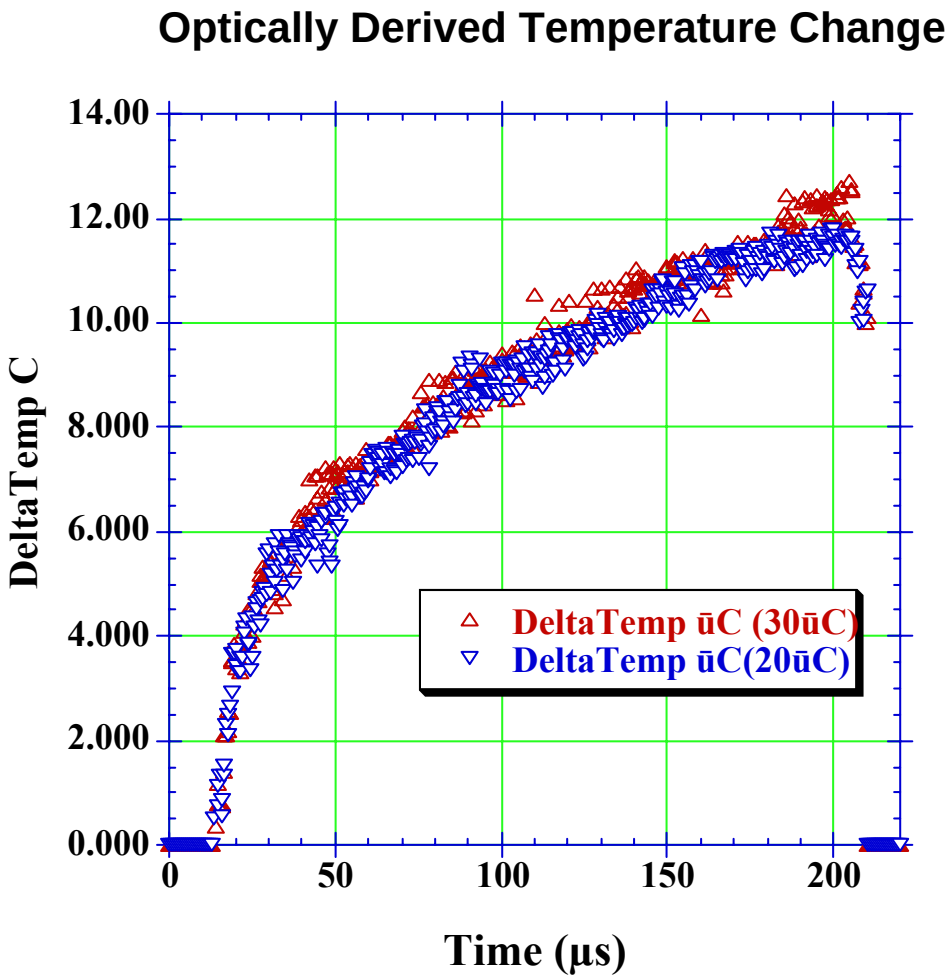




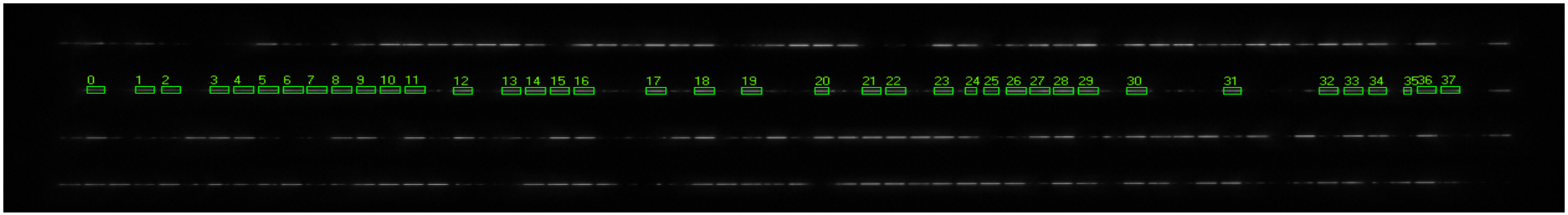
Temperature Behavior

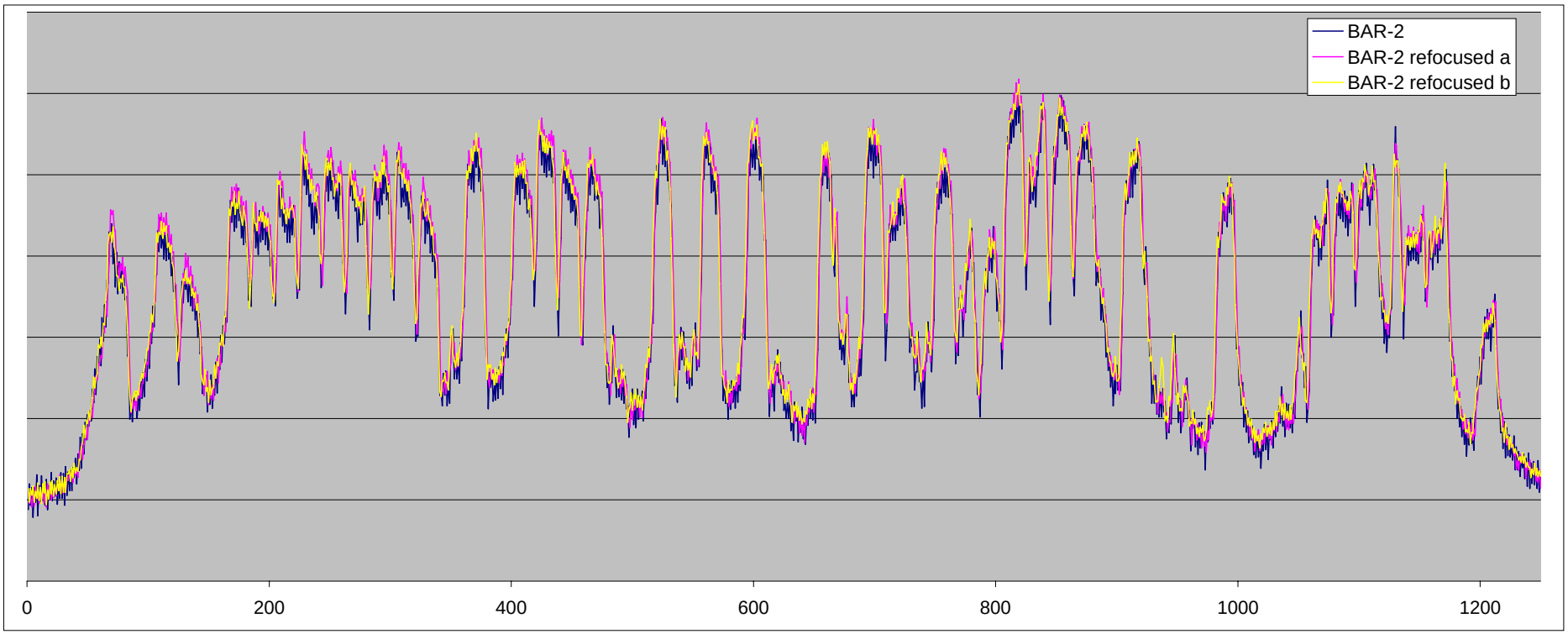




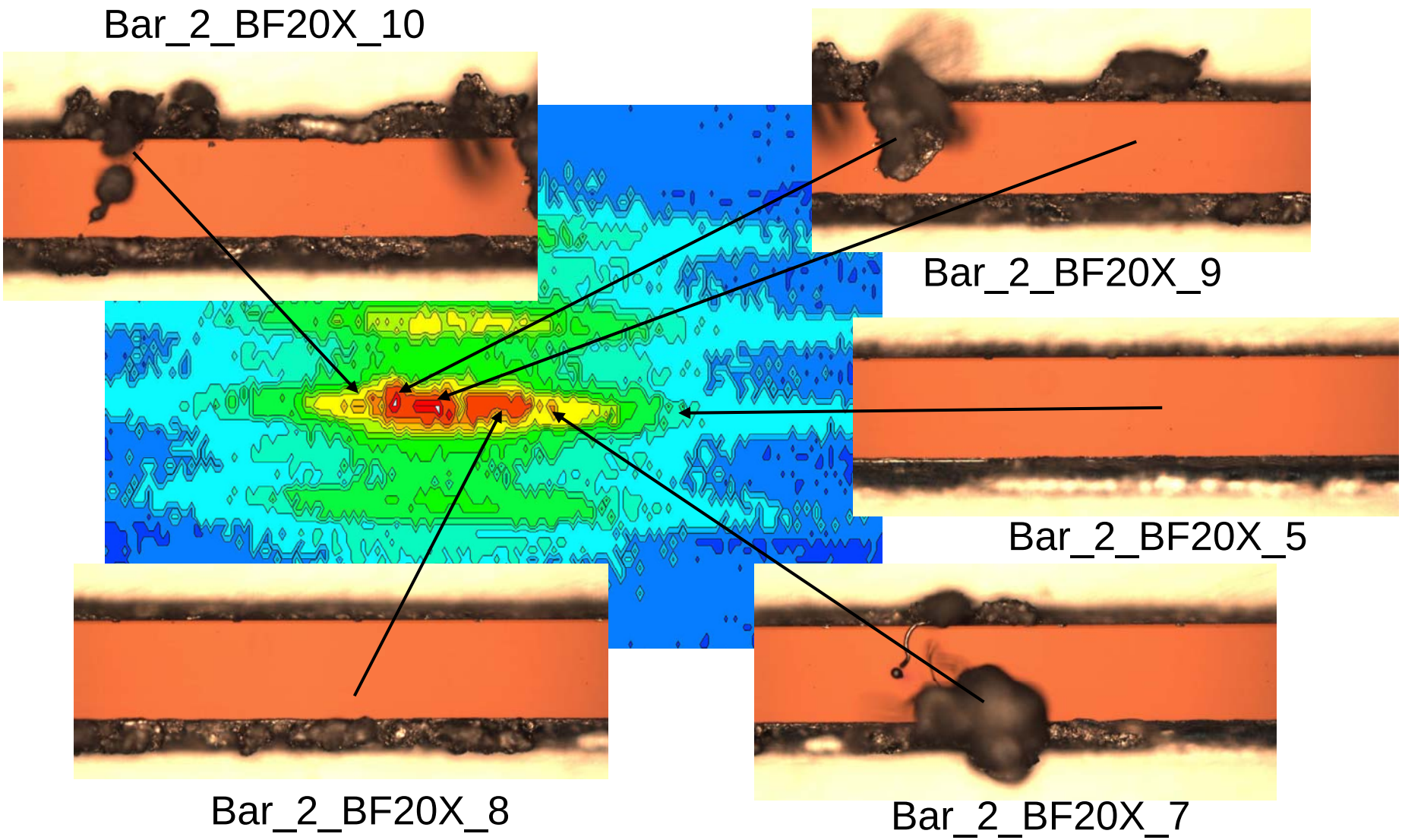


Spatially Resolved Power in Near Field



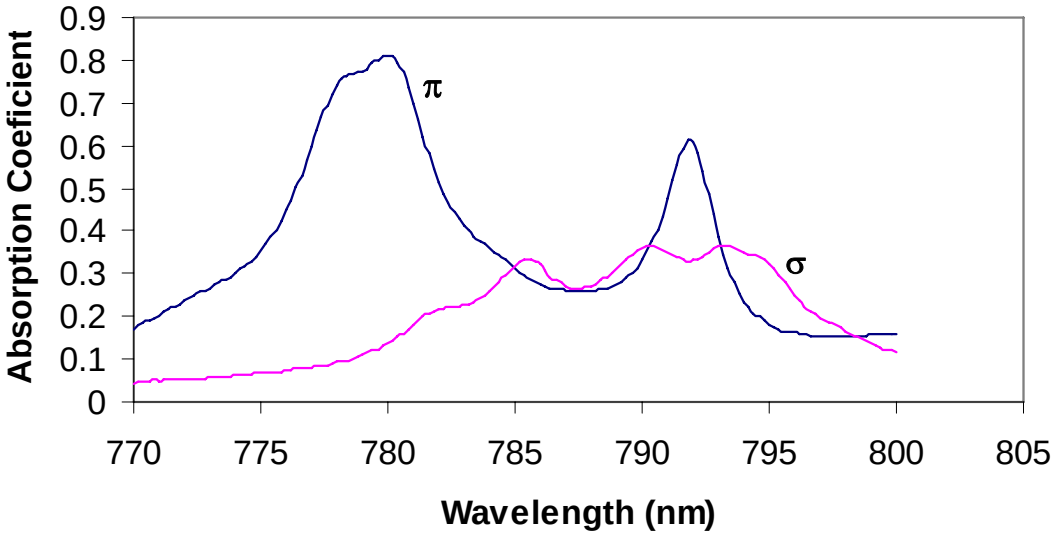


Facet Images Correlated to Thermal Image



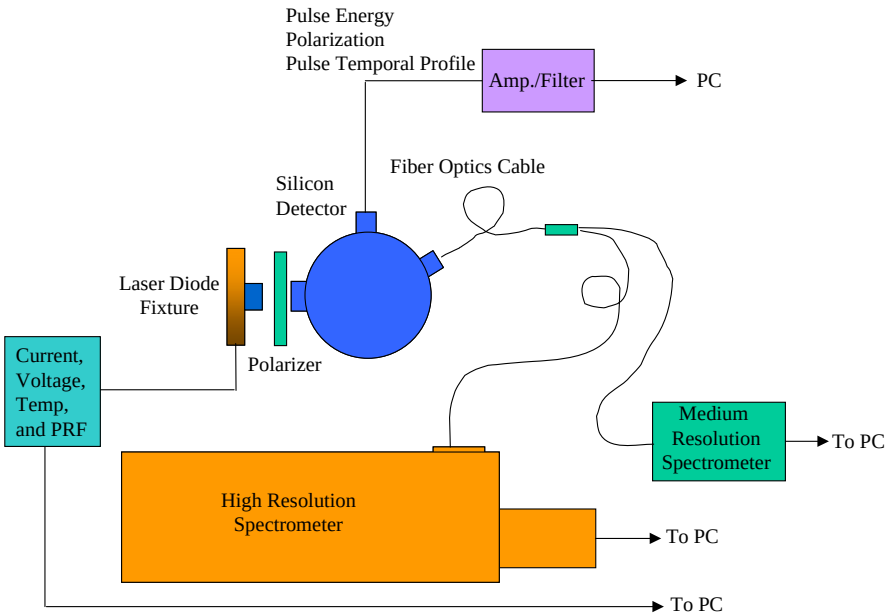
792-nm Test Program at LaRC

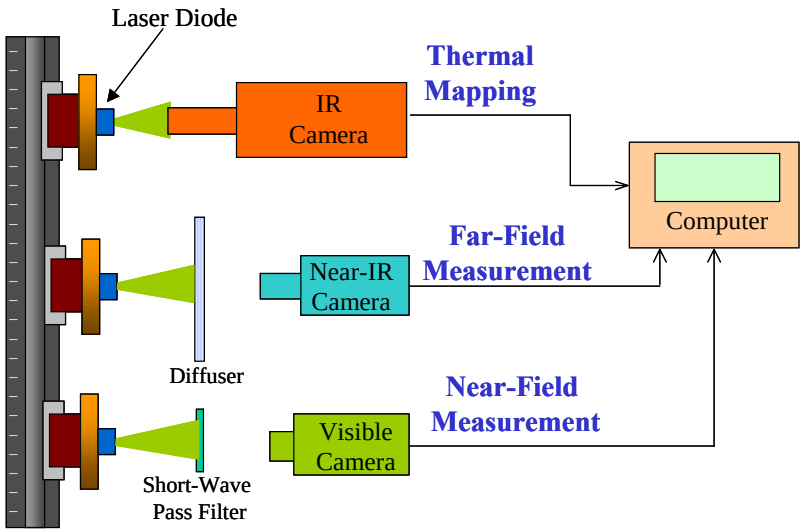
Focus is on lifetime and reliability of 790-nm LDAs operating in "***long pulse duration mode***" required for pumping 2-micron Tm- and Ho-based lasers:



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

792-nm Characterization Facility



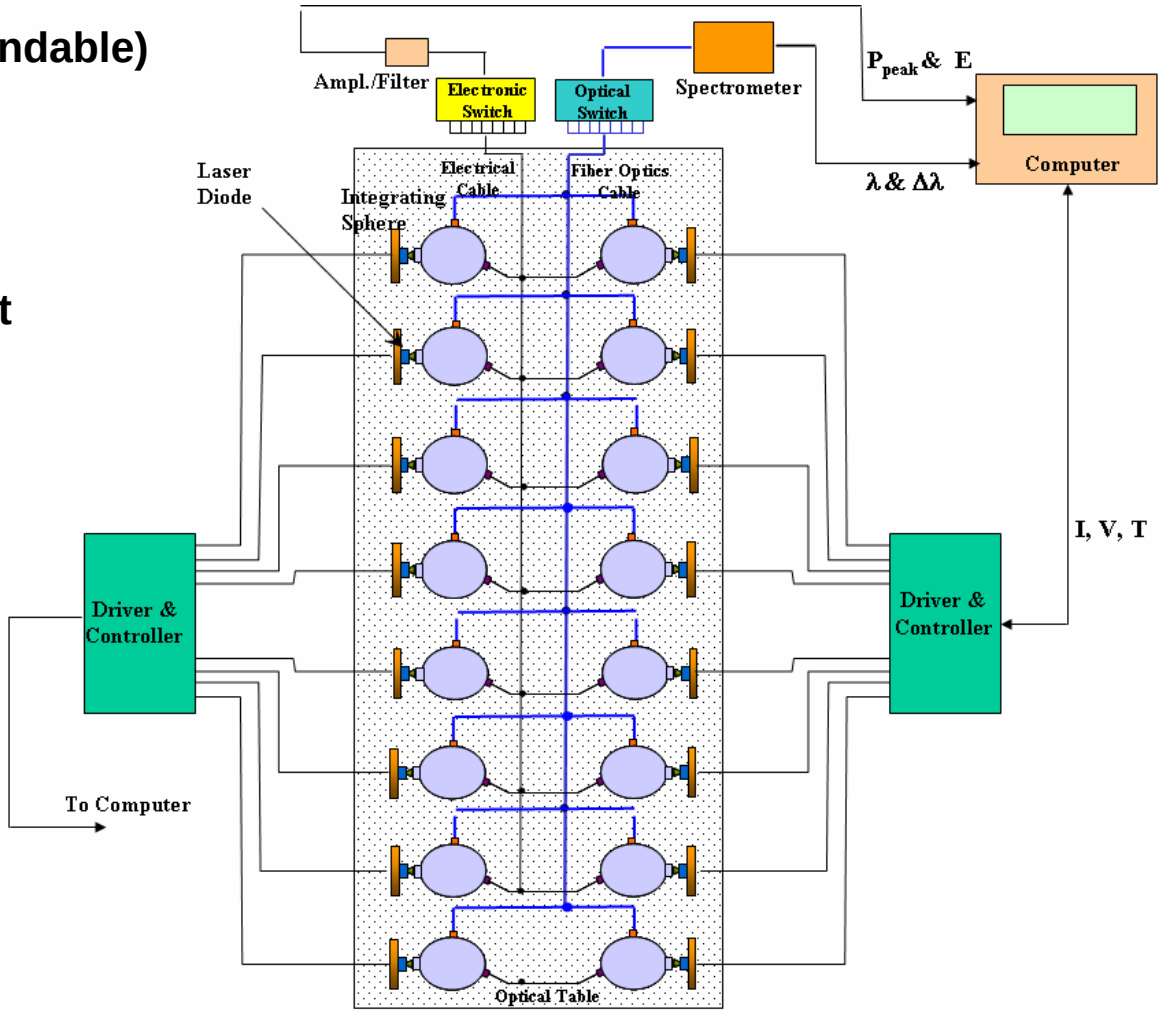


Measurements

- Power and Efficiency vs. Current
- Spectral Profile
- Near Field Imaging of LD Emitters
- Polarization
- Wavelength vs. Temperature and Current
- Pulse Temporal Profile
- Spatial Profile and Beam Divergence
- Thermal Profile and Heat Removal Efficiency

792-nm Lifetime Test Facility

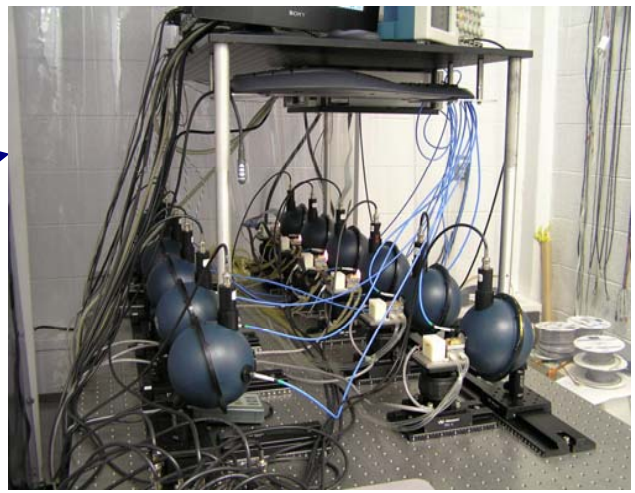
- Measures 16 LDAs simultaneously
- 24/7 operation (modularly expandable)
- Fully automated
  - Remotely operable
  - Data acquisition and archive (performance and all relevant environmental parameters)
  - Diagnosis and alert
  - PC/Web-based

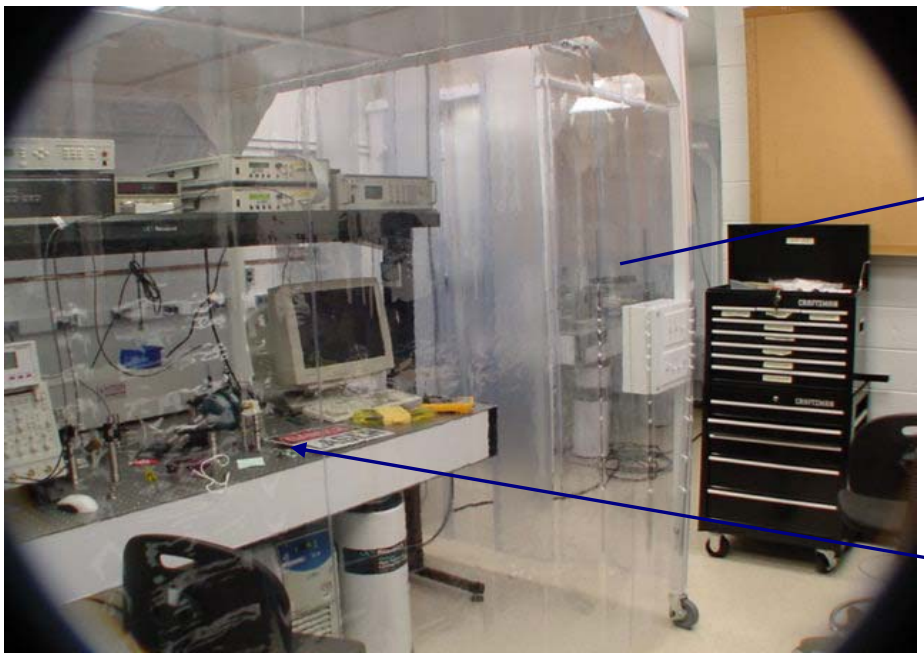


LDA Characterization/Lifetime Test Facility

- Characterized over 200 "6-bar Arrays" rated at 600W from 4 major suppliers
- Began lifetime testing of standard "A" and "G" packages in February 2004
- LDAs are being tested at full rated power and expected operational parameters for a "*space-based 2-micron lidar*" system
  - Drive current 100 A
  - PRF 12 Hz
  - Pulse duration 1 ms
  - Operating temp. 25 deg. C

LDA Lifetime Test Station

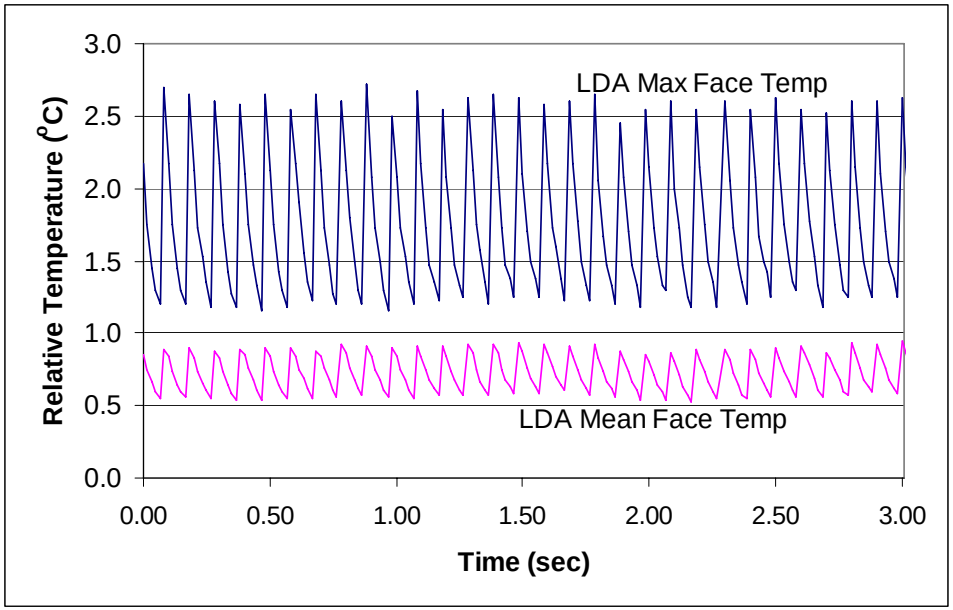


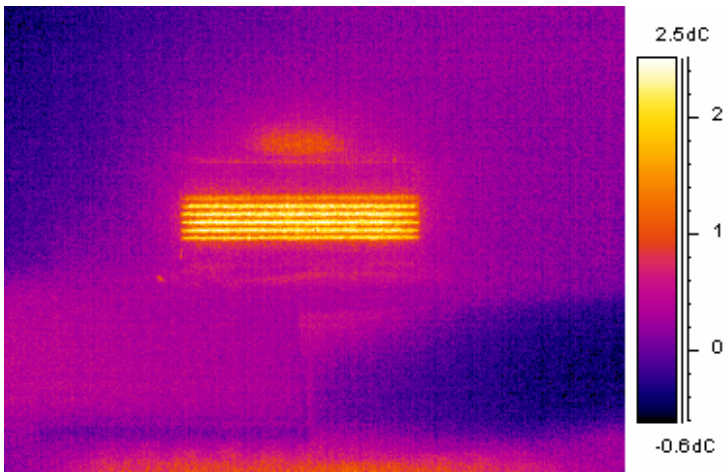


LDA Characterization Station

Thermal Cycling of LDAs

Thermal cycling is one of the leading causes of Quasi-CW LDA degradation

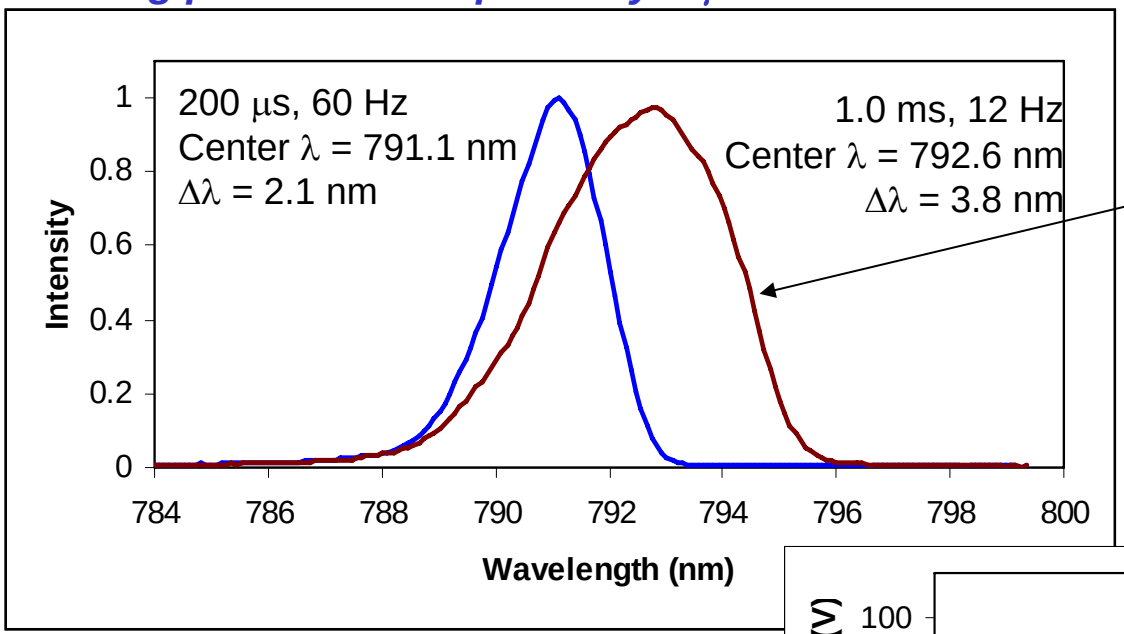




Pulsewidth	**1 ms**
Current	**80 A**
PRF	**10 Hz**
Op. Temp.	**15°C**

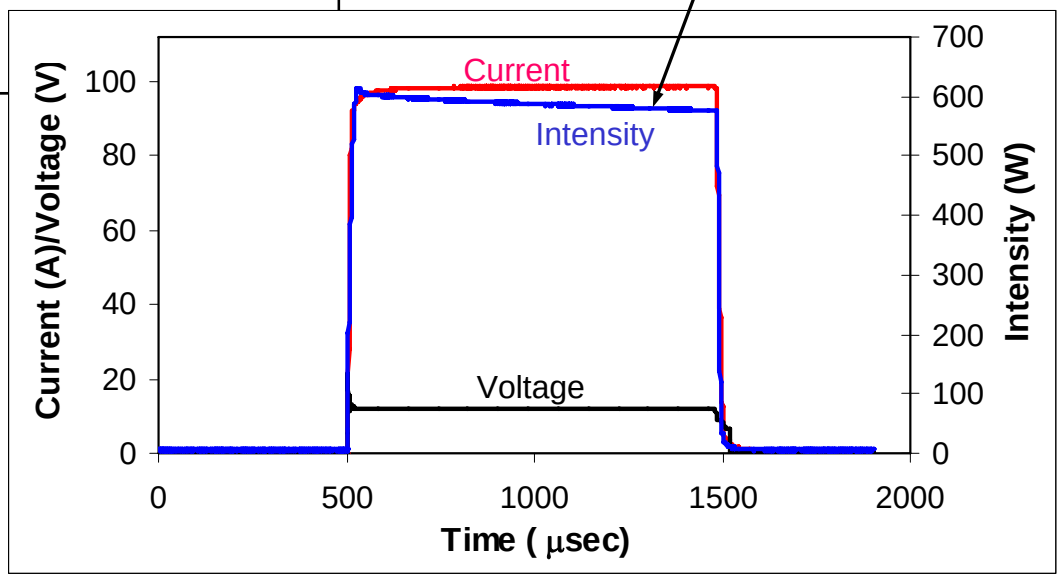
Thermal Effects of QCW 792-nm LDA

- *Long pulsewidth required by 2-μm lasers substantially accelerates LDA degradation*



Spectral shift and broadening due to thermal cycling

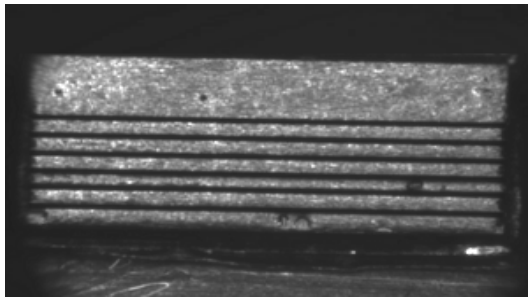
Intensity drops over 1.0 ms pulse duration due to temperature rise in diode active region



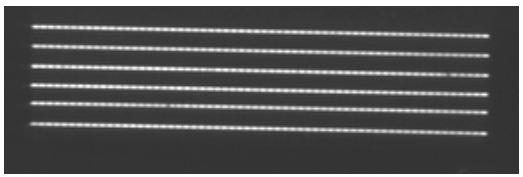
Vendor A G-Package

Current	**100 A**
Op. Temp.	**25°C**

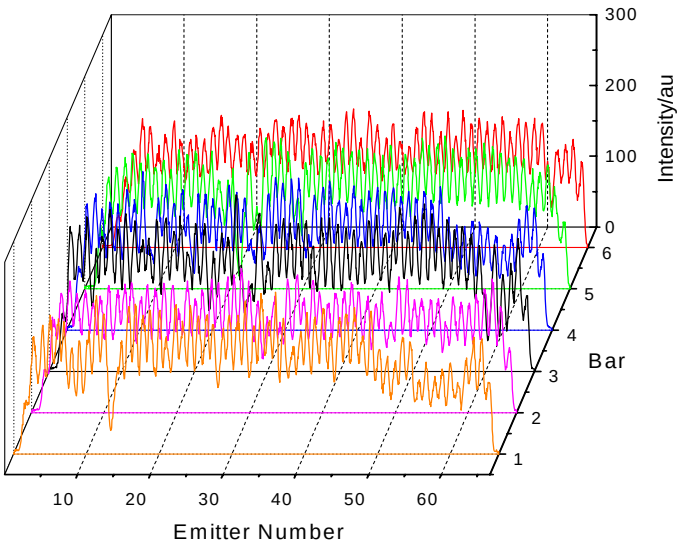
LDA Characterization



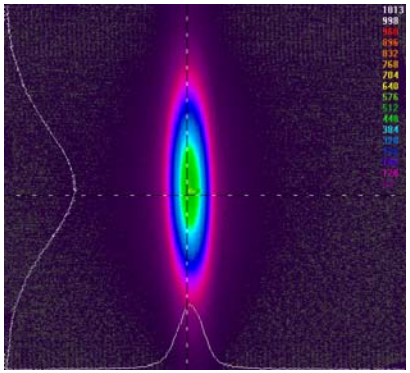
Visual Inspection

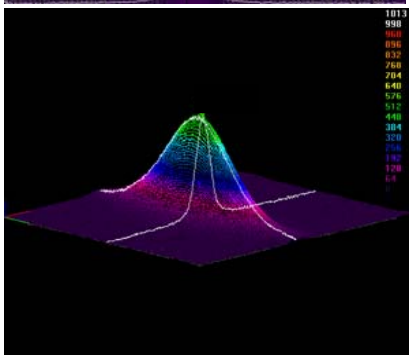


Near-Field Measurement

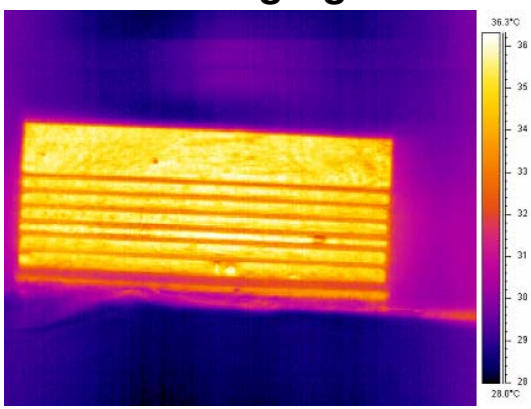


Far-Field Measurement



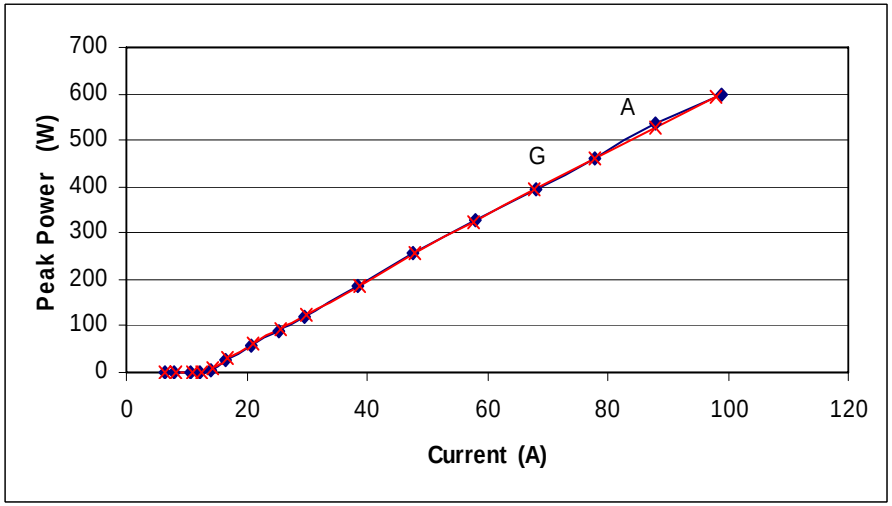


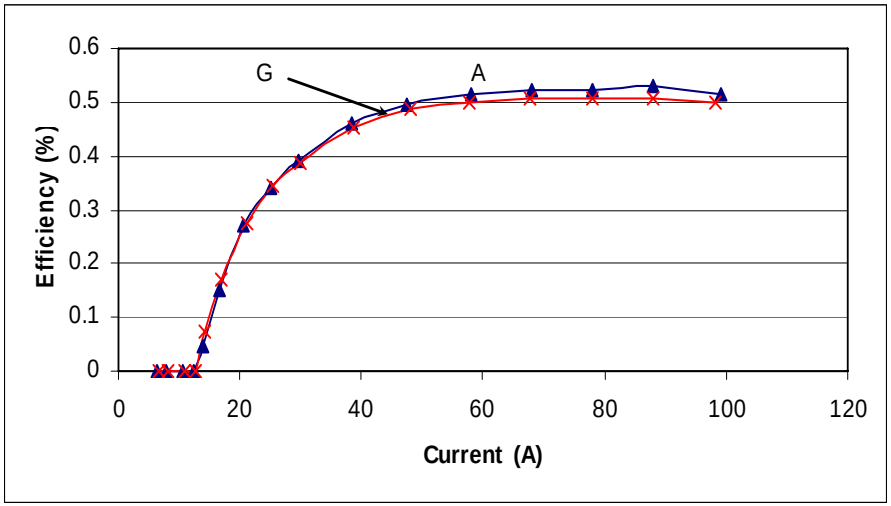
Thermal Imaging



LDA Characterization

Basic LDA Parameters: P-I, Efficiency, Spectrum



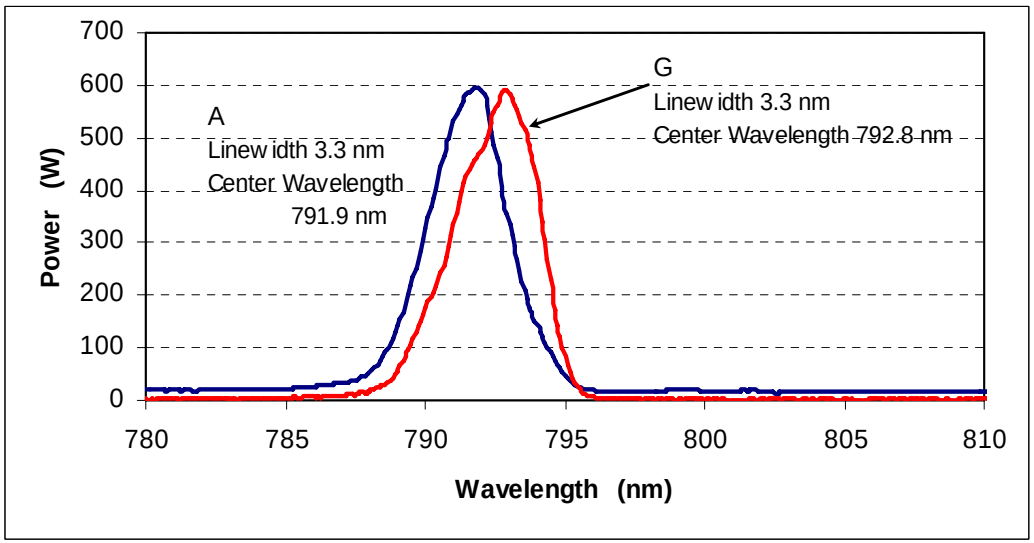


Pulsewidth 1 ms

PRF 12 Hz

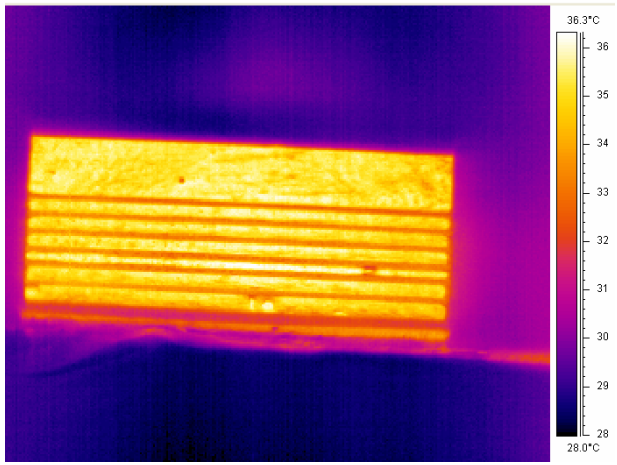
Op. Temp. 25 ºC

A and G packages

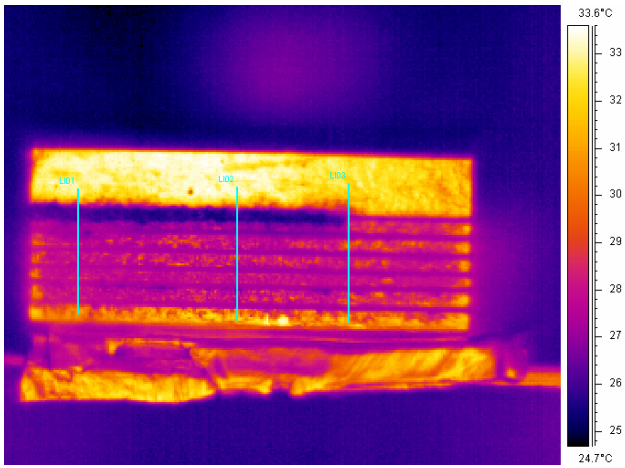


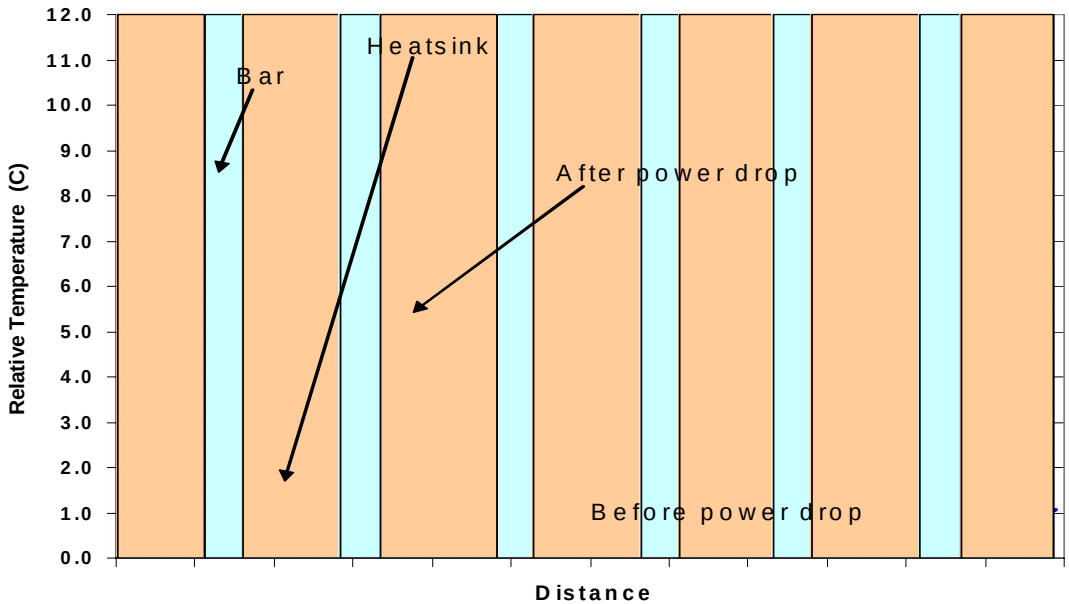
Anomalous event characterization

Thermal image before



Thermal image after



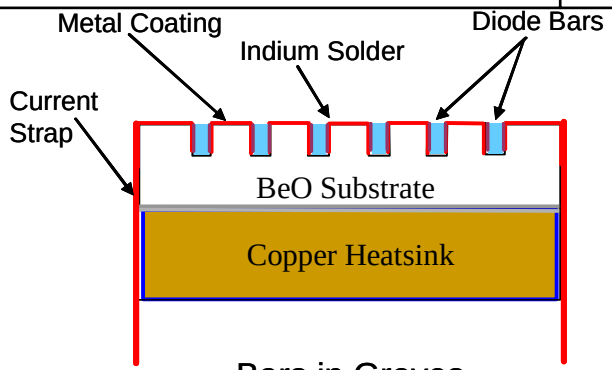


Thermal Characteristics of LDAs

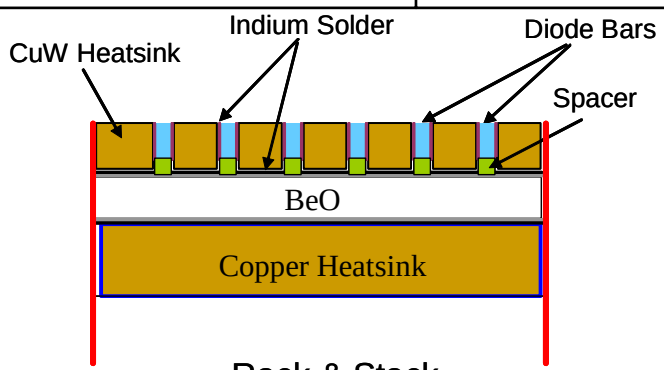
- Measurement of thermal characteristics of LDAs is critical to evaluating different packages and defining optimum operational parameters
- LDA temperature can measured by 3 different techniques
  - IR Imaging: Direct temperature measurement, LDA face temperature map, hot spots (Spatially averaged)
  - Output beam spectral measurement: Wavelength shift with temperature (junction temperature during the pulse)
  - Forward Voltage-Short Pulse Technique (junction temperature before, during, after the pulse)

Packaging Technology Advancement

	Material	Coefficient of Thermal Expansion (m/m-K)	Thermal Conductivity (W/m·K)
Standard	GaAs (wafer material)	6.8×10^{-6}	46-55
	Indium Solder	29×10^{-6}	86
	BeO	8×10^{-6}	260
	Copper/CuW	$6 - 8 \times 10^{-6}$	200-250
Advanced	Diamond	1×10^{-6}	1100-1600
	Carbon-Carbon Composites	$1\text{-}6 \times 10^{-6}$	300-600
	Metal Matrix Composites	$6\text{-}16 \times 10^{-6}$	820-890
	AuSn Solder	16	58



Bars in Groves



Rack & Stack

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 entering its third year.**
- **Group facilitates focused interaction between the LDA user and provider communities.**
- **Group will be authoring standards documents for 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:
    Mark Stephen; 301-614-6737; *mark.a.stephen@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:**
  - **Tuesday, September 26, 2006**
  - **Tuesday, January 23, 2007**
  - **Tuesday, May 29, 2007**

- **For more info:**
  - **Dave Tratt (JPL)**
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    dtratt@jpl.nasa.gov
  - **Farzin Amzajerdian (NASA LaRC)**
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    f.amzajerdian@nasa.gov