COHERENT TECHNOLOGIES

Amplification of Q-switched Pulses to 400mJ at 2051nm using a Conduction-Cooled Laser Pump Module

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Initial Concept - Coherent Doppler Lidar for Wind Measurements from the International Space Station

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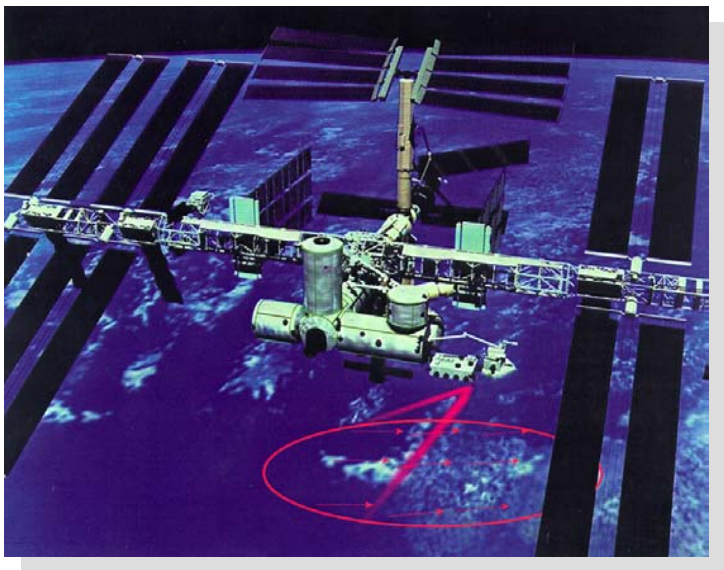
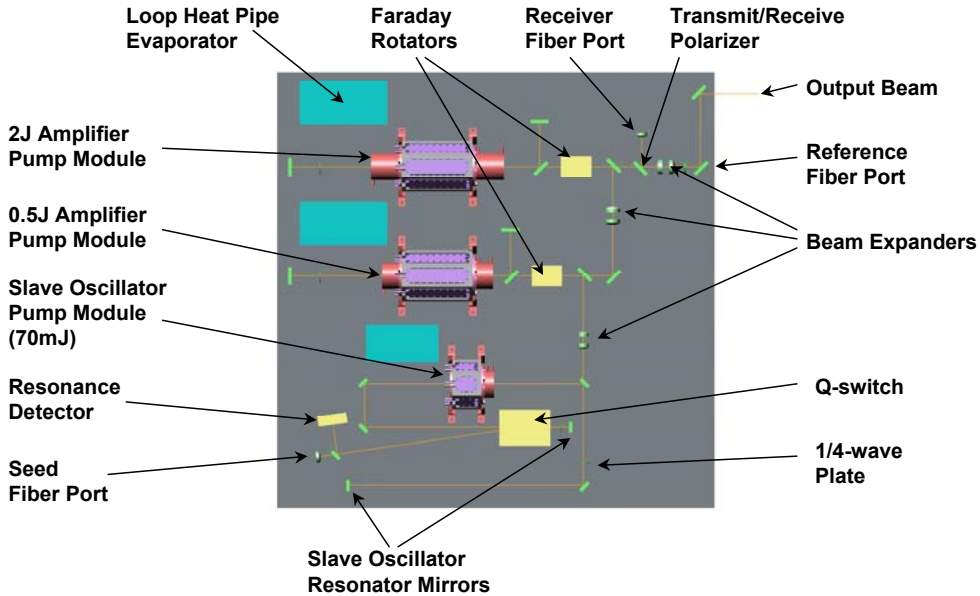
- CTI recently completed contract with Communications Research Laboratory (Japan) to demonstrate CDWL laser amplifier prototype with path to deployment on the International Space Station (ISS)
  - Final performance requirements: 2J, 10Hz, 300-400ns (bandwidth-limited)
  - Contract was for initial risk reduction demonstration, showing ~0.5J energy at 10Hz PRF in first stage amplifier





JEM-CDL Performance Specifications

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- **Planned transceiver location on JEM Facility had access to ISS cooling**
  - **2% wall-plug efficiency required (1kW power in at 2J, 10Hz operation)**
  - **Efficiency requirement best met by incorporating active cooling of rod to 200K**
  - **Design compatible with passive cooling using heat-pipes and space radiators on sun-synchronous platform with wind lidar as primary application**
- **Long-term transmitter objectives: Injection-seeded Q-switched operation with the following characteristics:**

Parameter:	Value:
Pulse energy	$\geq$ 2J
Pulse repetition rate (PRF)	10Hz
Pulse duration	300 +/-100ns
Laser material	Ho,Tm:YLF
Laser wavelength	2051nm
Mode	single longitudinal mode single transverse mode
Wall-plug efficiency	2%

Risk Reduction Demonstration

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- First stage amplifier assembled with closed loop refrigeration cooling
  - Hardware compatible with either passive heat-pipe or closed loop refrigeration cooling architecture
  - Rod and laser diodes conduction cooled to exchangeable cold-plates
- Goals of the funded activity
  - Demonstrate energy storage and extraction efficiency suitable for 0.5J, 10Hz amplifier operation with 2% wall-plug efficiency

Conduction-Cooled Laser Head Design

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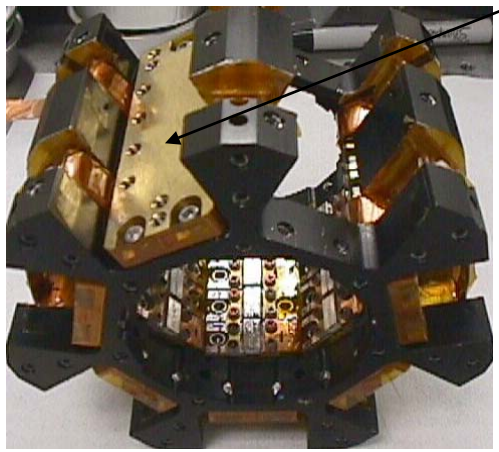
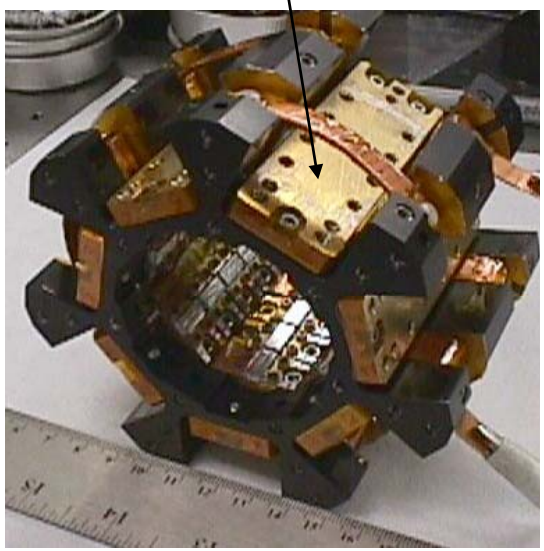
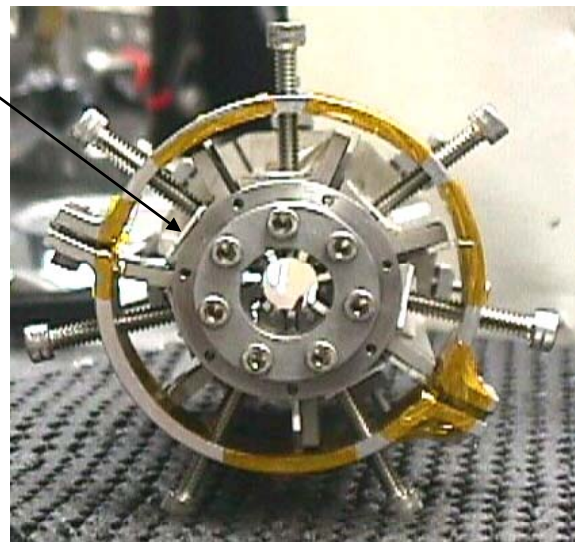
- Laser head in assembly (prior to cold plate installation)

Heat Transfer Surfaces



Laser Diode Assembly
(4x2x7 bars)
(56x100mJ = 5.6J max)





Laser Rod Assembly
(7-fold symmetry heatsink)

Small-signal gain measurements and modeling indicate sufficient gain for 0.5J amplifier demonstration

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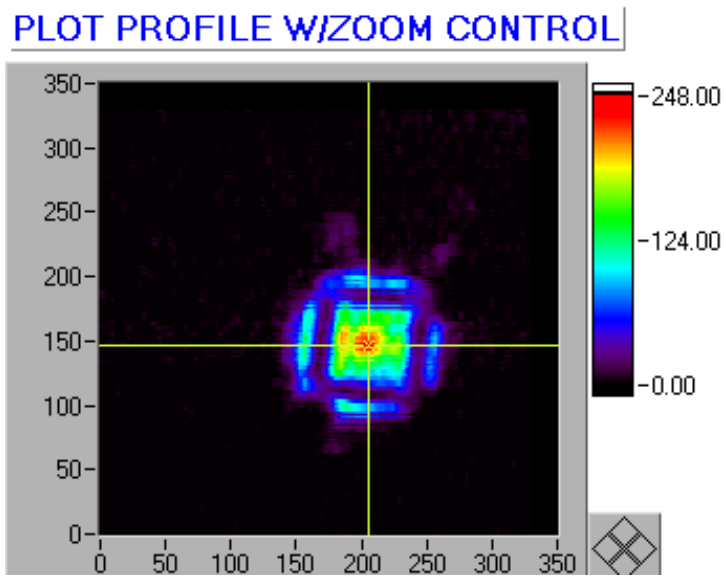
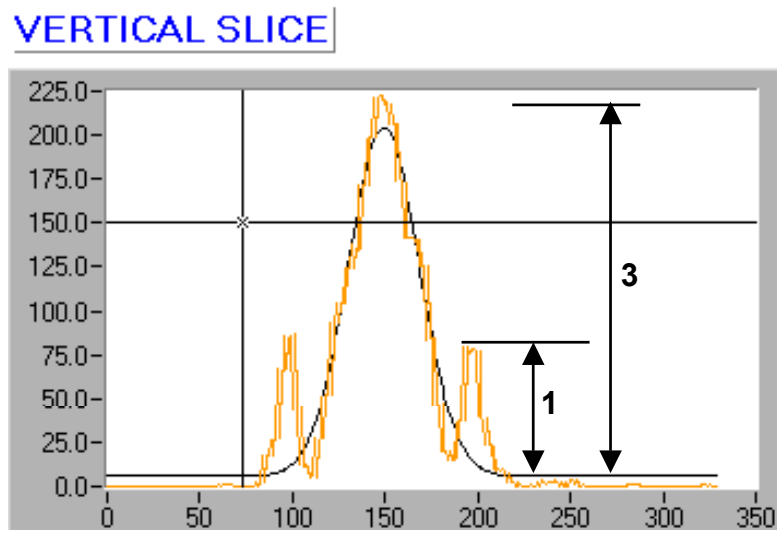
- **Small signal gain larger than initially planned due to reduced rod operating temperature**
  - **Initial 4-pass amplifier design based on single pass gain of 2 and 2mm mode radius in laser rod**
  - **Measured value of 3 at reduced diode operating current (75A out of 115A)**
  - **400-500mJ possible with just 2-pass amplification**
    - **Simpler design and lower combined fluence at rod endfaces, allowing mode radius reduction to 1.25mm in laser rod (improved mode quality)**





Layout of Amplifier and Q-Switched Laser Resonator

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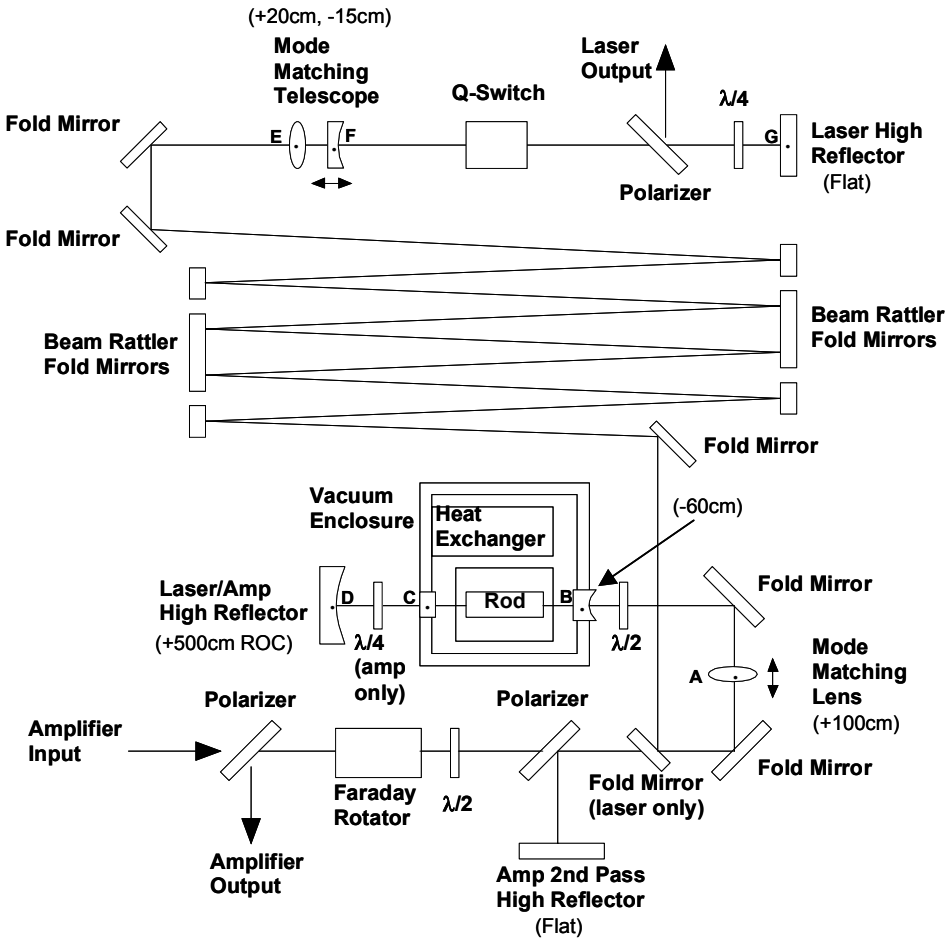
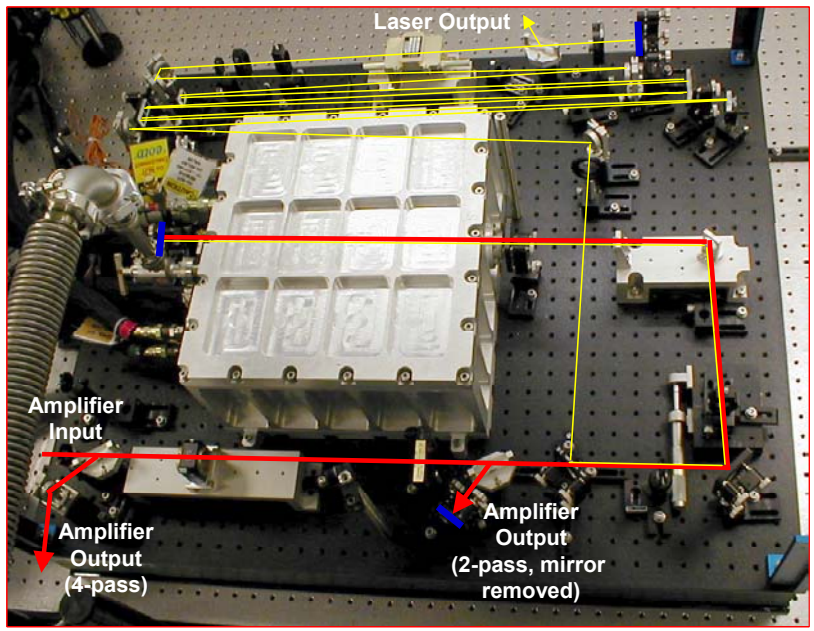
- **Hardware assembled both for operation as a long resonator Q-switched laser (for initial energy characterization) and as a multiple pass (2 and 4 pass) amplifier**





Q-Switched Operation (Long Resonator Laser)

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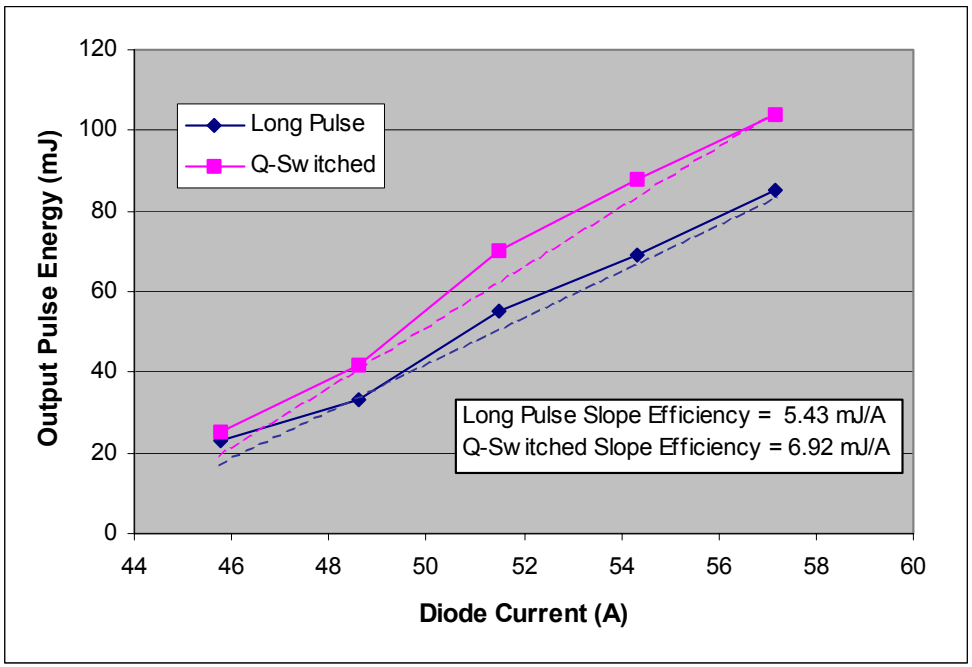
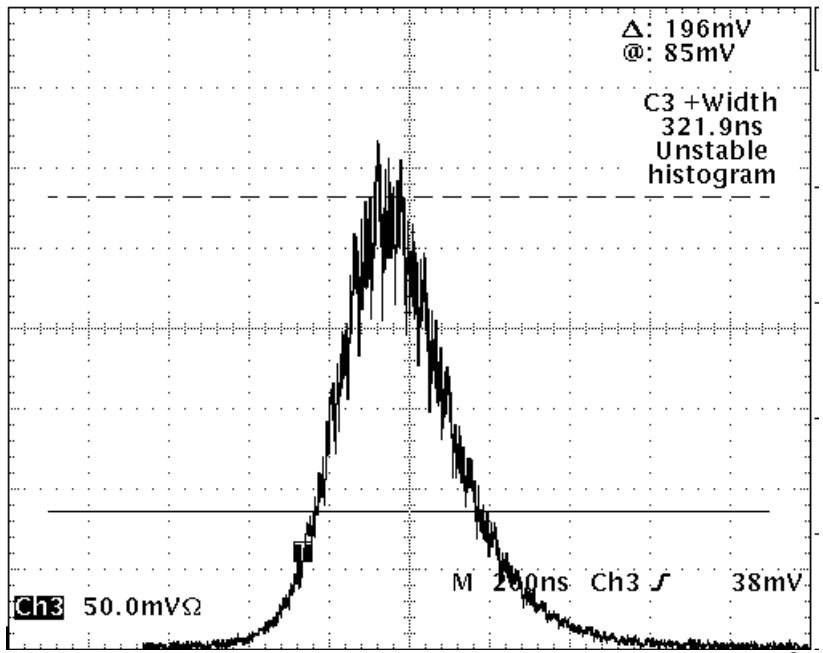
- Laser output coupling adjusted to limit maximum fluence to <20J/cm^2
- 105mJ, 10Hz, 320ns output obtained at 36% output coupling and 57A diode current
  - Increased energy possible by increasing output coupling and diode current
  - Laser diodes rated for 100W output power at 115A operating current (1% duty cycle)
  - Extrapolating Q-switched data: 400mJ emitted for 100A diode current (at same fluence level)





Packaged Hardware at CTI prior to shipping to CRL

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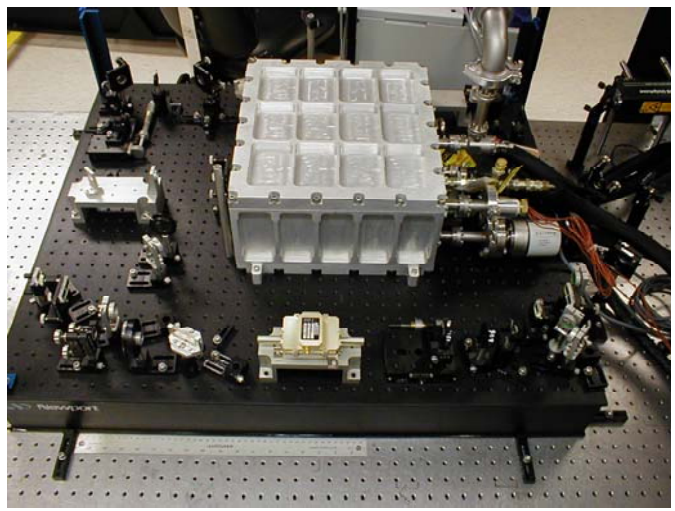
- **Laser Amplifier Head has 4 ports:**
  - **Q-switch Laser Output**
  - **Amplifier Input**
  - **Amplifier Output (2-pass)**
  - **Amplifier Output (4-pass)**



Prototype Laser Amplifier Delivered to CRL

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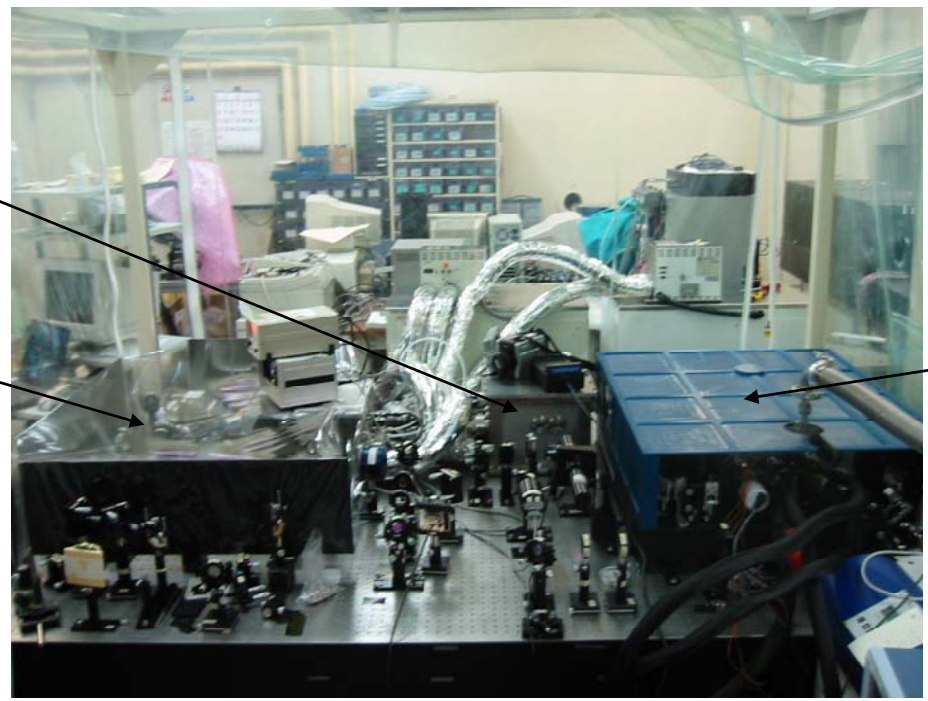
- CTI breadboard hardware includes both amplifier and long resonator optical assemblies
  - Amplifier configuration takes up a small fraction of breadboard dimensions
- CRL/NEC MOPA operated at 1Hz PRF during tests due to optical damage concerns
  - CTI amplifier hardware operated at 10Hz PRF, triggering CRL/NEC MOPA at 1Hz



2-Pass Amplifier Performance (35mJ input pulse energy)

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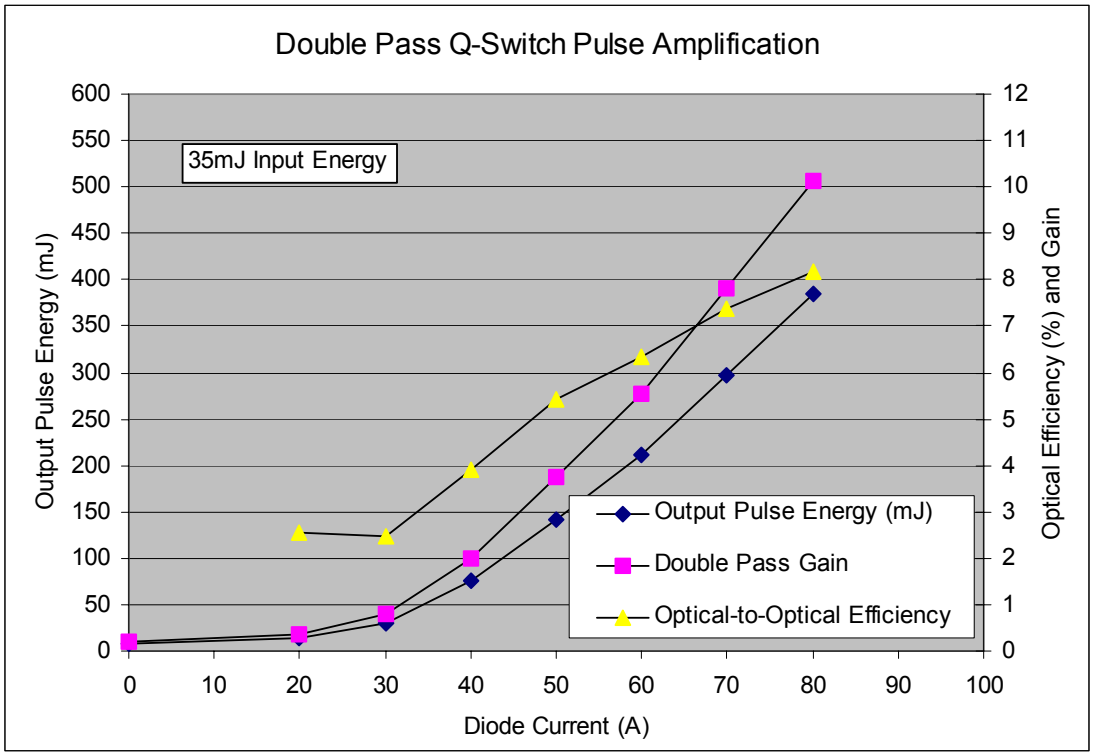

- **Laser Amplifier operated at 10Hz but input pulses only available and amplified at 1Hz (additional thermal load in amplifier)**
- **Pulse duration between 600 and 800ns (depending on laser and pre-amplifier settings)**
- **>10x 2-pass gain**

2-Pass Amplifier Performance (50mJ input pulse energy)

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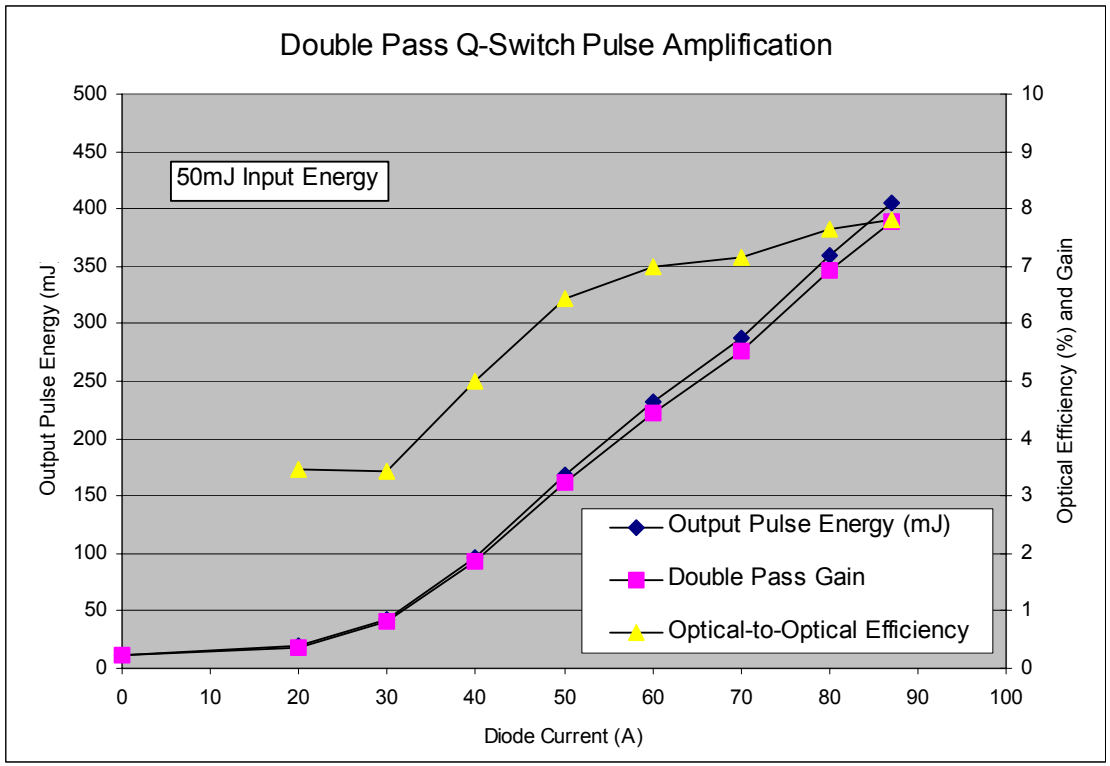

- **>400mJ output pulse energy obtained with on-axis double pass amplifier configuration and 50mJ input pulse energy**
  - **~8x double-pass gain**
- **Maximum output pulse energy limited to ~420mJ by optical damage to output Faraday rotator**
  - **Mitigated by adjusting beam magnification on second pass of amplifier (curvature of amplifier end reflector) or by going to slightly off-axis 2-pass configuration**

Amplifier Characteristics at 400mJ Pulse Energy (temporal and spatial)

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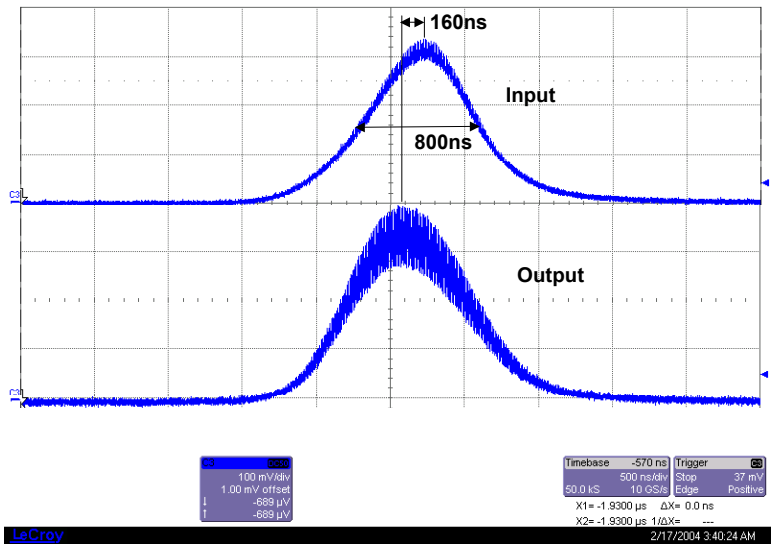
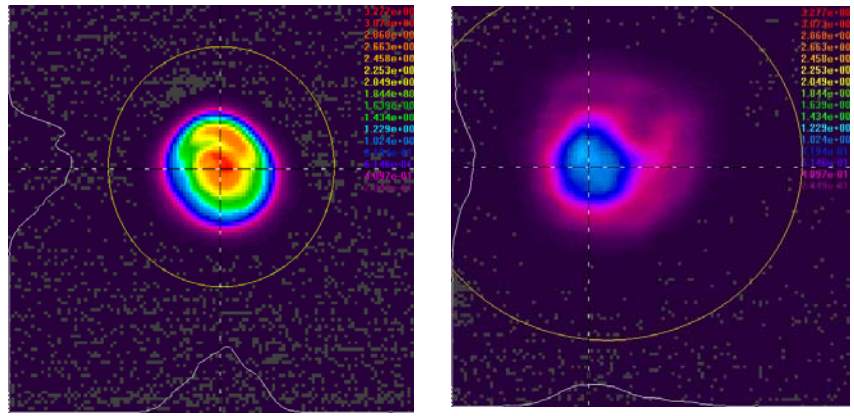


- Output Q-switch pulse profile "advanced" in time by 160ns compared with input profile due to partial amplifier saturation behavior



- Double-pass spatial beam profile (right) obtained during initial acceptance testing was not diffraction-limited – noise associated with input spatial noise feature from pre-amplifier beam (left)
- CRL plans to improve output mode profile for diffraction-limited operation by cleanup of input beam profile and optimization of mode-matching to laser amplifier rod core

Summary

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- CTI has demonstrated Q-switched pulse amplification in Tm,Ho:YLF to >400mJ output pulse energy
- On-axis 2-pass amplifier provides 10x gain for 35mJ input energy and 8x gain for 50mJ input energy
- Optical-to-optical efficiency at 400mJ output energy is ~8%
- Pulse duration used during initial testing was 700-800ns
  - Maximum fluence setting of 20J/cm^2 designed for shorter pulse operation around 300ns
- Temporal pulse distortion indicates modest level of gain saturation but with gain still available at back end of pulse
  - Higher energy extraction possible with higher input pulse energy
- First demonstration of multiple hundred millijoule output (and >10x double-pass amplification) in an all conduction-cooled two micron laser pump module
- Embedded cold-plate design directly compatible with heatpipe and space radiator technology for efficient thermal management in a space environment
- All amplifier results obtained in a 10 day visit to CRL this February, including a 4 day installation and mode-matching period
  - Results from acceptance test are preliminary and far from optimized, both in terms of pulse energy extraction and output beam profile