Development and Risk Reduction of a 2-Micron Laser Transmitter for a Space-Based Coherent Doppler Wind Lidar System

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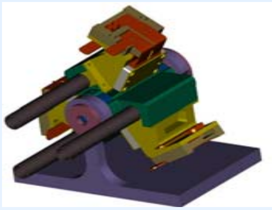
Meeting of the Working Group on Space-Based Lidar Winds, Miami, Florida, February 6 – 9, 2007

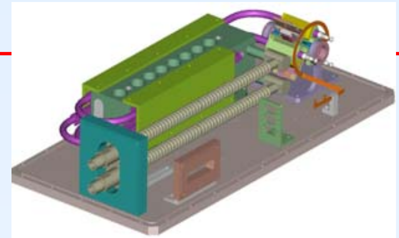
Outline

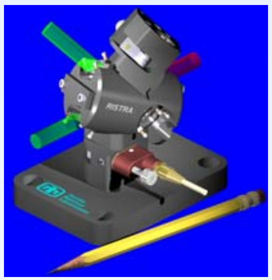
- Laser Risk Reduction Program
- Coherent Doppler Wind Lidar Transmitter
- Overview of 2-micron Solid state lasers
- Partially conductive cooled Compact laser
- One Joule 2-micron Laser
- Conductively cooled Laser Development
- Conclusions

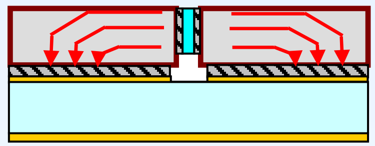
Laser Risk Reduction Program (LRRP)

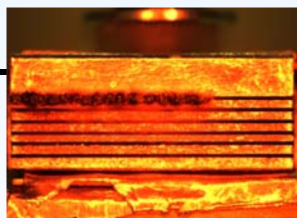
Products

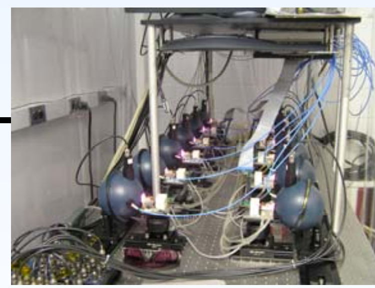












Approach & Partners

Upendra N. Singh, LaRC and William S. Heaps, GSFC – Co-PI

This is a joint LaRC-GSFC program. The primary output product is knowledge that will reduce risk of future NASA laser/lidar space missions. Investigations are primarily performed at the two Centers, with frequent inter-Center communication, collaboration, and review. Numerous partnerships with other agencies, academia, and industry have been initiated and are ongoing.

Description and Objectives

The objective is to reduce the risk of failure in future NASA laser/lidar space missions. Laboratory experiments will be conducted to gain understanding and demonstrate advancement of the high-energy, 1 and 2-micron laser; the laser diode arrays that pump the pulsed laser; wavelength conversion technologies to permit, wind, CO_2, and O_3 profiling; related detector and receiver technologies advancements; and lifetime effects from contamination, radiation, etc for space-based measurements.

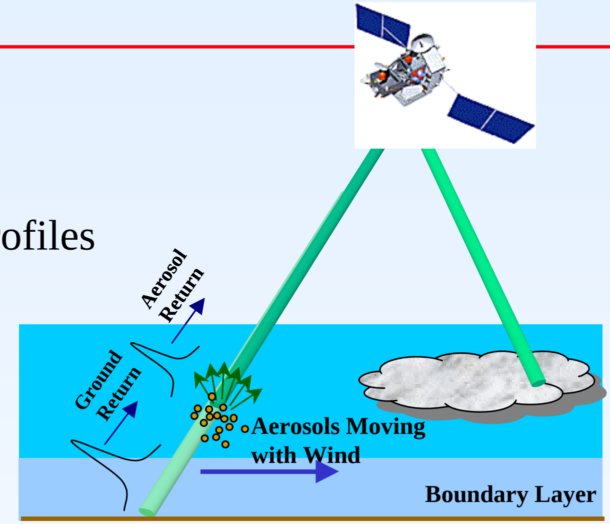
Schedule & Deliverables

The LRRP began in FY02. It has already assisted the GLAS and CALIPSO lidar missions, and a RTF activity. Elements of LRRP should be continued since the knowledge is vital to the success of future multi-$100M missions.

Applications/Mission

Global tropospheric wind profile measurements
Global CO_2 profile measurements
Global O_3 profile measurements
Global aerosol measurements
Global cloud measurements
Mars exploration

Coherent Doppler Lidar

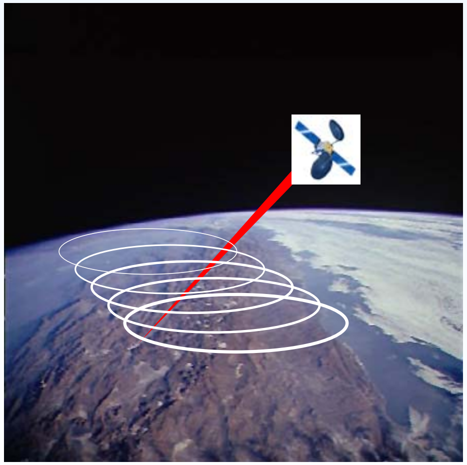


Measurements:

- Boundary Layer and Lower Troposphere Wind Velocity Profiles
- Cloud Height and Velocity
- Aerosol Concentration
- River Flow

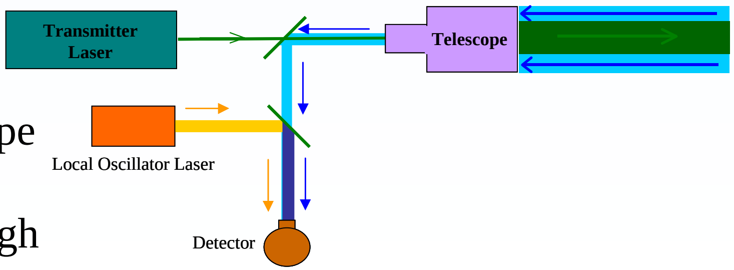
Instrument Description:

- Transmit medium duration laser pulses (τ_p > 150 nsec)
- Reflected photons from atmospheric aerosols are collected by a telescope
- Wavelength of the backscattered light is Doppler shifted by aerosols moving with wind
- Doppler shift is measured using heterodyne detection similar to FM radio

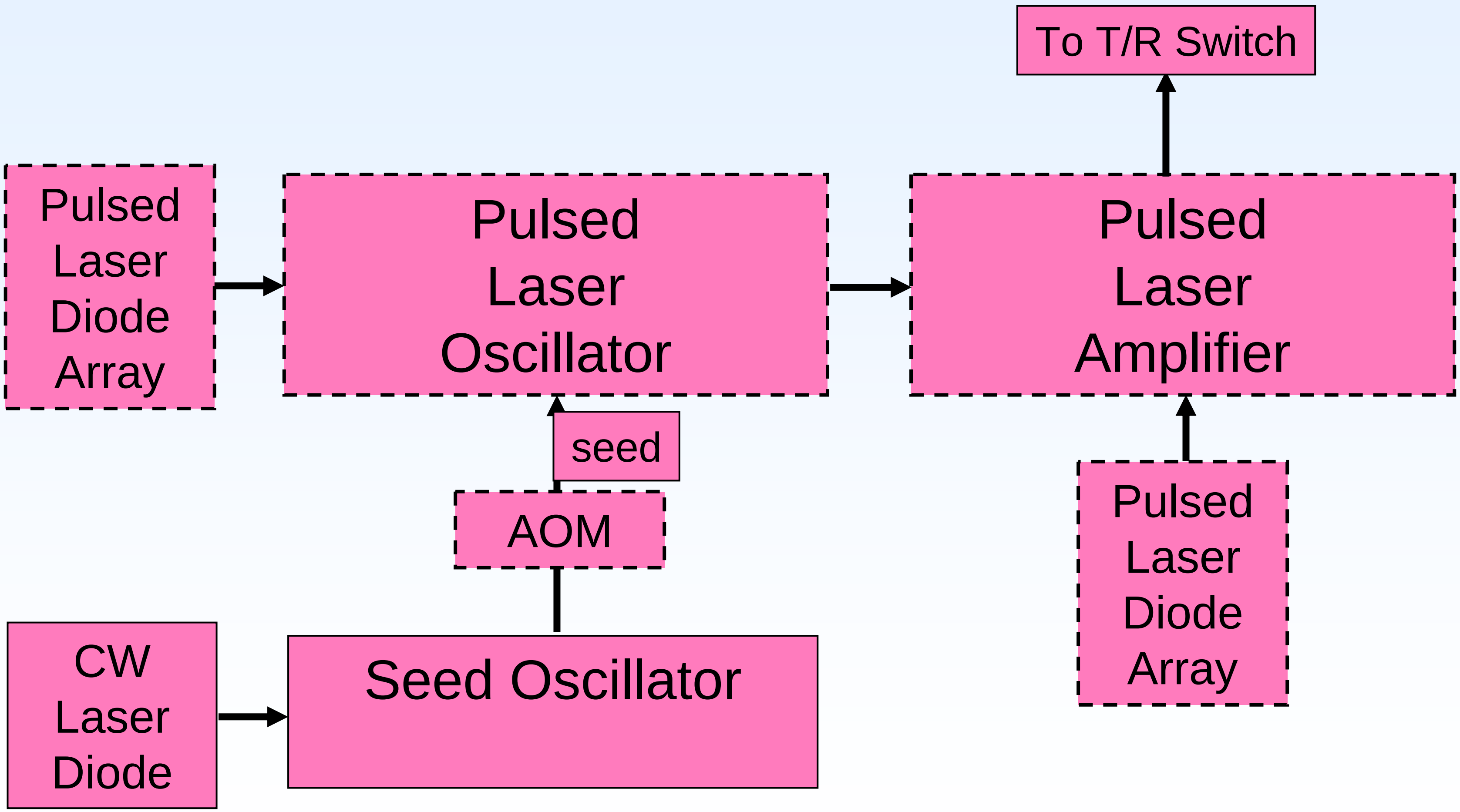


Instrument Attributes:

- Scanning
- Sub-Meter class Telescope
- 2-micron Laser
- Level of Complexity: High



Coherent Wind Transmitter Laser

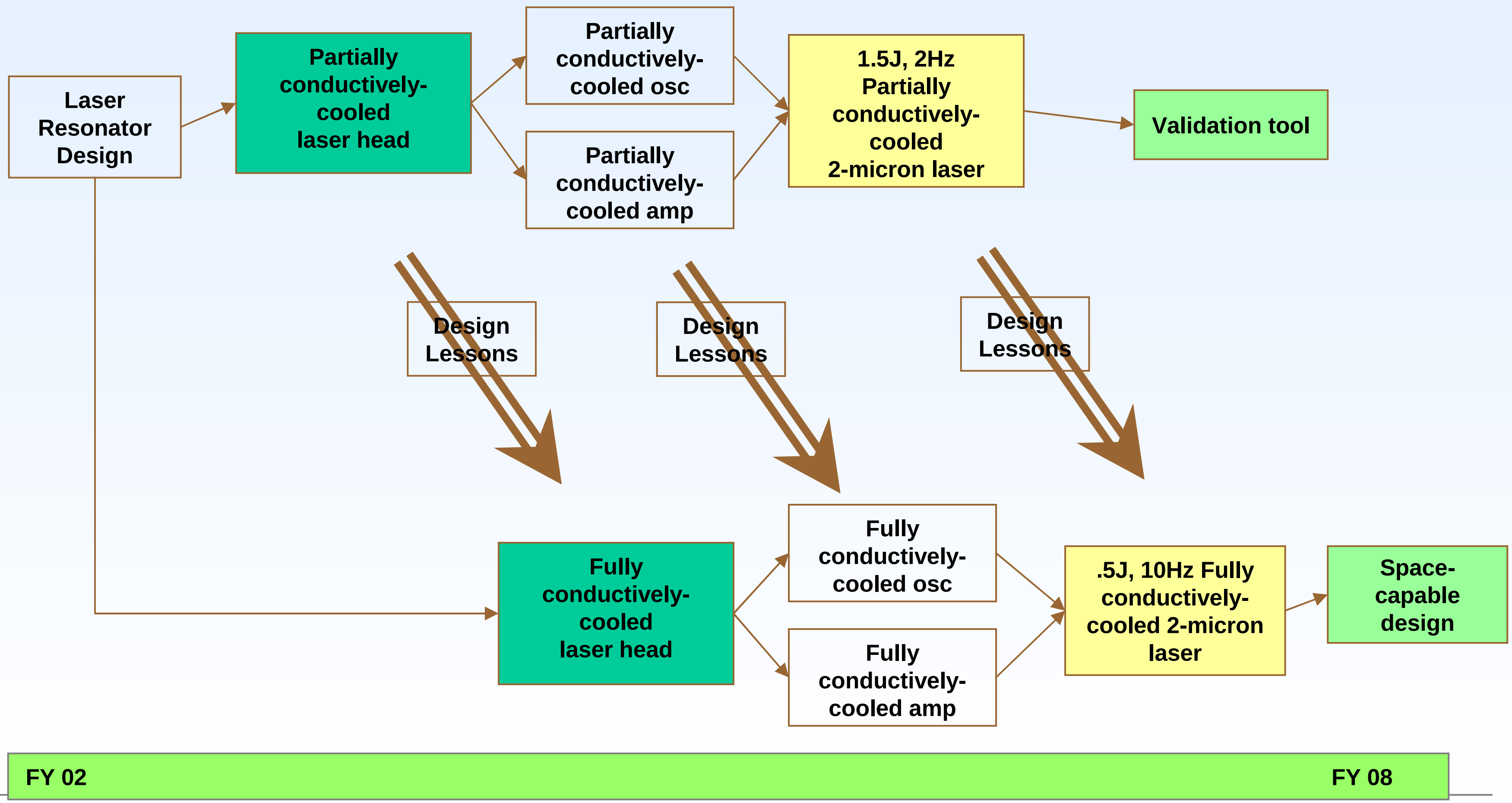


Wind IIP Packaged Transceiver Requirements

Category	Requirement	Goal (if different) and/or Space Requirement	Reason
Laser Architecture	Master Oscillator Power Amplifier (MOPA)		High energy, beam quality, optical damage
Laser Material	Ho:Tm:LuLiF		High energy, high efficiency, atmospheric transmission
Nominal Wavelength	2.053472 microns		Atmospheric transmission
Pulse Energy	150 mJ	250 (space)	Computer modeling of measurement performance
Pulse Repetition Frequency	10 Hz	10-20 (space)	Shot accumulation, optimum laser diode array lifetime
Pulse Beam Quality	< 1.4 x diffraction limit		Heterodyne detection efficiency influence
Pulse Spectrum	Single Frequency	Few MHz (space)	Frequency estimation process
Injection seeding success	95%	99%	Shot accumulation
Laser Heat Removal	Partial Conductively Cooled	FCC (space)	No liquid lines in space
Packaging	Compact, engineered	Aircraft ready Space qual. (space)	As ready as possible for aircraft follow on

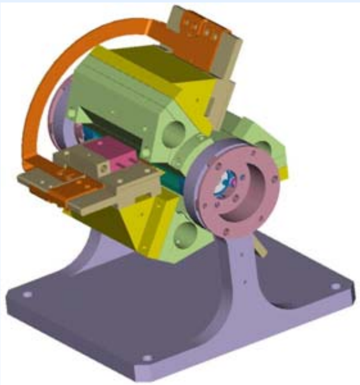
2-Micron Laser Development

Laser Risk Reduction Program
2-micron Technology Roadmap

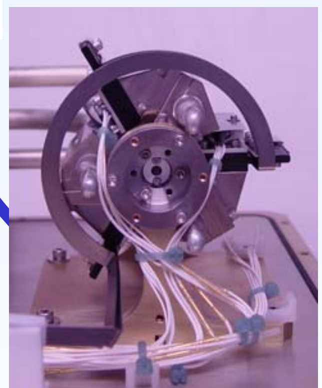


Technology Maturation

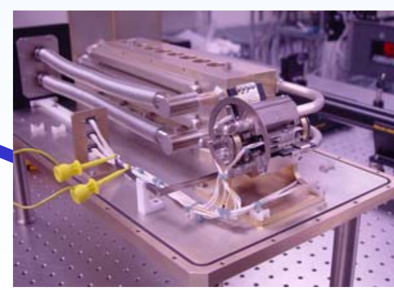
A fully conductively cooled 2-micron solid-state pulsed laser has been demonstrated for the first time. TRL advancement of 3 to 4



Analysis & Design



Fabrication



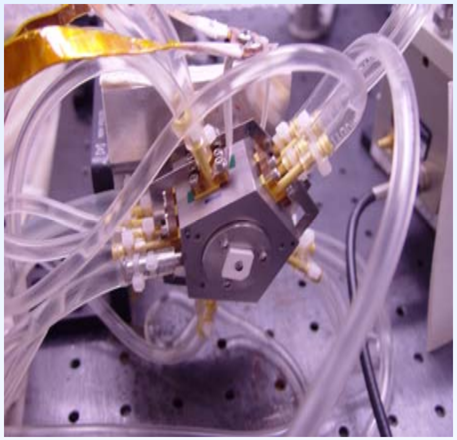
System Integration

Space qualifiable design

Testing and Model Verification

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

Laser Head Design Advancement

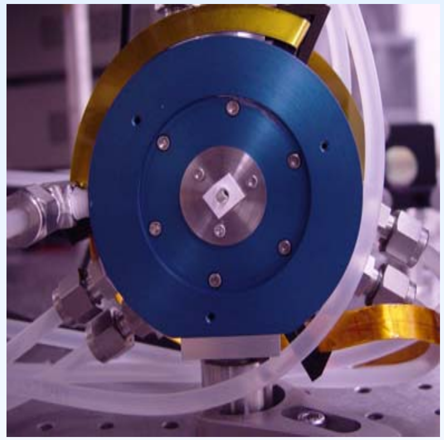


1995

10 diode arrays with total pump energy 3.6 Joules

22 water channels

All liquid cooled

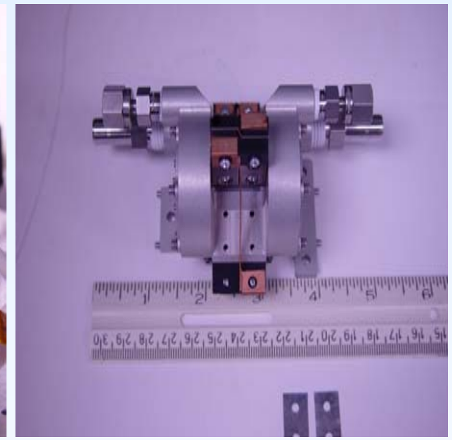


2002

6 diode arrays with total pump energy 3.6 Joules

8 water channels

LDAs cond. cooled



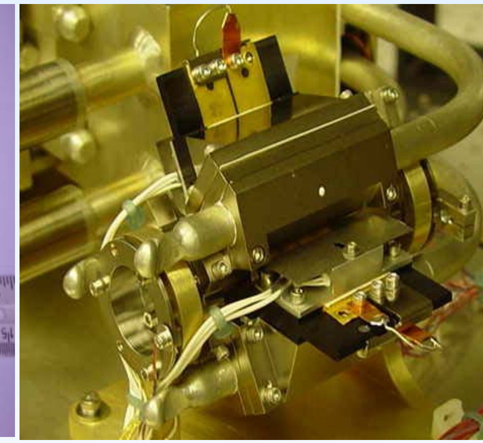
2003

6 diode arrays with total pump energy 3.6 Joules

4 water channels

LDAs cond. cooled

Monolithic design



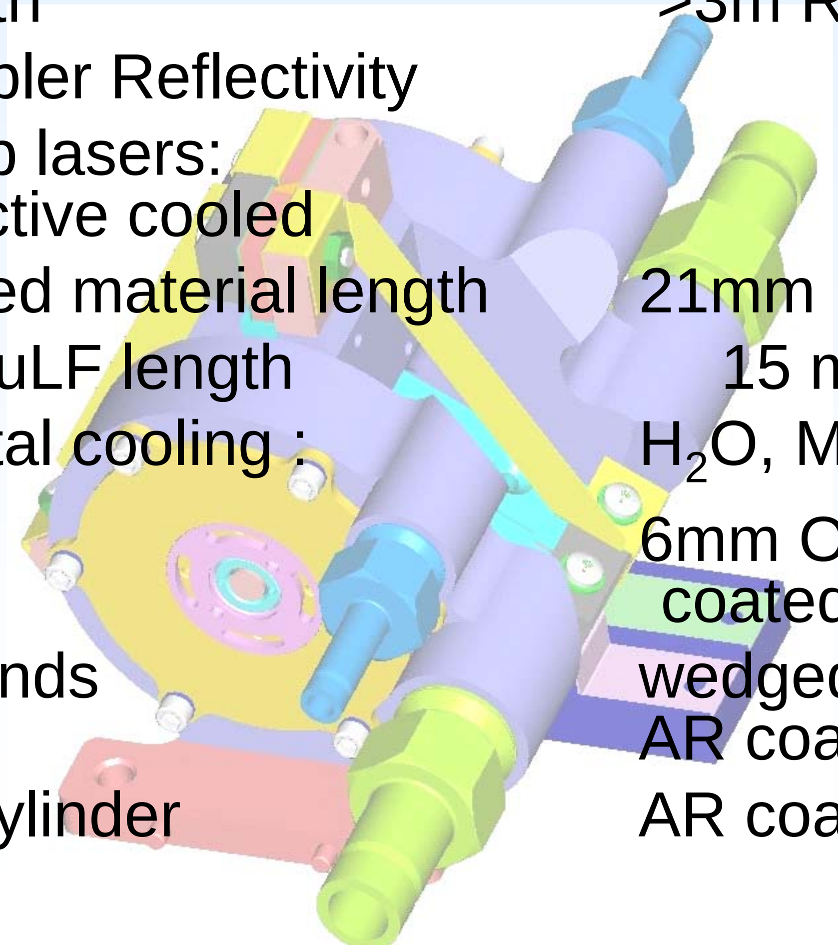
2004

6 diode arrays with total pump energy 3.6 Joules

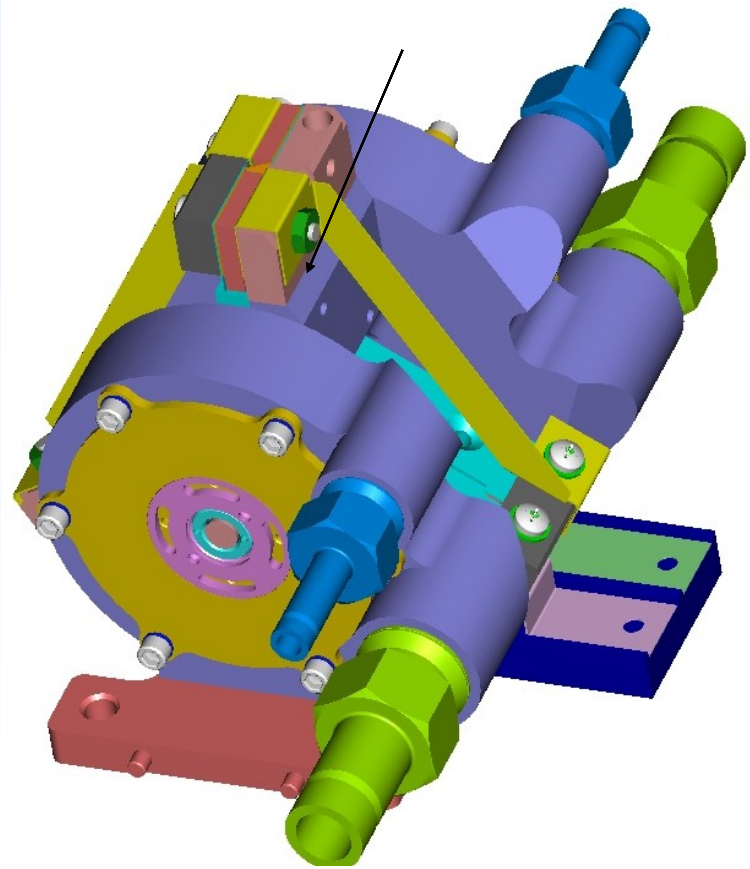
LDAs & laser rod conductively cooled

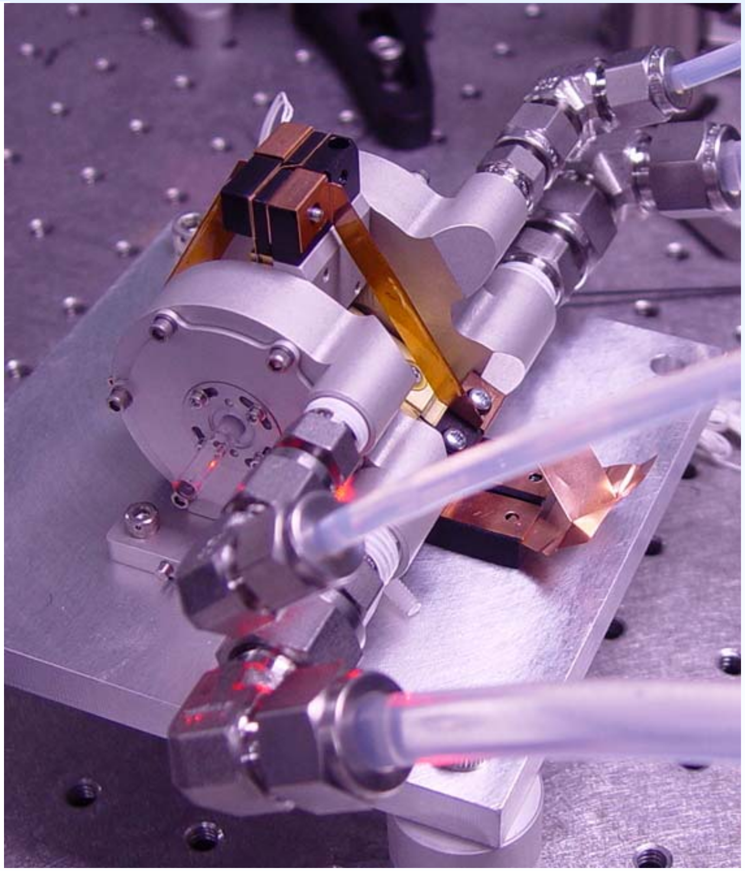
Oscillator features

- Injection seeded
- Cavity length >3m Ring
- Output coupler Reflectivity ~70%
- Diode pump lasers: 36 bars 100W/b
  conductive cooled
- crystal doped material length 21mm
- undoped LuLF length 15 mm
- Laser crystal cooling : H_2O, Methanol
- Tube size: 6mm OD 5mm ID AR
  coated for 792nm
- Laser rod ends wedged 0.5° along c-axis
  AR coated for 2.053µm
- Laser rod cylinder AR coated for 792nm

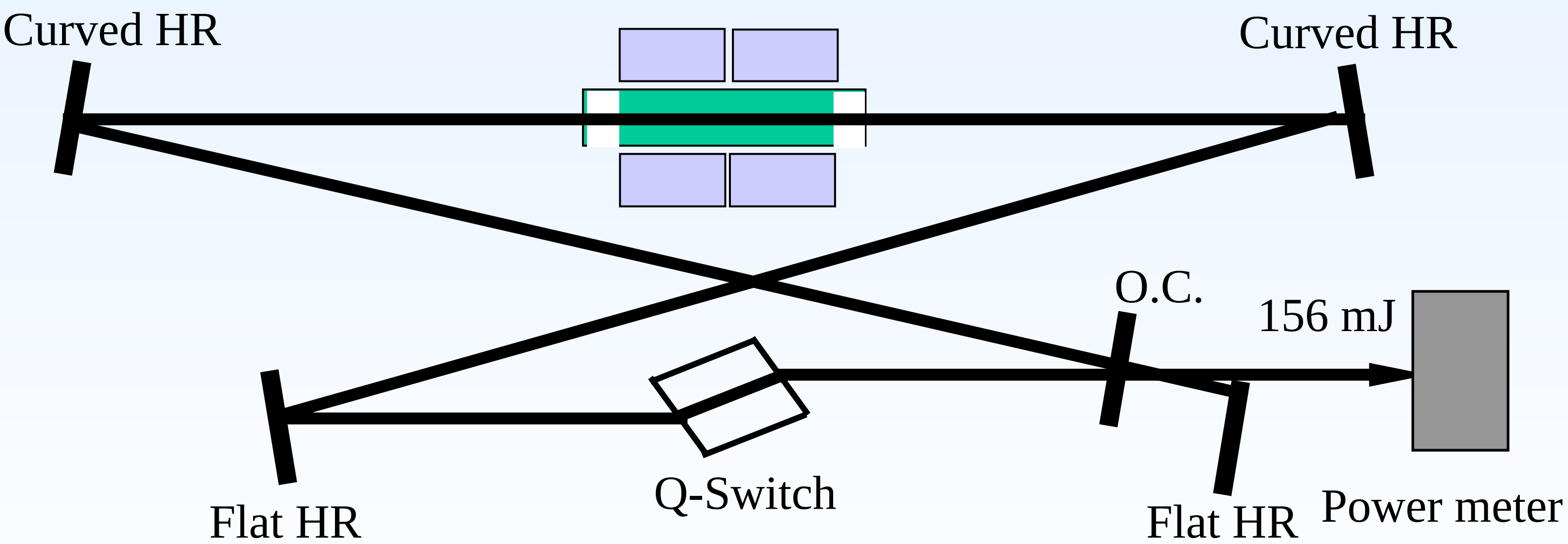


Diode-pumped Laser Oscillator Head



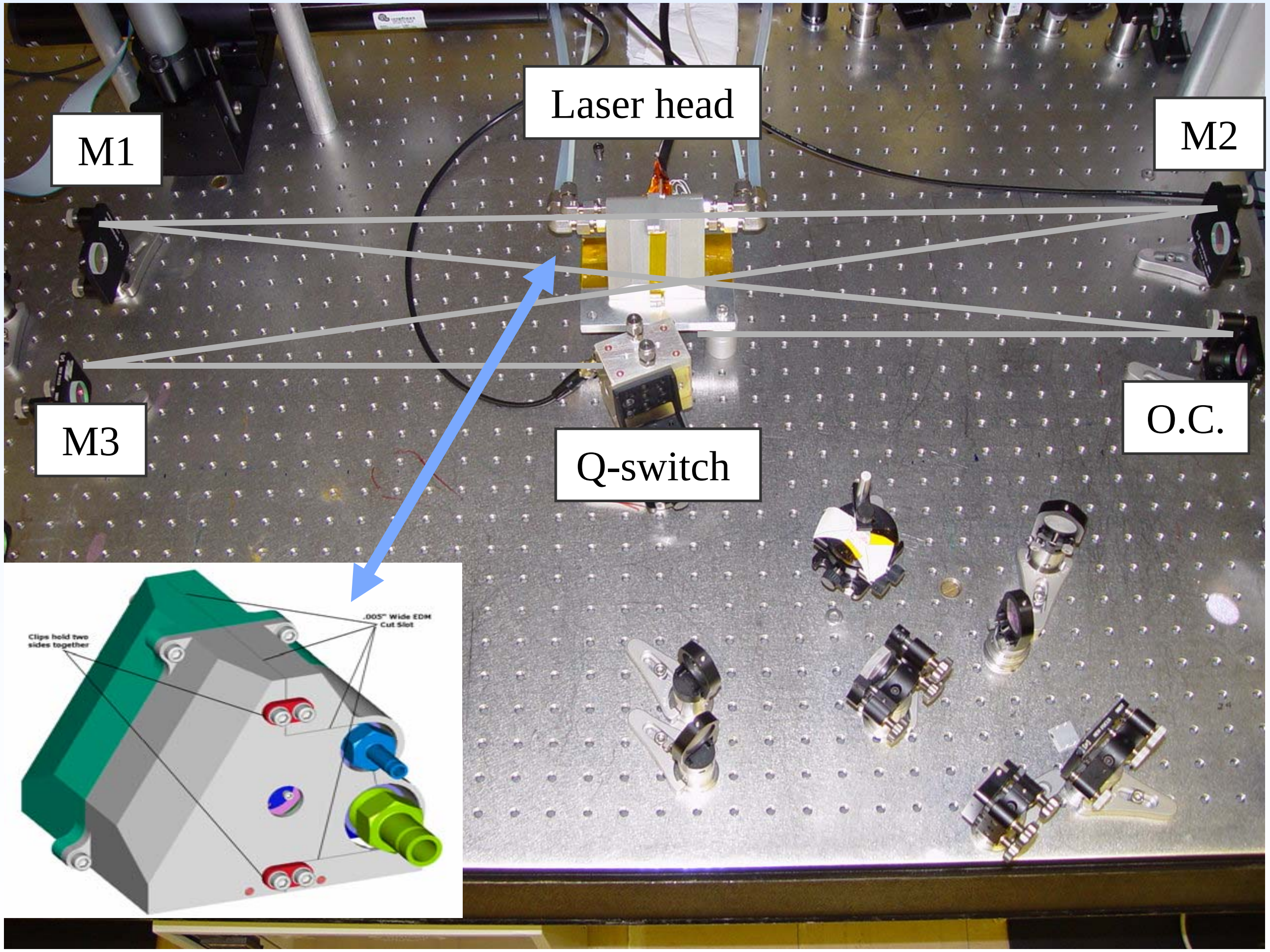


Ho: Tm: LuLF Laser Oscillator

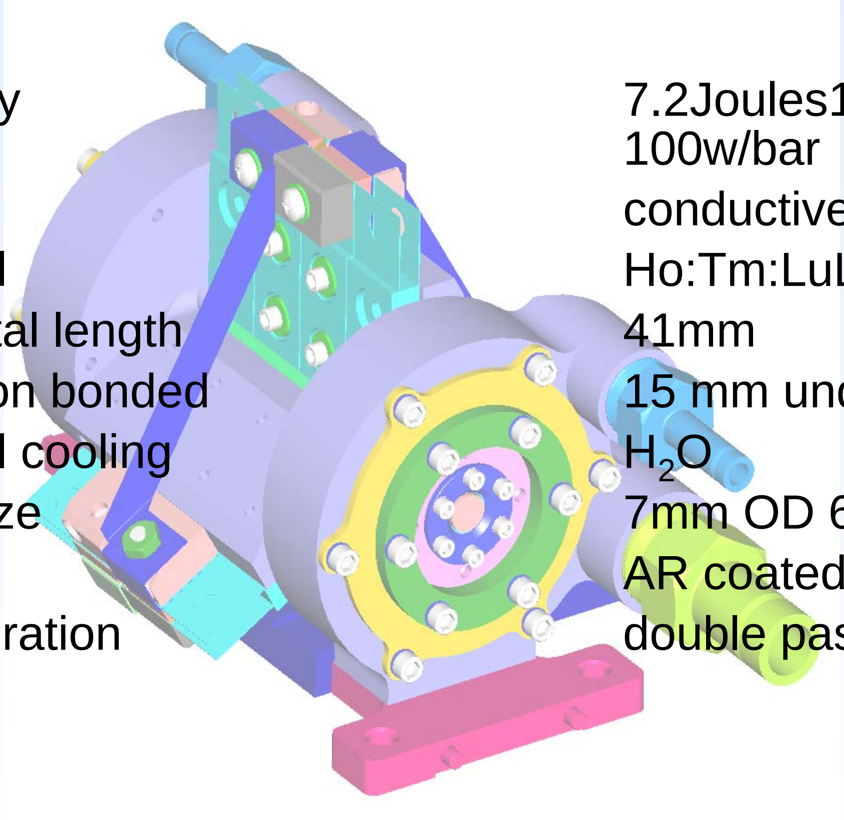


Output pulse energy: 156 mJ @ pump energy of 3.7 J

Diode-pumped Laser Oscillator
(Ring Cavity)

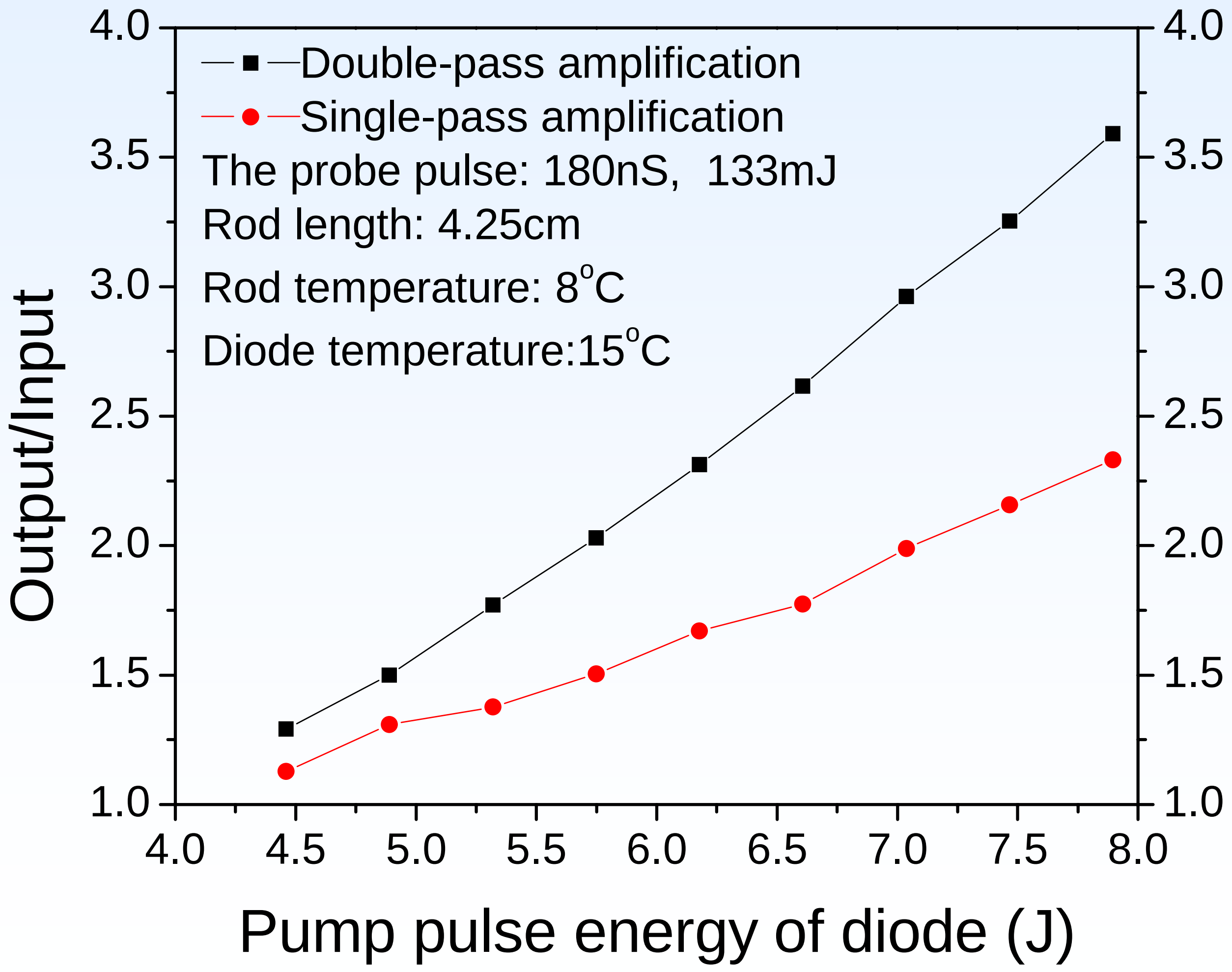


Amplifier Head Features

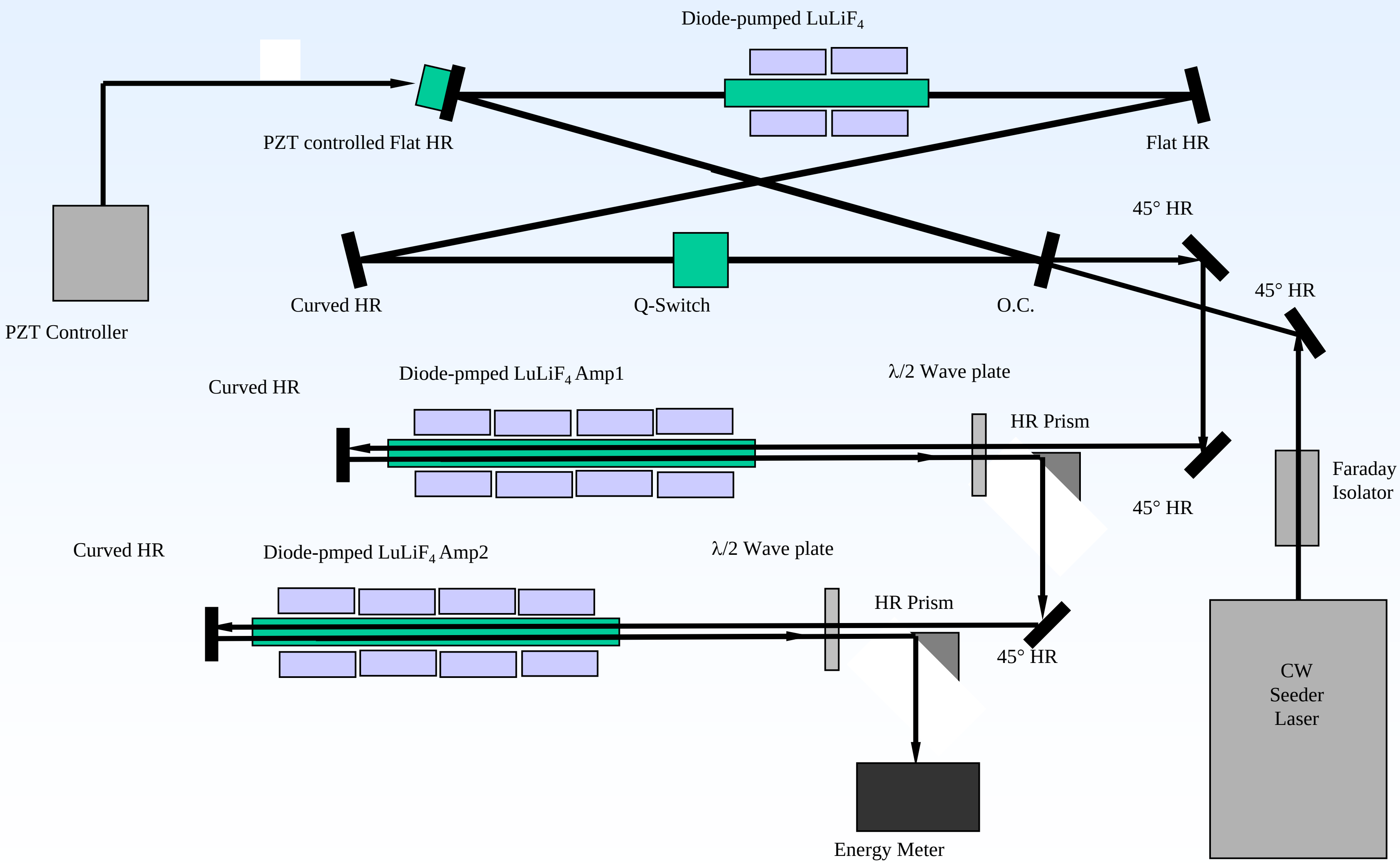


• Pump energy	7.2Joules12x6 bar arrays with 100w/bar
• Diode laser	conductive cooled ‘A’Pkg
• Laser crystal	Ho:Tm:LuLF 0.5% Ho 6%Tm
• Doped Crystal length	41mm
• Ends diffusion bonded	15 mm undoped LuLF crystals
• Laser crystal cooling	H_2O
• Flow tube size	7mm OD 6mm ID AR coated
• Rod ends	AR coated for 2.053μm flat
• Path configuration	double pass

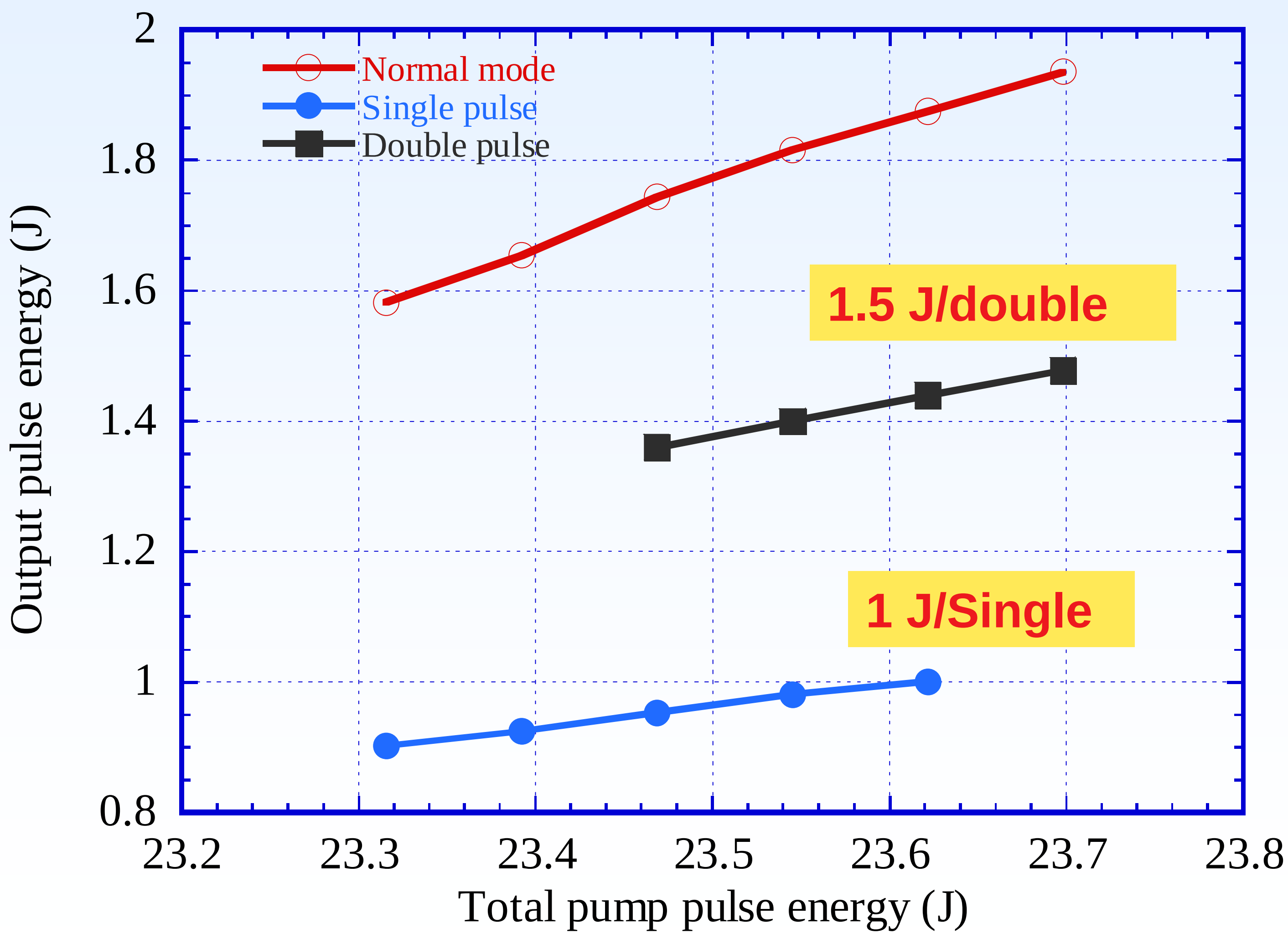
Single and Double Pass Amplification



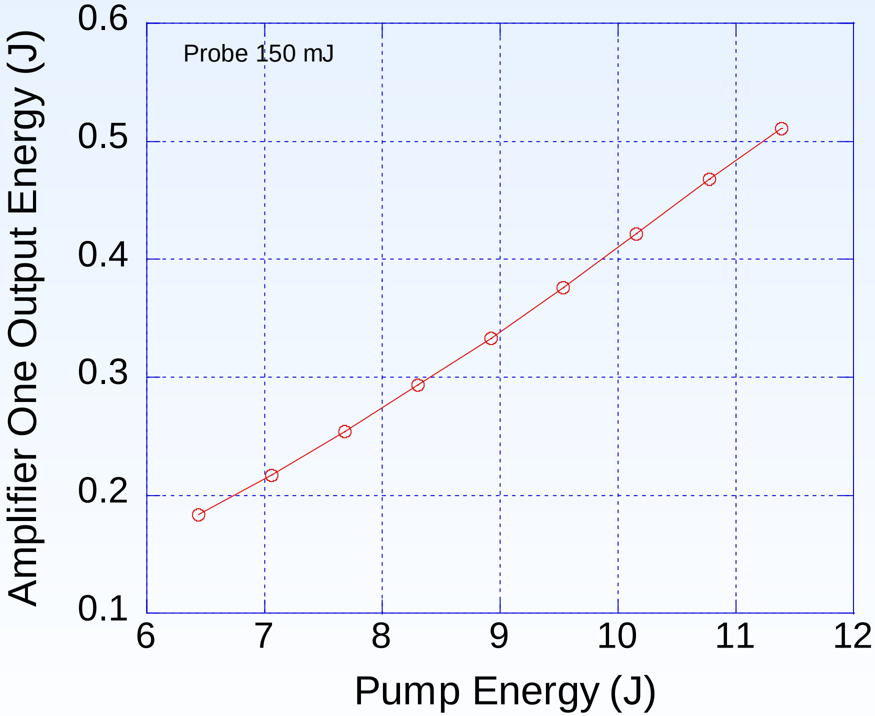
MOPA Experimental Diagram

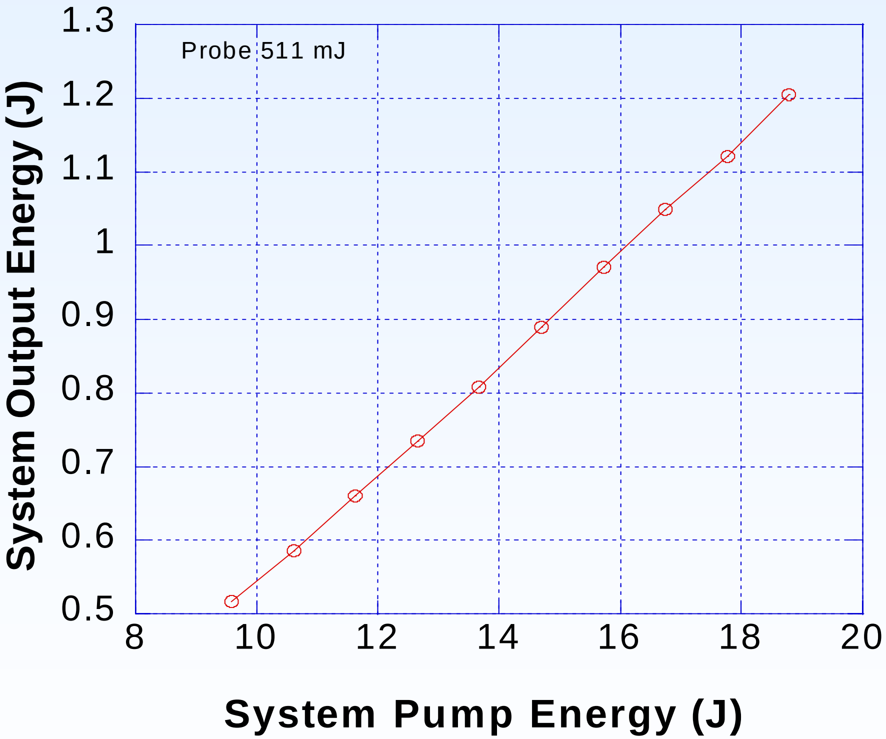


2-micron Osc/Amp Output Energy



Amplifier Performances





Compact Laser Design

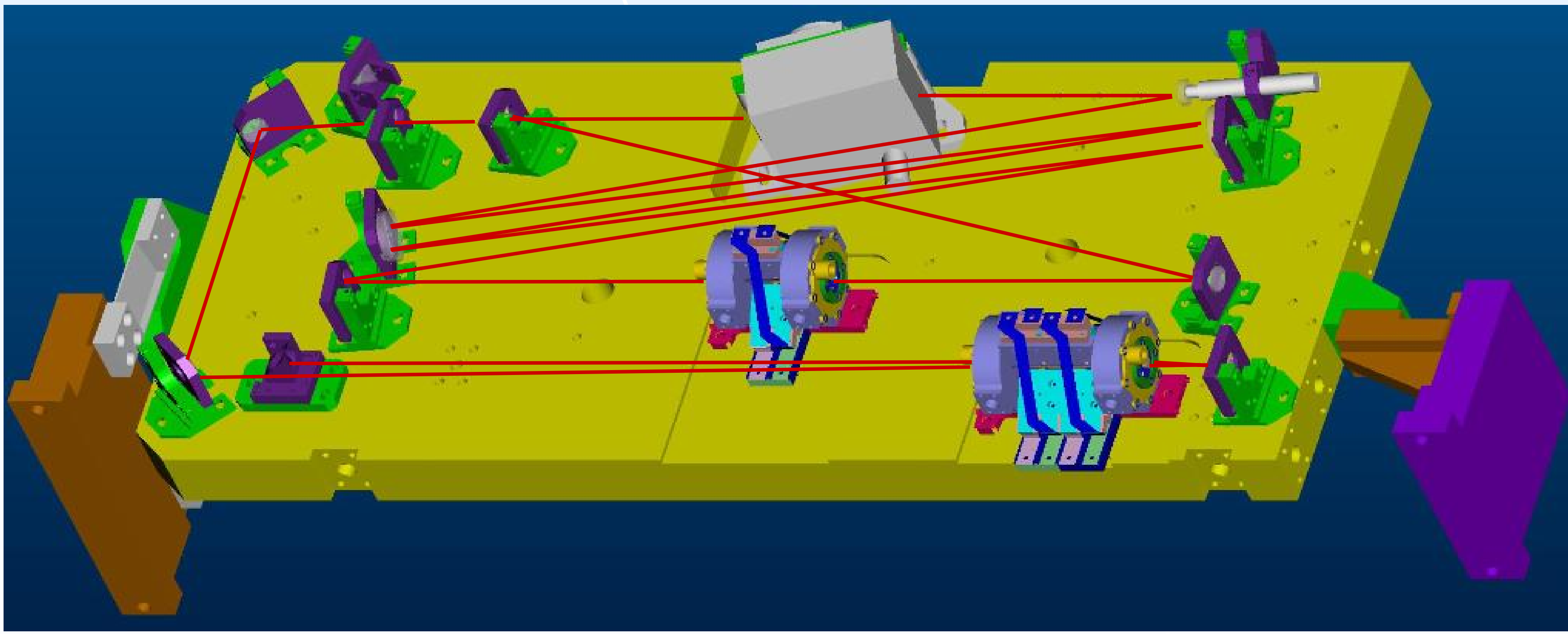
Compact Laser Design Goal

• Pulse energy:	>250 mJ
• Repetition rate:	10 Hz
• Wavelength:	2.053 μm
• Pulse length:	> 100 ns
• Line width:	< 2.5 MHz
• Heterodyne frequency offset:	105 MHz
• Beam quality:	<1.3 diff limit
• Beam size:	6 mm at the amplifier output

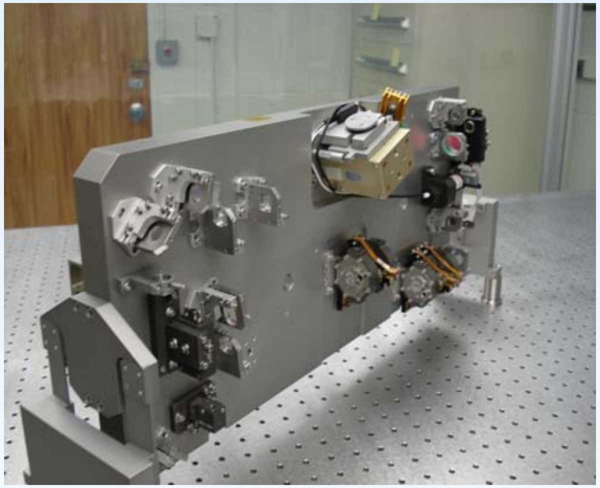
Mechanical Design Guidelines

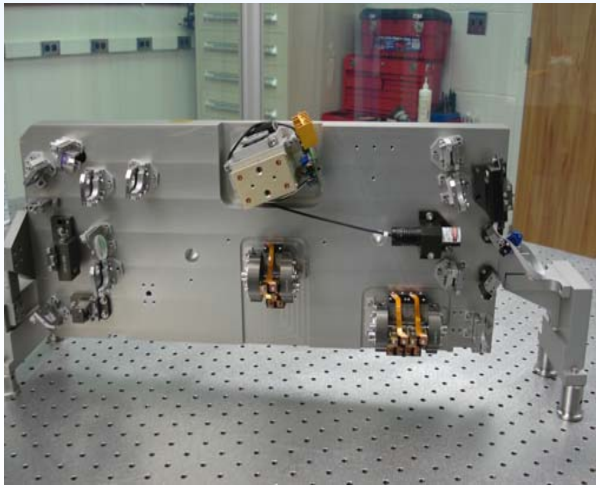
- Laser enclosure
  - Compact, sealed, and Nitrogen purged
- Optical bench
  - Populated on both sides
  - Temperature controlled
- Optical mounts
  - Hardened- space laser inheritance
  - Optical height 1 inch

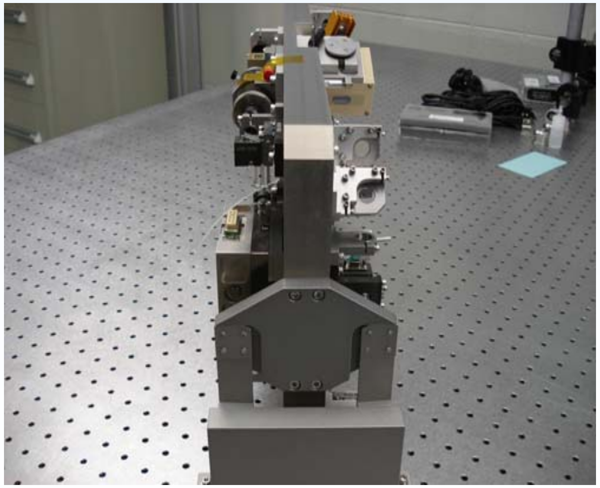
Pulsed, 2-Micron Laser Transmitter



Dual-sided Laser Transmitter

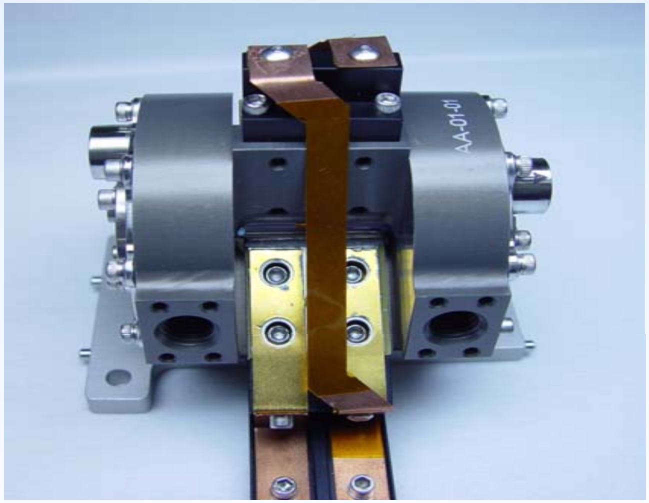




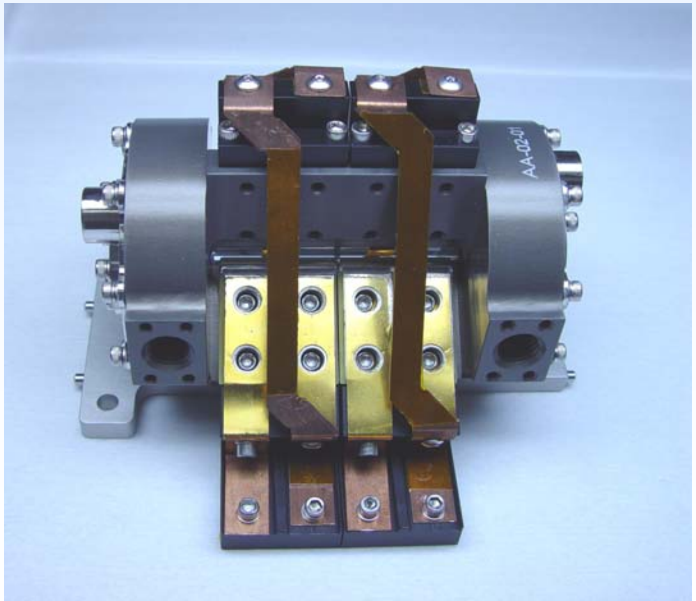


Laser Head

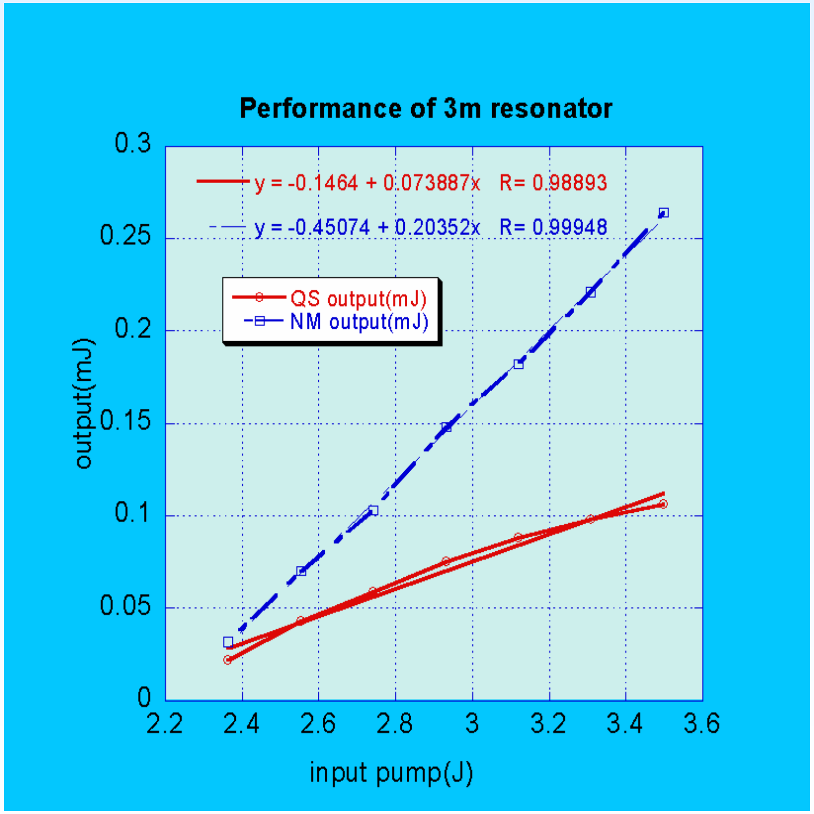
Oscillator laser head

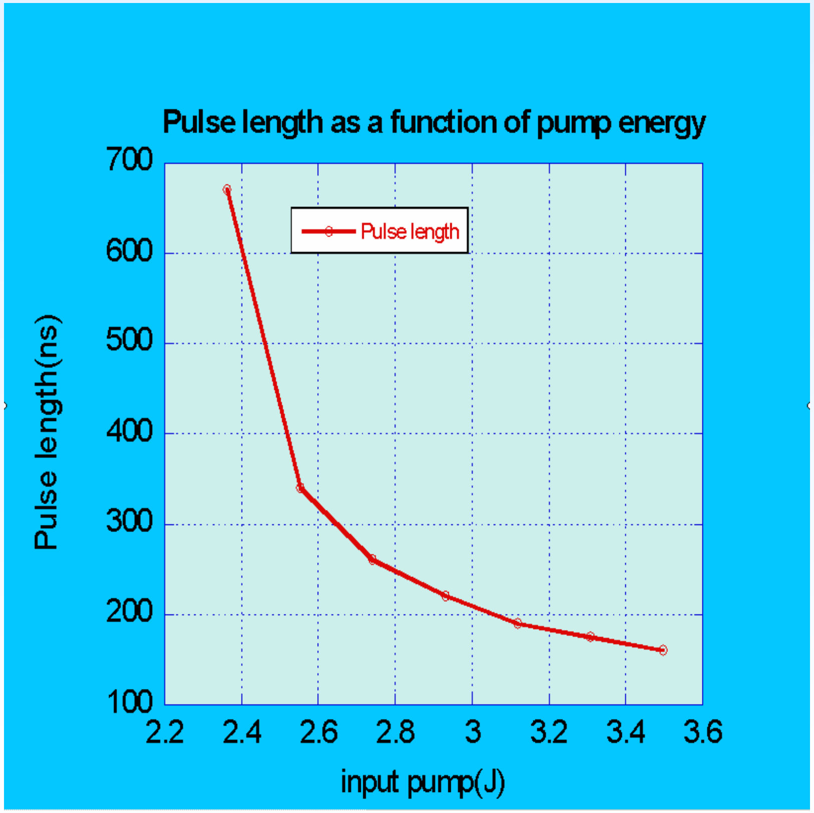


Amplifier

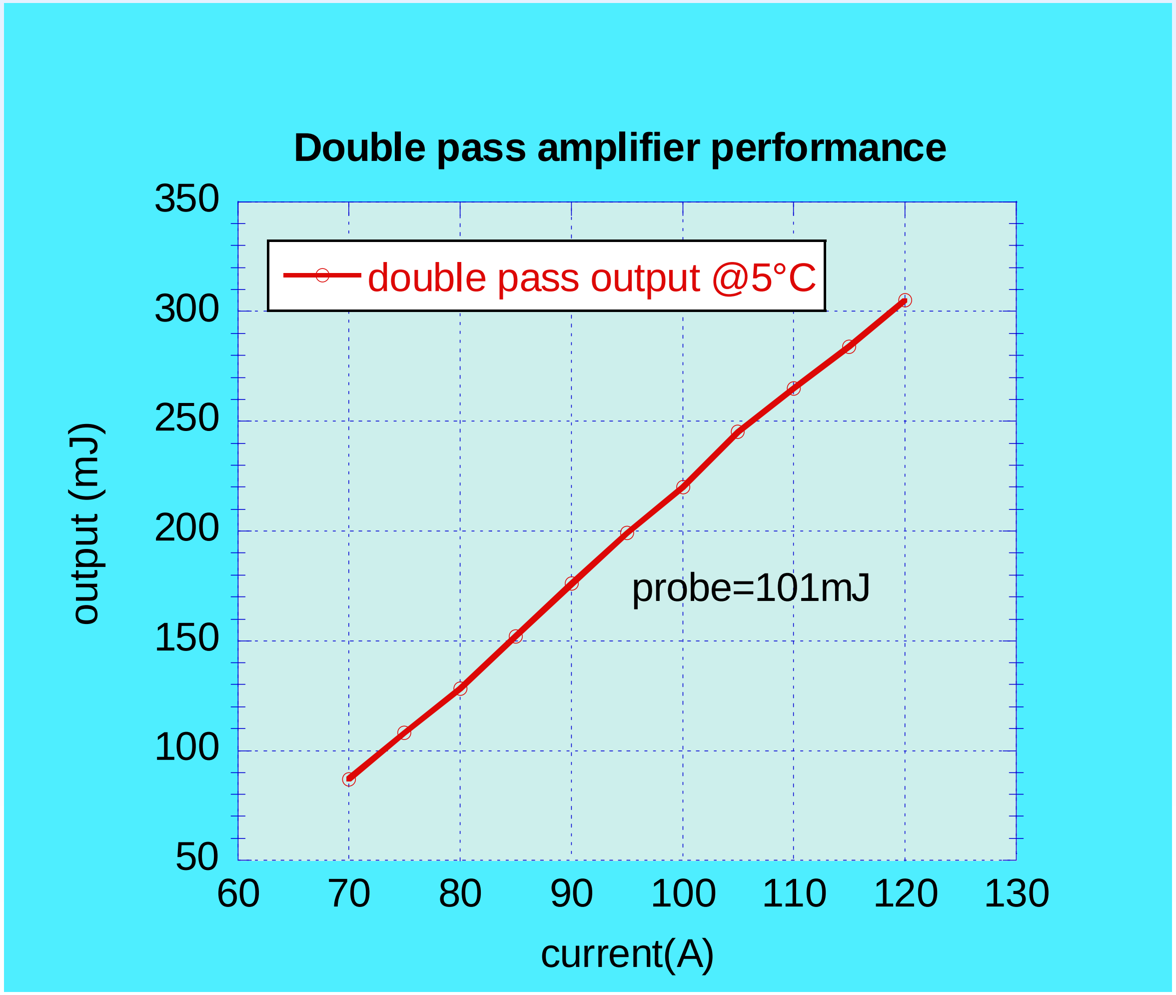


10 Hz Oscillator Performance



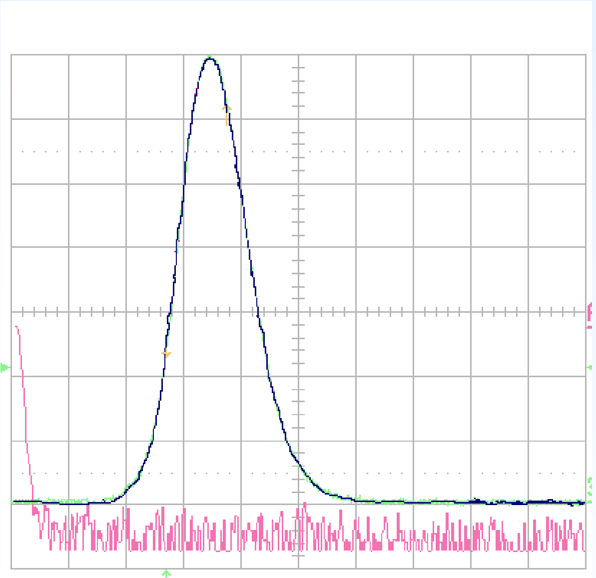


Double Pass Amplifier Performance

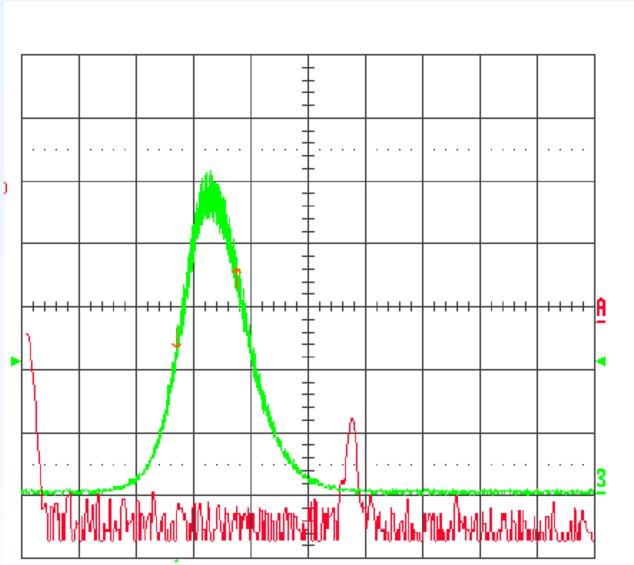


Amplifier gain: double pass ~3

Seeding Verification

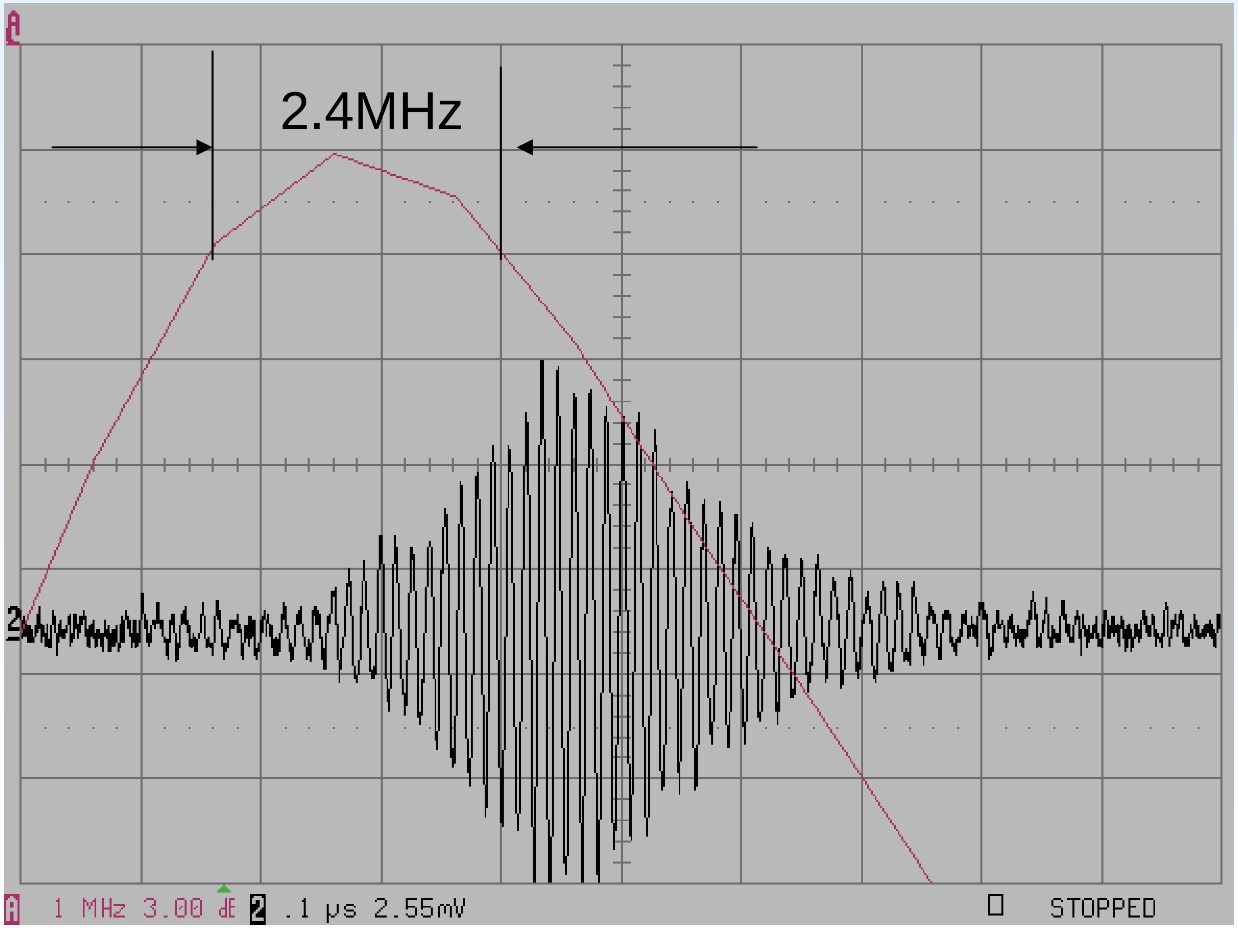


Seeded pulse has no mode-beating



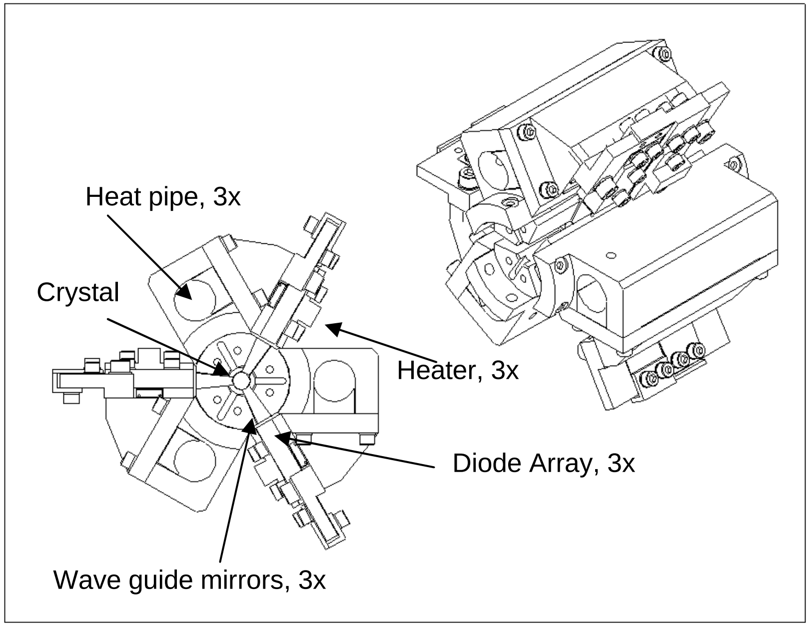
Unseeded pulse

Oscillator Linewidth

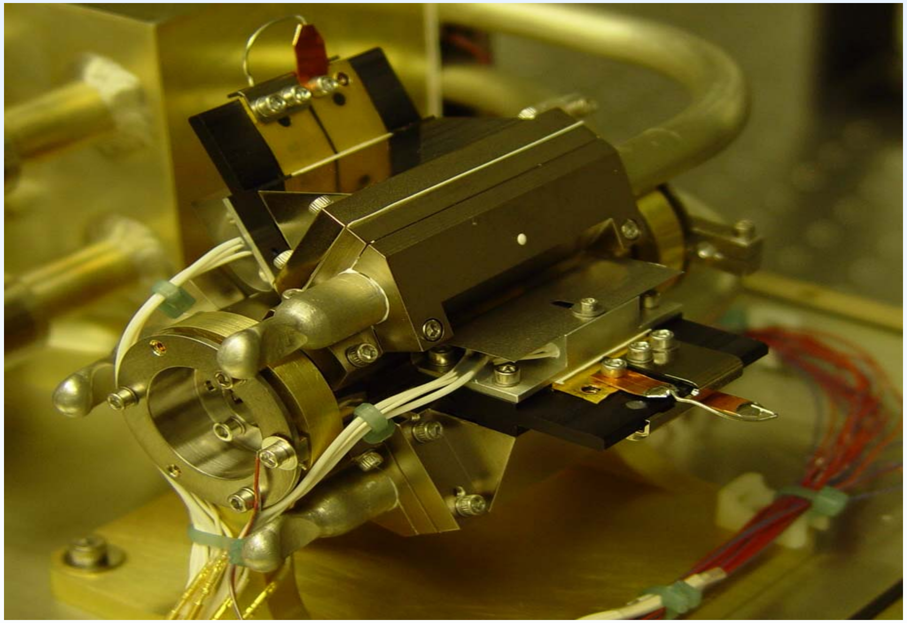


Conductive Cooled Laser

Conductive Cooled Oscilator Head



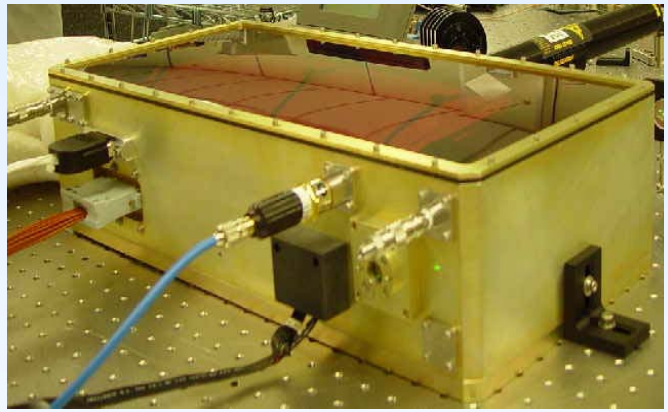
Design of CC Oscillator head

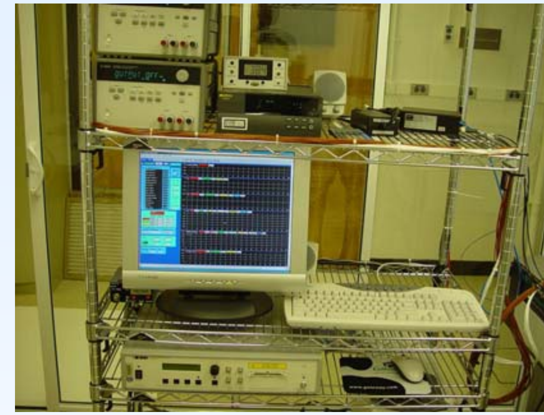


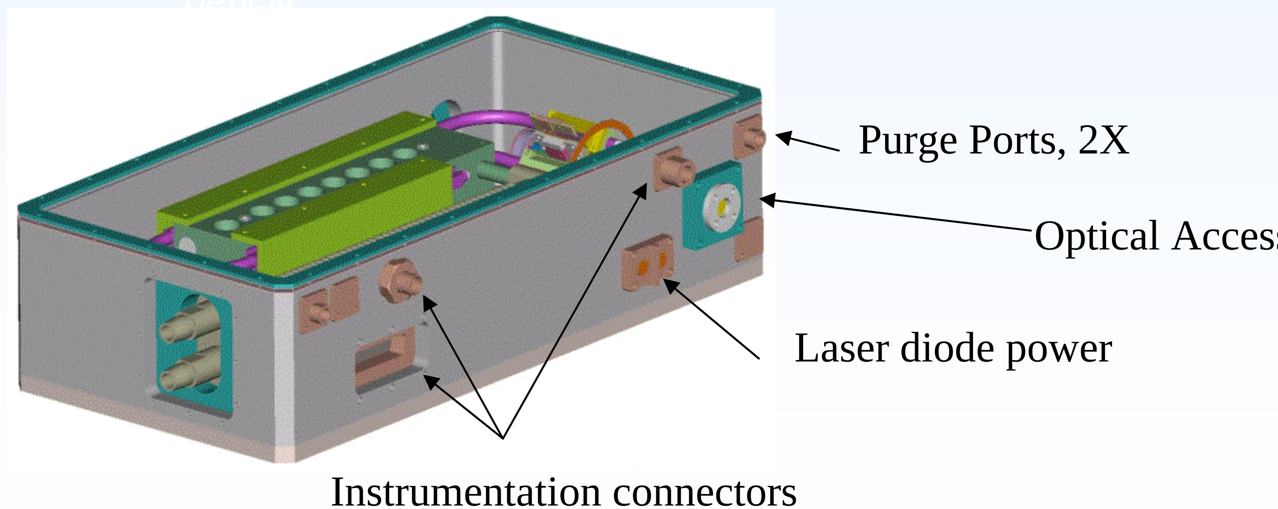
Completed CC Oscillator head

2 Micron Oscillator Prototype

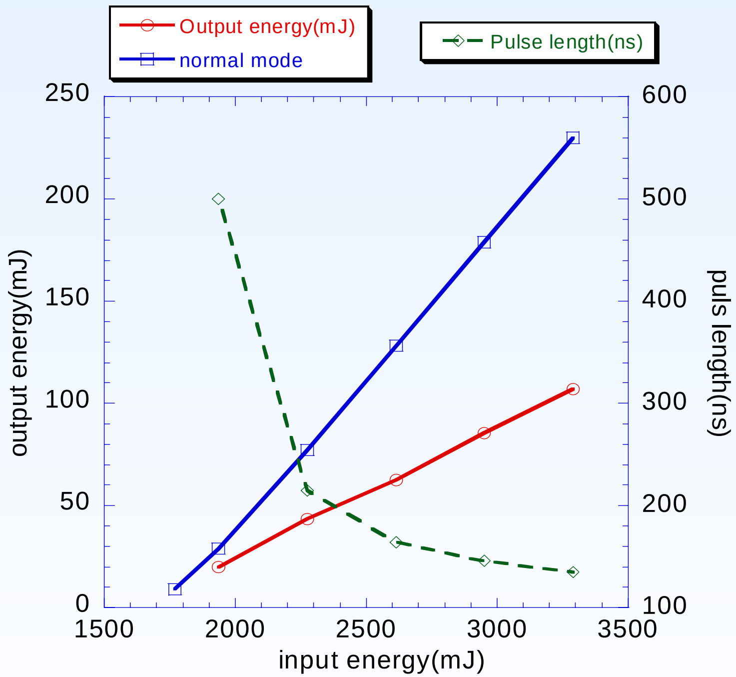
- OSCILLATOR PUMP HOUSING
  - **THREE POINT MOUNT TO PURGE BOX**
- HEAT PIPES
  - **ALL PIPES HORIZONTAL**
- CONDENSER BLOCK
  - **THERMALLY ISOLATED FROM PURGE BOX**
  - **INSULATED TO MINIMIZE HEAT GAIN FROM PURGE BOX**
- ELECTRICAL TERMINAL BLOCK
  - **LOCATED CLOSE TO PUMP HEAD TO MINIMIZE LEAD LENGTHS TO DIODES**
- THERMOCOUPLES
  - **LOCATED ON BOX, CHILLER BLOCK, PUMP HOUSING, DIODE HEAT SINKS, ROD HEAT SINKS, DIODES, AND HEAT PIPES**



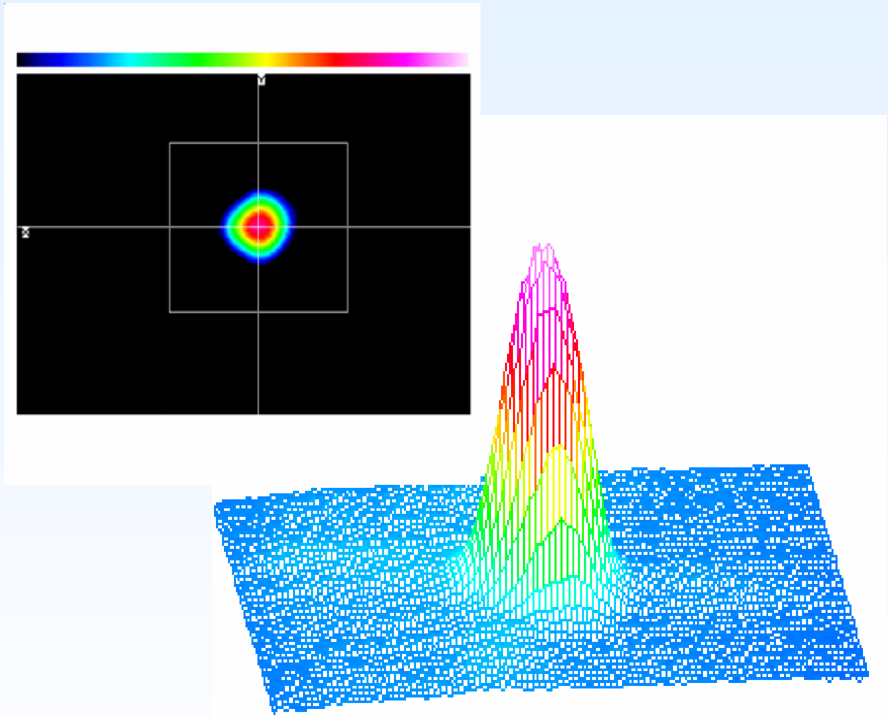




Conductive Cooled Oscillator Performance



At 2 Hz, Q-S mode produced 107 mJ with pulse length of 140 ns



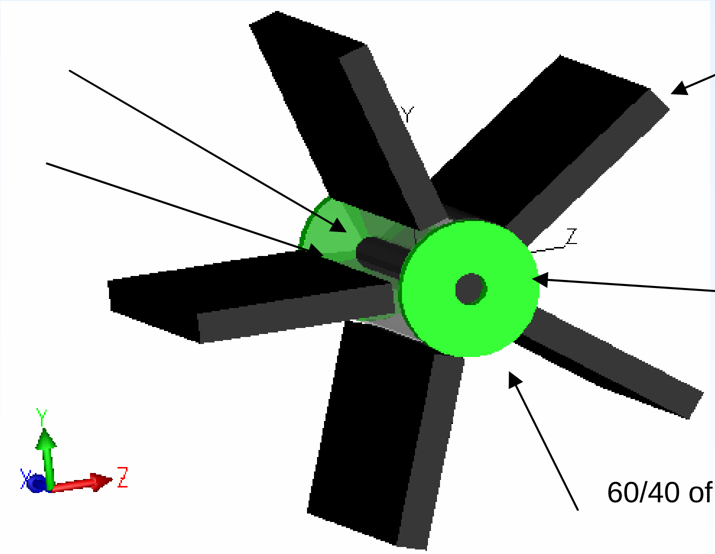
Near field beam profile at 2Hz.
Gaussian with overall beam quality (M^2) of 1.1

5-sided Amplifier Head Concept

Laser Rod (5mm x 40mm long)

Light wave guide

Pump-diode modules, 5x
4 – 4W arrays for 16W/module
(Total 80W pump power)

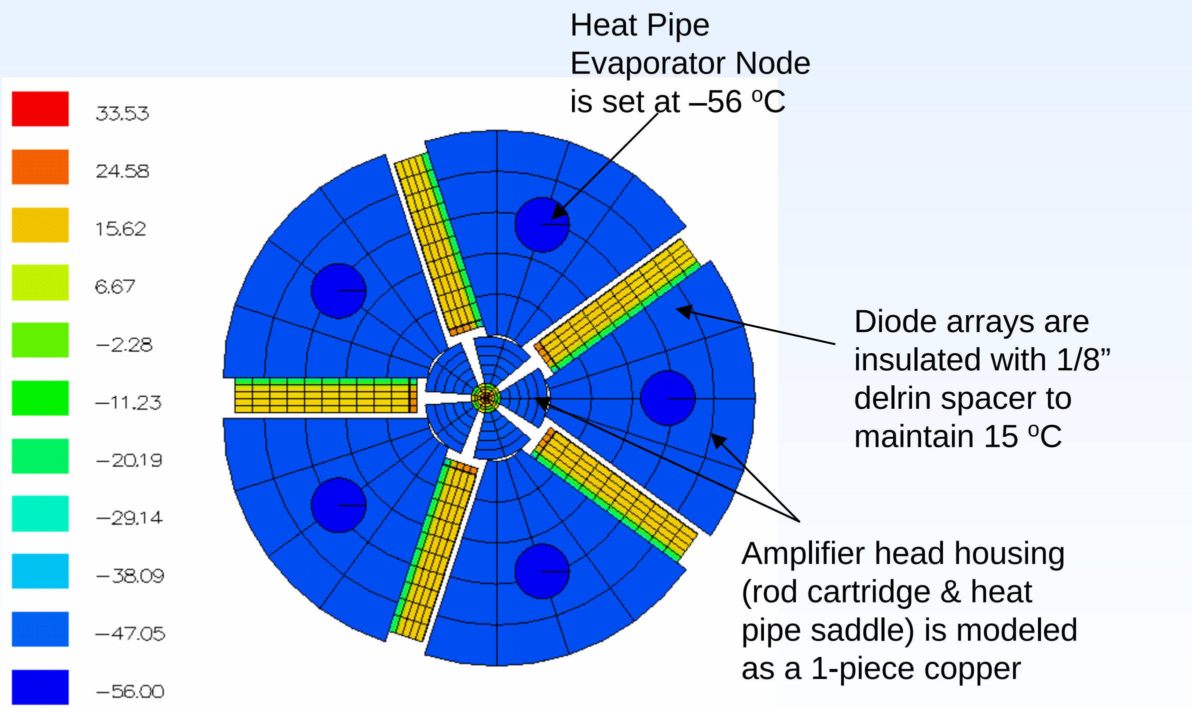


Laser Rod Housing

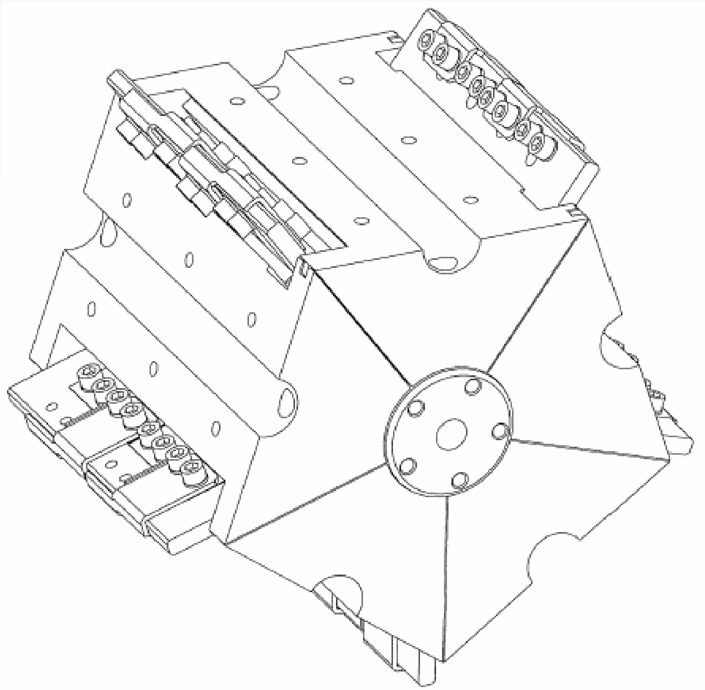
60/40 of arc-length is allocated for conductive cooling

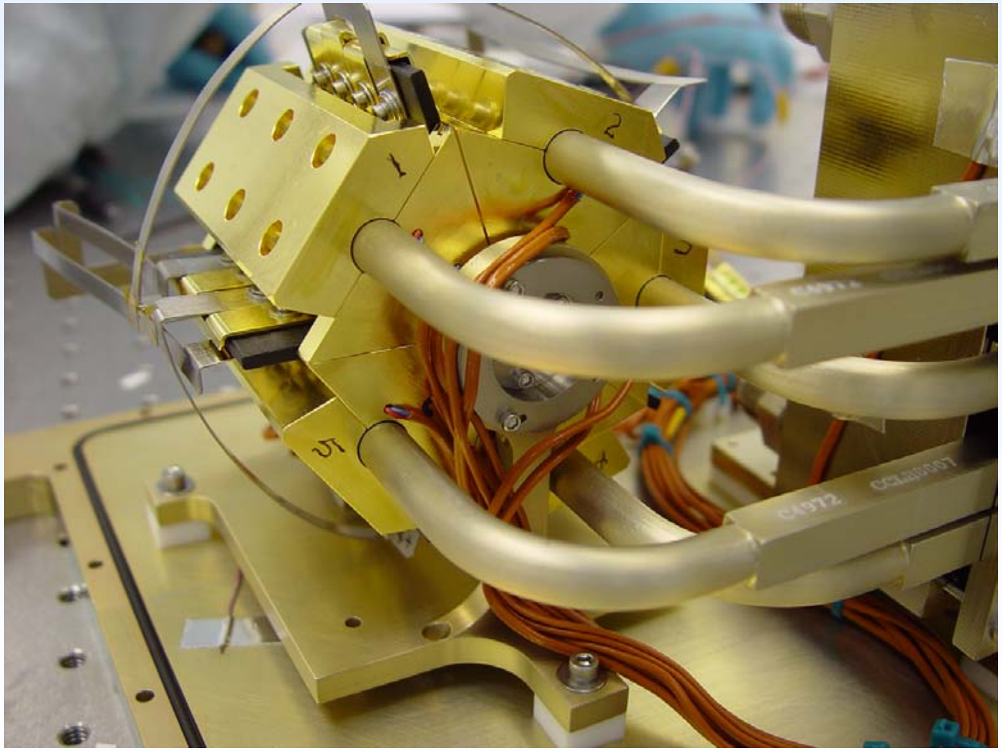
Amplifier Head Design Over-all Thermal Map

- Tradeoff studies were performed to optimize amplifier housing for minimum thermal gradient
- Optimization parameters included physical geometry and material selection.
- Optimized solution is to combine crystal cartridge with heat pipe saddle into a single piece amplifier head housing make from copper



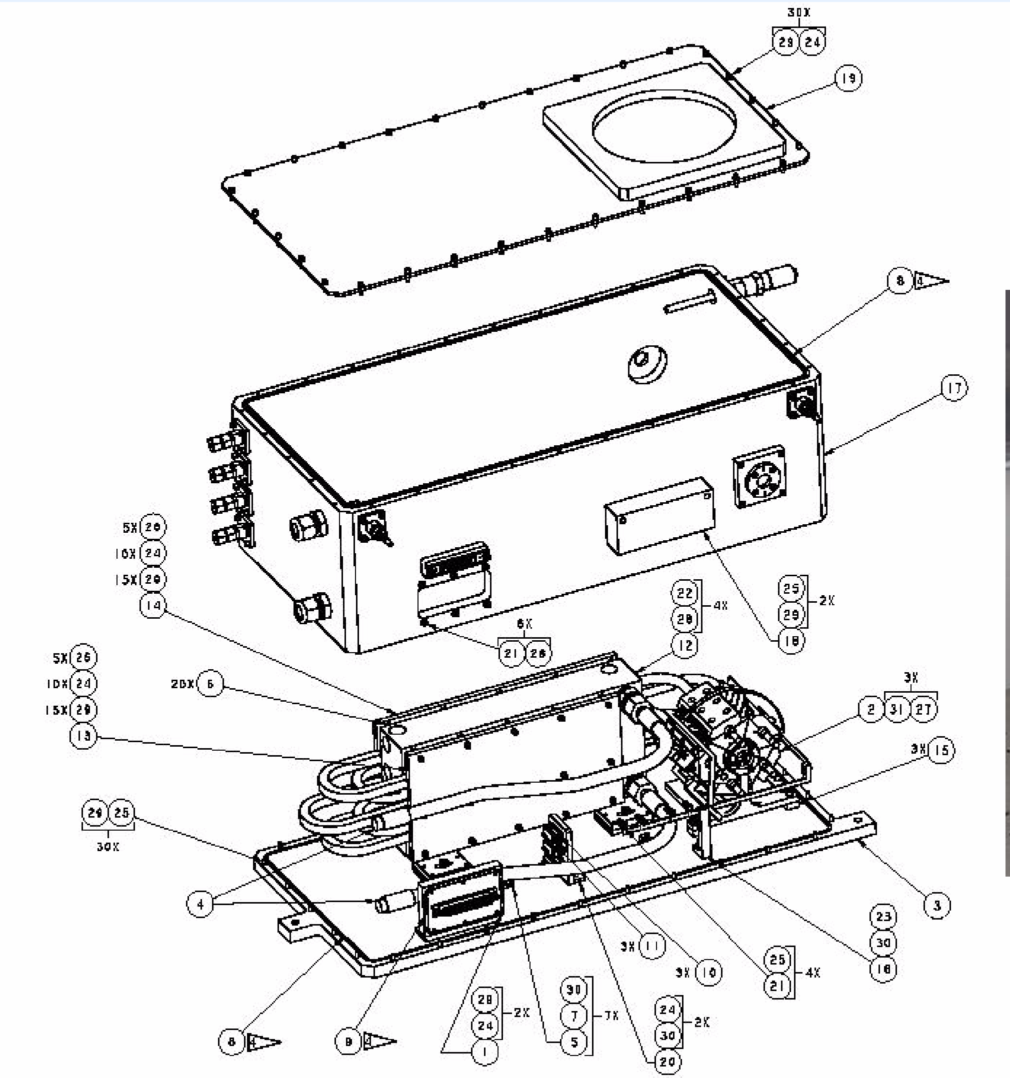
CC Amplifier Head

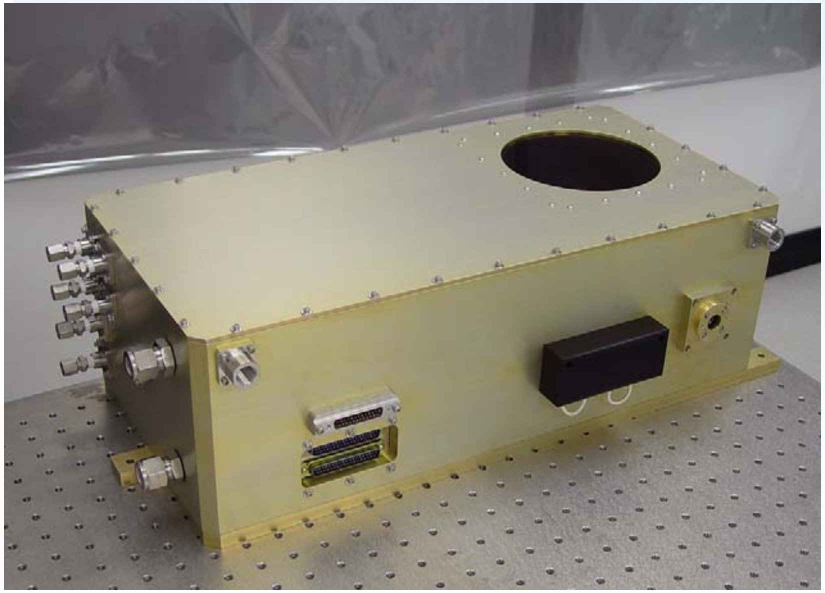




(a) 5-sided, 1-piece amplifier head

CC Amplifier Assembly





Conclusions

- Successfully demonstrated, for the first time, a high energy 2-micron laser that breaks one Joule per pulse barrier

- Partially cooled, compact laser transmitter for Doppler wind lidar design is complete and fabrication is underway
- The performance has been evaluated using a verification laser.
  - Oscillator produced 100mJ and distortion free output.
  - The amplifier produced a maximum of 300 mJ at 10 Hz
  - All the compact laser requirements have been satisfied

- Demonstrated a diode-pumped, fully conductive cooled, Q-Switched, 2-micron oscillator, which enhanced the technical readiness level of the instrument for space qualification.
- Developed a fully conductive cooled 2-micron amplifier