Advancement of Lidar Technologies at NASA Langley

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NASA Langley Research Center

Meeting of the Working Group on Space-Based Lidar Winds

Frisco, Colorado

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Laser Risk Reduction Program

Langley Research Center (LaRC)

Program Description

- **Pro-actively targets deficiencies in laser technology for focused development and risk mitigation**
  - Technology readiness overestimated in past due to extrapolation from prior heritage
  - Flight lasers are still at the "build-to-order" R&D stage
- **Primary focus is on high-power (i.e., transmitter-class) lasers for space-based remote sensing applications**
  - High-performance Nd:YAG systems (1 μm)
  - Emerging holmium- and thulium-doped lasant materials (2 μm)
  - Nonlinear generation schemes based on 1- and 2- μ m pump sources
    - Harmonic generation
    - Optical parametric amplification/oscillation (OPA/OPO)
- **Small investments in ancillary enhancing and enabling technologies which offer potential to reduce demand for laser power (detectors, innovative receiver approaches)**

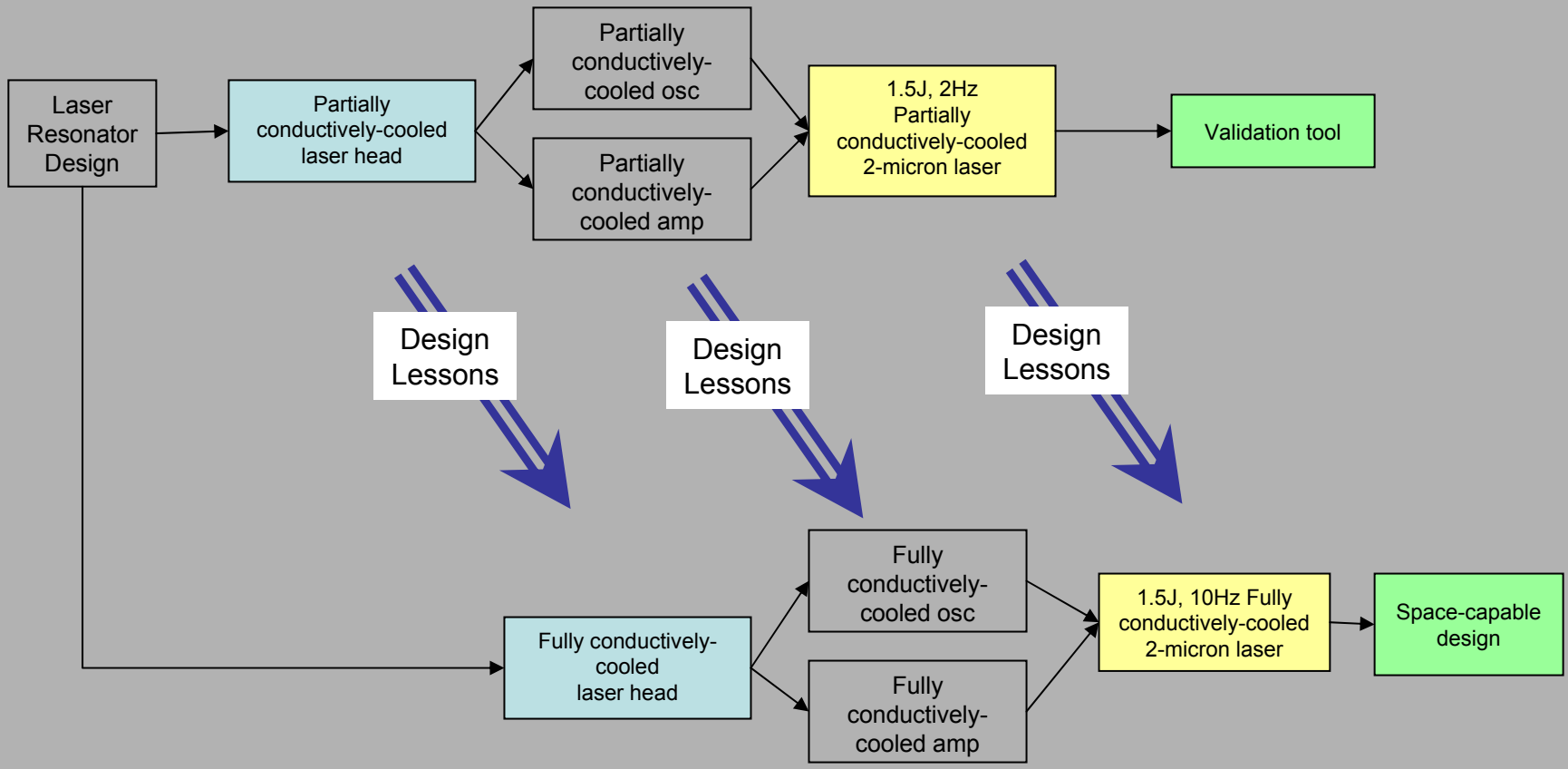
LRRP Application Driven Elements

Langley Research Center (LaRC)

- **2-micron laser transmitter**
  - Demonstrate technologies leading to a conductively cooled, diode-pumped 2-micron laser suitable for space-based lidar application
  - Address major laser development issues: High energy, high efficiency, laser-induced optical and thermal damage, system thermal management
- **High-power diode laser pump arrays**
  - Evaluate currently available laser diode arrays for performance, life and configuration required for future space-based laser missions
  - Establish Characterization and Lifetime Test Facility to address laser diode issues:
    - Limited reliability and lifetime
    - Lack of statistical and analytical bases for performance and lifetime prediction
  - Conceive advanced laser diode array architectures with improved efficiency and thermal characteristics
  - Develop, scale, and qualify long-lived, space-compatible laser diode arrays
- **Nonlinear optics research for space-based ozone DIAL**
  - Spectrally narrow, tunable, robust UV laser architectures
  - Develop long-lived, efficient, space-compatible, nonlinear optical materials/techniques
- **Receiver technologies**
  - Develop integrated heterodyne receiver to demonstrate 3-dB improvement of coherent lidar system efficiency with 80% reduction of required local oscillator power
  - Develop improved quantum efficiency photon-counting detectors at 2 micron
- **Laser physics and advanced materials research**
  - Develop line tunable diode-pumped Nd laser system for pumping nonlinear UV generation schemes
  - Develop narrowband, long pulse, low average power pump laser for wavelength control of lidar systems

2-micron Laser Technology Roadmap

Langley Research Center (LaRC)

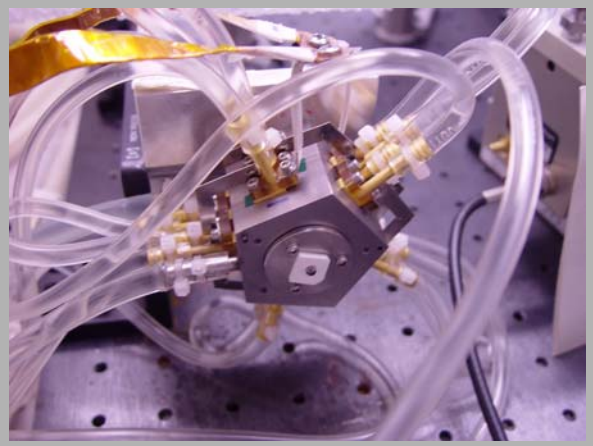


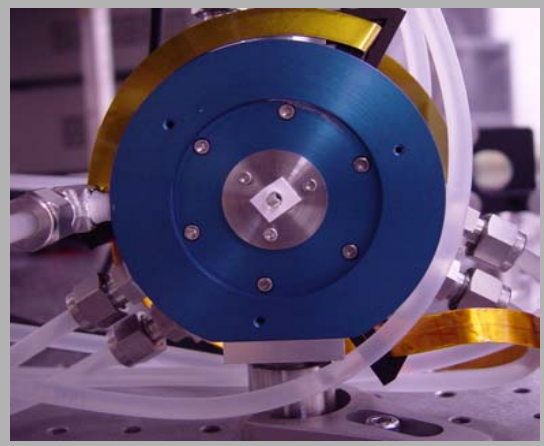
FY 02 | FY 03 | FY 04 | FY 05 | FY 06 | FY 07

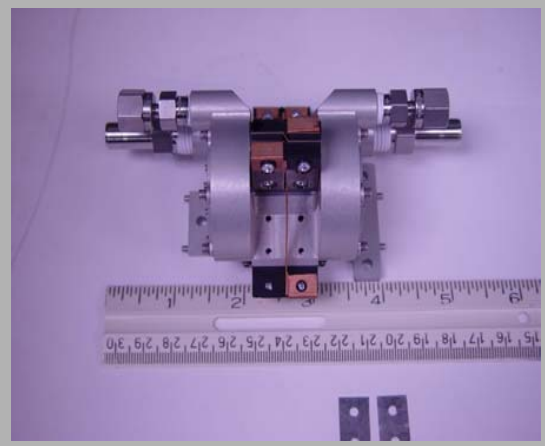
2-micron Laser Technology Development

Langley Research Center (LaRC)

Liquid Cooled Laser
Laser head assembly







10 diode arrays with total pump energy 3.6 Joules

22 water channels

6 diode arrays with total pump energy 3.6 Joules

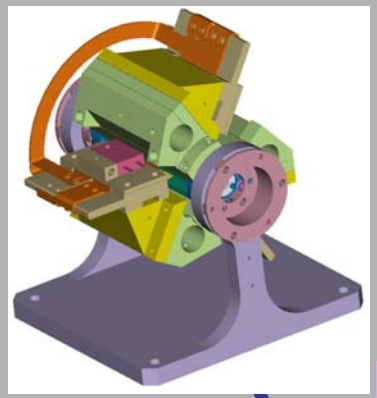
8 water channels

6 diode arrays with total pump energy 3.6 Joules

4 water channels

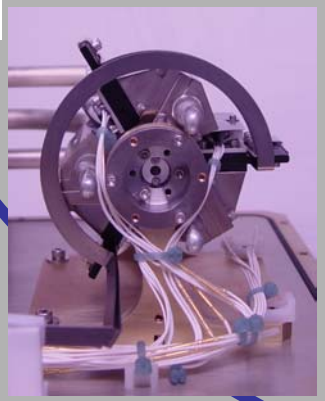
2-micron Laser Technology Development

Langley Research Center (LaRC)



Demonstrated Fully conductively cooled 2-micron solid-state pulsed laser.

Analysis & Design



Fabrication

System Integration

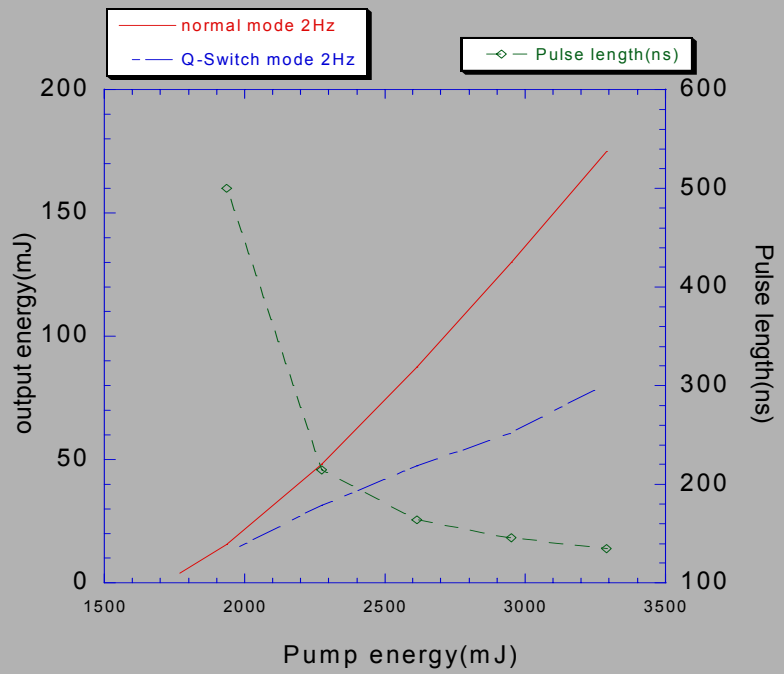
Testing and Model Verification

<u>Technology Enables</u>: Measurement of global CO_2 and/or tropospheric winds from a space platform

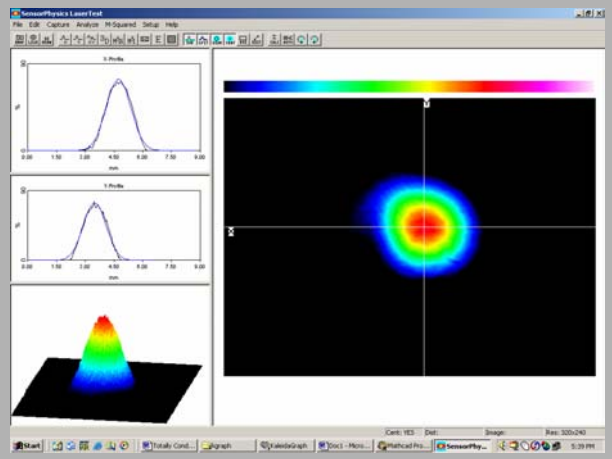
2-micron Laser Technology Development

Langley Research Center (LaRC)

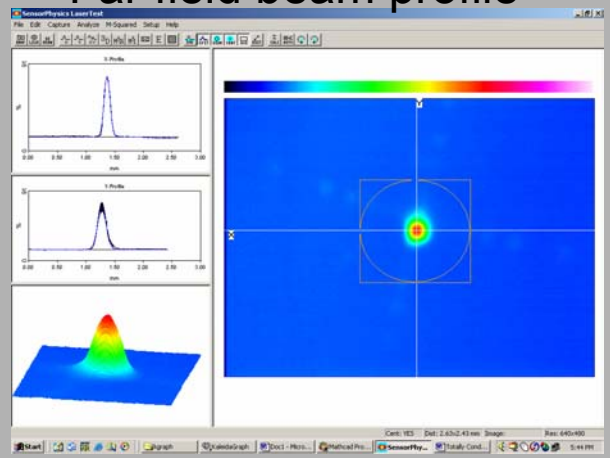
Fully conductive cooled laser output performance



Near field beam profile



Far field beam profile



2-micron Laser - Status

Langley Research Center (LaRC)

- Successfully advanced the laser head design, fabrication, and assembly technologies. The laser head had progressed from liquid cooled to partially liquid cooled to monolithic partially liquid cooled and in parallel, fully conductively cooled development stages. A 2-micron coherent wind lidar quality laser transmitter with high energy has been demonstrated and delivered for Validar.

- Successfully demonstrated Ho:Tm:LuLF laser system with 1050 mJ Q-switched output energy. It is accomplished by one power oscillator and two amplifiers at double pulses format. It is the first time that a Q-switched 2-micron laser exceeds 1 J level, and it is one order of magnitude higher energy than previously demonstrated by any other group. In the last 10 years, LaRC has advanced the energy from 20 mJ to 1 J

- Successfully demonstrated the first fully conductive cooled 2-micron pulse laser. The heat from both the laser crystal and the pump diode laser arrays was successfully removed using heat pipe technology that is appropriate to future space applications. The experimental Ho:Tm:LuLF laser oscillator operated in normal mode and produced pulses of 220 mJ at 10 Hz pulse repetition frequency.

Advancement and Risk Reduction of Laser Diodes

Langley Research Center (LaRC)

Laser Diode has been identified as a major risk area in deployment of Lidar instruments in space

Laser Diodes Establish Instrument Lifetime

OBJECTIVE

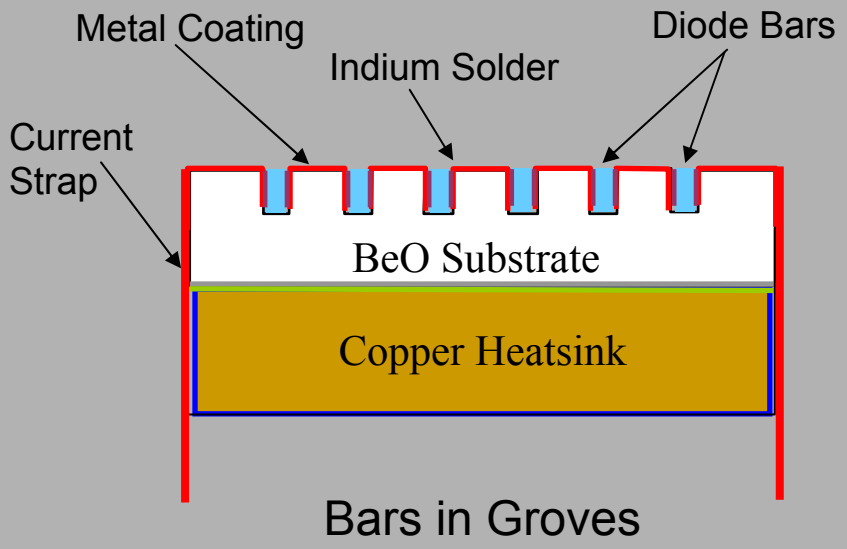
Address Laser Diode issue:

- **Limited reliability and lifetime**
- **Lack of statistical and analytical bases for performance and lifetime prediction**
- **Limited commercial availability**

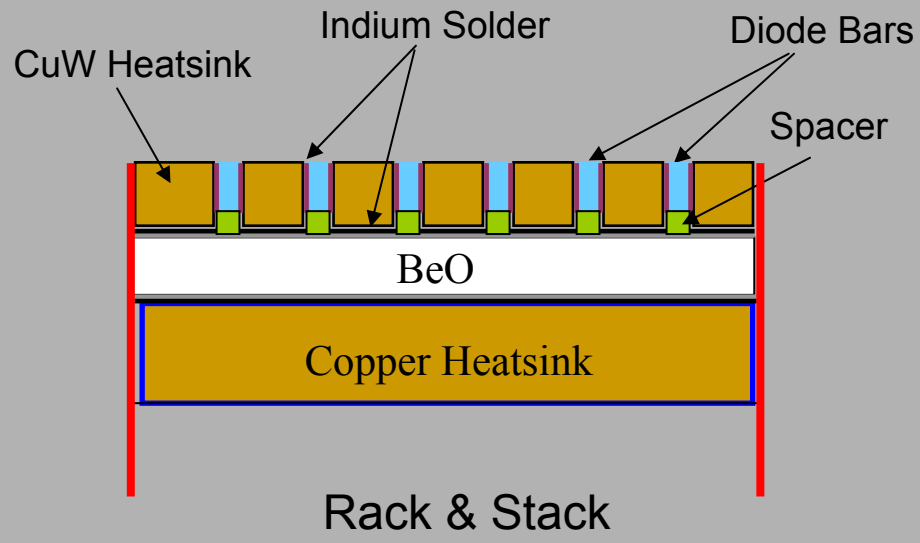
Emphasizing 792 nm arrays used for pumping 2-micron Lasers

Current Laser Diode Array Packages

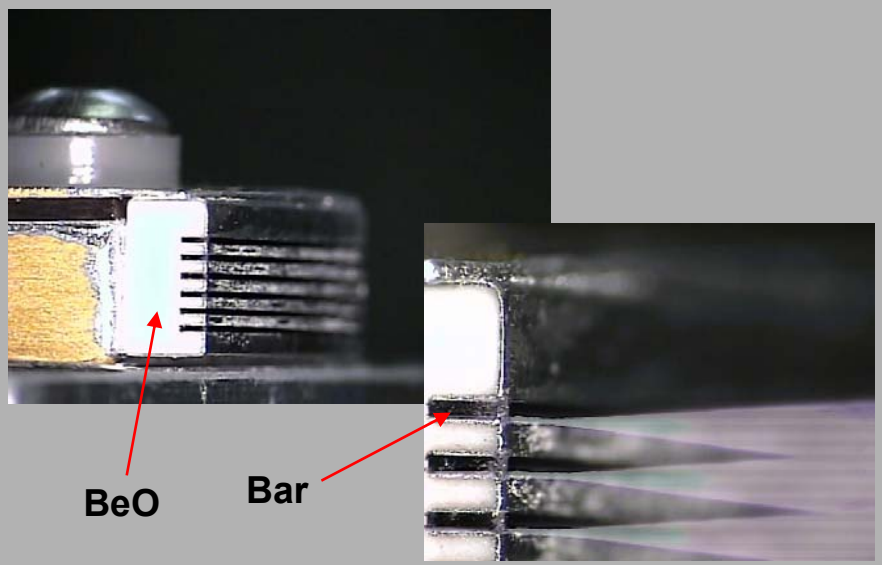
Langley Research Center (LaRC)

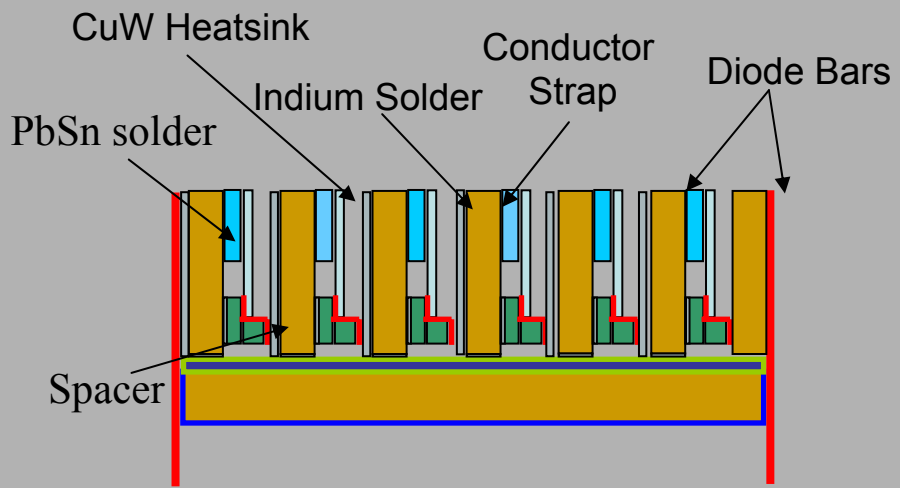


Bars in Groves



Rack & Stack





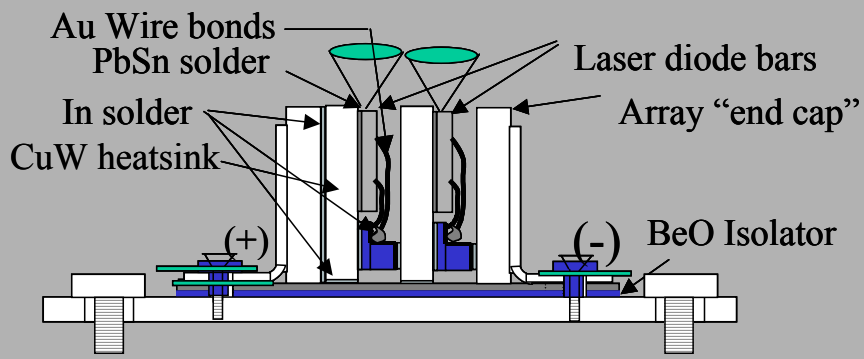
Stacked Subassemblies

Causes of Laser Diode Failure

Langley Research Center (LaRC)

Failure Cause	Effect	Comment
Laser Bar Material Defect	Bar Shunt	Wafer growth has improved substantially
Thermal Cycling	Accelerated Aging	Major issue for 2-micron Laser Diode Pump
Solder Creep/Migration	Short Circuit	Soft Indium solder is commonly used
Solder De-bonding	Premature Failure	Production practices and workmanship
Bond Wire Failure	Open Circuit	Used in old SDL diodes (MOLA, GLAS, CALIPSO)

SDL Package



Thermal Effects on Laser Diode Lifetime Degradation

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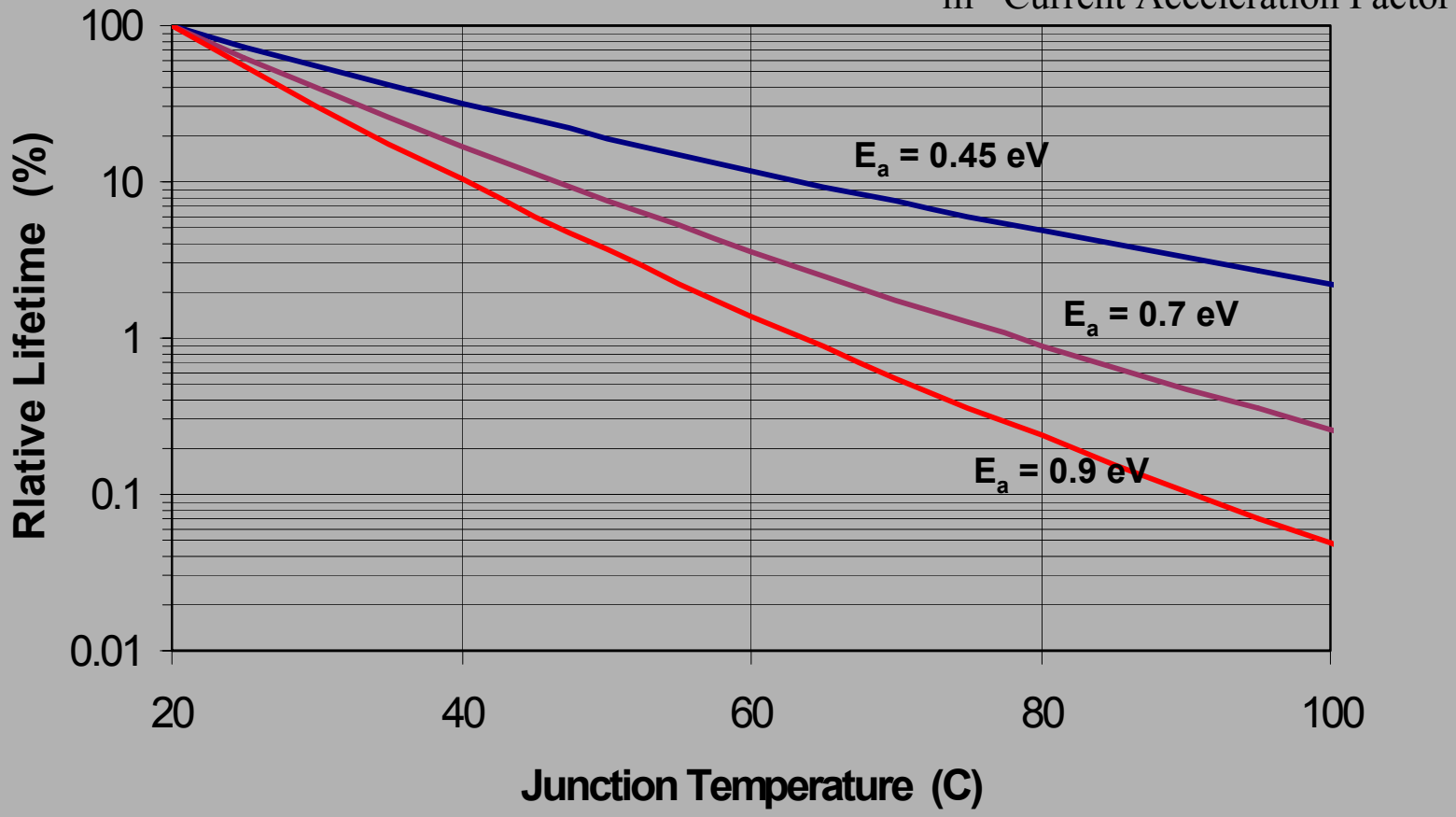
Arrhenius equation:

Lifetime $(\tau) \propto I^{-m} e^{(Ea/kT)}$

T Junction Temperature
I Drive Current
E_a Activation Energy
m Current Acceleration Factor



Thermal Effects of Quasi-CW 792 nm Laser Diode Array

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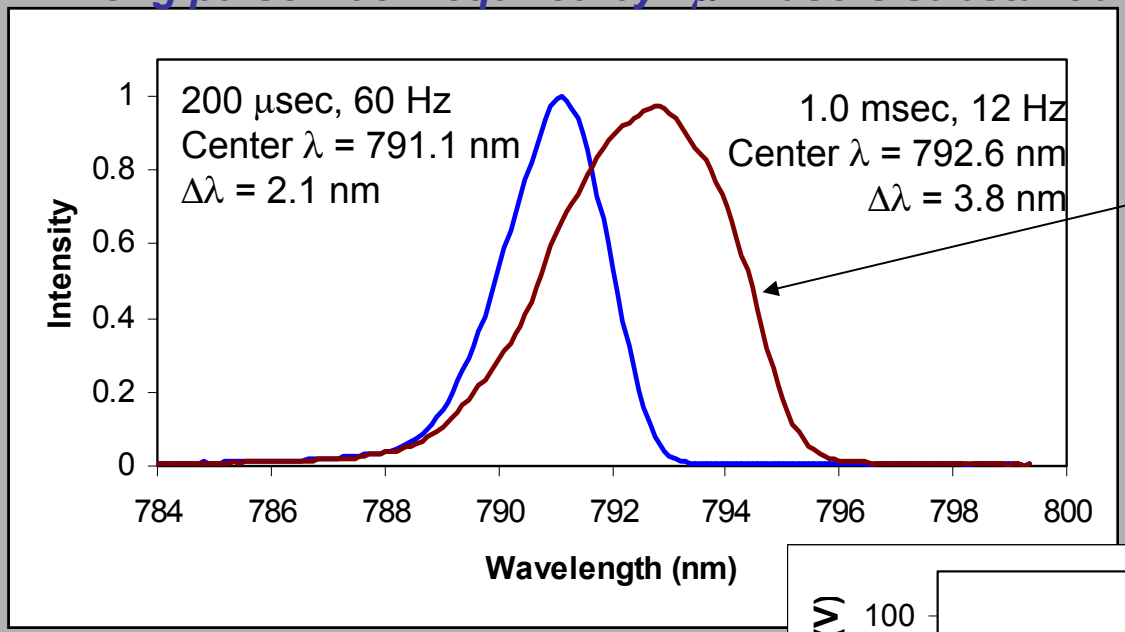
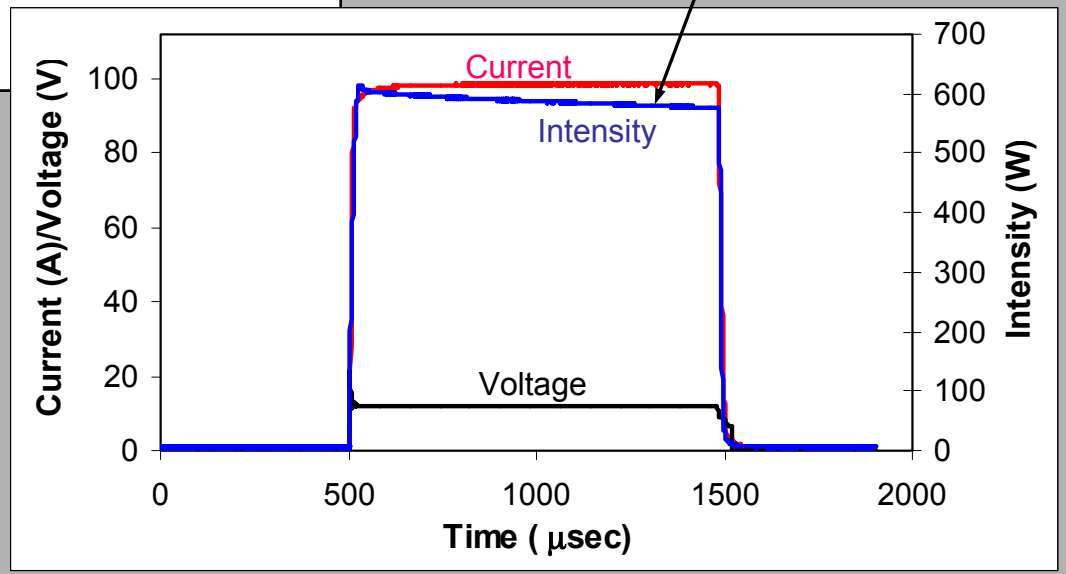
- *Thermal Cycling is one of the leading causes of Quasi-CW LDA degradation*
- *Long pulsewidth required by 2μm lasers substantially accelerates LDA degradation*



Spectral shift and broadening due to thermal cycling

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



Coherent G-Package
Current 100 A
Op Temp 25°C

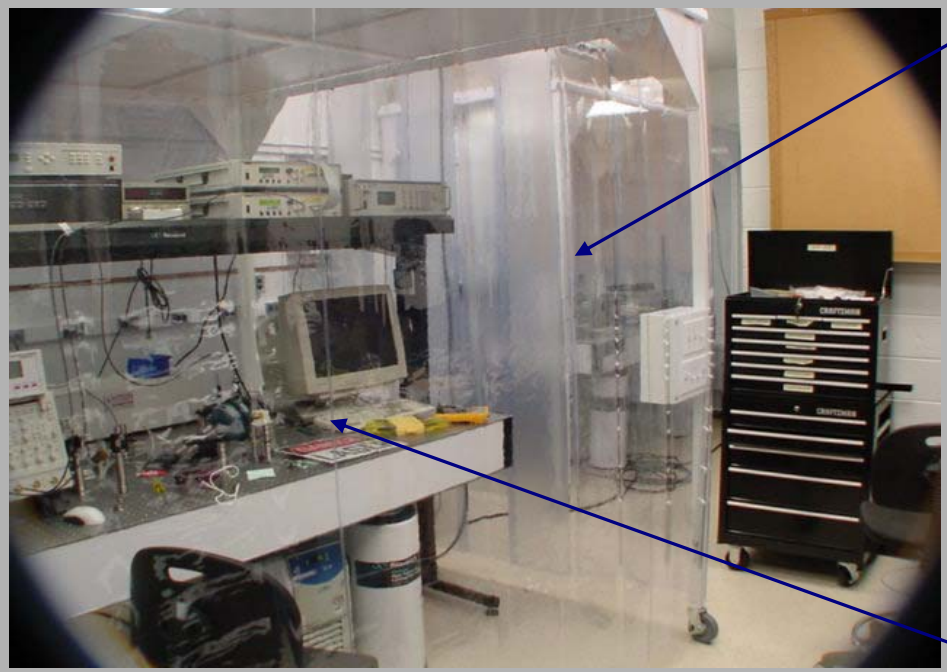
Laser Diode Characterization/Lifetime Test Facility

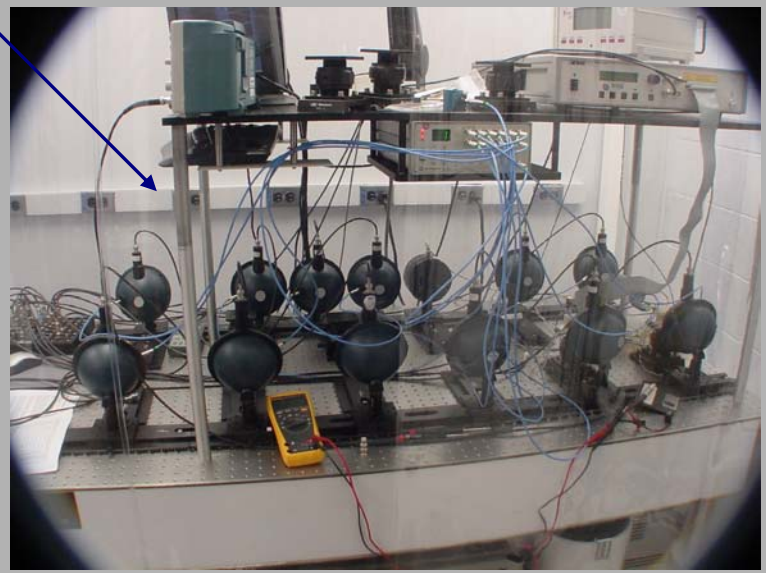
Langley Research Center (LaRC)

STATUS

- Completed Characterization Test Station and Measured 70 LDAs
- Completed Lifetime Test Station
  - Initiated lifetime testing of A-Package LDAs
  - Expansion from 8 to 12 LDAs is near completion

LD Lifetime Test Station





LD Characterization Station

Comparison of Different LDAs

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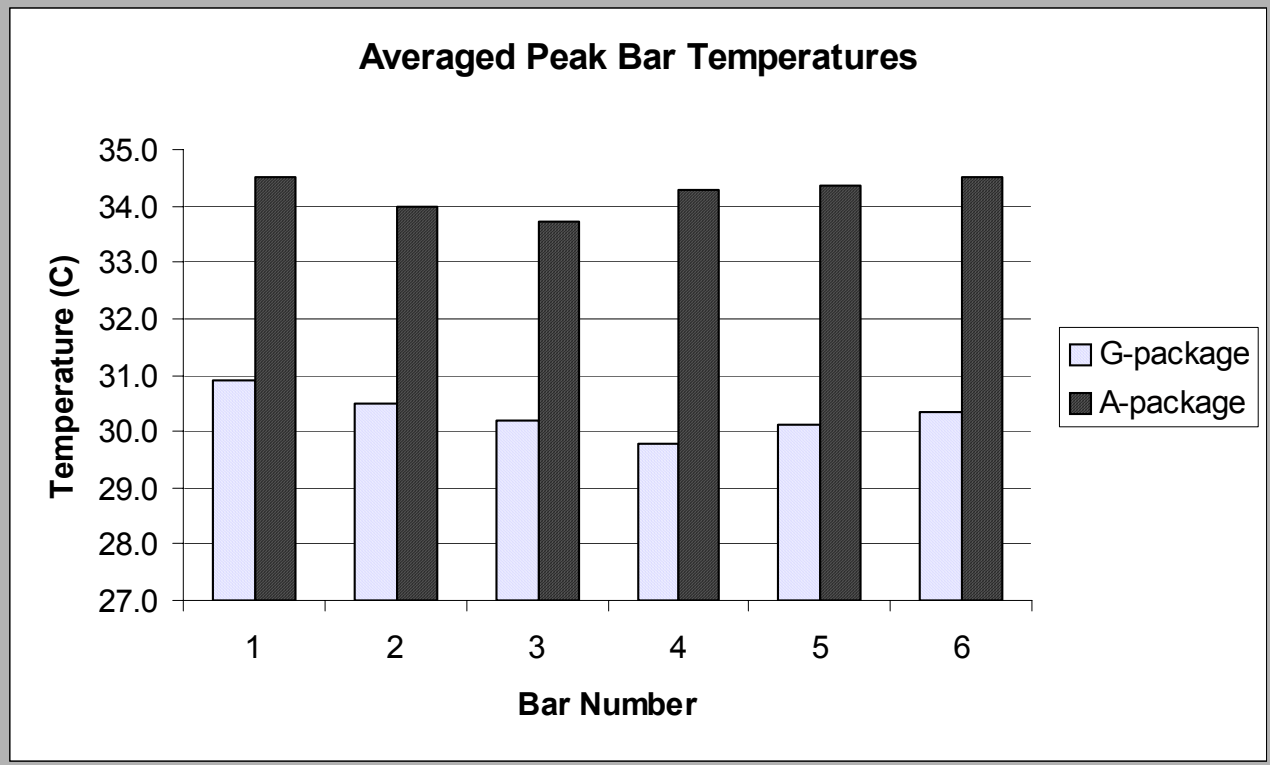
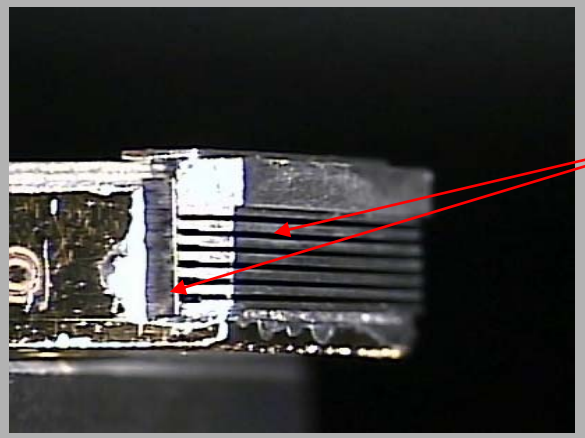
G-package bars run about 4 degrees cooler than A-package

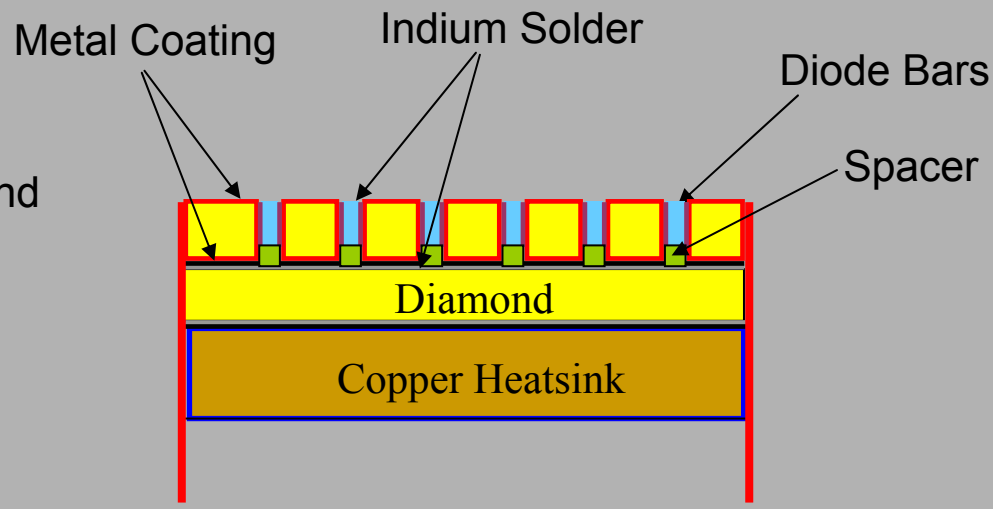


Diamond Laser Diode Array

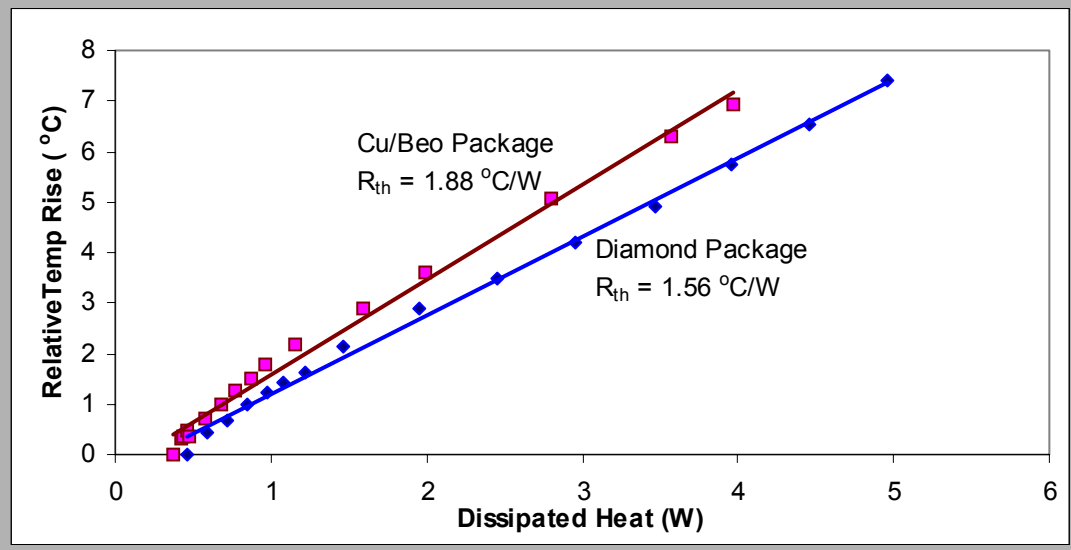
Langley Research Center (LaRC)

Fabricated several experimental Laser Diode Arrays using diamond substrate and heatsink for improved thermal characteristics and lifetime.





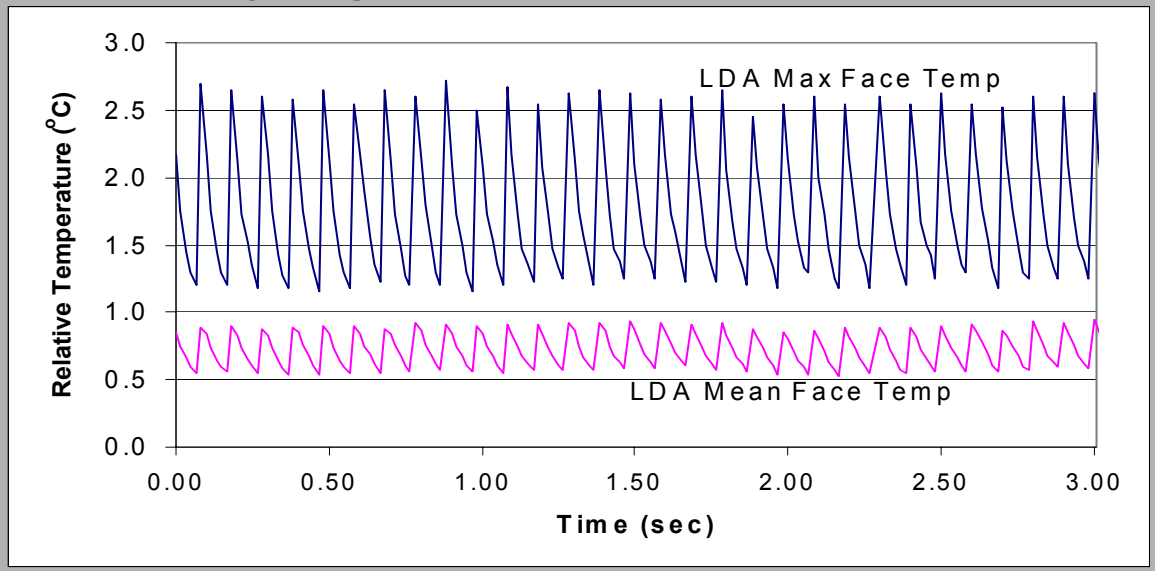
Thermal resistance of diamond package is 17% lower than BeO/Cu package

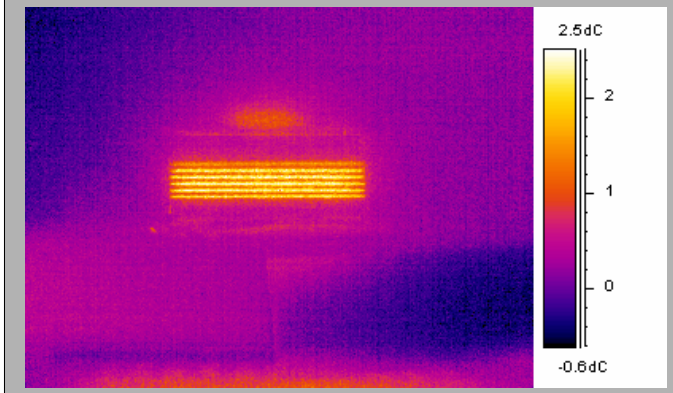


Thermal Characteristics of Diamond LDA

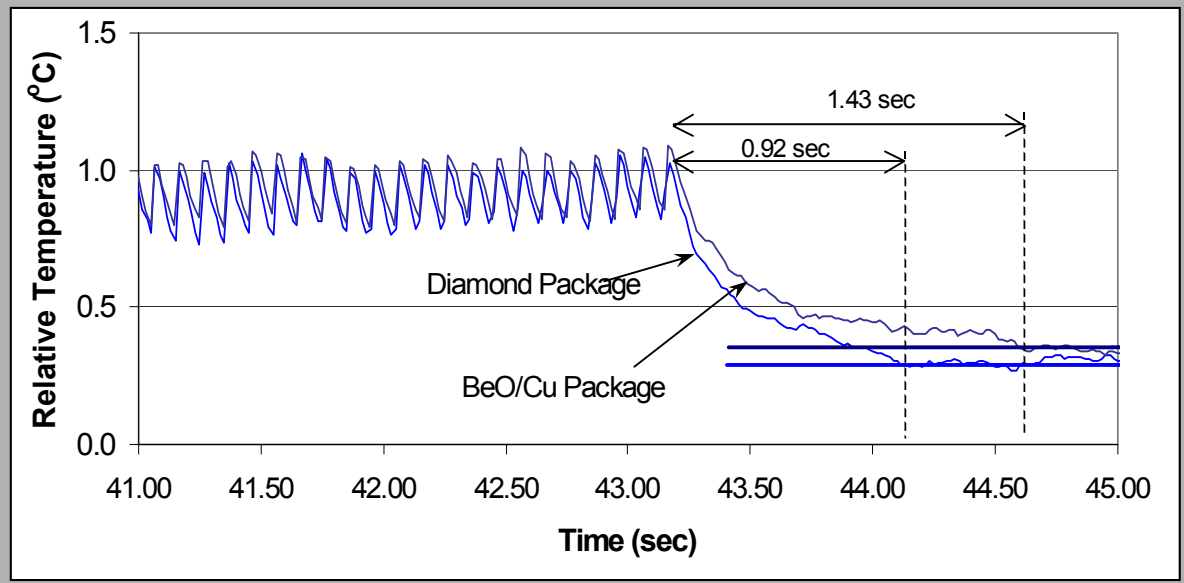
Langley Research Center (LaRC)

Thermal Cycling with applied pulsed current at 10 Hz





Diamond Package cools 36% faster than BeO/Cu Package



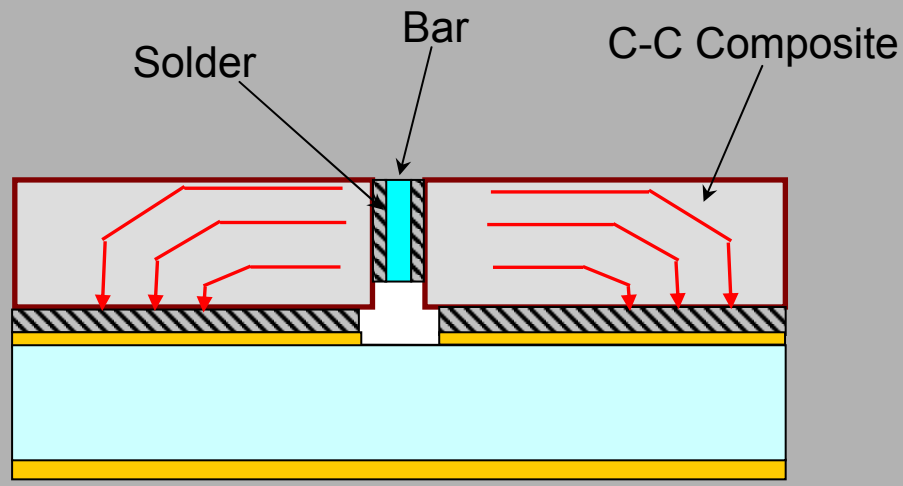
Pulsewidth	1.0 msec
Current	80 A
Rep Rate	10 Hz
Op Temp	15°C

Carbon Composite Laser Diode Array

Langley Research Center (LaRC)

- Began a new joint effort with ***Northrop Grumman/CEO*** for improving thermal properties and reducing mechanical stresses of Laser Diode Arrays

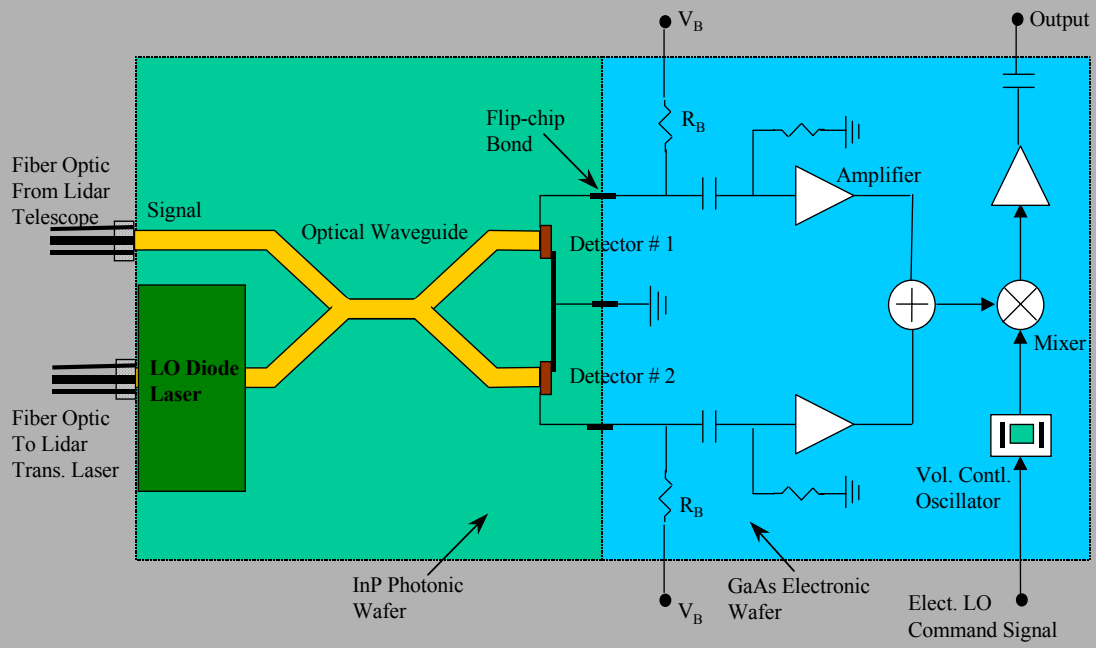
- Carbon Composite materials provide high directional thermal conductivity and possibility of matching CTE
  - Reduce thermal resistance - Longer Lifetime
  - Dissipate heat from bars uniformly - Narrower Linewidth
  - Reduce solder thickness or use hard solder - Lower Catastrophic Failure Rate



Integrated Heterodyne Photoreceiver

Langley Research Center (LaRC)

- Integrated Opto-Electronic Packaging Technology
- Dual-Balanced Detector Configuration
- Hybrid package includes all the receiver components:
  - Local Oscillator Diode Laser
  - Optical Mixer
  - Detectors
    - Amplifiers
    - Electronic Interface



Integrated Heterodyne Photoreceiver

Langley Research Center (LaRC)

Advantages

- Integrated Opto-Electronic package allows for full optimization of detector/electronic interface and eliminates excess losses due electronic interconnects
  - Improve Coherent Lidar system efficiency by more than 3dB
- Dual-Balanced Detector configuration reduces the required Local Oscillator (LO) power by about 80% and allows the use of a semi-conductor LO laser
- Integrated photoreceiver will allow for a compact hybrid design insensitive to thermal and vibration environments of space

Impact on Space-based Doppler Wind Lidar (2J X 12 Hz, 75 cm):

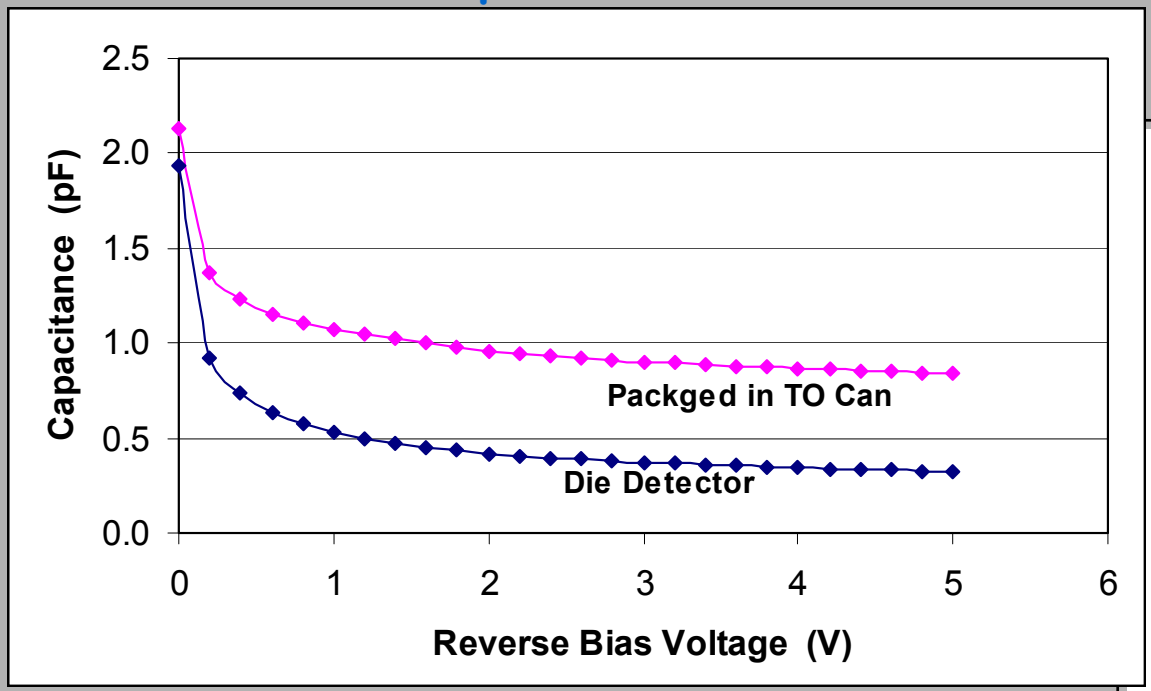
Mass Reduction	*125kg (20%)*
Power Savings	*600W (35%)*

Integrated Heterodyne Photoreceiver

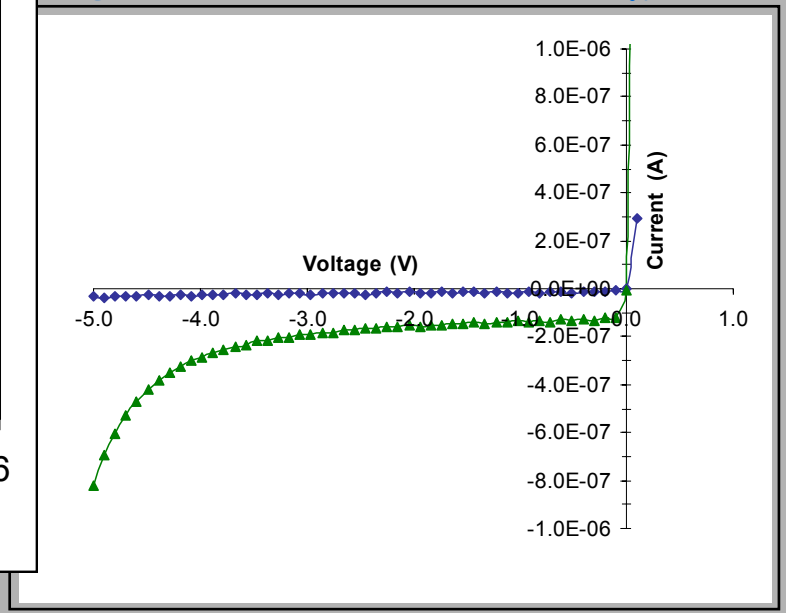
Langley Research Center (LaRC)

Detector Characterization

Detector Capacitance Measurement



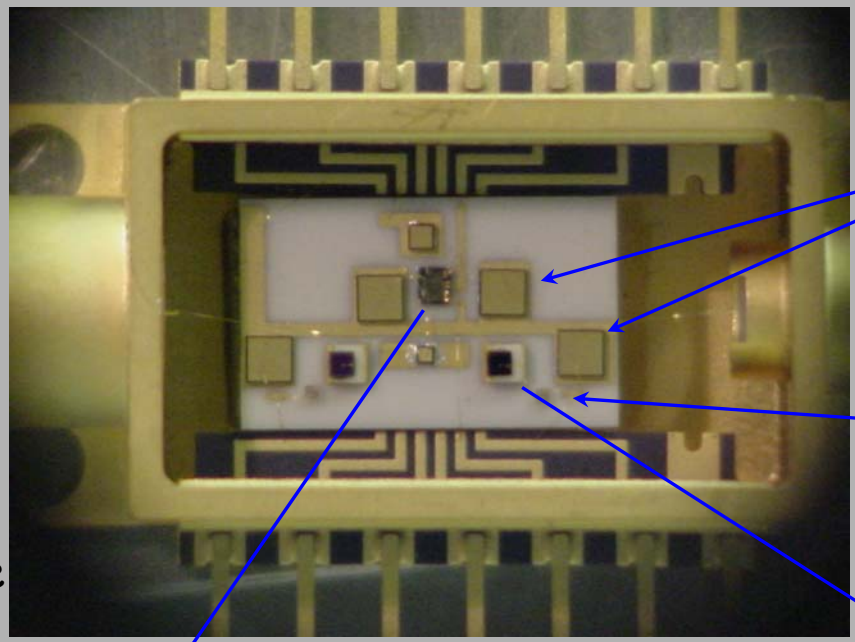
Detector I-V Measurement



- Measured Capacitances are practically identical for all 20 detectors
- Capacitance Reduced by 2.6X Compared with standard TO46 Can Package

Multi-Chip Module Receiver

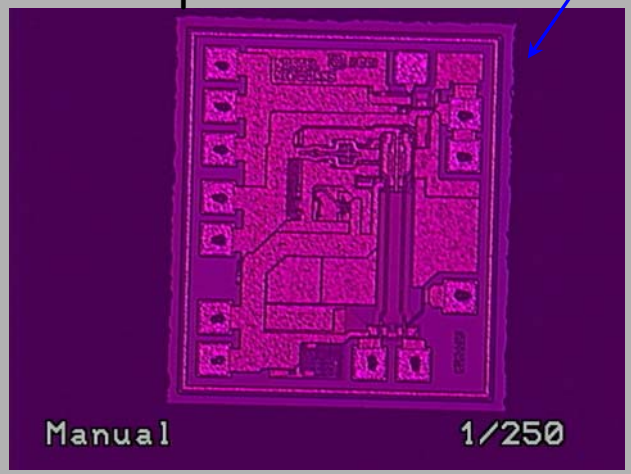
Langley Research Center (LaRC)



Capacitors

Resistor

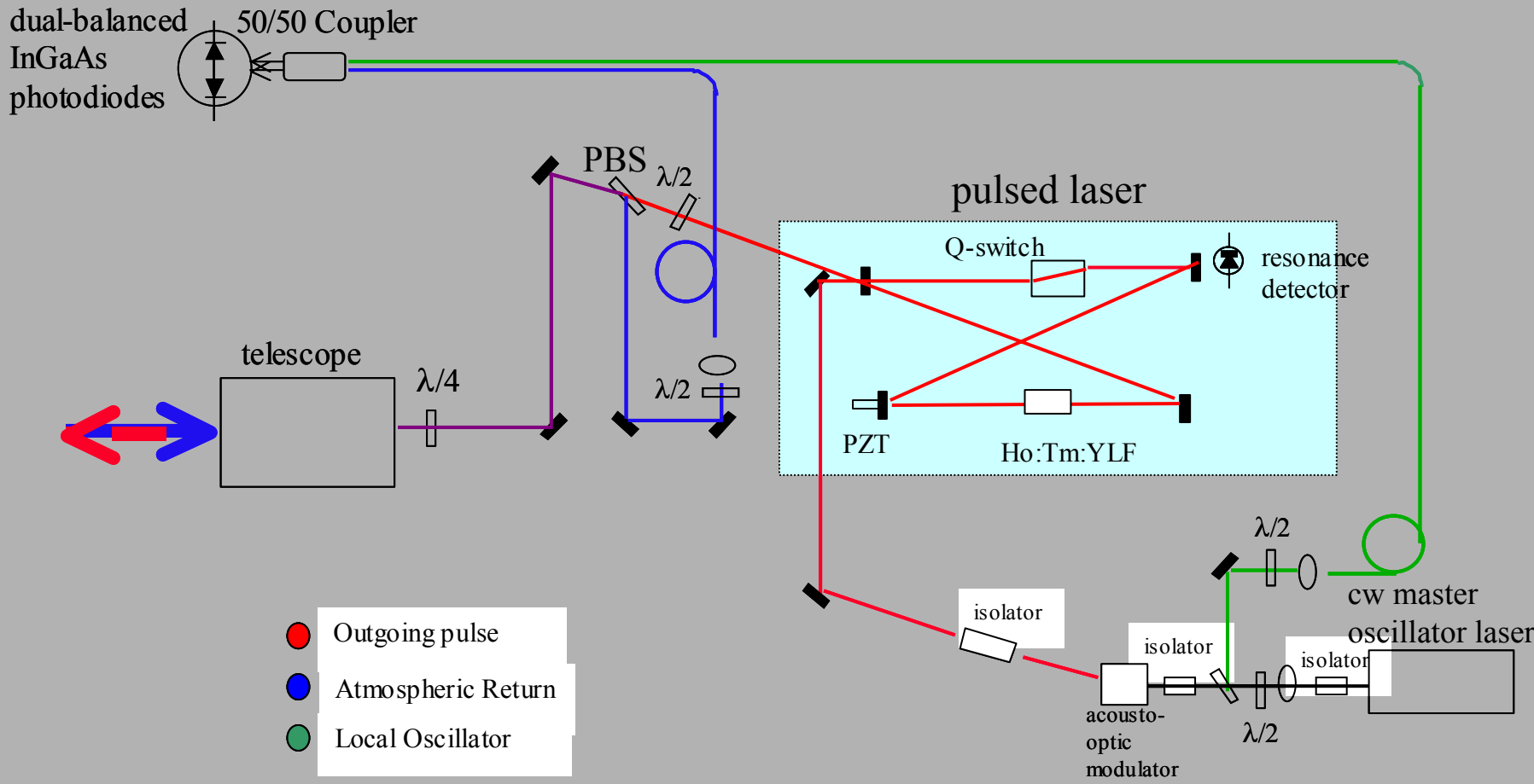
Transimpedance Amplifier



Detector

Mobile Validation Lidar - VALIDAR

Langley Research Center (LaRC)



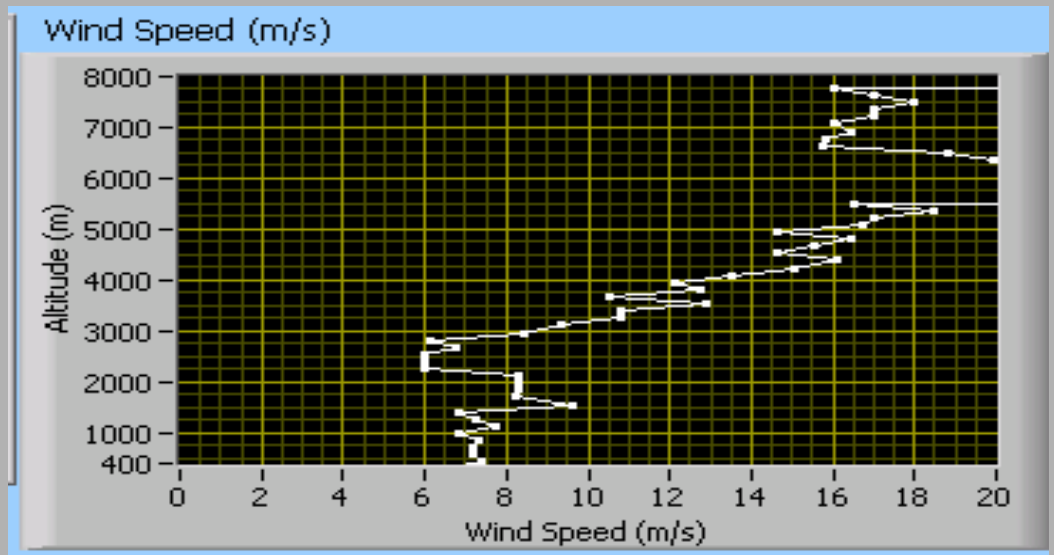
Validar Upgrades

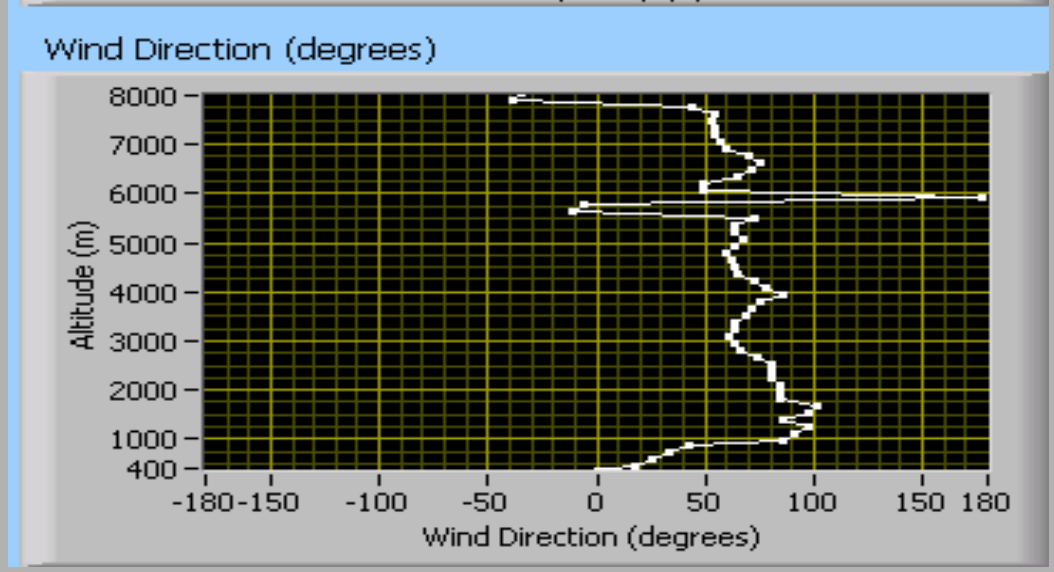
Langley Research Center (LaRC)

	Previous (2003)	Upgraded (2004)
Laser material:	Ho:Tm:YLF	Ho:Tm:LuLiF
Pulse energy:	75 mJ	95 mJ
Pulse width:	150 ns	140 ns
Pulse repetition rate:	5 - 10 Hz	5 - 10 Hz
Spectrum:	single frequency	single frequency
Wavelength:	2051.0 nm	2053.5 nm
Wavelength tuning:	3-4 nm including CO_2 lines	
Beam quality:	< 1.3 times diffraction limit	
Detector:	InGaAs in dual-balanced heterodyne configuration	
Telescope aperture:	4 inches	6 inches
Scanner:	8.5 inch aperture full hemispherical coverage	

Horizontal Wind Profile

Langley Research Center (LaRC)

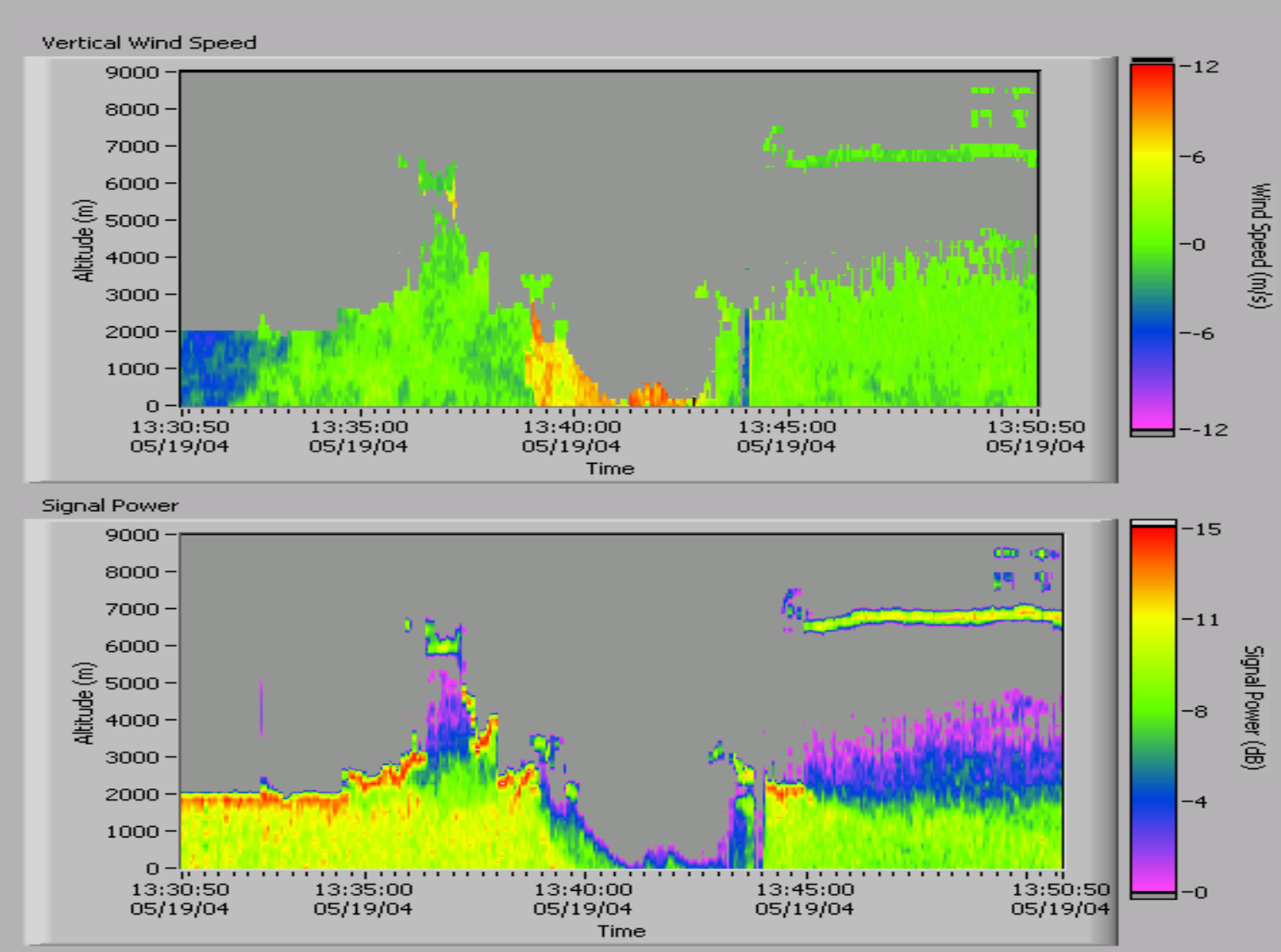




- vector sum of two azimuth components at 45 deg. elevation
- 20 pulses averaged at each az/el.

Vertical Wind Profile During a Thunderstorm

Langley Research Center (LaRC)

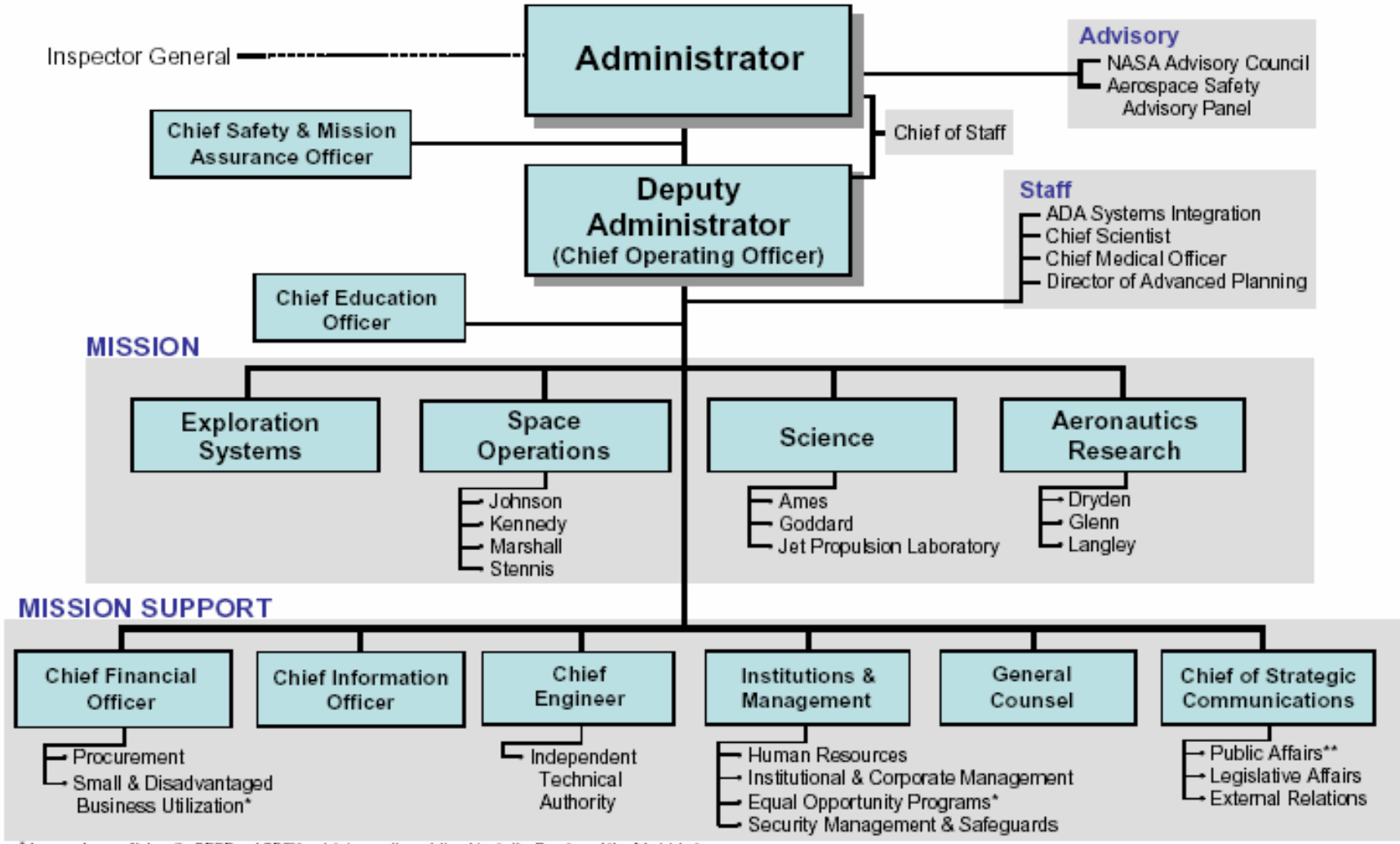


Advancement of Lidar Technologies at NASA Langley

Langley Research Center (LaRC)

- LRRP has been the main source of funding for the Lidar technology development activities at Langley for the past 3 years
- Planned for 5 years completing in FY 07
- LRRP sponsored jointly by Code Y/ESTO and Code R/MSMT
- Realignment of NASA's missions and subsequent reorganization are expected to drastically affect the LRRP
- MSMT Office moved to the Exploration Systems
- Earth Science merged with Space Science

Transformed Structure



Earth Sciences Application Focus

Langley Research Center (LaRC)

2 Lasers, 4 Techniques, 6 Priority Measurements

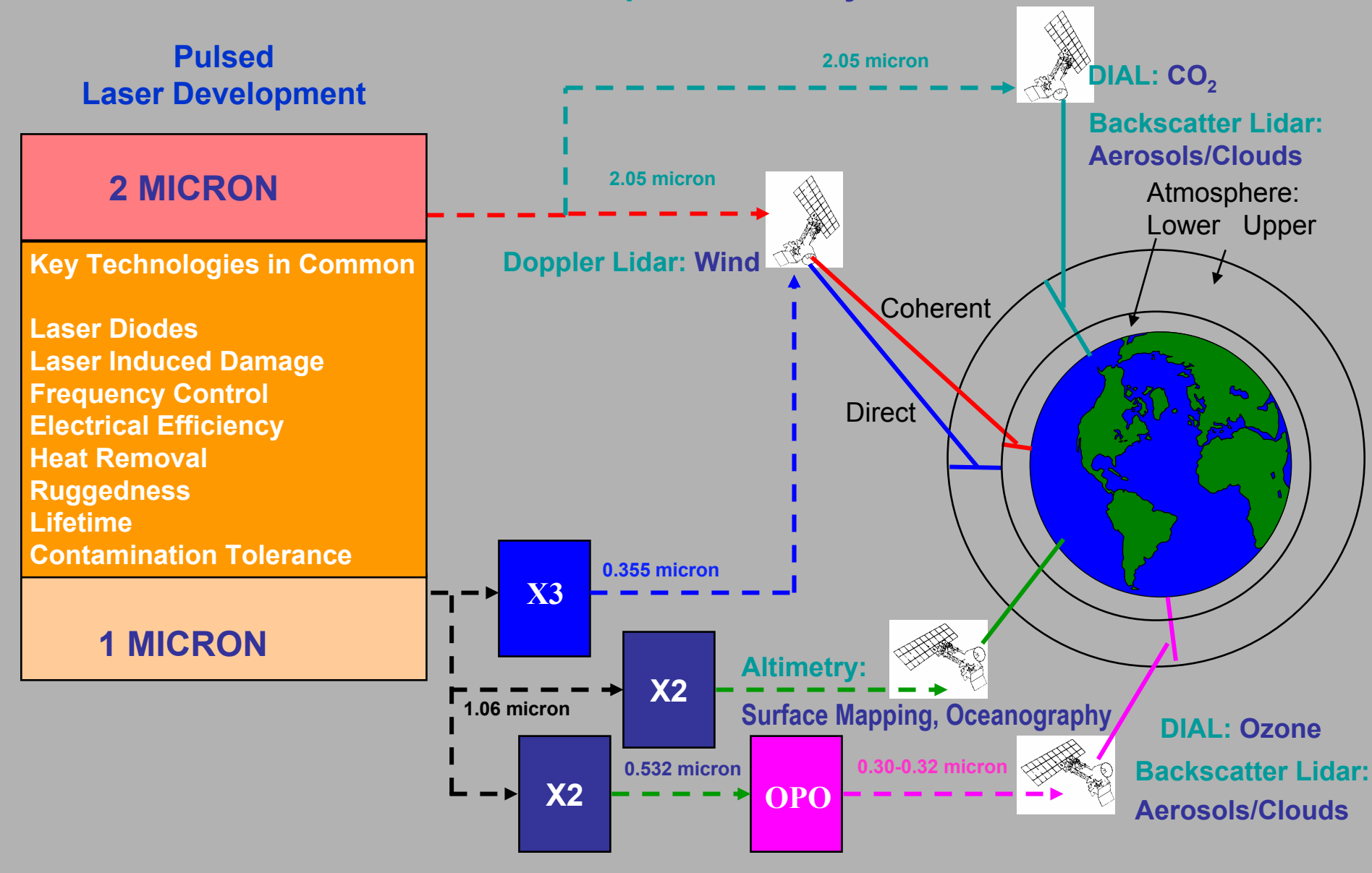
Pulsed Laser Development

2 MICRON

Key Technologies in Common

- Laser Diodes
- Laser Induced Damage
- Frequency Control
- Electrical Efficiency
- Heat Removal
- Ruggedness
- Lifetime
- Contamination Tolerance

1 MICRON



LRRP: Exploration Focus

Langley Research Center (LaRC)

2 Lasers, 4 Techniques, Numerous Measurements

2 MICRON LASER

2.05 micron

COHERENT DOPPLER

DIAL

Key Technologies in Common

- Pump Laser Diode Arrays
- Optics Damage
- Frequency Control
- Beam Quality
- Electrical Efficiency
- Heat Removal
- Ruggedness
- Lifetime
- Contamination Tolerance
- Radiation Tolerance

0.355

X3 → **DIRECT DOPPLER**

0.532

X2 → **BASIC**

1 MICRON LASER

1.06 micron

Planetary Orbit

- Wind Profiles
- Water Vapor Profiles
- CO_2 Profiles
- Aerosol Profiles
- Altimetry

Descent

- Range
- Velocity
- Attitude/Rotation
- Wind Conditions
- Hazard Detection

Rendezvous

- Range
- Velocity
- Attitude/Rotation

Lander/Rover

- Wind, Water Vapor
- CO_2, Aerosols
- Ranging
- Imaging
- Mineralogy
- Biosensing

Enabling Technology Elements

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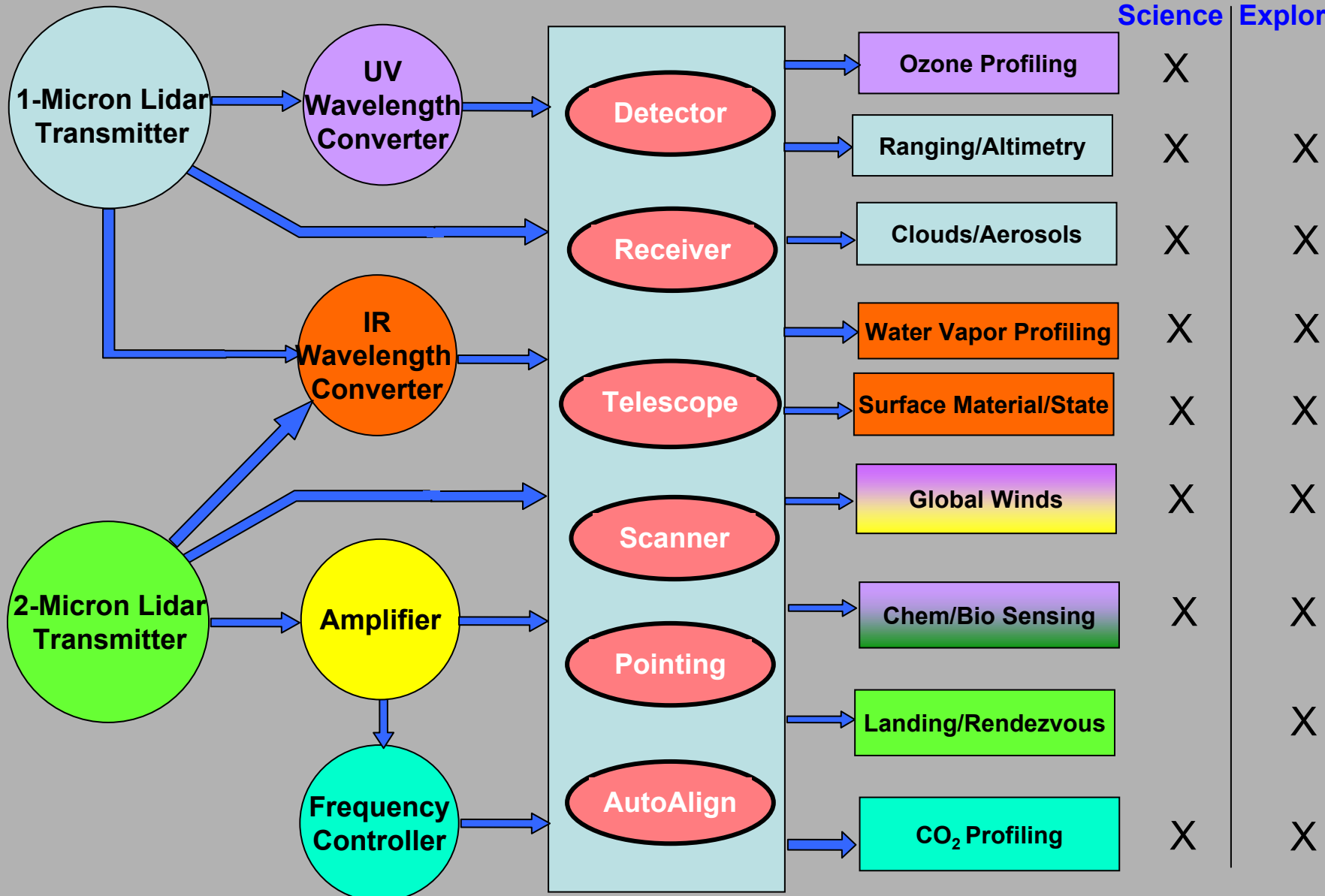

Enabling Technology Elements

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