High Energy 2-micron Laser Developments

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2007 Solid State Diode Laser
Technology Review

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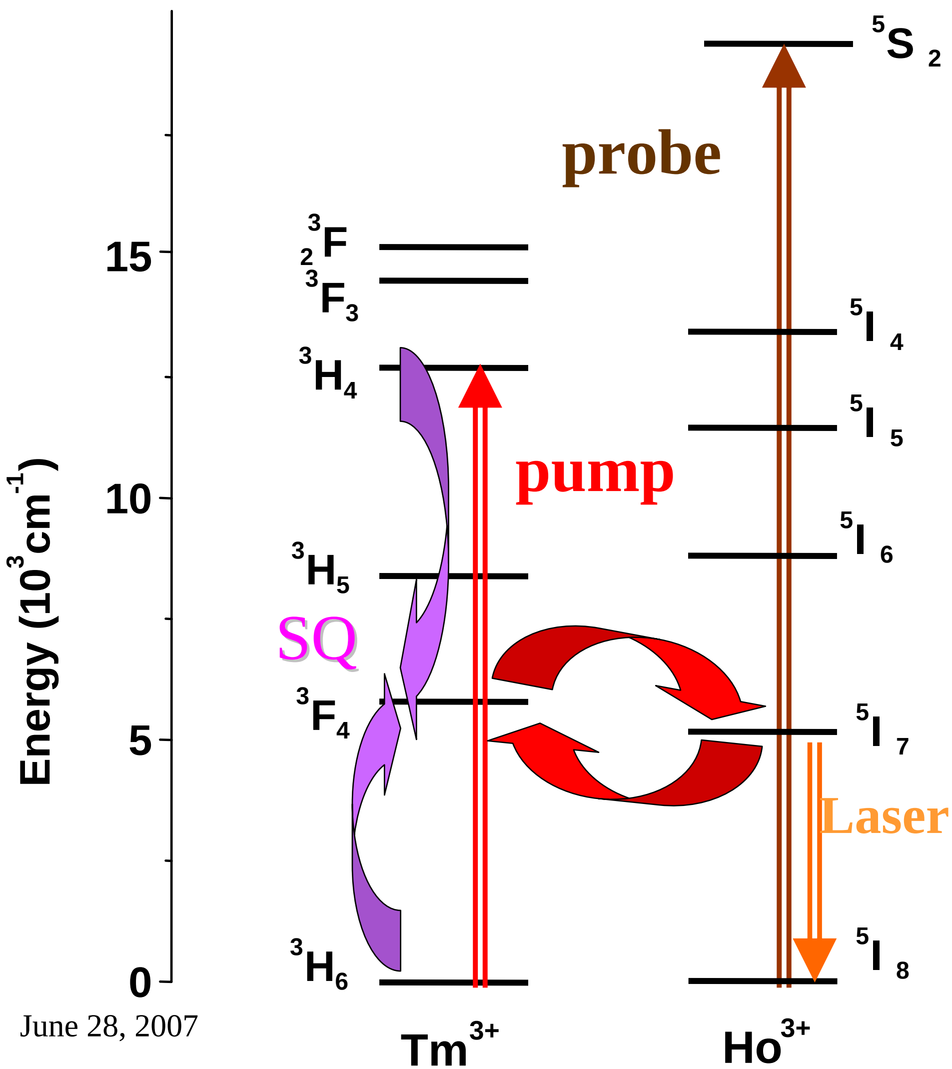
Outline

- Overview 2-micron solid state lasers
- Modeling and population inversion measurement
- Side pump oscillator
- One Joule 2-μm Laser
- Conclusion

Solid State 2-micron Lasers

- Tm Lasers (pump diodes 780-805nm)
  - YAG, YLF, $YAlO_3$, YVO_4
- **Ho:Tm Lasers** (pump diodes 780-805nm)
  - LuLF, YLF, GdLF, YAG, YVO_4
- Tm pumped Ho lasers (pump diodes 780nm)
  - Tm solid state laser pumped Ho Laser
  - Tm fiber laser pumped Ho Laser
- Ho Lasers (pump diodes 1900nm)
  - YAG
- Tm Fiber Lasers

Energy transfers between Ho^{3+} and Tm^{3+} ions and Pump-probe experiment



- **Pump at 792nm ($^3H_6 \rightarrow {}^3H_4$ transition)**

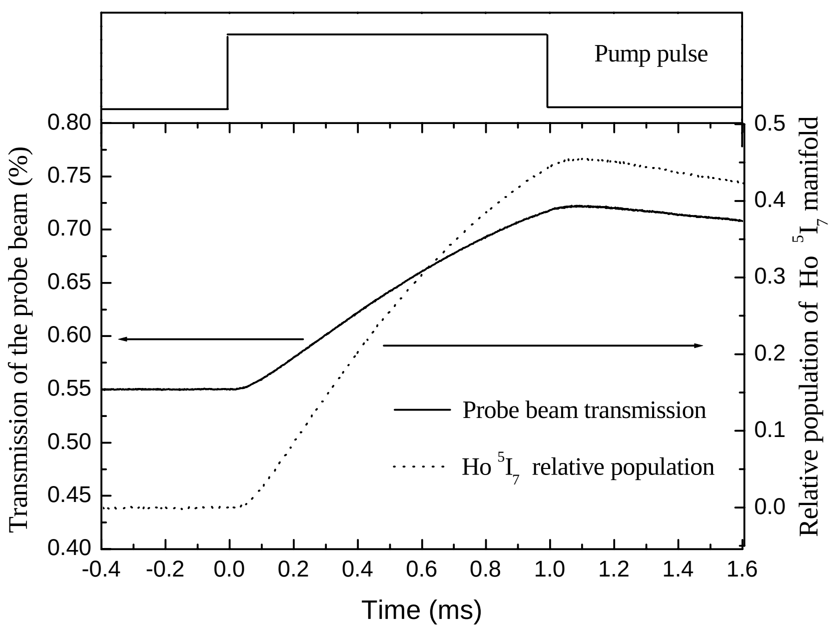
- **Energy transfers :**

- Self-quenching (P_{SQ})
  two Tm^{3+} ions in the $^3F_4$ manifold
- ($^3F_4 \Rightarrow {}^5I_7$) energy transfer ($P(Tm \rightarrow Ho)$)
- ($^5I_7 \Rightarrow {}^3F_4$) energy transfer ($P(Ho \rightarrow Tm)$)
- Ho , Tm upconversion (P_{UC})

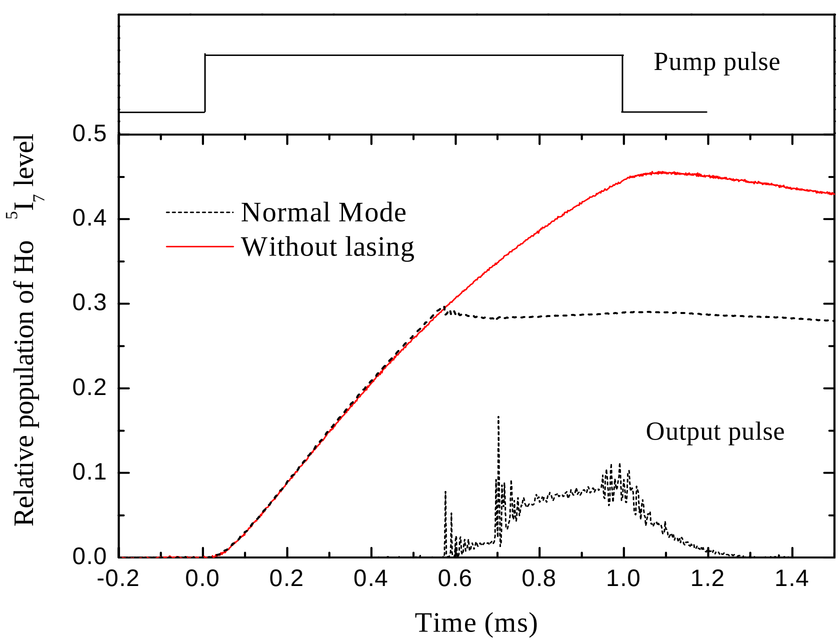
- **Probe at 543nm ($^5I_8 \rightarrow {}^5S_2$ transition)**
  - **Probe the $^5I_8$ ground-state depletion**

Evolution of the probe beam transmission and the corresponding population of the Ho $^5I_7$ manifold

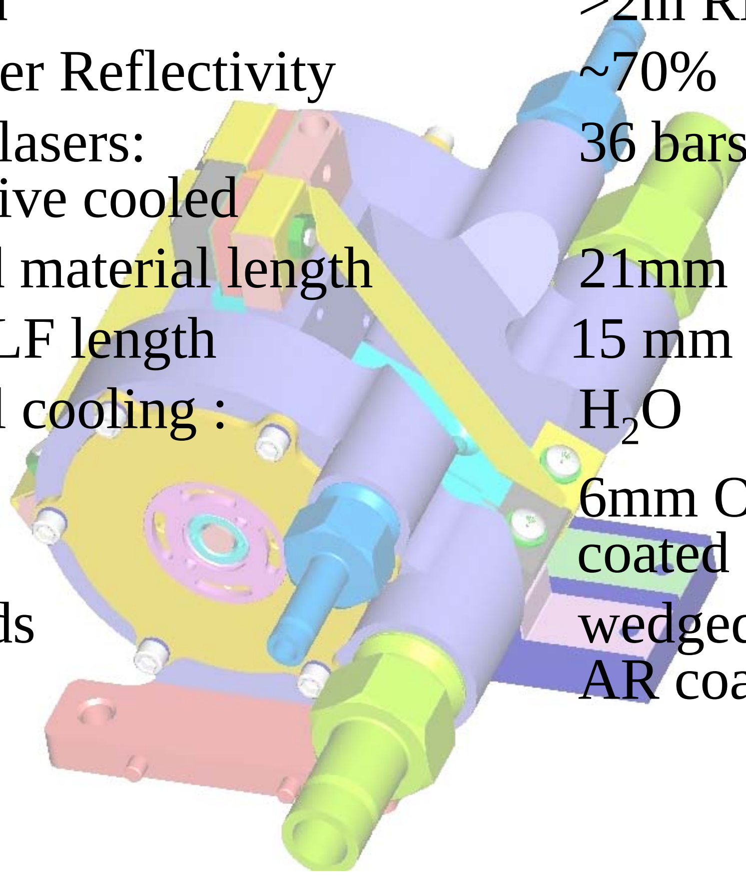
Probe beam transmission and the population of the Ho $5I_7$ manifold



Ho $5I_7$ population at lasing and without lasing condition

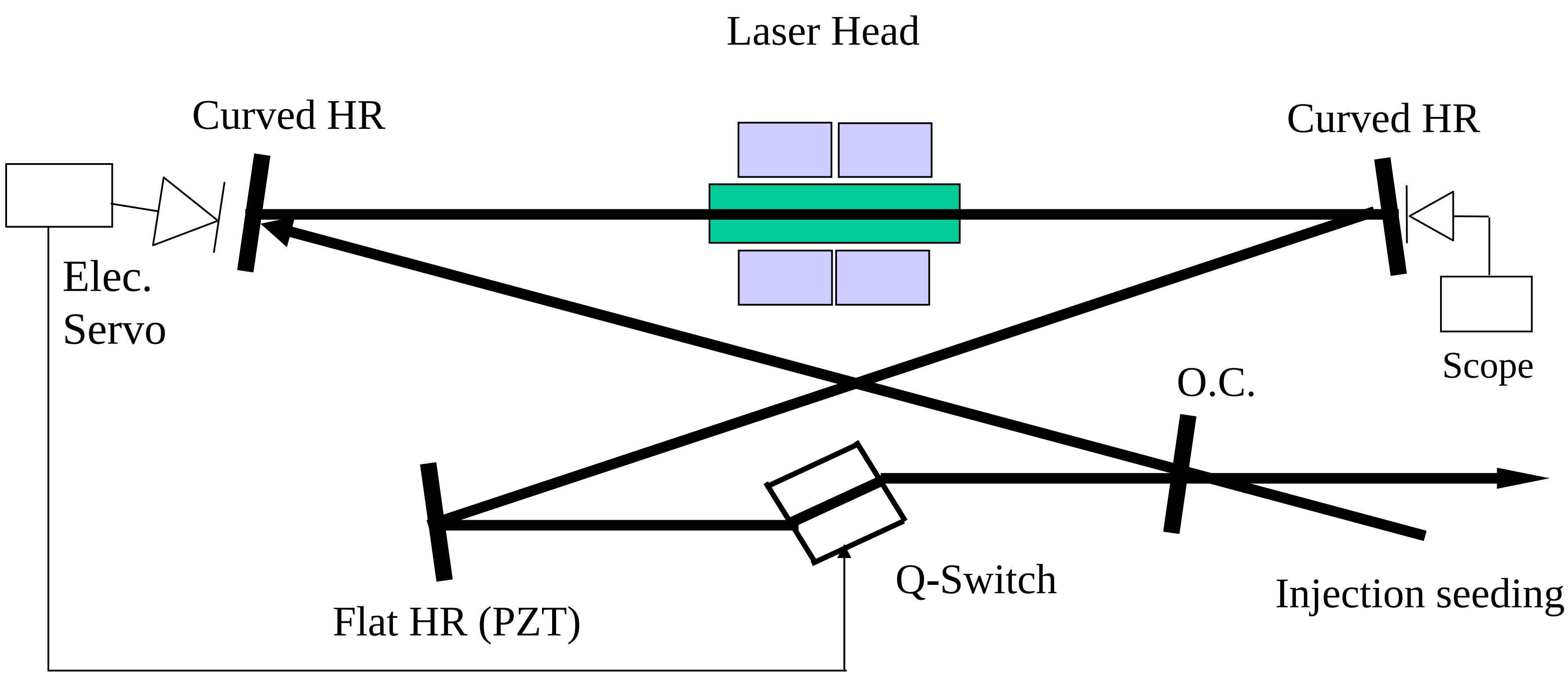


Oscillator features



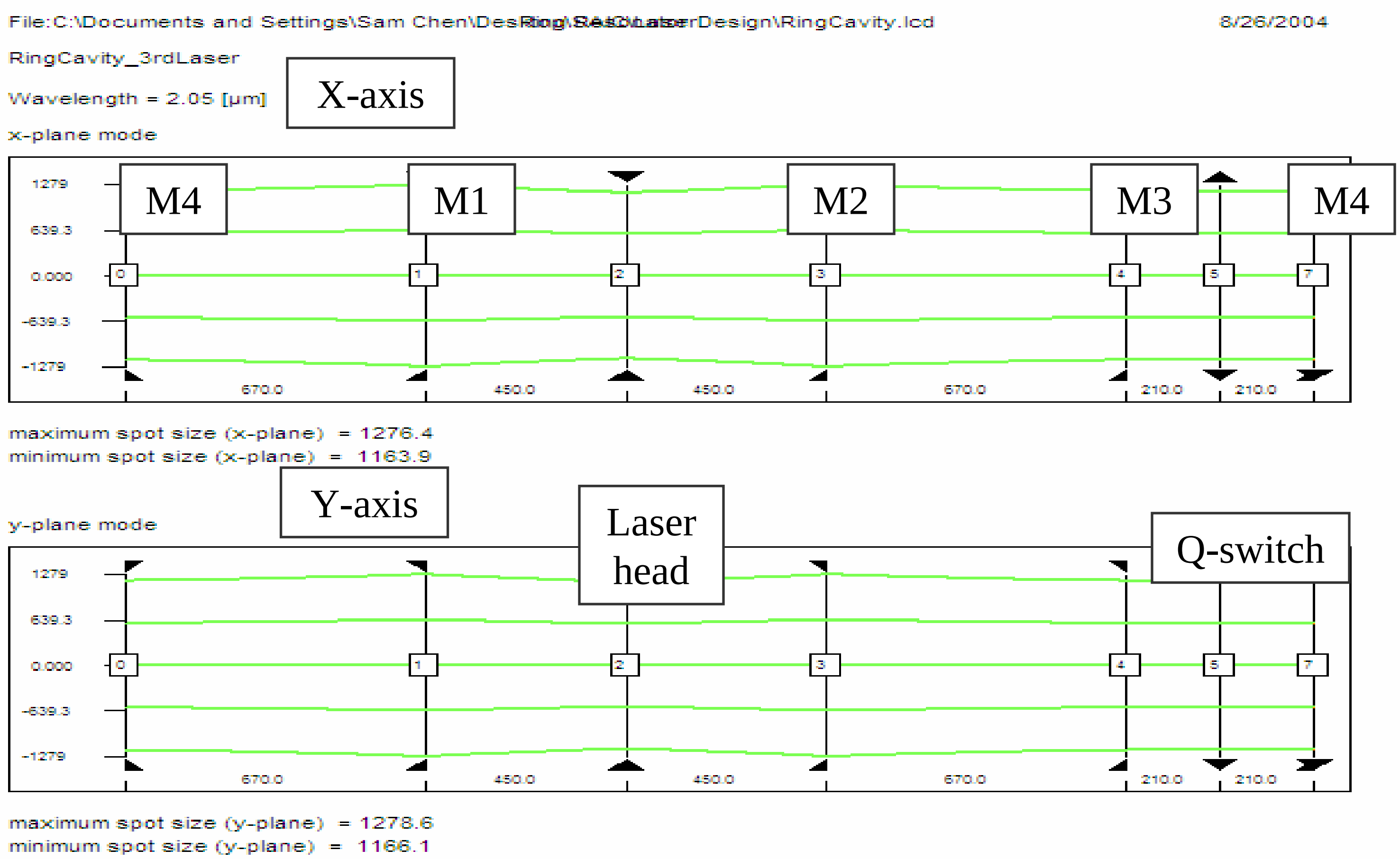
- Injection seeded
- Cavity length: >2m Ring
- Output coupler Reflectivity: ~70%
- Diode pump lasers: conductive cooled — 36 bars 100W/bar
- crystal doped material length: 21mm
- undoped LuLF length: 15 mm
- Laser crystal cooling : H_2O
- Tube size: 6mm OD 5mm ID AR coated for 792nm
- Laser rod ends: wedged 0.5° along c-axis AR coated for 2.053µm

Laser Oscillator Ring Cavity

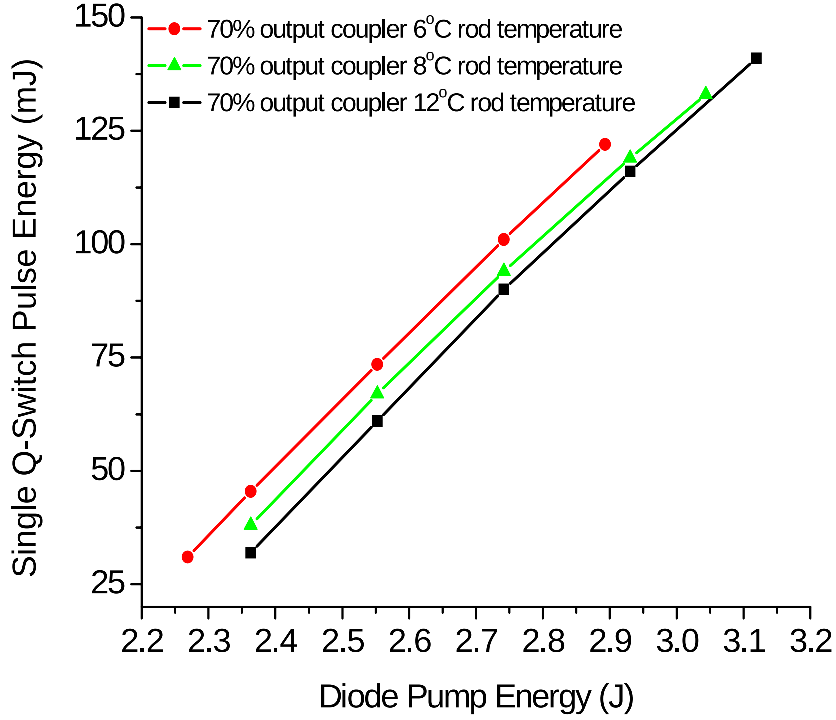


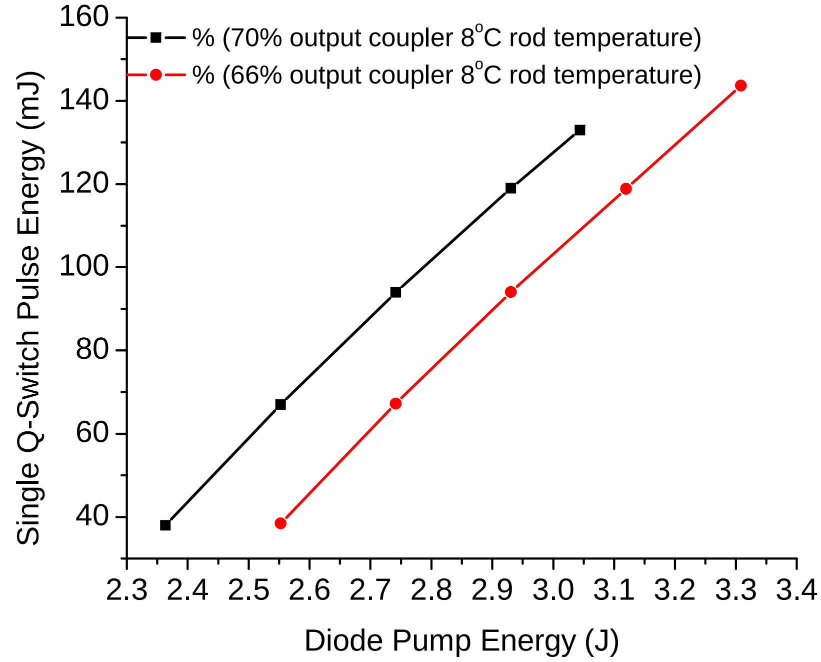
Cavity Mode Simulation

(Ring Cavity with two curved high reflectors)

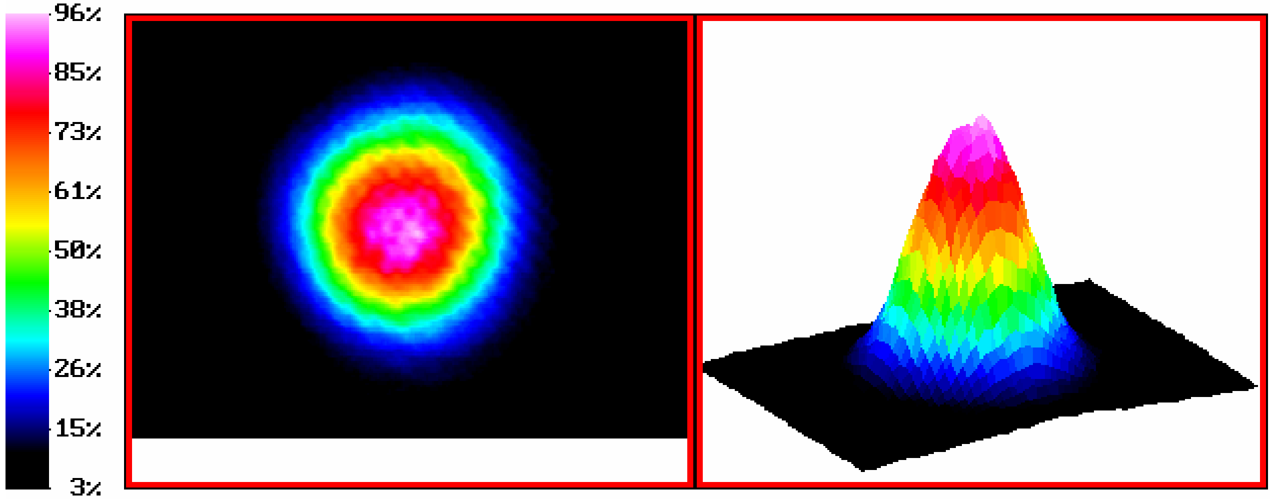


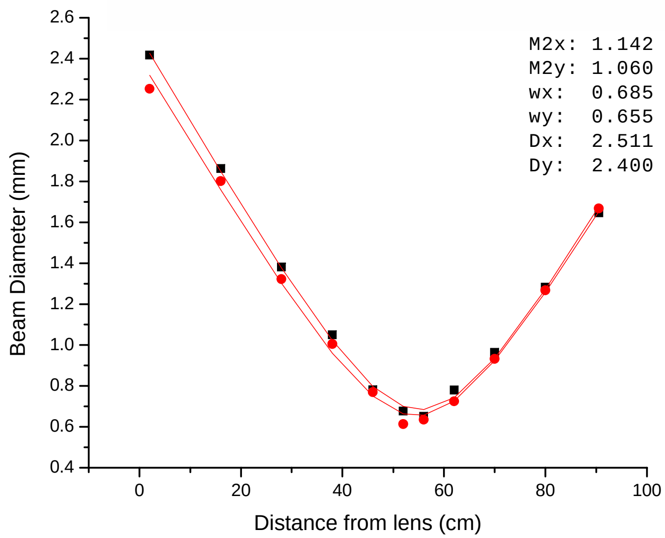
Laser Output Energy

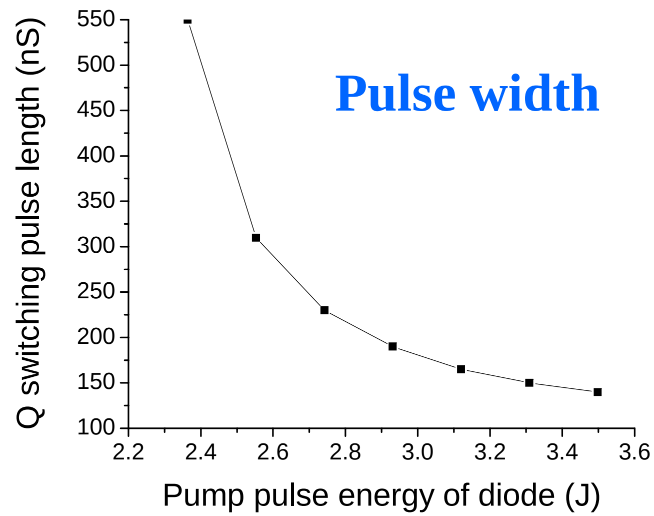




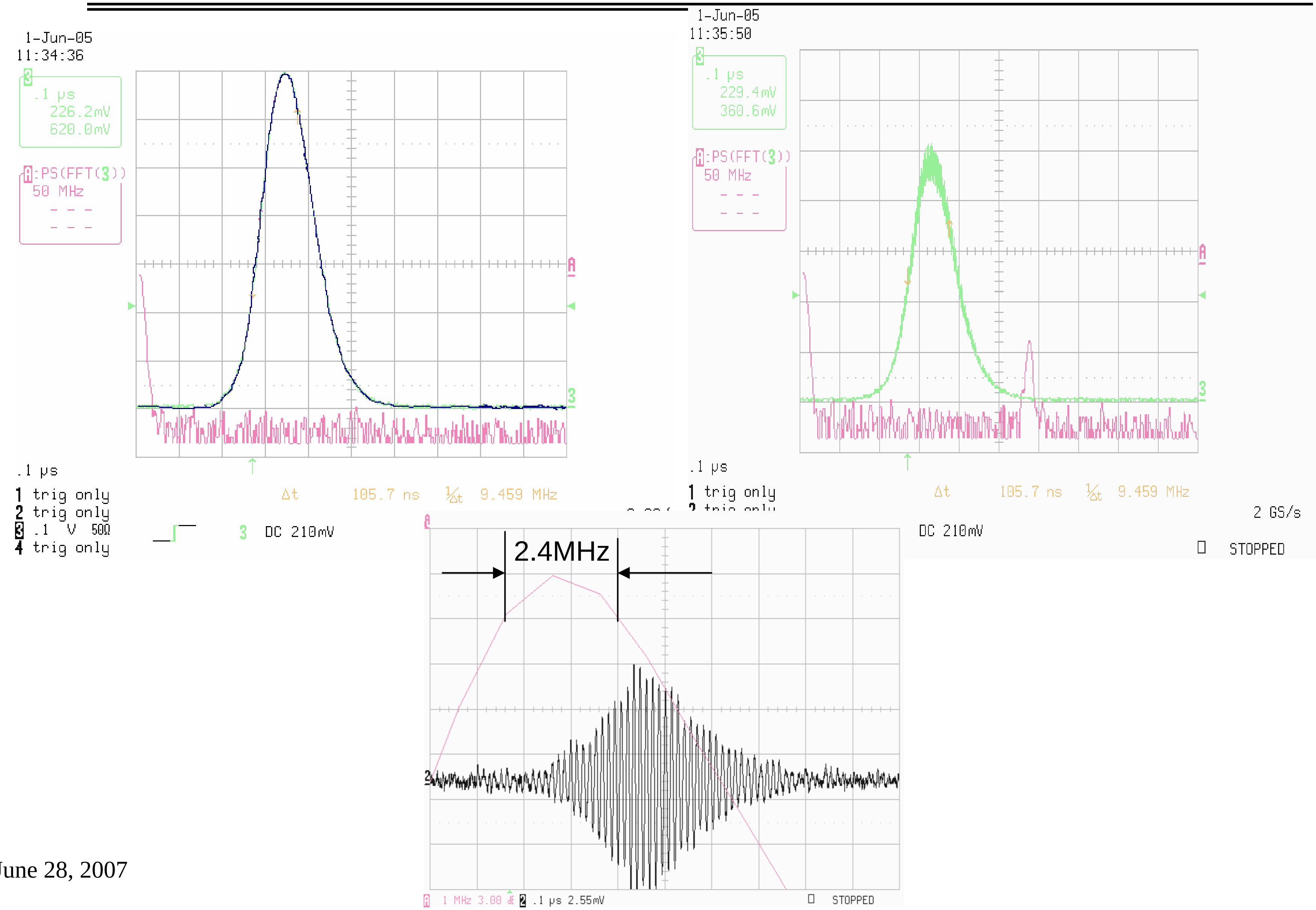
Laser beam profile



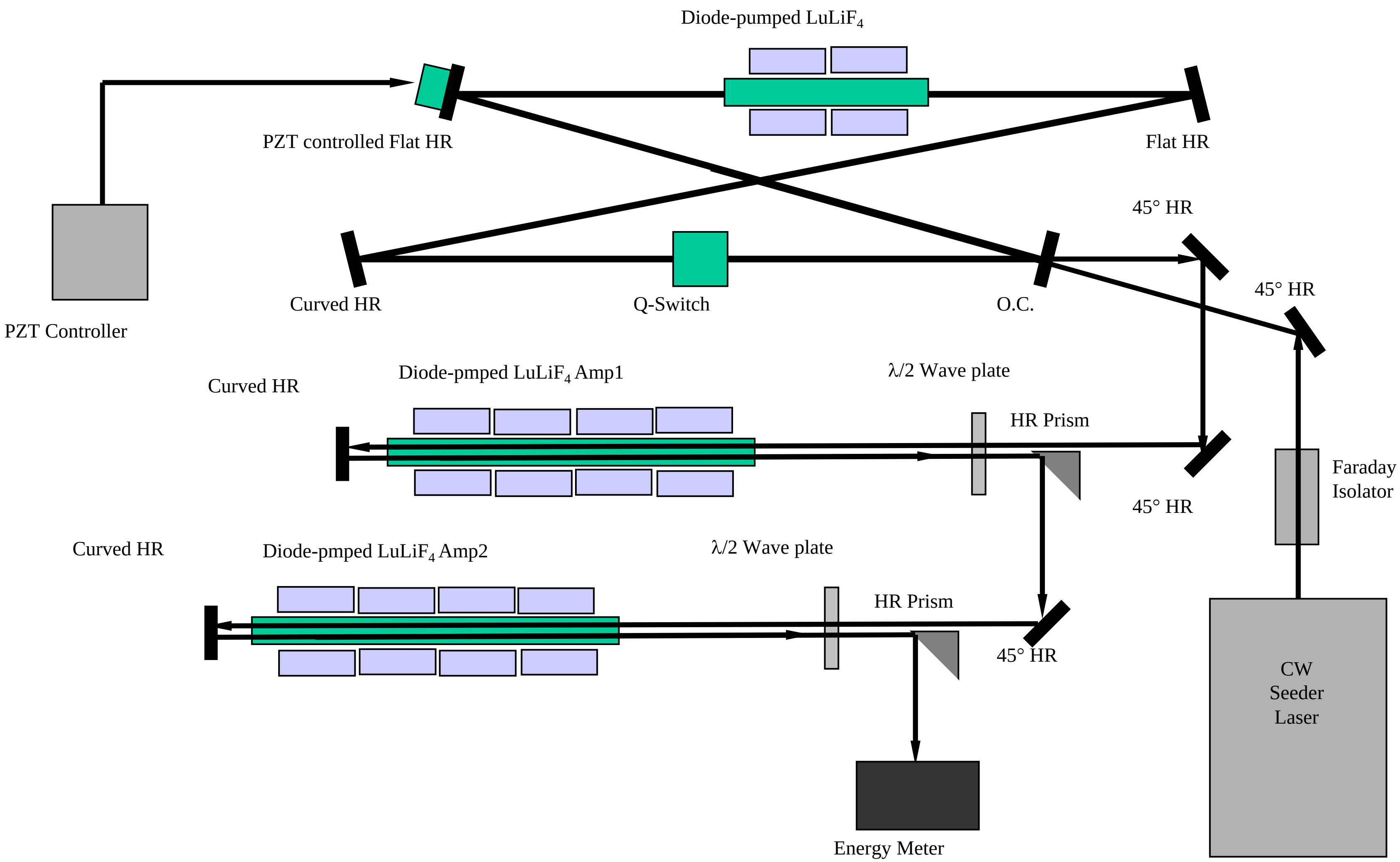




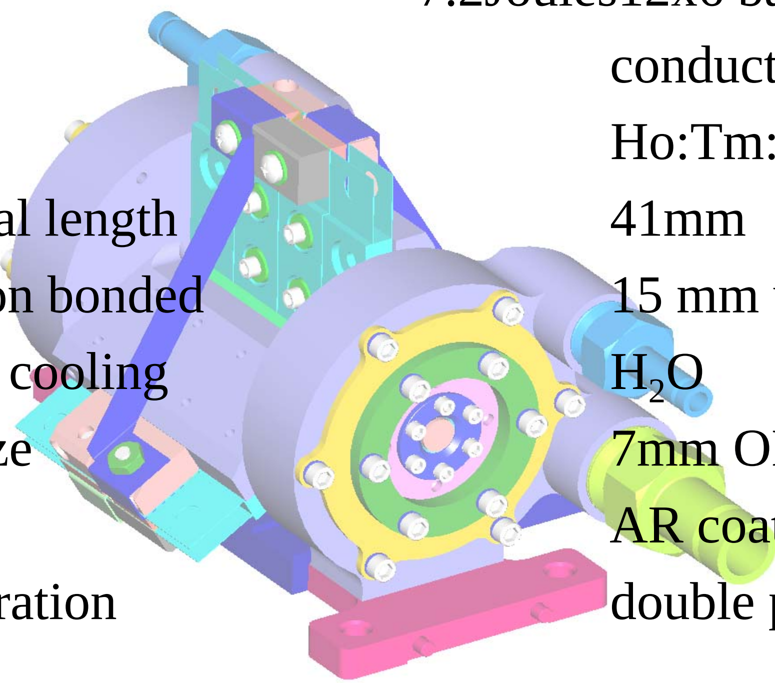
Seeding verification



MOPA Experimental Diagram

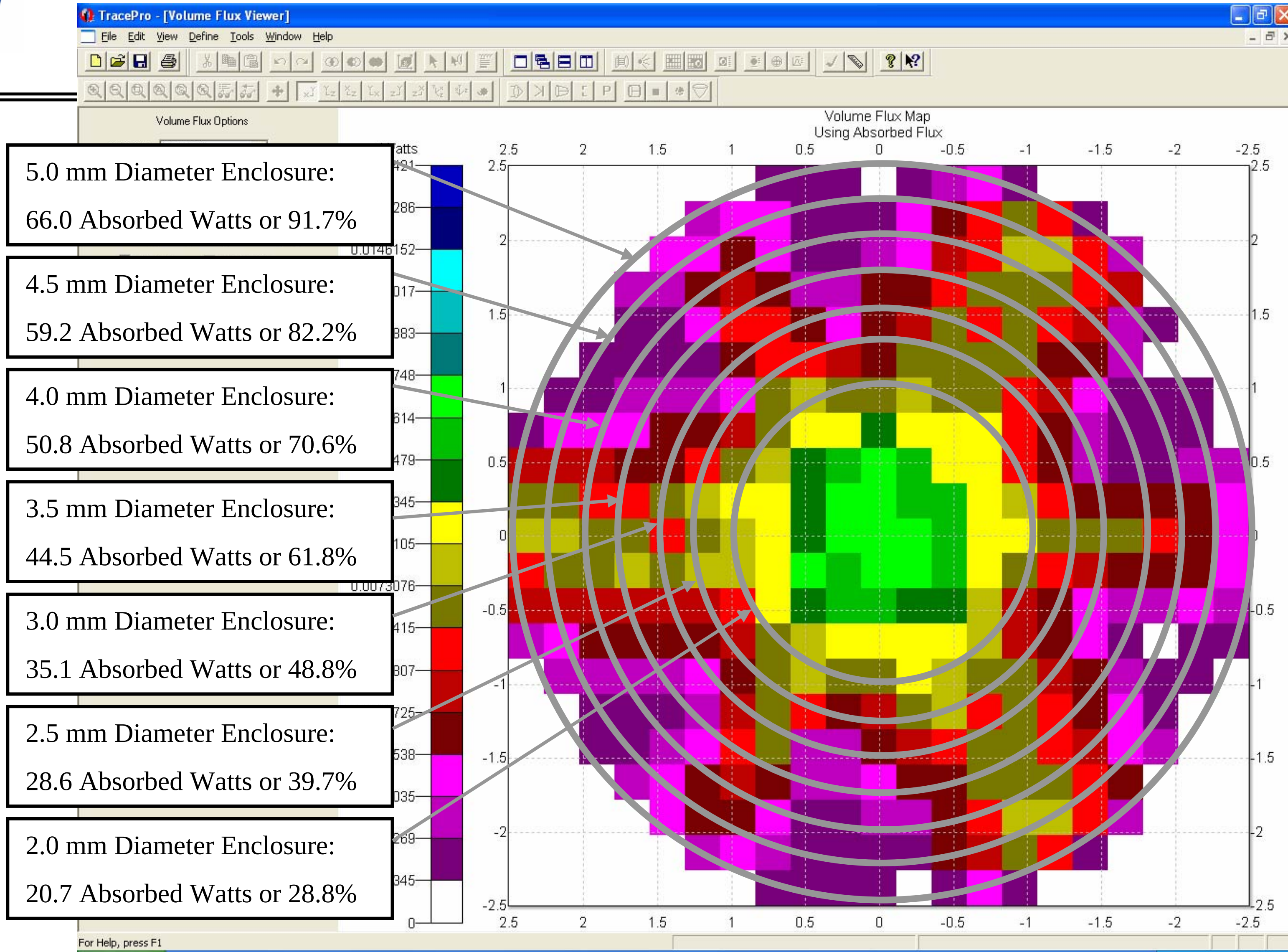


Amplifier features

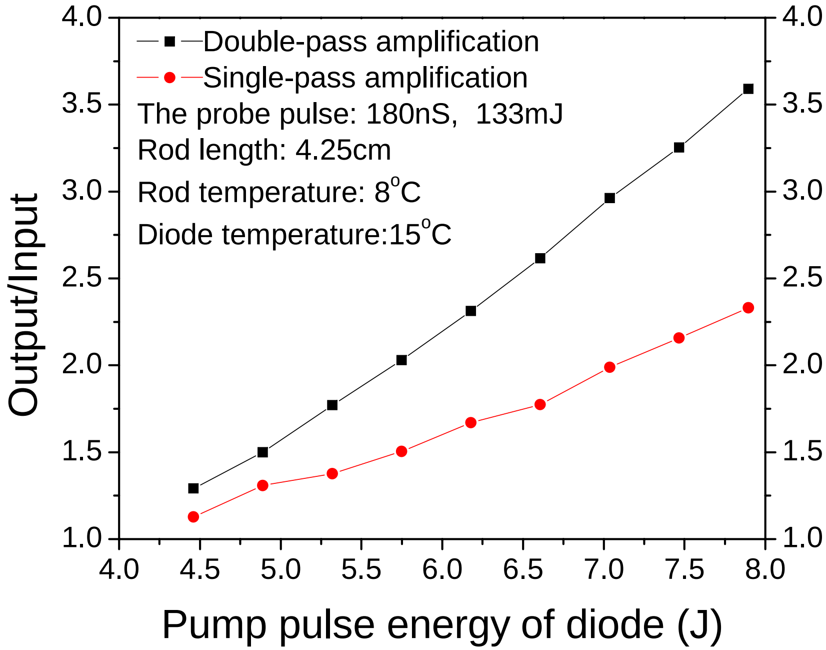


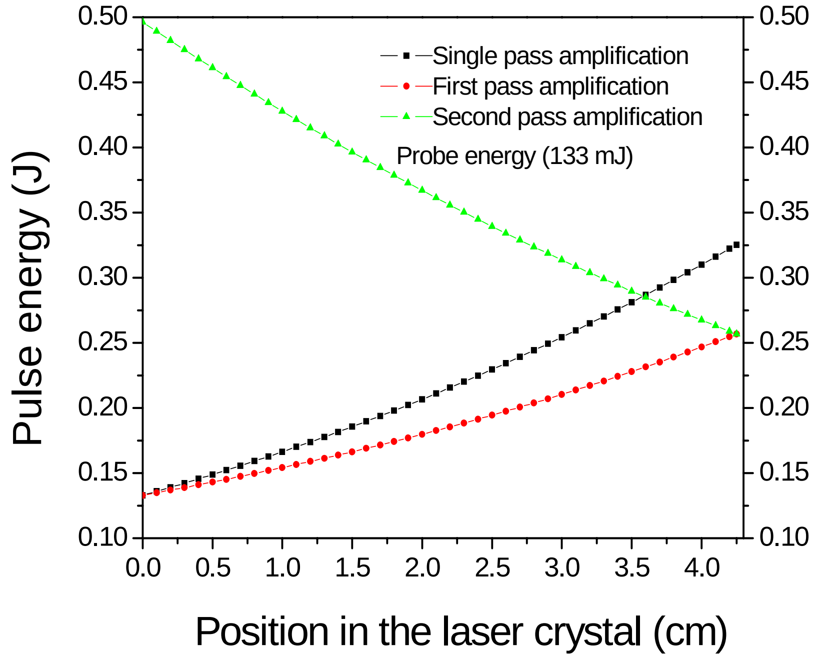
Pump energy	7.2Joules
Diode laser	12x6 bar arrays with 100w/bar conductive cooled ‘A’Pkg
Laser crystal	Ho:Tm:LuLF 0.5% Ho 6%Tm
Doped Crystal length	41mm
Ends diffusion bonded	15 mm undoped LuLF crystals
Laser crystal cooling	H_2O
Flow tube size	7mm OD 6mm ID AR coated
Rod ends	AR coated for 2.053µm flat
Path configuration	double pass

Absorbed pump power distribution

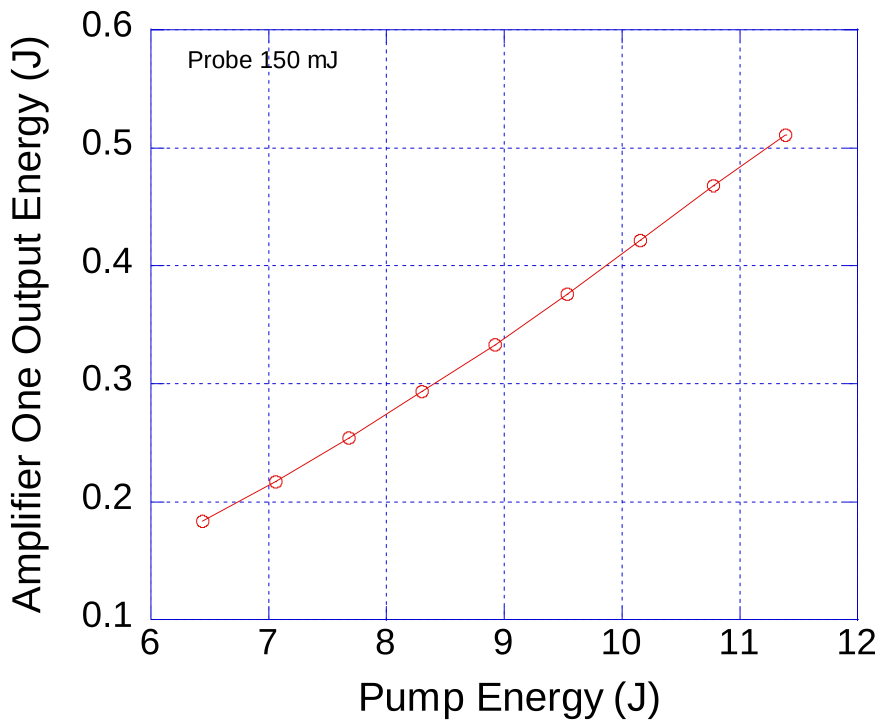


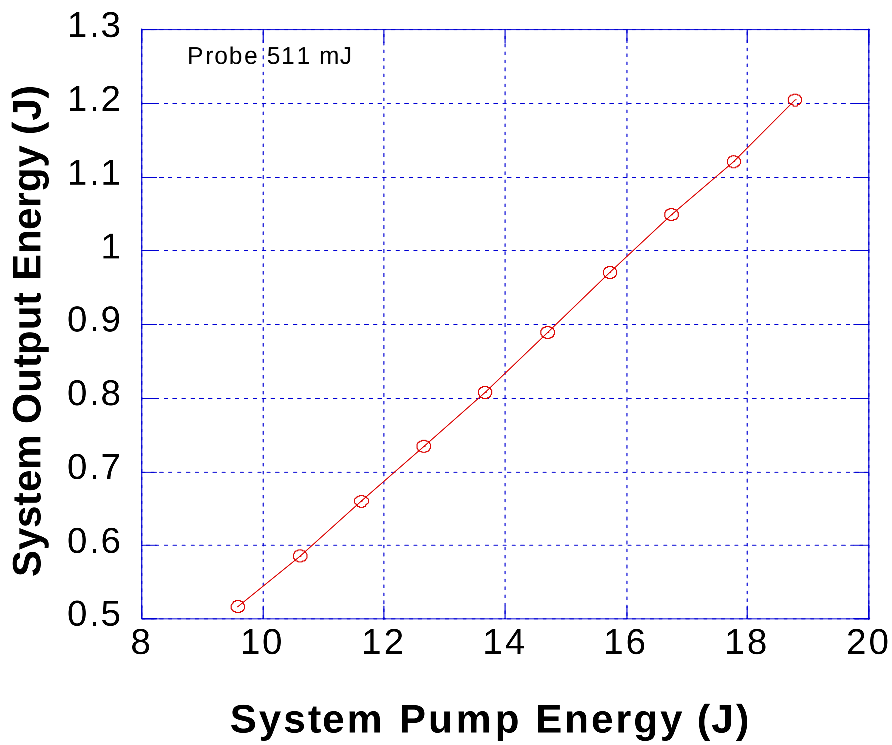
Single and Double Pass Amplification





Amplifier Performances





Objective

- Develop a technology that enables the production of a high-energy and a high- efficiency 2 mm LIDAR transmitter capable of measuring global wind from various platforms.
- Enhance the understanding atmospheric phenomena and improve weather prediction accuracy.
- Reduce risks associated with Doppler Lidar transmitter.
- Identify lifetime sensitive components and initiate early testing.

Compact Laser Design Goal

• Pulse energy:	>250mJ
• Repetition rate:	10Hz
• Wavelength:	2.053 µm
• Laser material:	LuLF 0.5% Ho, 6%Tm
• Pulse length:	> 100ns
• Line width:	< 2.5 MHz
• Heterodyne frequency offset:	105 MHz
• Beam quality:	<1.3 diffraction limit
• Beam size:	6 mm at the amplifier output

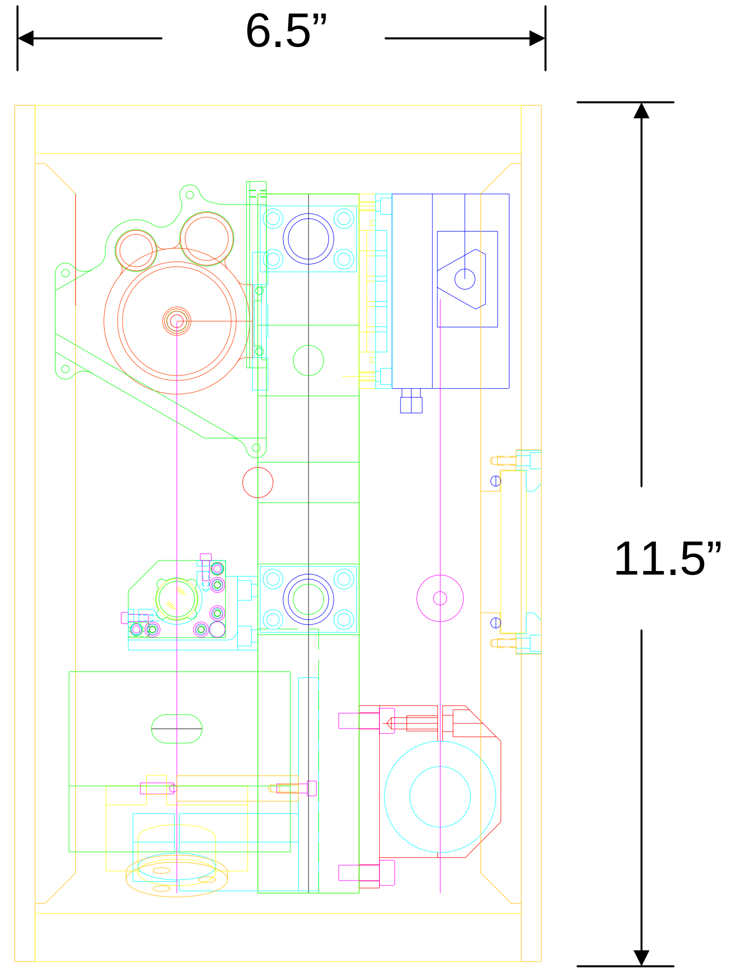
Environment Requirements

• Platform:	ground-based (Airborne qualify-able)
• Operational Temperature	0°C -30°C
• Operating Altitude Range	Sea level to 30,000 ft
• Vibration	2.0 g-rms
• Coolant Temperature	5 °C and 15 °C
• Coolant Flow	
– Laser rod	.5 GPM
– Diode Laser	2 GPM
– Bench	2 GPM
• Coolant Pressure	50 psi at 6 GPM

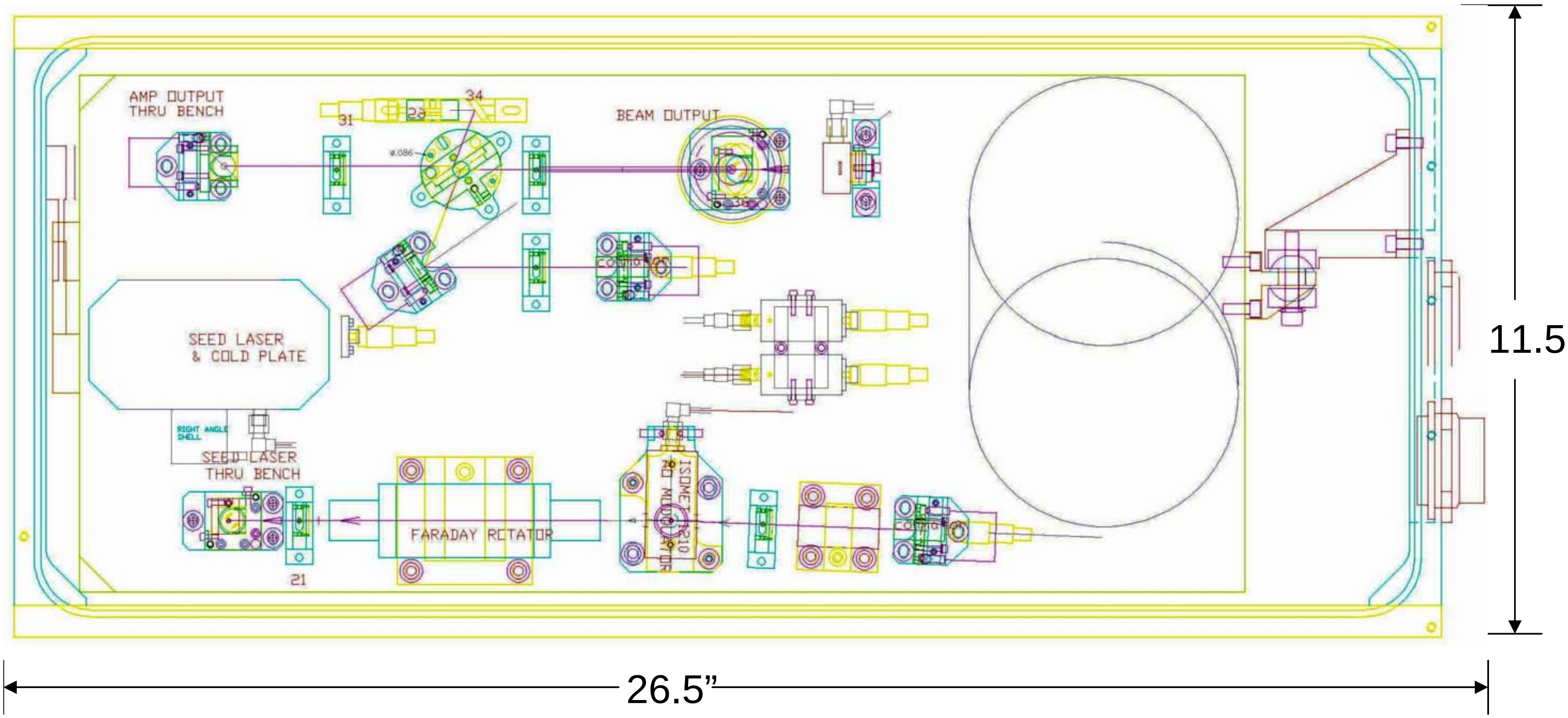
Mechanical Design Guidelines

- Laser enclosure
  compact, sealed, and dry air purged
- Optical bench
  populated on both sides
  temperature controlled
- Optical mounts
  hardened- space laser inherited
  Optical height 1 inch

Enclosure & Optical Bench



Optical Layout Side 1



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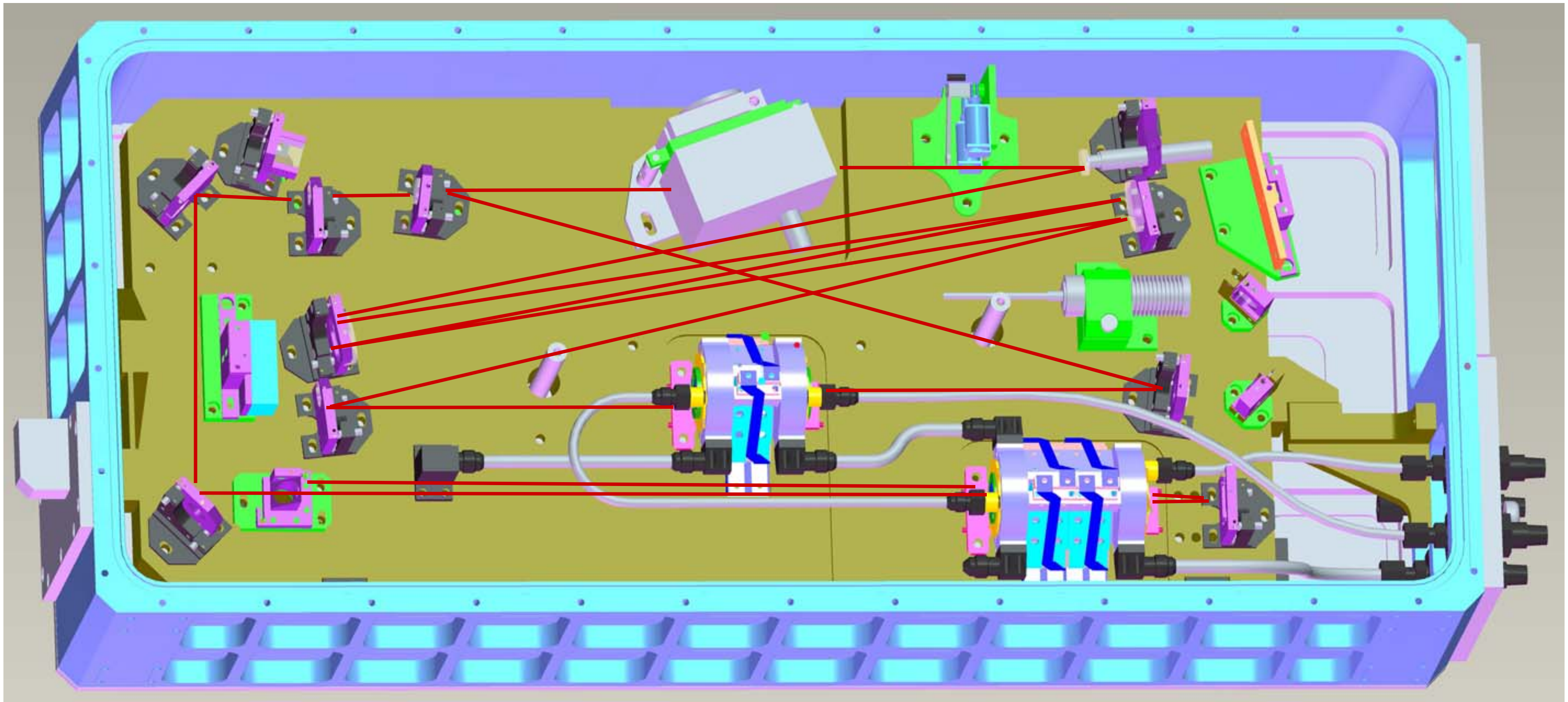
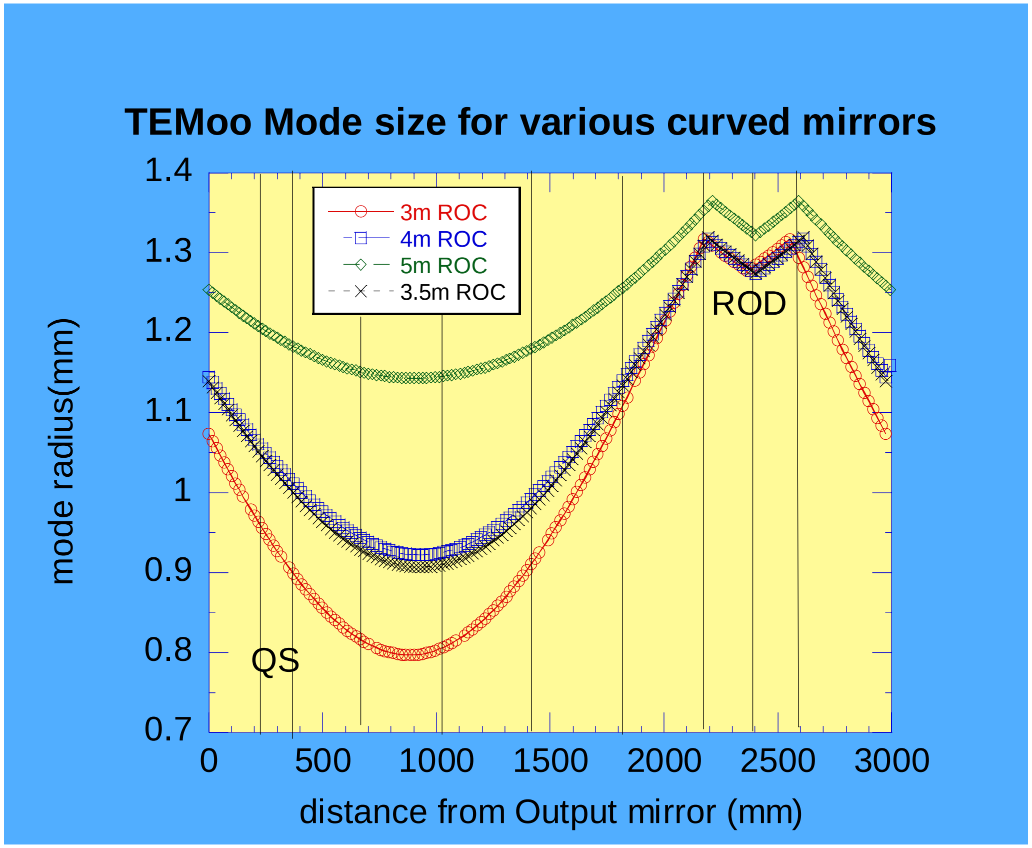
Optical Layout Side 2

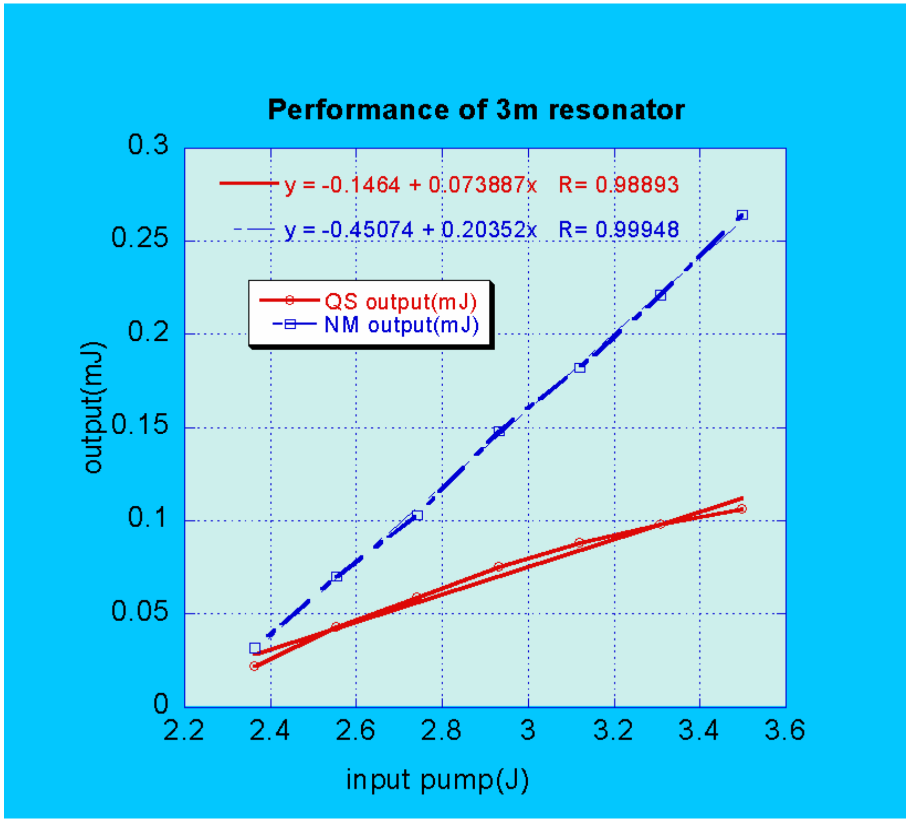


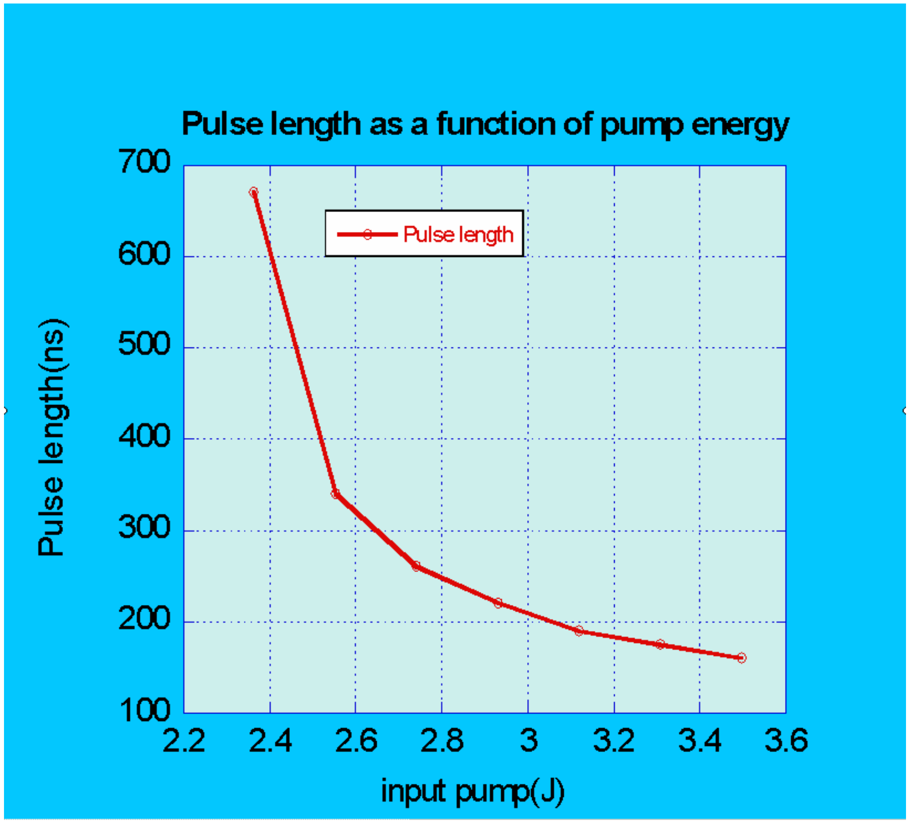
3m Long Ring Resonator Design



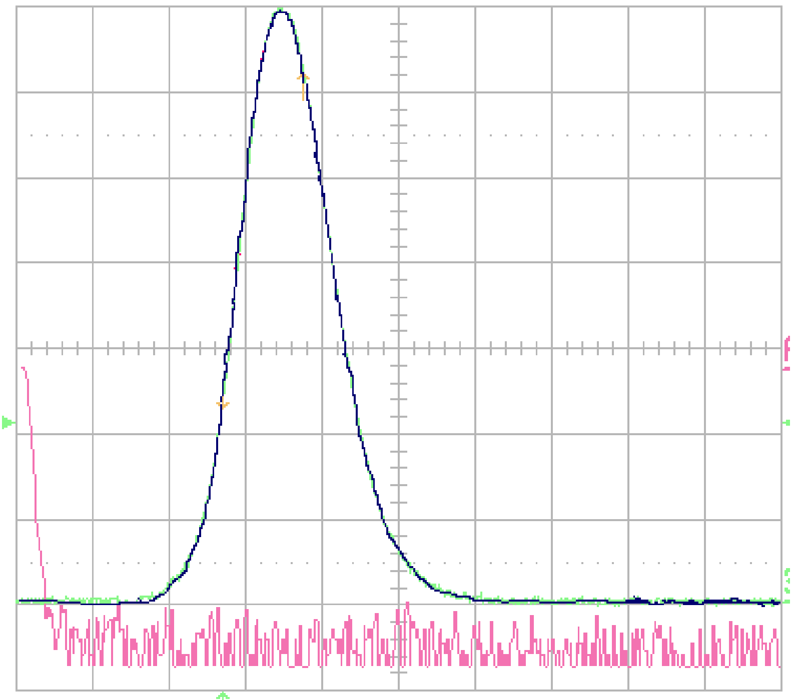
- The rod is placed between two curved mirrors.
- Angles between the folding mirrors minimized.
- In the final configuration a 4m radius of curvature mirror is selected.

10Hz Oscillator Performance

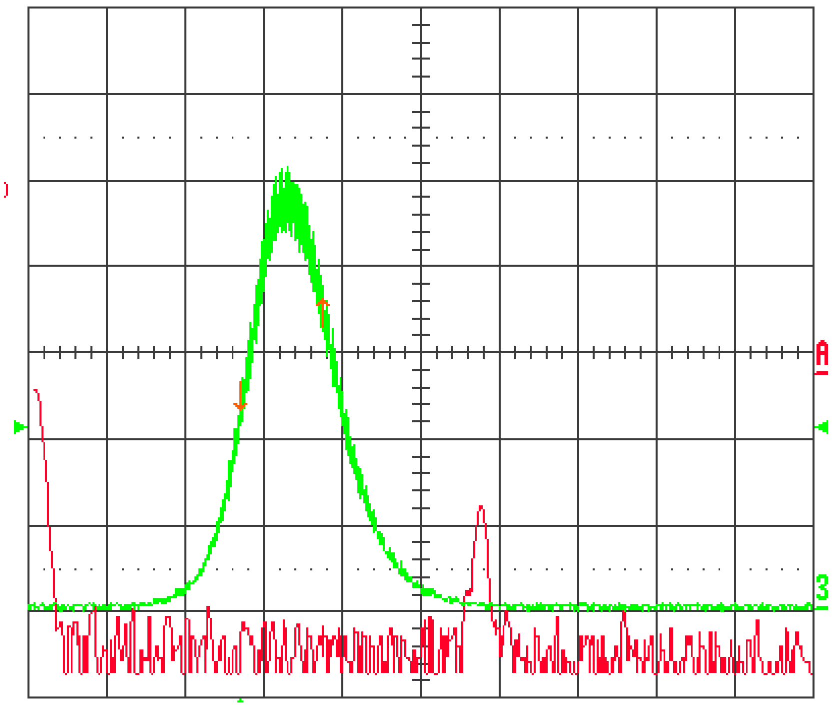




Seeding Verification

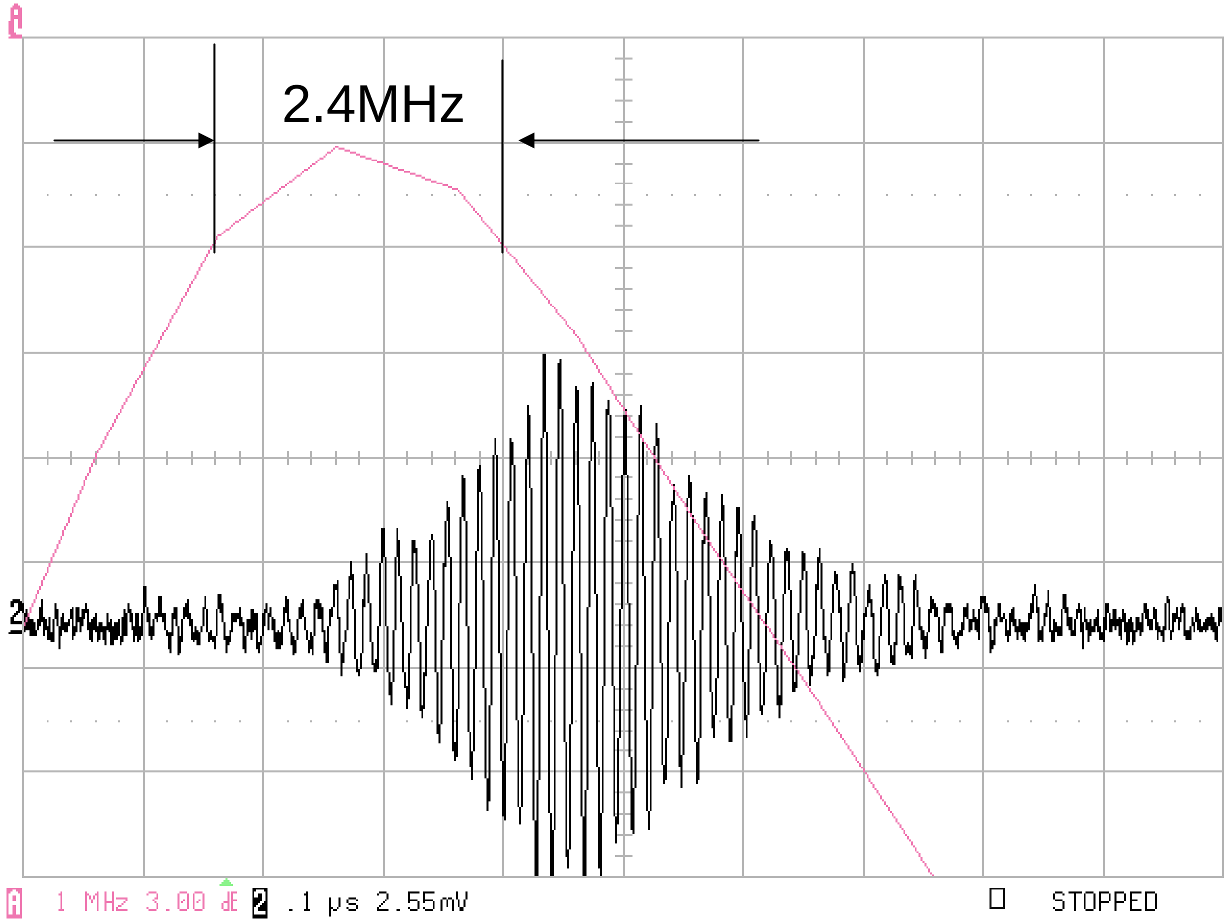


Seeded pulse has no mode-beating

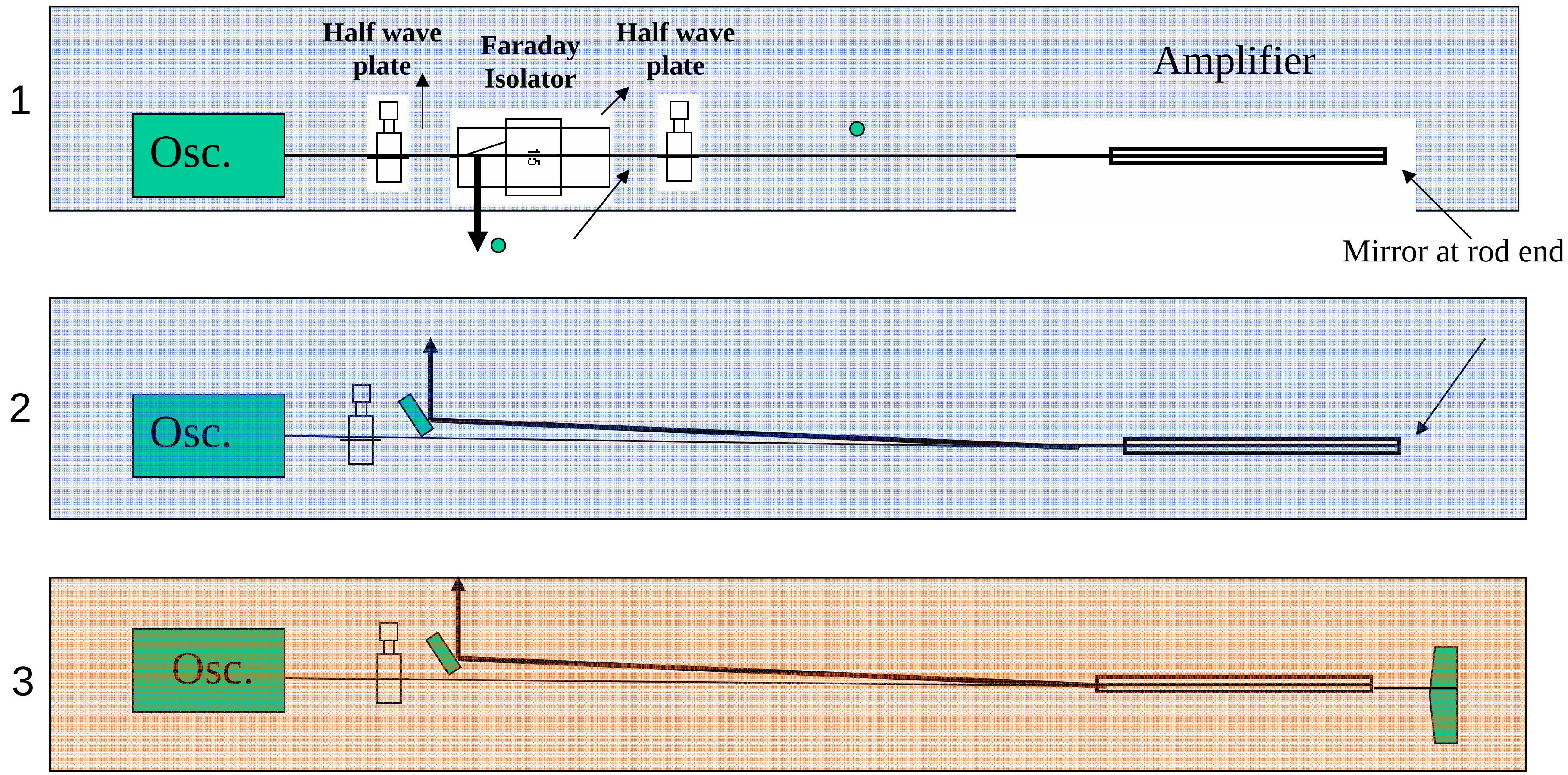


Unseeded pulse

Oscillator Line Width



Amplifier Architecture Considerations



Option 3 selected - Minimum loss, No optical damage, and Optical distortion corrected

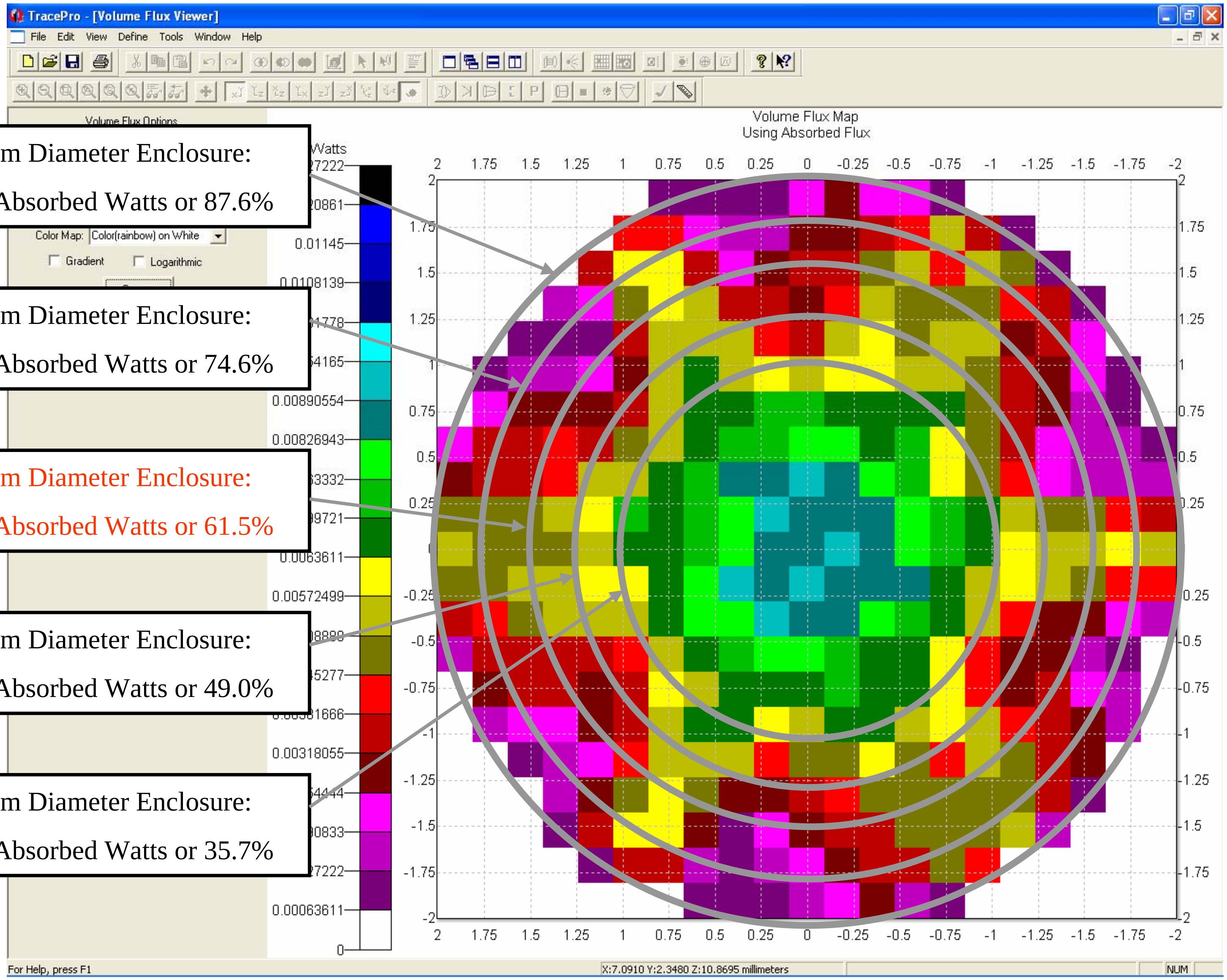
Amplifier rod size selection

- 4 and 5 mm diameter rods were compared
- Probe energy and size were varied

Probe E (mJ)	45			70			90		
Probe dia. (mm)	2	3	4	2	3	4	2	3	4
5mm rod E. (mJ)	89	96	82		136	134		172	180
4mm rod E. (mJ)	108	119		158	170		190	215	

Single pass gain for 4mm rod ~ 2.3
4mm rod with a 3mm probe performs better.

4.0 mm Diameter Laser Rod Absorption



4.0 mm Diameter Enclosure:
63.1 Absorbed Watts or 87.6%

3.5 mm Diameter Enclosure:
53.7 Absorbed Watts or 74.6%

3.0 mm Diameter Enclosure:
44.3 Absorbed Watts or 61.5%

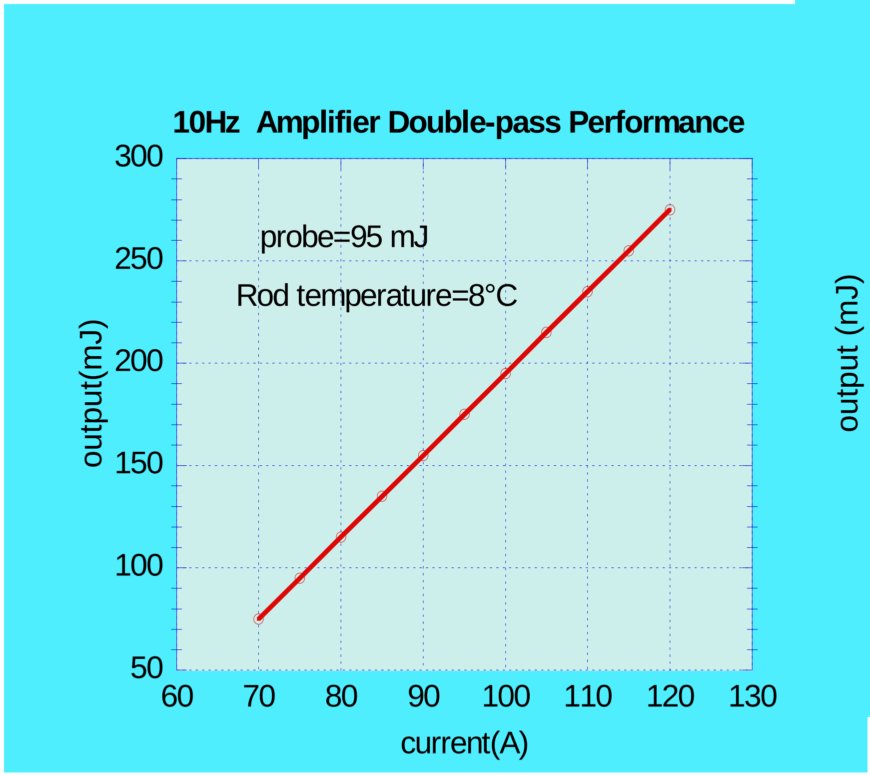
2.5 mm Diameter Enclosure:
35.3 Absorbed Watts or 49.0%

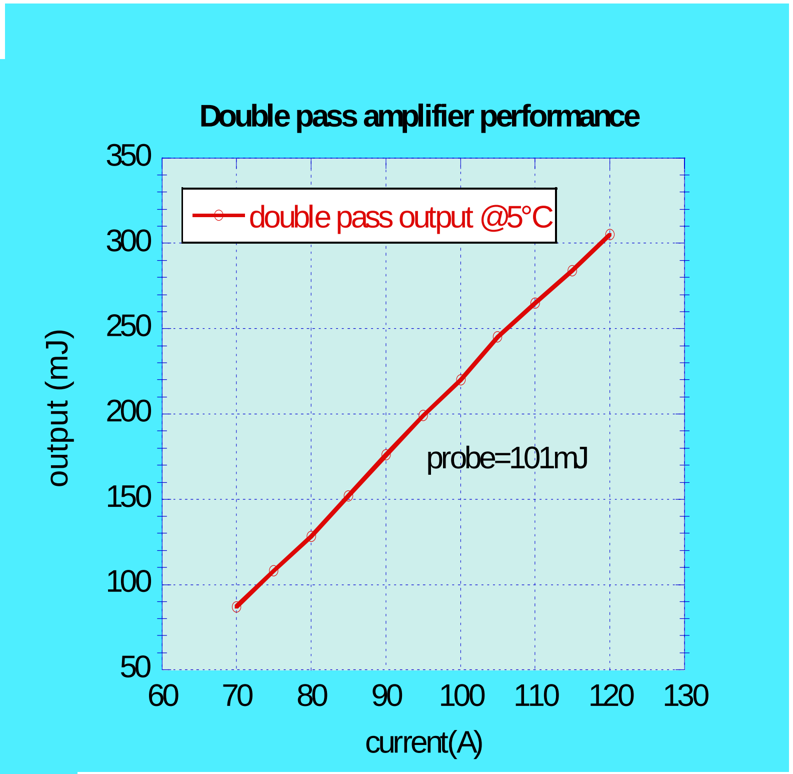
2.0 mm Diameter Enclosure:
25.7 Absorbed Watts or 35.7%

Amplifier Thermal Lensing

- Amplifier thermal lensing is -1.1m in the x-axis and -1.8m in y-axis.
- To reduce this effect the c-axis of the amplifier rod is oriented orthogonal to the oscillator rod.
- Once the thermal lensing was measured, the parameter is used in an optical model and a cylindrical correction lens was chosen and implemented that circularized the beam.

Double pass amplifier performance





Amplifier gain: double pass ~3

Conclusion

- **A diode-laser-side-pumped 2 μm Ho:Tm:LuLF laser oscillator and two amplifiers (MOPA) have been developed**

	Master Oscillator	MOPA
Output energy	142 mJ (SP)	1.2 J(SP)
Optical efficiency	4.3 %	6.5 %