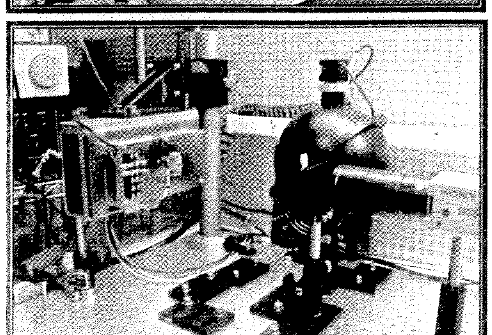
NASA GODDARD SPACE FLIGHT CENTER
LASER RISK REDUCTION PROGRAM
LRRP

ONE MICRON LASER TECHNOLOGY ADVANCEMENTS AT GSFC

William S. Heaps
William.S.Heaps@nasa.gov, 301-286-5106

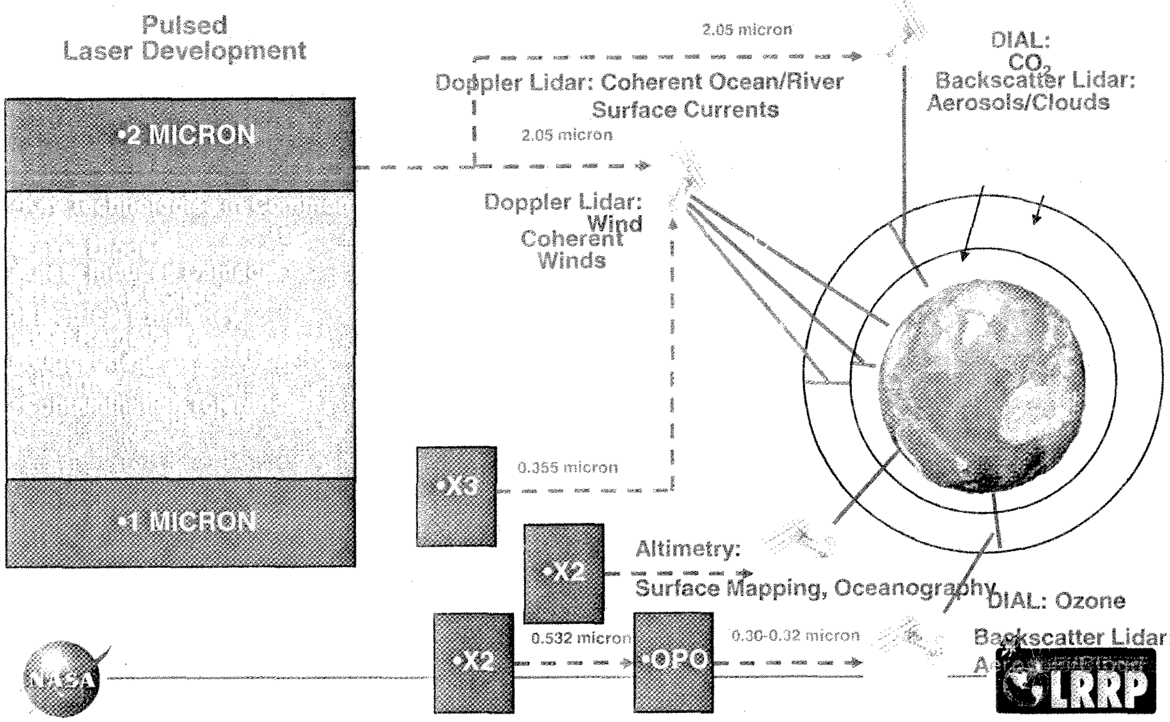
Functional Organization of GSFC Tasks

- **One Micron Laser Architecture**
  - Oscillator Theory
  - Oscillator Development
  - Amplifier Development
  - Thermal Management
  - Mechanical Tolerances and Packaging
  - Electronics
  - Laser Seeder
- **High Power Laser Diode Arrays**
  - Laser Diode Testing
- **Environmental Effects**
  - Gas Phase Contamination
  - Contamination Mechanisms
  - Radiation Testing
- **Frequency Conversion & Nonlinear Materials**
  - OPO Development for Ozone LIDAR
  - OPO Development for CO_2 LIDAR
  - Nonlinear Materials Life Test
- **Detectors**
  - Low Noise APD development
- **Knowledge Capture and Management**
  - Mechanical Mounts Database
  - Knowledge Database Development



Earth Sciences Application Foci

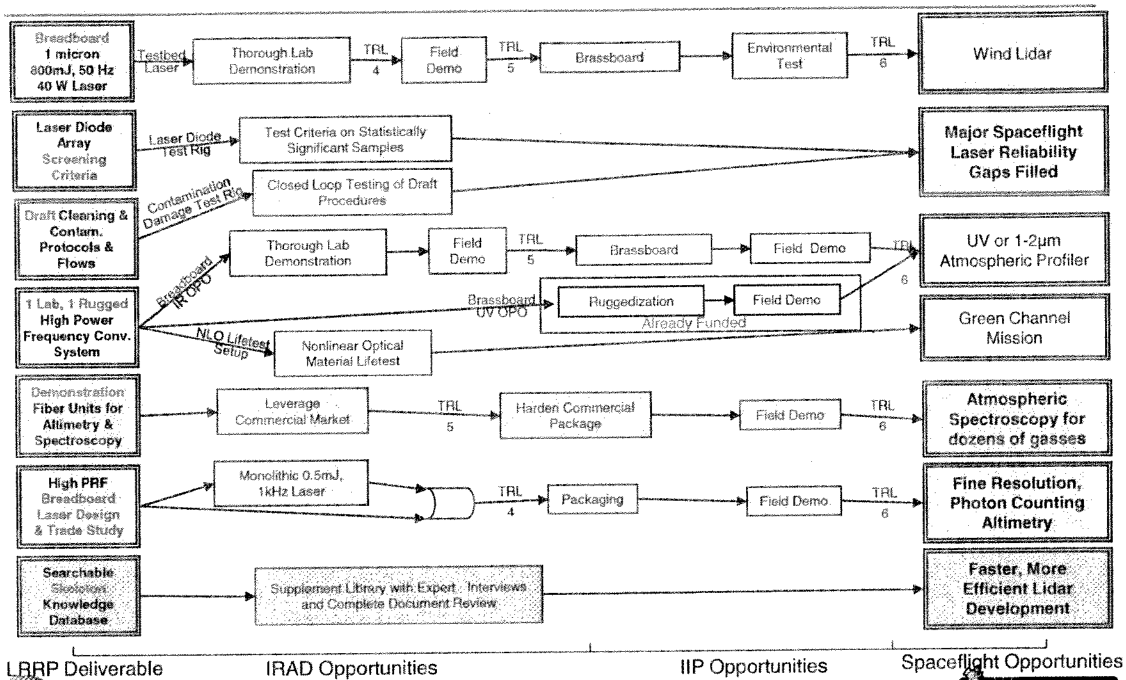
2 Lasers, 4 Techniques, 6 Priority Measurements



Risk Factors addressed by GSFC Tasks

	Diode Pumping	Architecture	Single Frequency	Electrical Efficiency	Heat Removal	Ruggedness	Lifetime	Graceful Degradation	Contamination Tolerance	Laser Induced Damage	Spectroscopic Frequencies
1 micron Oscillator Development	●	●	●	●	●	●		●			
1 micron Frequency Stabilization		●	●	●	●	●		●			
1 micron Amplifier Development	●	●		●	●	●		●			
Vacuum Lifetest of Heritage laser	●	●	●	●	●	●	●	●	●		
High Pulserate Laser	●	●			●	●		●			
Fiber Laser/Amplifier	●	●	●	●	●	●	●	●	●		●
OPO Development for CO2 LIDAR		●			●	●					●
OPO Development for Ozone LIDAR		●			●	●					●
High Power Laser Diode Arrays	●					●	●	●			
Contam. Induced Optical Damage						●	●	●	●	●	
Radiation Testing	●					●	●	●			
Knowledge Capture & Management	●	●	●	●	●	●	●	●	●	●	●

2007 Forecast for the 1 micron Future



Overview of Tasks

Thermal Management

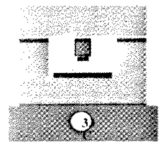
258-80-077

Dan Butler, NASA GSFC

Objective

Develop robust techniques for management of 100W space-based laser systems, with 2500 W of thermal heat load

Conductively Cooled Amp

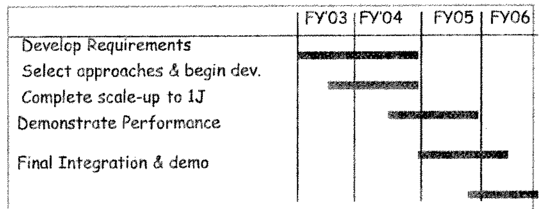


Spray Cooling

Approach

Develop/scale-up innovative technologies and demonstrate compatibility with a space mission
- CPLs and LHPs
- Spray Cooling
- Electrohydrodynamics
- Vapor Compression Systems

Schedule and Deliverables



Co-I's/Partners

Lou Fantano, Jeff Didion, Eric Silk, GSFC
LaRC, University of MD, Office of Naval Research (ONR), Illinois Institute of Technology, Wright-Patterson Air force Base, Swales

Applicability

Broad applicability to high-power laser systems intended for deployment in space.

TRL In = 3

Instruments Active Optical

Earth Sc... LRRP

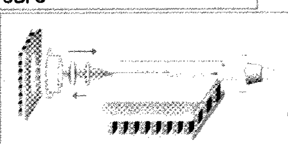
Diode Laser-Based Injection Seeder

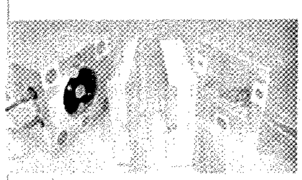
258-80-045

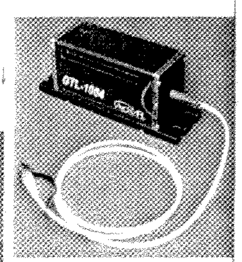
Barry Coyle, NASA GSFC

Objective

High power, Q-switched lasers must be injection seeded to guarantee single mode operation, thereby eliminating optical damage due to multi-longitudinal mode beating. A compact, efficient, single frequency, stabilized diode laser is being developed as a seed laser that can be readily configured for altimetry, wind and molecular lidar applications.







Accomplishments

Prototype seeder units have demonstrated 400-kHz linewidth operation.

1st prototype in use to identify seeding variables.
2nd prototype is currently being assembled.
Mechanical design for flight qualification in progress.

Schedule and Deliverables

1st prototype for preliminary injection seeding of HOMER received (3/03)
2nd prototype with PM fiber-coupled, ultra-stable design delivered (10/03)
Mechanical design for flight qualified use complete (9/03)

Projected Infusion

Incorporation into 1-micron testbed.

TRL Current = 4

Instruments Active Optical

Earth S... LRRP

Determination of Gas-phase Compounds Responsible for Lowering Damage Threshold of Optics in Sealed Lasers

258-80-0xx

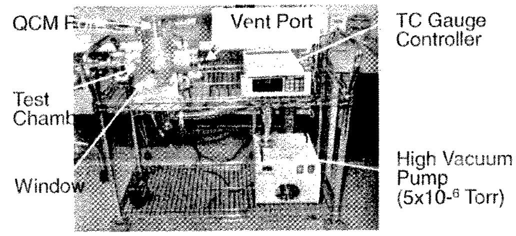
Christopher Scurlock, Genesis Engineering

Objective

Determine remediation procedure for "must use" compounds that present concerns.

Determine mechanism of damage.

Provide input for computational effort.

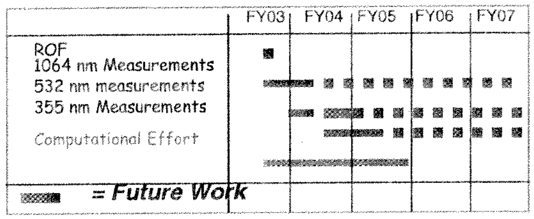


Approach

Compile database of compounds of concern which reduce optical damage threshold. Include parameters of concentration/film thickness, wavelength, atmosphere. (Determine "safe" compounds also.)

Perform tests to validate computational results.

Schedule and Deliverables



Co-I's/Partners

Dr. John Canham, Swales Aerospace
Fibertek, Inc
GSFC Code 545, Code 541

Applicability

Broad applicability to optical materials intended for deployment in space.

$TRL_{In} = 3$

Photon Counting Detectors for the 1-2 Micron Wavelength Range

258-80-082

Michael Krainak, NASA GSFC

Objective

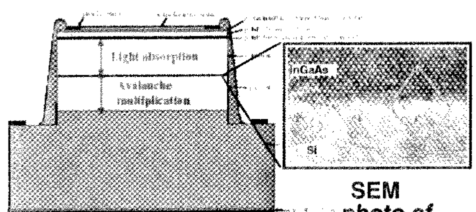
Optical detectors with photon counting sensitivity over the 1.0 - 2.0 micron wavelength range:

Quantum efficiency: 10 - 70%

Detector size: 200 mm diameter

Dark counts: < 100 kcps

Solid State APD: InGaAs photocathode, silicon or InAlAs avalanche region.



InGaAs-on-Si APD

SEM photo of InGaAs-Si interface

Approach

Most commercial InGaAs APDs are grown on indium phosphide (InP) substrates. To access improved noise performance it will be necessary to investigate alternative substrate materials. This task will procure InGaAs-Si APDs from Nova Crystals and InGaAs-InAlAs APDs from Spectrolab and conduct photon counting experiments at low temperature.

Schedule and Deliverables

Nov. 2003 - 1st gen InGaAs-InAlAs APD mfg. & test.

Mar. 2004 -1st gen InGaAs-Si APD mfg. & test.

Jul. 2004 - 2nd gen InGaAs-InAlAs APD mfg. & test.

Sep. 2004 -2st gen InGaAs-Si APD man. & test.

Co-I's/Partners

N/A

Applicability

Optical instruments operating in the 1-2 micron wavelength range.

$TRL_{In} = 2$

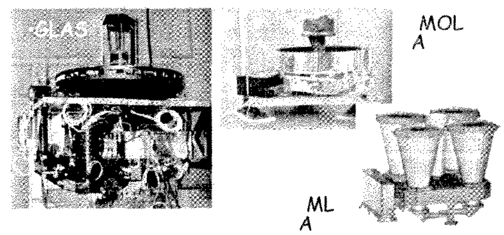
Optomechanical Mounts

258-80-081 | Andrea Poulin, NASA GSFC

Objective

Provide the LRRP with an informative collection of laser mount designs.

Provide engineers with multiple options/solutions to choose from for different laser configurations.



Approach

Conduct a study of several flight laser instruments to develop a database of different optomechanical mounts that have been used for mounting the various components of the lasers.

Document any issues/problems found with previous laser optomechanical mounts.

Develop new concepts and/or suggest improvements on previous laser mount designs.

Schedule and Deliverables

Task Name	Duration
Optomechanical Catalog of Lase	120 days
Research on MOLA I & II	30 days
Research on VCL	20 days
Research on GLAS	25 days
Research on MLA	25 days
Collaboration on Report	20 days

Co-I's/Partners

Armando Morell, James Marsh, William Mamakos, GSFC

LaRC, Industry

Applicability

Optomechanical mounting systems are a critical part of all laser instruments.

TRL = 3
In

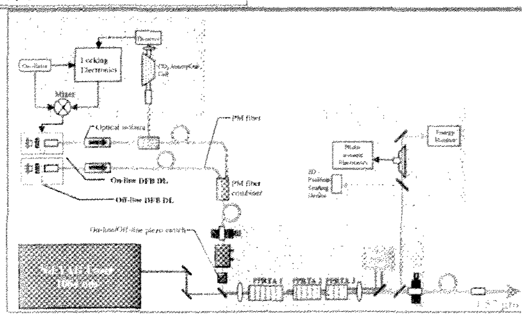
High Power, Narrowband, Infrared OPO

258-80-083 | John Burris, NASA GSFC

Objective

Develop and demonstrate efficient non-linear optics technologies for the conversion of 1-micron pump laser light into tunable IR wavelengths suitable for profiling CO_2 at very high precision (0.3%) from ground and space.

Develop and demonstrate narrow time averaged linewidth for IR optical parametric oscillator.



Approach

Apply optical parametric conversion techniques to downshift 1-micron radiation into the 1.57-micron CO_2 sounding band.

Schedule and Deliverables

Develop/characterize IR OPO

Demonstrate narrow time averaged linewidth

Deliverable: narrowband, tunable, highly efficient IR light source to enable active profiling of atmospheric constituents (esp. CO_2) from space.

Co-I's/Partners

Dale Richter, ITT

Applicability

High precision measurement of CO_2 from ground and space.

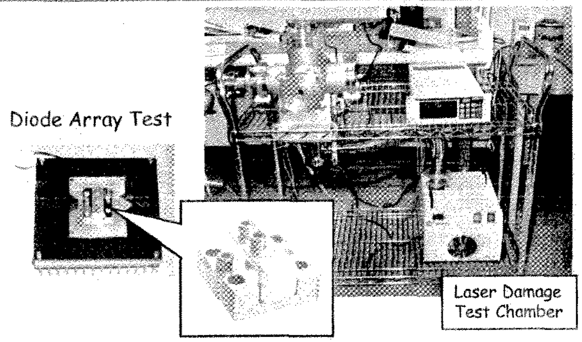
TRL = 3
In

Environmental Effects on Optical Mat'ls (FY07 220K$)

PI: Brad Boone JHU-APL

Objective

- Identify and test compounds used in the assembly of space-based lasers that may result in or cause laser induced optical damage.
- Evaluate radiation effects of laser diode arrays and nonlinear crystals to determine their reliability and suitability in the space environment for extended missions.



Approach

- Measure the effect of beta (Cobalt 60) and proton exposure on nonlinear optical mat'ls.
- Measure intrinsic differences in performance of non-linear optical materials

Co-I's/Partners

- Matthew Bevan, JHU-APL
- Galina Malivichko, Mont St

Key Accomplishments/Milestones

FY06 Conduct proton testing on "G" style laser diode package.

- FY06 Complete laser damage testing of original series of sample compounds.
- FY06 GC-MS measurements of space materials.
- FY07 evaluate non-linear material performance and correlate with differences in ENDOR spectra

TRL_{in} =3/4

Lifetime and Efficiency Studies of Nonlinear Optics Materials

258-80-044

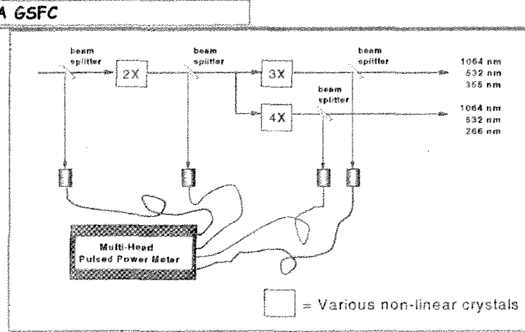
Edward Dowdye, NASA GSFC

Objective

Many lidar applications require coherent light at a wavelength other than 1.0 micron, requiring the use of nonlinear frequency conversion materials.

The longevity and durability of these materials is not well understood.

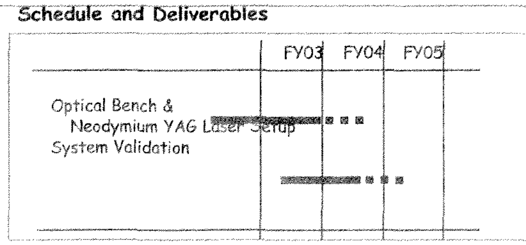
Our objective is to measure the operational lifetime and efficiency of various nonlinear crystals to determine their suitability for use in space.



Approach

Materials will be exposed to 1-micron laser radiation and used for frequency doubling, tripling, etc. Changes in performance as well as physical changes in the materials will be monitored.

Schedule and Deliverables



Co-I's/Partners

Dr. Hossin A. Abdeldayem, William L. Maynard, Dr. Chris Scurlock (GSFC);
Industry, Academia

Applicability

Broad applicability to optical materials and devices intended for deployment in space.

TRL_{In} = 3

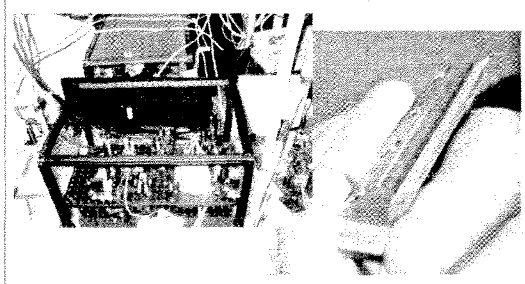
High Output Maximum Efficiency Resonator (HOMER) Development

258-80-080

Barry Coyle, NASA GSFC

Objective

Final goal is to significantly advance the state of the art for present and future laser mapping altimeters for vegetation, ice sheets and topography (earth and planetary) as well as atmospheric and wind lidars.



Approach

- Develop flight qualified one micron laser transmitter (LT).
- Target output energy = 100 mJ. Plan is to use this design for the oscillator stage of the 1.0 J LT.
- Final LT is to be fully environmentally tested, flight qualified and characterized.
- Parallel oscillator breadboards being built for margin, stability, and component studies.

Schedule and Deliverables

	FY'03	FY'04	FY05	FY06
Investigate new techniques for efficiently removing contamination				
Develop controlled test program				
Complete test program				
Complete final guidelines/protocols				
Publish guidelines/protocols				

Co-I's/Partners

GSFC Code 920/544 joint effort

Applicability

Altimetry, winds, ozone.

$TRL_{In} = 3$

Oscillator Architecture Evaluation

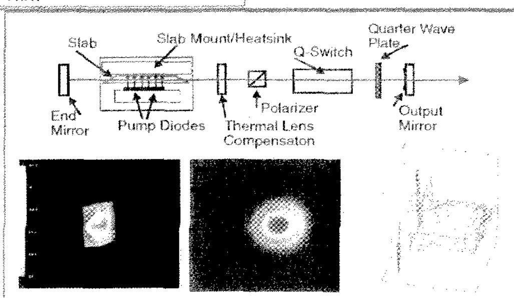
258-80-076

Richard Kay, American Univ.

Objective

Determine the state of the art of current laser oscillator architecture as it applies to space based applications.

Improve our current modeling techniques for laser oscillator design.



Approach

Review current oscillator designs: GLAS, VCL, MLA, MOLA, others

Improve Modeling Techniques, add software GLAD, LasCAD, OptiCAD,+

Create new oscillator designs

Breadboard and evaluate the new designs: Incorporate results in new designs

Schedule and Deliverables

- Existing designs modeled & evaluated
- New models made for 5-7 mJ lasers & breadboard side pumped 6-mJ zig-zag laser constructed & being evaluated
- Breadboard end pumped laser under construction.
- 100-mJ oscillator design undertaken

Co-I's/Partners

D. Poulios, American Univ.

Applicability

Broad applicability to laser system architectures intended for deployment in space.

$TRL_{In} = 3$

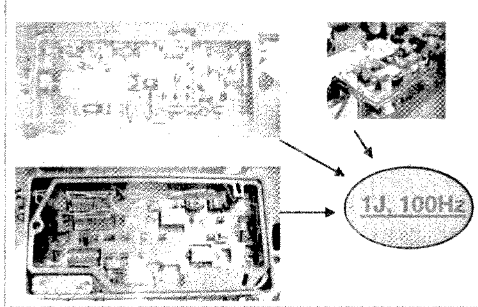
1 Micron Testbed (FY07 670 K$)

PI: Steve Li, NASA Goddard Space Flight Center, Code 554

Objective

- Develop and demonstrate technologies leading to a diode-pumped 1-micron, 800 milliJoule, 50 Hz laser for space-based lidar applications.
  - 100 mJ oscillator
  - 40 Watt optical amplifier unit.
- Demonstrate frequency stabilization on a 1064 nm oscillator.
- Construct a 10-20 mJ laser based on the space laser heritage existing within NASA. Demonstrate the capability of that laser to perform continuously, in vacuum environment over 3 billion shots.

1-Micron Testbed Laser



Approach

- Develop 1-micron, 800mJ Joule, 50 Hz "Testbed Laser". Use testbed to identify challenges to development of high average power space flight lasers. Test the design modifications which address those challenges.
- Develop 10-20 mJ "Heritage Laser" based on MOLA/GLAS/MLA flight programs. Place Heritage Laser in extended vacuum life test.

Co-I's/Partners

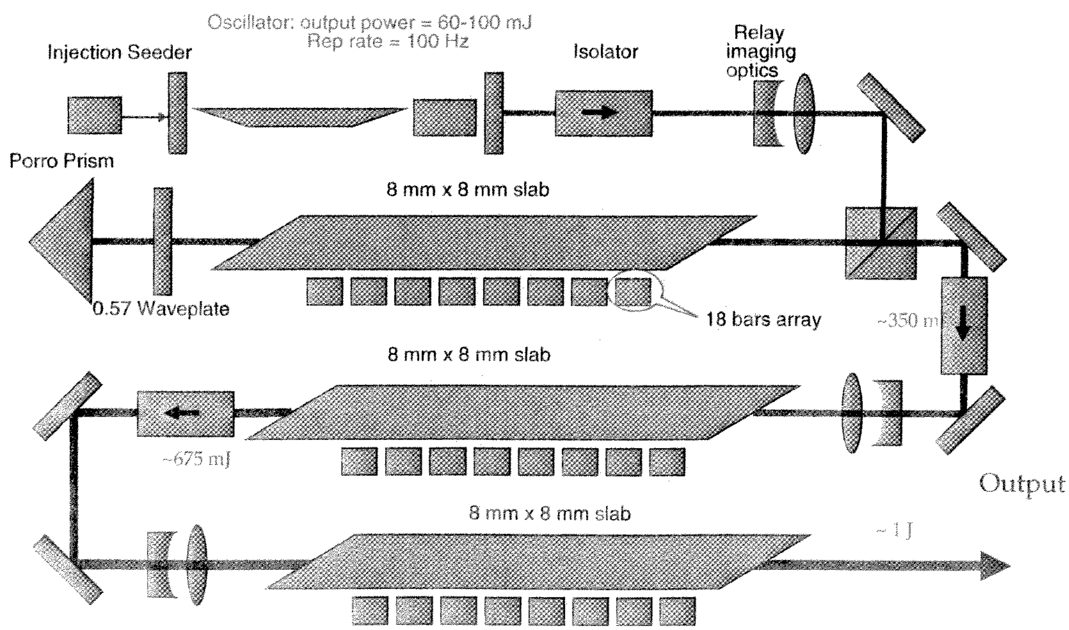
- Barry Coyle, GSFC 920
- Dr. R. Kay, American U.
- Dan Krebs, GSFC 554
- Alan Lukemire, SPE
- A. Rosanova/S. Chen. SSAI
- A. Novo-Gradac, GSFC 554

Key Accopmplishments/Milestones

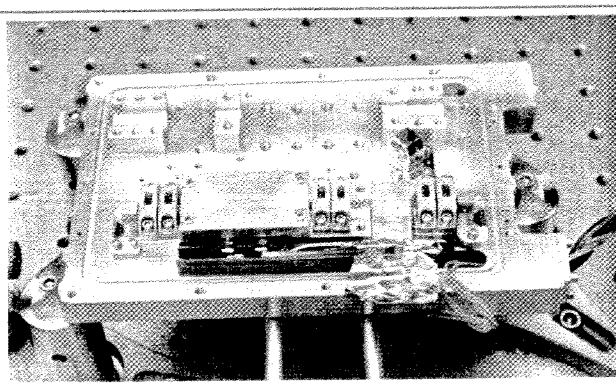
- 10/05 Amplifier integrated with 100mJ oscillator ✓
- 1/06 350 mJ output achieved from testbed. ✓
- 2/06 Vacuum Test Laser (Heritage Laser) operational. ✓
- 3/06 Vacuum test started.
- 8/06 All testbed pieceparts inspected & tested.
- 8/06 Vacuum test laser reaches 0.5B shots.
- FY07 Diagnose heritage laser degradation
- Fy07 Initate further Heritage design tests
- FY07 Complete build of laser amplifier

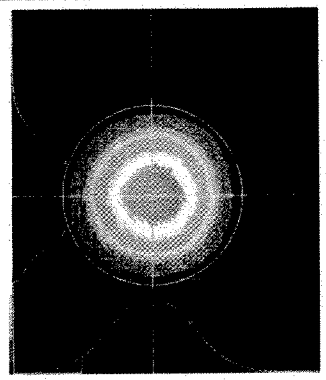
TRL_{in} =4

1 micron, 1 Joule Laser Design



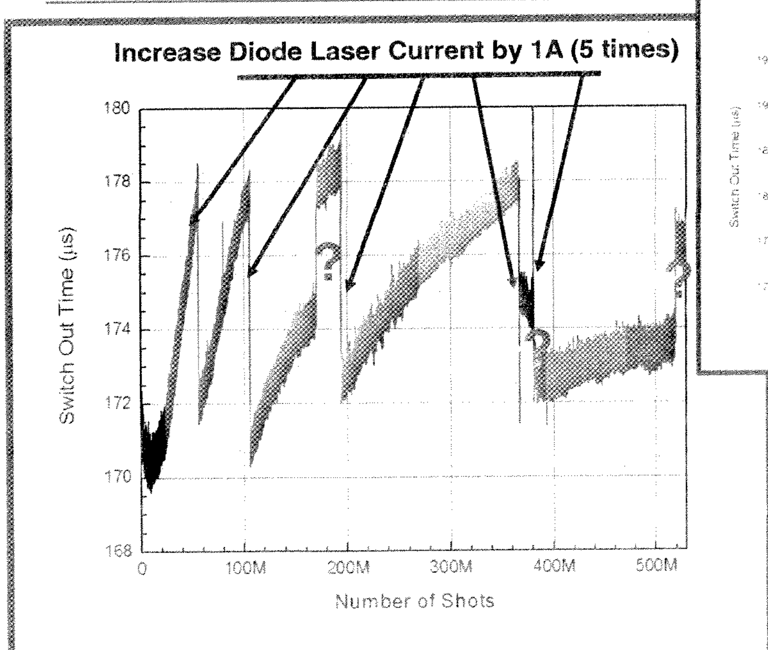
Heritage Laser Vacuum Test Unit: Oscillator Only

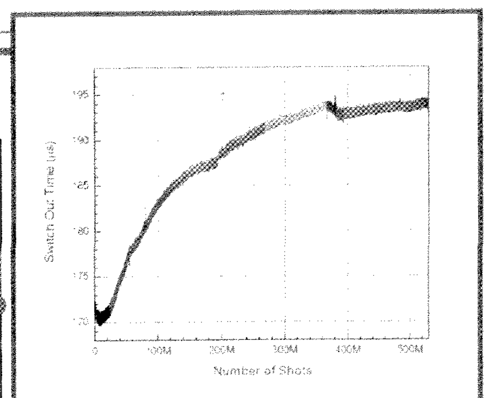




- Oscillator completed Feb. 2006.
- Highly stable TEMoo operation.
- 2.7 mJ, 80Hz, 170 microsecond switchout.
- Diode current 60A (MLA = 100A)
- Stable over wide thermal range.
- Pump diodes = CEO

Switch Out Time Behavior



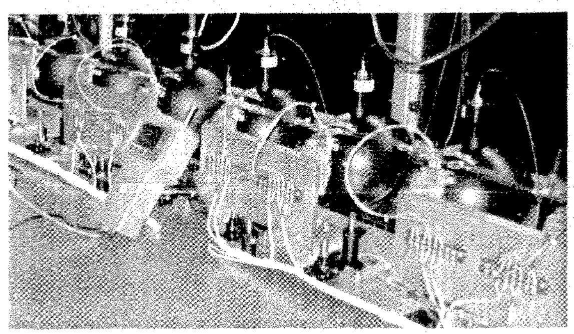


6-7 µs decrease in switch out time per 1A increase of diode laser current

PI: Mark Stephen, NASA Goddard Space Flight Center, Code 554

Objective

- Quantify effect of operational and environmental parameters on Laser Diode Array (LDA) performance.
- Develop procedures for purchasing, handling, storage and operation.
- Develop prediction/screening capability.
- Enable improved reliability and performance of future laser missions.



Approach

- Develop complete characterization capability of LDAs to establish a baseline for individual array performance and status.
- Test LDAs under various operational and environmental conditions and measure effects.

Co-I's/Partners

- Applied Physics Lab (APL)
- Coherent Photonics Group
- Cutting Edge Optronics (CEO)
- SSAI
- Sigma

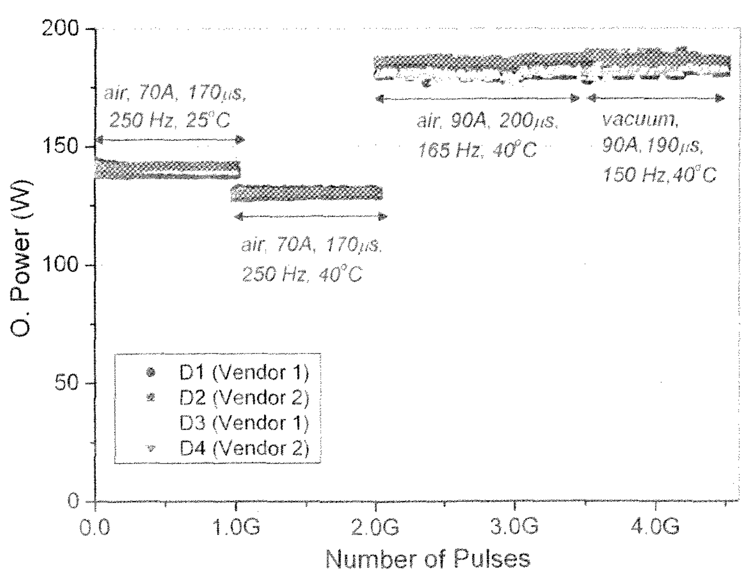
Key Accomplishments/Milestones

- New measurement capabilities - time-resolved thermal imaging, polarized near-field analysis, Micro-photoluminescence spectroscopy.
- 1 billion pulses on LDA test measuring effects of power and temperature cycling.
- Results of proton radiation and vibration testing.
- Second generation, extended operation performance test.
- FY07 Testing of newer diode designs.

TRL_{in} =4

4-LDA Accelerated Performance Test

Nuvonyx & Coherent Arrays – Engineering Models (EM) for Lunar Orbiter Laser Altimeter (LOLA)



This is accelerated performance test of 4 LDAs (G2 packages) to qualify two vendors [Nuvonyx (1) & Coherent (2)], observe potential problems and compare performance to assist choosing the flight vendor for LOLA mission.

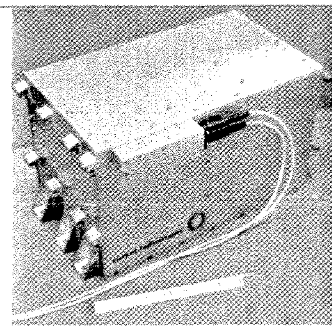
Test was stopped after **4.86 billion pulses.**

Space Qualifiable Fiber Lasers/Amplifiers (FY07 430 K$)

PI: Michael Krainak, NASA Goddard Space Flight Center, Code 554

Objective

To develop low-risk space-qualifiable fiber laser/amplifier technology for NASA Earth science, lunar and planetary active-remote-sensing exploration and scientific instruments.



Lucent Technologies 10 W optical power - CW Space Qualifiable Erbium Fiber Amplifier [developed for communications].

NASA science and exploration instruments have unique requirements that call for additional development but will use this technology as a foundation.

Approach

- Leverage present capability from US DoD and telecom industry (high power fiber amps for comm) to develop space-qualifiable fiber laser and amps for NASA science & exploration applications
- Emphasize 2 near term NASA applications: Atmospheric Spectroscopy (e.g. Mars/Earth H2O, CO2 and CH4) and 3-D mapping (e.g. Moon/Mars landing sites & topography)

Co-I's/Partners

- US Commercial and Aerospace Industry: Northrop-Grummann, Hughes, Lucent, IPG Photonics, Keopsys, Nufern, Aculight, Fianium

Key Accomplishments/Milestones

- 8/06 SBS model validated with experimental data and including temp and ε
- 10/06 Demonstrate optimized narrow-λ high peak pwr Nd, Er, and Yb fiber amps.
- Evaluate units under procurement
- Fy 07 Increase output power with narrow Bandpass
- FY 07 Complete model of SBS

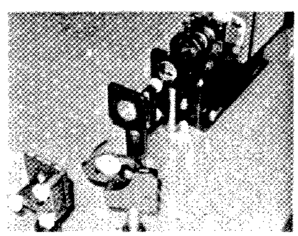
TRL_{in} =3 (for this NASA application specific te

High Pulserate Laser for Altimetry (FY07 100K$)

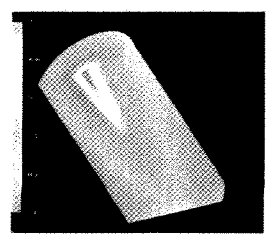
PI: George B. Shaw, NASA Goddard Space Flight Center, Code 554

Objective

- Develop breadboard, high pulse rate (1-10 kHz) lasers with pulse energies greater than 750μJ for altimetry applications .
- Perform design trades of passive versus active q-switching and monolithic versus non-monolithic laser designs.
- Evaluate the new, high power fiber-coupled pump arrays that are becoming commercially available.



End pumped Laser



Temperature Profile Calculation

Approach

- Model and construct end-pumped lasers using the new fiber coupled pump arrays.
- Evaluate design limits and q-switching methods for this class of laser.
- Evaluate various design schemes to meet the desired specifications.

Co-I's/Partners

- Steven Li, GSFC 554
- Antonio Seas, GSFC 554

Key Milestones

Beginning with 0.5 mJ 1 kHz laser:

Increase rep rate to 5-10 kHz

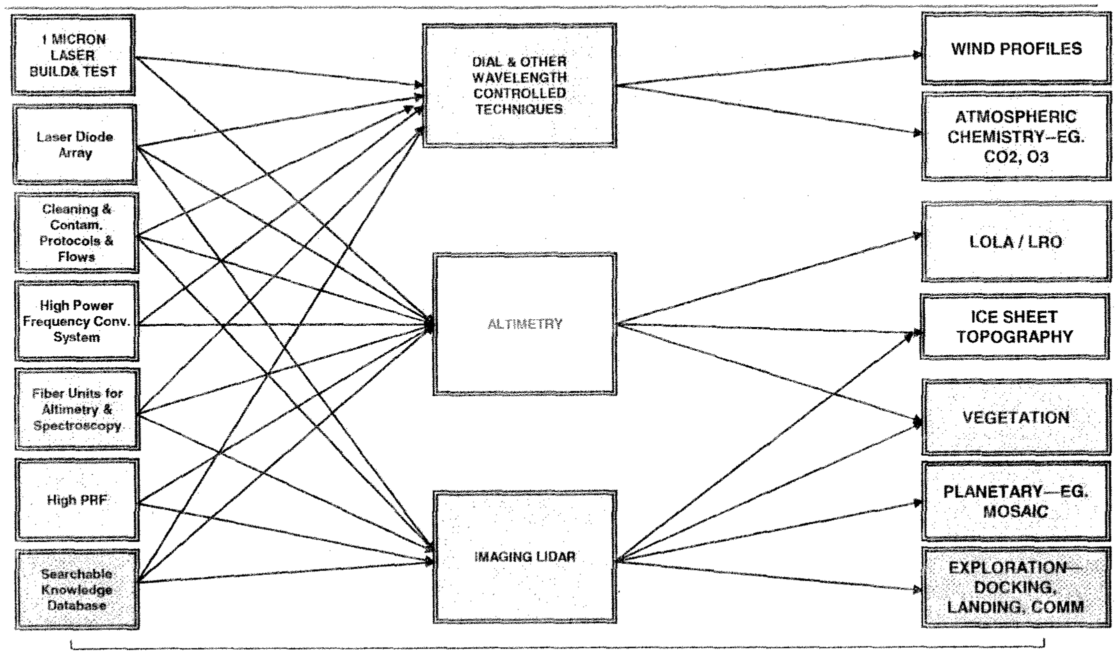
Increase Energy to 1.0 mJ

Improved beam quality

All tasks completed by end of FY07

TRL_{in} =3

LRRP supports NASA mission opportunities



Highlights

- Over 25 publications and conference presentations. One national award, and several patents in application process.
- Many Tasks in LRRP directly or indirectly support missions recommended in the NRC Decadal Survey
  - Ice Sheet Laser Altimeter
  - Column CO2 Laser Sounder
  - Wind Lidar

Partnering with Industry and Academia

- Industrial Partners
  - AdvR Corporation
  - Genesis Engineering
  - ITT Advanced Engineering Systems
  - Science Systems and Applications Inc. (SSAI)
  - Space Power Electronics
  - Mantech
- Academic Partners
  - American University
  - Johns Hopkins University
  - Montana State University
  - University of Maryland

LRRP

Publications (1/3)

- H. Abdeldayem, E. Dowdye, J. Canham, S. Ghazanshahi. "Micro-gravity and contamination roles in spaceflight laser failures." Proc. SPIE Int. Soc. Opt. Eng. 5912, 59120H (2005)
- H. Abdeldayem, E. Dowdye, J. Canham, T. Jaeger. "Contamination and radiation effects on spaceflight laser systems." Proc. SPIE Int. Soc. Opt. Eng. 5897, 589705 (2005)
- G. R. Allan, A. Vasilyev, E. Troupaki, N. Kashem, M. A. Stephen, "Time-Resolved Optical & Thermal Analyses of High-Power Laser Diode Arrays", 2005 Earth-Sun System Technology Conference, Adelphi, MD, June 28 - 30, 2005
- J. S. Canham. "Identification and measurement of changes in the properties of molecular-contamination-related laser induced damage to fused silica." Proc. SPIE Int. Soc. Opt. Eng. 5647, 95 (2005)
- J. S. Canham. "Short path thermal desorption GC/MS for screening of molecular contamination in laser systems." Proc. SPIE Int. Soc. Opt. Eng. 5647, 427 (2005)
- J. S. Canham. "Coalescence of phenomenological laser damage, materials properties, and laser intensity: moving toward quantitative relationships." Proc. SPIE Int. Soc. Opt. Eng. 5273, 93 (2004)
- J. S. Canham. "Cleaning to the monolayer level." Proc. SPIE Int. Soc. Opt. Eng. 5273, 207 (2004)
- J. S. Canham. "Molecular Contamination damage prevention: Lessons learned from vacuum laser operation." SPIE Code 5991-9
- J. S. Canham. "Surface Analytical evaluation of contamination related laser induced damage to a TIR slab." SPIE Code 5991-47
- D. B. Coyle, R. B. Kay, P. R. Stysley, D. Poulios. "A Diode Pumped, Nd:YAG, Q-Switched Unstable Resonator Developed for Multi-Billion Shot, Spaced-Based Remote Sensing Applications." CLEO/PHAST Conference Proceedings, (Baltimore, MD, May 2005).
- D. B. Coyle, R. B. Kay, P. R. Stysley, D. Poulios , "High Output Maximum Efficiency Prototype Diode-Pumped Laser for Space Application." ESTO Conference Proceedings, (College Park, MD, June 2005).
- D. B. Coyle, R. B. Kay, P. R. Stysley, D. Poulios. "High Reliability, Long Life, Diode Pumped Nd:YAG Unstable Resonator for Space-Based Vegetation Altimetry and Terrain Mapping." Appl. Optics, 43, 5236-5242 (2004).

LRRP

Publications (2/3)

- J. R. Didion. "Advanced Research and Development for Two Phase Spacecraft Thermal Control." International Two Phase Thermal Control Technology Workshop, March 2005
- J. R. Didion. "Thermal Control of Robotic and Laser Systems." International Two Phase Thermal Control Technology Workshop, March 2005
- J. R. Didion. "Intelligent, Optimized Thermal Control Systems." Interagency Power Group Meeting, May 2005
- W. Heaps, A. Novo-Gradac. "Progress in Laser Risk Reduction for 1 micron lasers at Goddard Space Flight Center." Earth Science Technology Conference, 2005.
- W. Heaps, A. Novo-Gradac. "Progress on Space Borne Laser Risk Reduction at Goddard Space Flight Center." 22nd Internation Laser Radar Conference (ILRC 2004), 12-16 July, 2004, Matera, Italy
- S. Jeong, J. Didion. "Thermal Control Utilizing an Elelctrohydrodynamic Conduction Pump in a Two Phase Loop with a High Heat Flux Source." International Mechanical Engineering Congress and Exposition, Paper no. IMECE2004-60210, November 13 - 19, 2004, Anaheim California
- S. Jeong, J. Didion. "Perfromance Characteristic of Electrohydrodynamic Conduction Pump in Two-Phase Loops." To be published in AIAA
- R. B. Kay, D. Poulios. "Q-Switched Rate Equations for Diode Side-Pumped Slab and Zig-Zag Slab Lasers Including Gaussian Beam Shapes." IEEE JQE October 05.
- F. Peri, W. Heaps, U. Singh. "Laser risk reduction technology program for NASA's Earth Science Enterprise." Lidar Remote Sensing for Industry and Environment Monitoring III. March 2003, pp. 166-175
- U. N. Singh, W.S. Heaps. "Laser technology maturation and risk reduction for space-based remote sensing." Lasers and Electro-Optics Europe, 2003. CLEO/Europe. 2003 Conference on 22-27 June 2003 Page(s):67

Publications (3/3)

- M. A. Stephen, A. Vasilyev, "Characterization of 808 nm Quasi-constant Wave Laser Diode Arrays" in *Earth Science Technology Conference*, (2003)
- M. A. Stephen, A. Vasilyev, J. Schafer, G. R. Allan, "Qualification of Laser Diode Arrays for Mercury Laser Altimeter", *International Laser Radar Conference*, July 2004.
- M. A. Stephen, A. Vasilyev, E. Troupaki, G. R. Allan, N. Kashem, "Characterization of 808-nm quasi-CW laser diode bars", *(Invited Paper)*, (Optical Engineering and Instrumentation), Proceedings of SPIE vol. #5887 [5887-10] SPIE Optics & Photonics 2005 San Diego, CA, 31 July - 4 Aug 2005
- E. Troupaki, N. B. Kashem, G. R. Allan, A. Vasilyev, M. Stephen, "Space Qualification of Laser Diode Arrays", 2005 Solid State & Diode Laser Technology Review, Los Angeles, CA, 7 -9 June 2005
- A. Vasilyev, G. R. Allan, J. Schafer, M. A. Stephen, S. Young, "Optical and thermal analyses of high power laser diode arrays" in the Directed Enegy Professional Society's *2004 Solid State and Diode Laser Technology Review*, Albequerque, June, 2004.

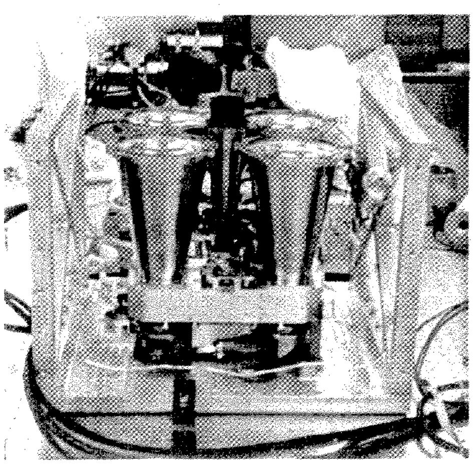
The 1 micron legacy

Several successful missions and missions in planning have benefited from advances by the LRRP:

Messenger Laser Altimeter
Lunar Orbiter Laser Altimeter
ICESAT II
DESDYNI
ASCENDS
WIND LIDAR

Messenger Laser Altimeter

MLA used laser diodes whose performance was verified by LRRP protocols.

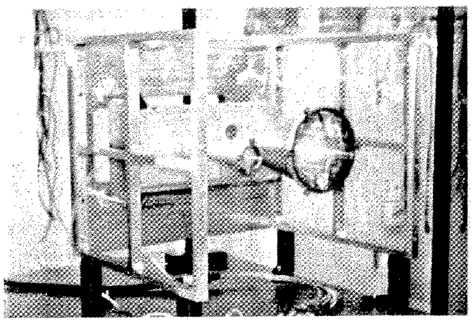


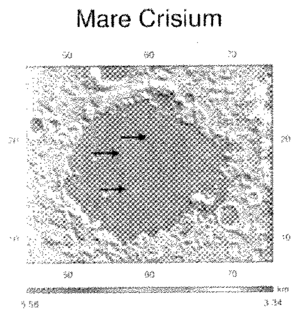
Two-Way Laser Link over Interplanetary Distance
David E. Smith,[1] Maria T. Zuber,[1,2] Xiaoli Sun,[1] Gregory A. Neumann,[1,2] John F. Cavanaugh,[1] Jan F. McGarry,[1] Thomas W. Zagwodzki[1]

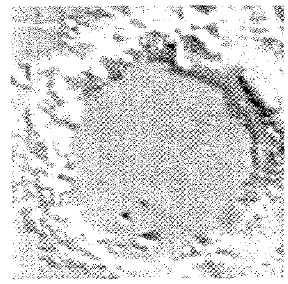
Here we report timed observations with subnanosecond precision of short laser pulses at a distance of nearly 24 million kilometers between the Mercury Laser Altimeter (MLA) aboard the MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) spacecraft and the NASA Goddard Geophysical and Astronomical Observatory (GGAO). Forty MLA downlink observations and 90 uplink observations were obtained during observing sessions on 27 and 31 May 2005. Precise standard ground timing allowed a solution for spacecraft range, range rate, and acceleration, as well as clock bias. This experiment established a new distance record for laser detection and accomplished a two-way laser link at an interplanetary distance.

Lunar Orbiter Laser Altimeter

LOLA was designed built and flown in record time because of knowledge gained in LRRP

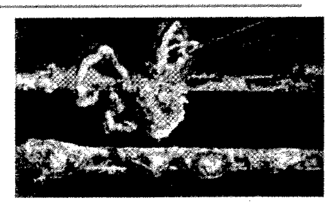


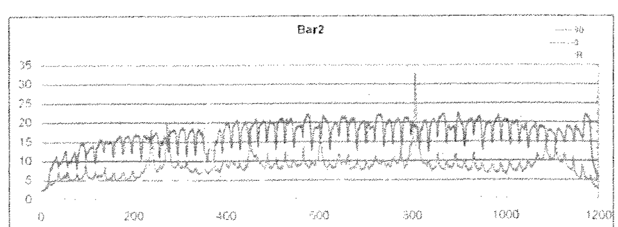




We Have Learned a Lot about Diodes

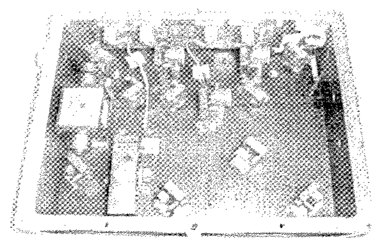
- >6 years diode life testing
- Diode design improvements
- Established working group with vendors
- Diagnostic tests for acceptance
- Radiation tolerance is excellent
- Knowledge base for other NASA programs





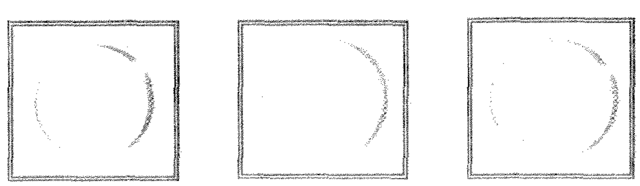
We Have Learned a Lot about non-Linear Materials

- Developed new robust OPO's and OPA's
- Examined radiation damage and observed self healing
- Consulted with other NASA programs on crystal degradation
- Uncovered new diagnostics for material quality



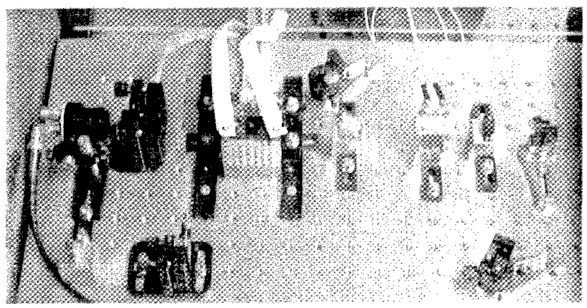
We Have Learned a Lot about Contamination

- Some commonly used cleaning solvents enhance laser damage
- Some commonly use adhesives enhance laser damage
- Presence of oxygen in laser container can reduce risk
- Developed comprehensive diagnostics to evaluate damage when it occurs
- Consultant to other NASA programs



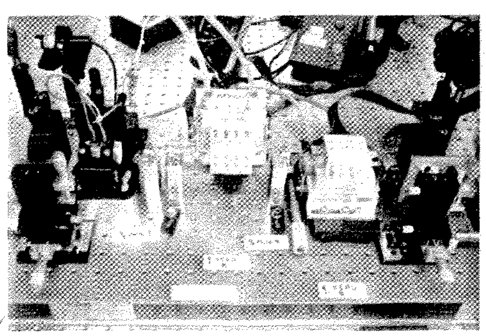
We Have Learned a Lot about Wavelength Control

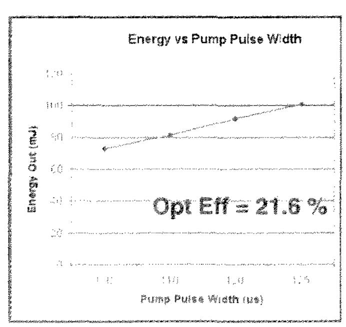
- Supported development of new low cost solid state seeder
- Developmental work on seeding techniques for space
- Seeding reduces risk of laser damage



We Have Learned a Lot about Laser Design

- Developed several new oscillator types
- Developing "BIG" Amplifier
- Lifetime testing of HOMER Laser
- Vacuum Lifetime testing of "Heritage" laser
- Developmental work on Fiber Lasers





We Have Learned a Lot More......But

New applications for lasers in space proposed every day

We have not tested some types of diodes that we will need in the future

We have not tested diodes for as long as some missions propose to operate

We have techniques to differentiate between materials and components but we have not determined which are good and which are bad

FOR MOST MISSIONS EMPLOYING LASER TECHNOLOGY THE LASER REMAINS THE HIGHEST RISK ELEMENT FOR THE MISSION

All good things must end but...

We wish to thank NASA's Earth Science Technology Office for its continued support and encouragement.