UCRL-PRES-213314

Status of the Mercury Laser

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High Average Power Laser
Program Workshop
Livermore, CA
June 20-21, 2005

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

The Mercury Laser is the first step toward building a MW, 10 Hz class of IFE lasers

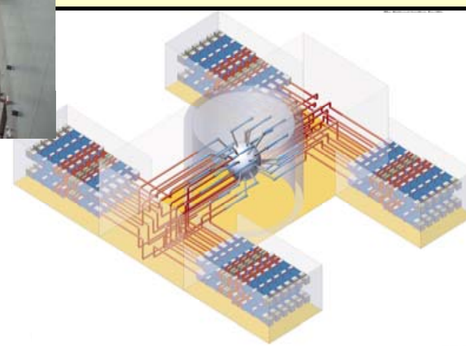
Mercury

100J IR

IRE (NIF bundle)

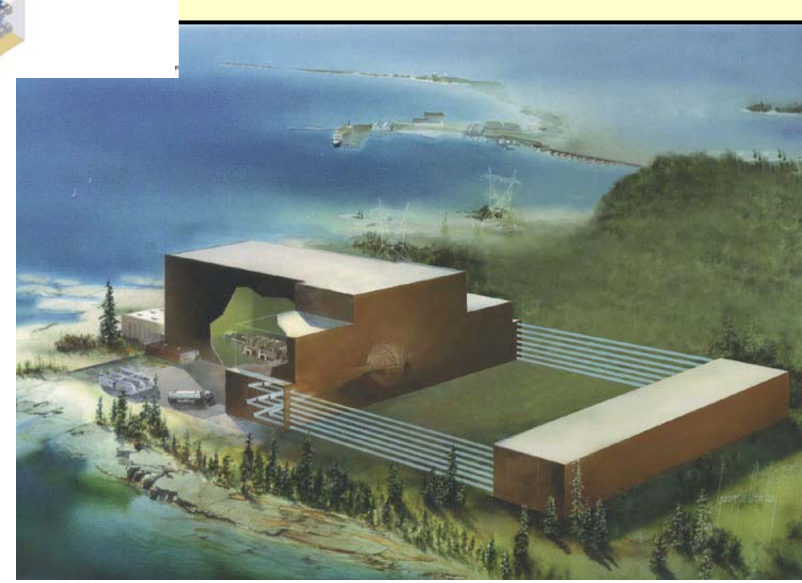
20kJ UV

ETF



2MJ UV

IFE



	Mercury Goals	Status
Energy	100 J, 1ω	55 J, 1ω
Efficiency	10 %	4.5 %
Repetition rate	10 Hz	10 Hz
Pulse length	3-10 ns	3-15 ns
Wavelength	0.53/0.35 μm	0.53 um
Bandwidth	>150 GHz 1ω	–
Beam quality	5 xDL	10 xDL, 80%

HEC-DPSSL 2005

2nd International Workshop on High Energy Class Diode Pumped Solid State Lasers

The 2005 International Workshop on High Energy Class Diode Pumped Solid State Lasers (HEC-DPSSL 2005) will be held in Jena , Germany from June 10-12, 2005.

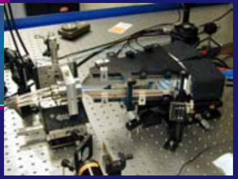
This second workshop on HEC-DPSSL will cover all key aspects of high energy (~100Joules) and high repetition rate (above 0.1 Hertz) DPSSL. Three of such laser program are already under construction:

- The Mercury program from the Lawrence Livermore national Laboratory (LLNL), Livermore, CA, USA.

- The Halna program from the Institute of Laser Engineering(ILE), Osaka University, Japan.

- The Polaris program from the Institut für Optik und Quantenelektronik (IOQ), Friedrich-Schiller-Universität, Jena, Germany.

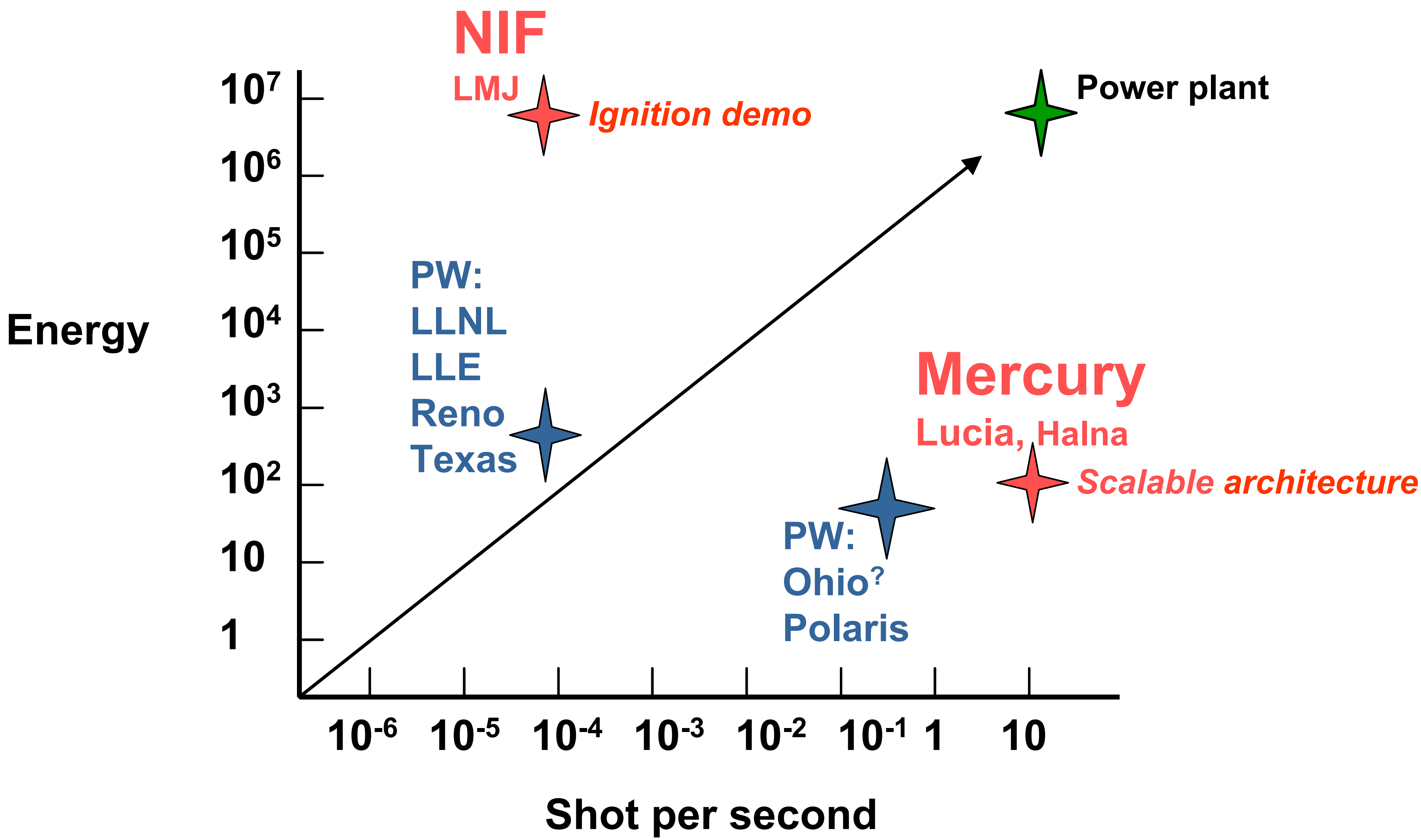
- The Lucia program from the Laboratoire pour l'Utilisation des Lasers Intenses (LULI), Ecole Polytechnique, Palaiseau, France.



Scientists from these groups will present their laser systems and share knowledge on various issues through several technical sessions:

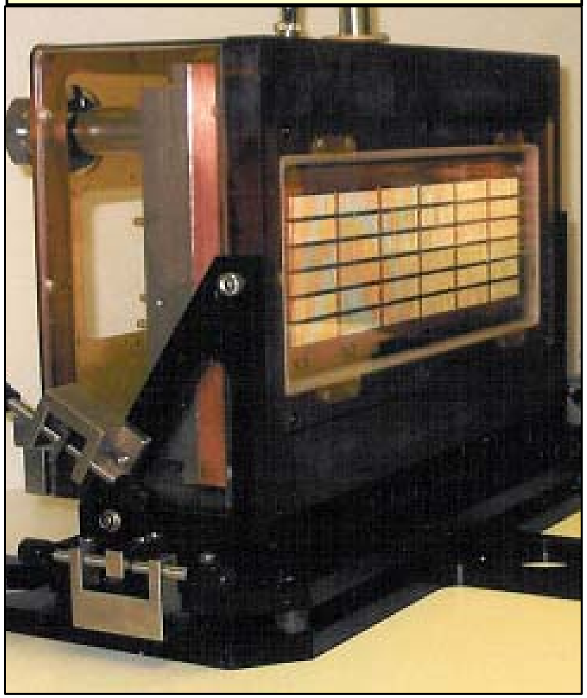
Session 1 - Laser Programmes presentation
Session 2 - Pumping architectures
Session 3 - Extraction architectures
Session 4 – Modelling
Session 5 - Materials issues
Session 6 - Optical Damage issues
Session 7 – HEC DPSSL Command-Control (CC)

Many rep-rated solid-state lasers are being developed that complement large energy - single shot systems

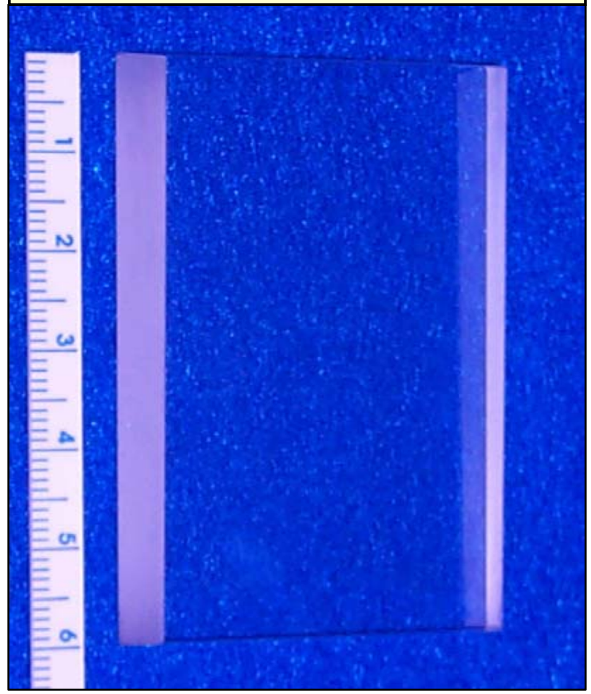


The Mercury Laser amplifier technologies

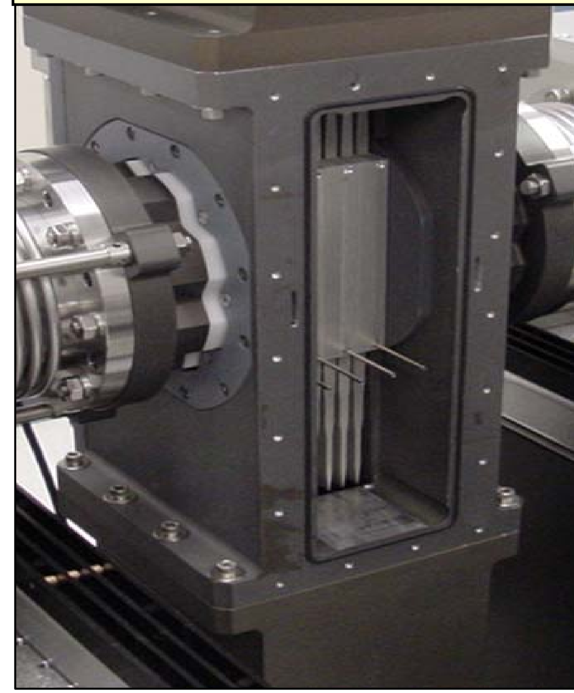
Diode pump arrays



Solid-state amplifier

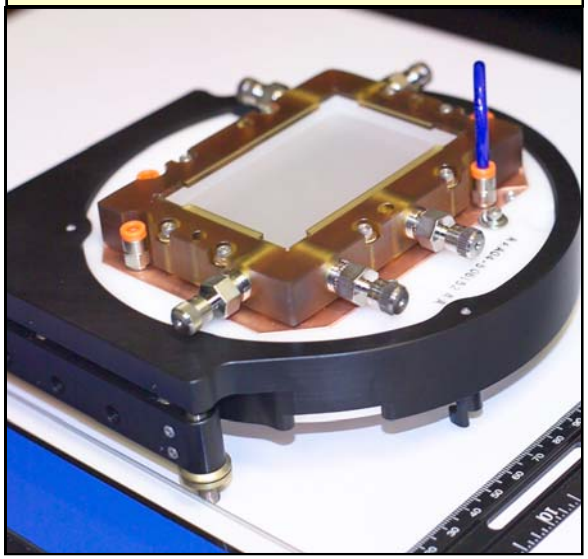
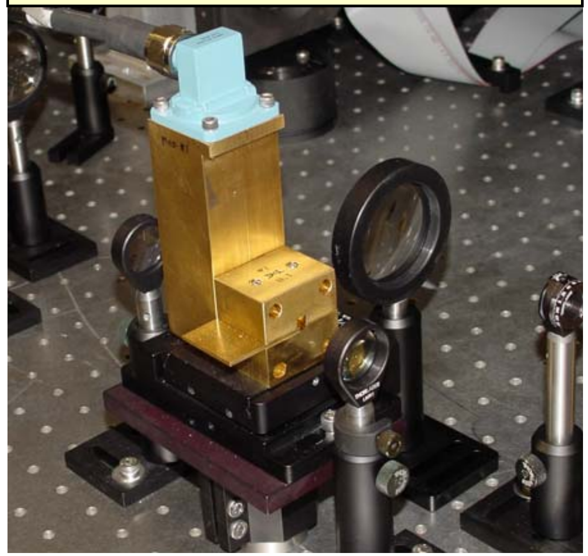


Helium gas cooling



These components comprise the essential building blocks of an amplifier

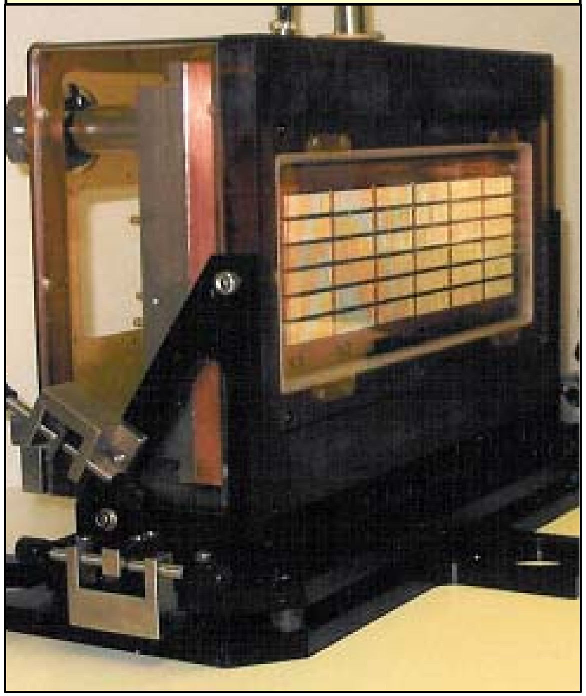
Advanced beam control technologies

Wavelength	Bandwidth	Wavefront
		
Frequency Converter	Bulk Modulator	Adaptive Optic

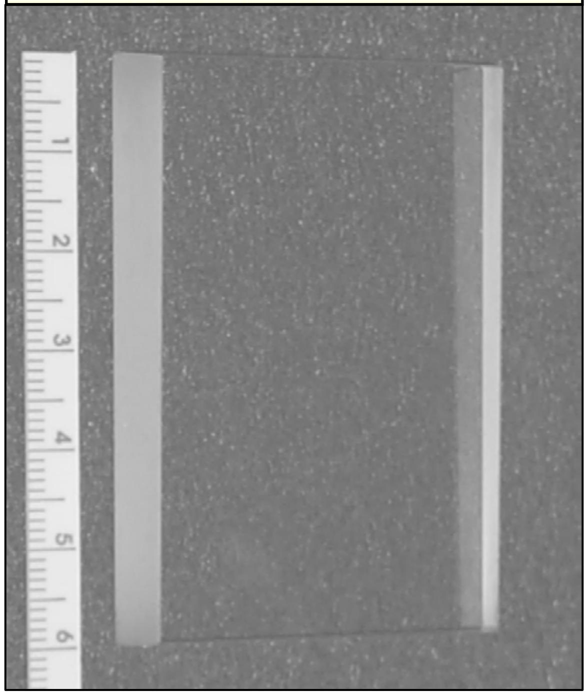
Some components are being commissioned this year for frequency conversion to 2ω and improved beam quality

Progress in diode arrays

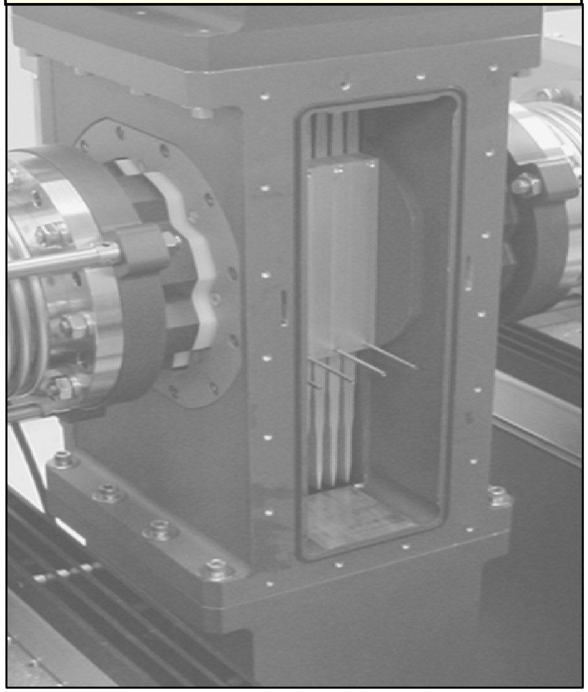
Diode pump arrays



Solid-state gain media



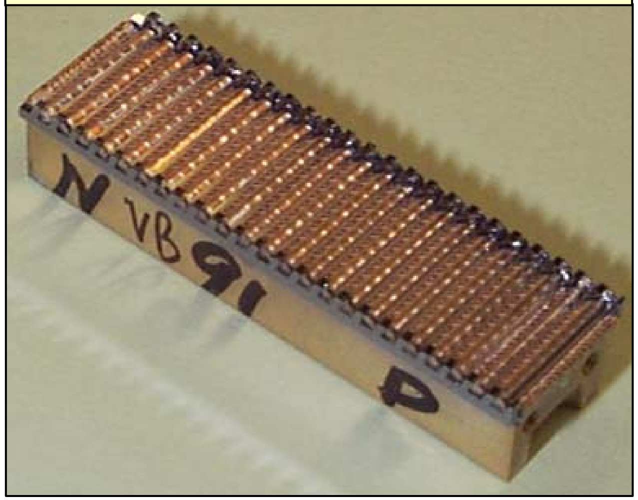
Helium gas cooling



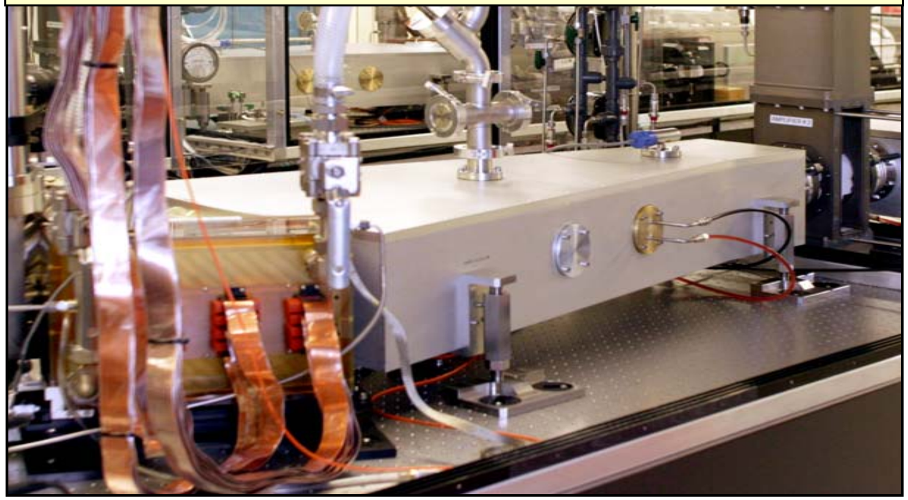
Commercialization of diode array technology is leading to new technological breakthroughs

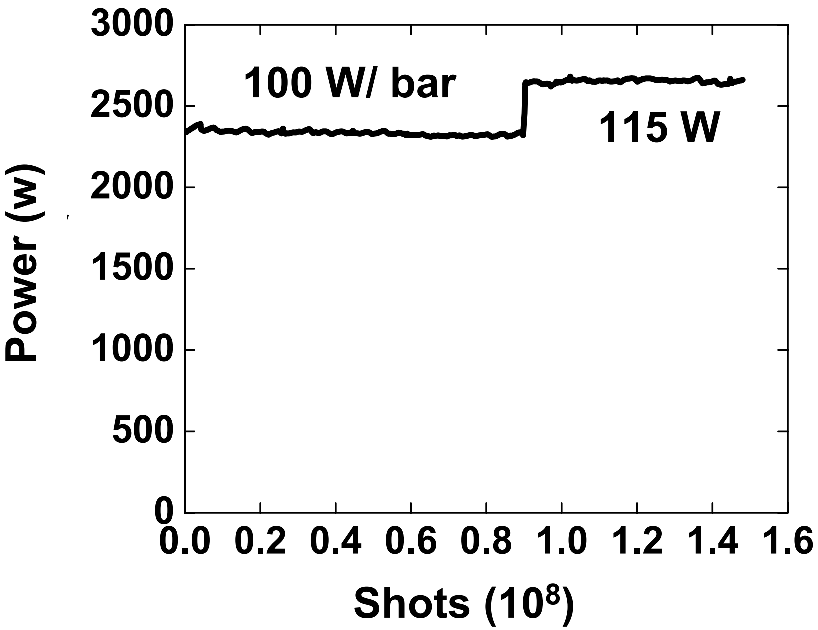
Mercury Laser diode tiles and arrays have incurred up to >10^7 integrated shots with no intrinsic failures

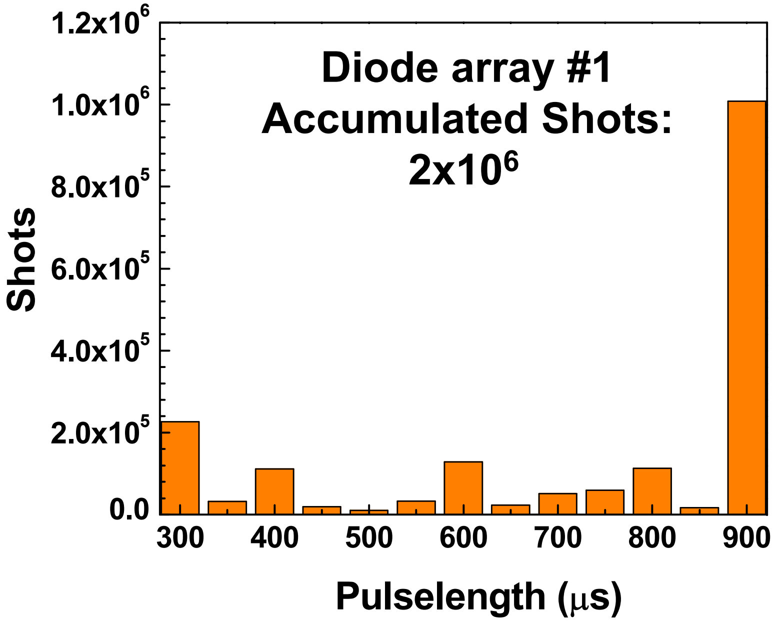
Offline tests > 10^8 shots



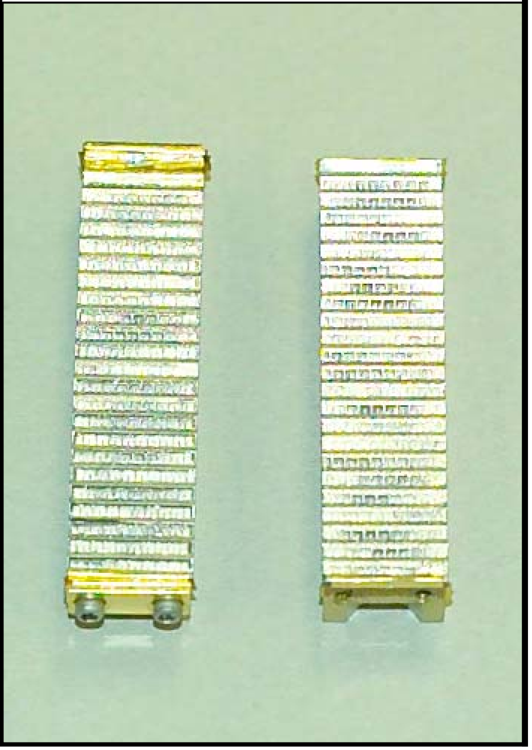
In-line arrays with 1.4 x 10^7 shots total







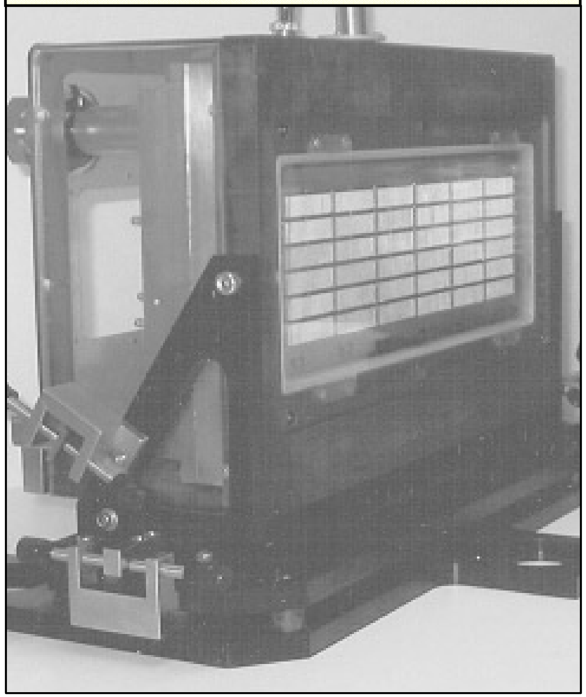
The amplifier system is pumped by > 800 kW of peak diode power

Diode tile attributes	Goal	LLNL Tile Performance	Commercial Tile Performance
Power	100 W / bar	120 W / bar	
Reliability	2 x 10^8 shots at 100 W / bar	1.4 x 10^8 shots at 115 W / bar	
Power droop over 1 msec	15%	4.3%	
Linewidth	5 nm	2.3 nm	
Integrated linewidth over 1 msec	8.5 nm	4.1 nm	
Divergence	18 x 180 mrad	15 x 140 mrad	
Efficiency	50%	45%	

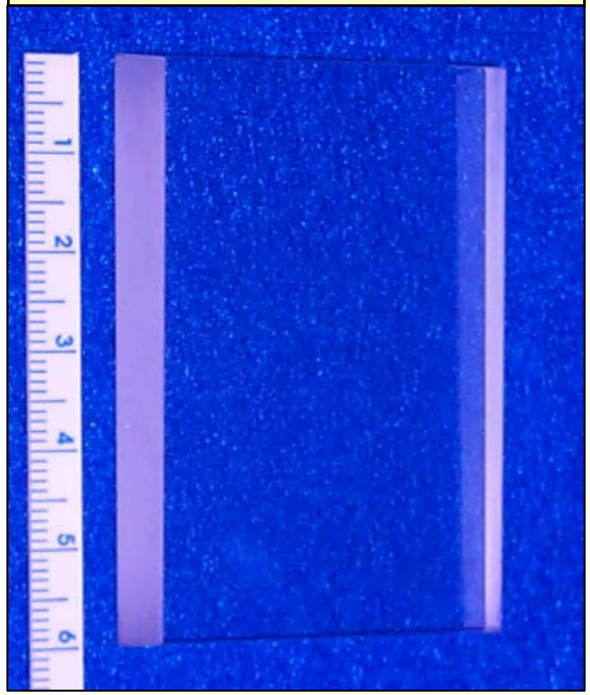
- A company has just delivered the second batch of diode tiles
- Compliance testing look promising

Progress in gain media fabrication

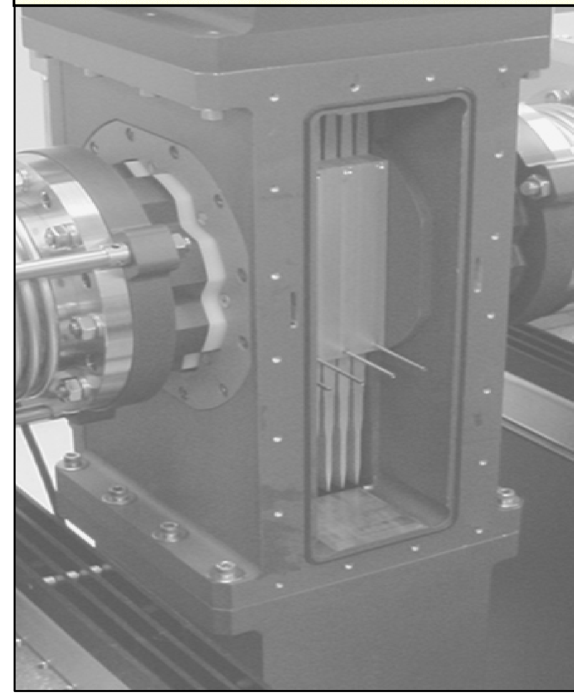
Diode pump arrays



Solid-state gain media



Helium gas cooling



We have transitioned nearly all the furnaces to produce full-size amplifier slabs (4x6 cm^2)

Yb:S-FAP crystalline boules are being produced with the Czochralski Growth method

LLNL

Northrop Grumman

Boule

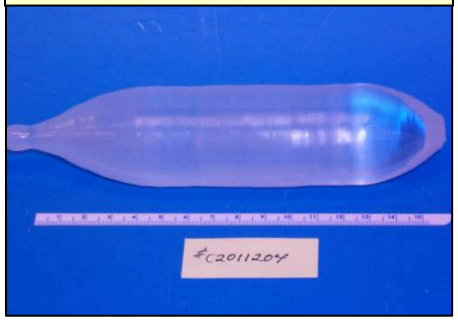
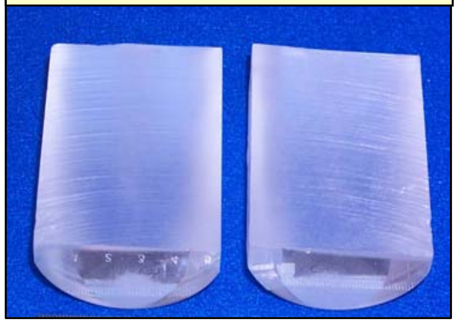
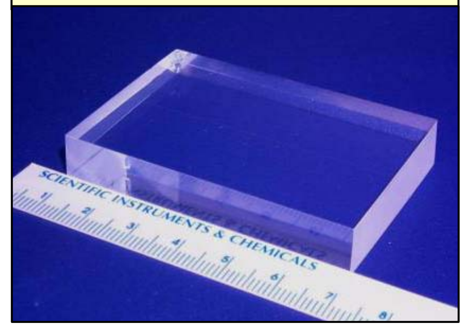
18 cm

6.5 cm

We now produce slabs from LLNL and Northrop boules, which no longer require high temperature bonding

Poster: K. Schaffers

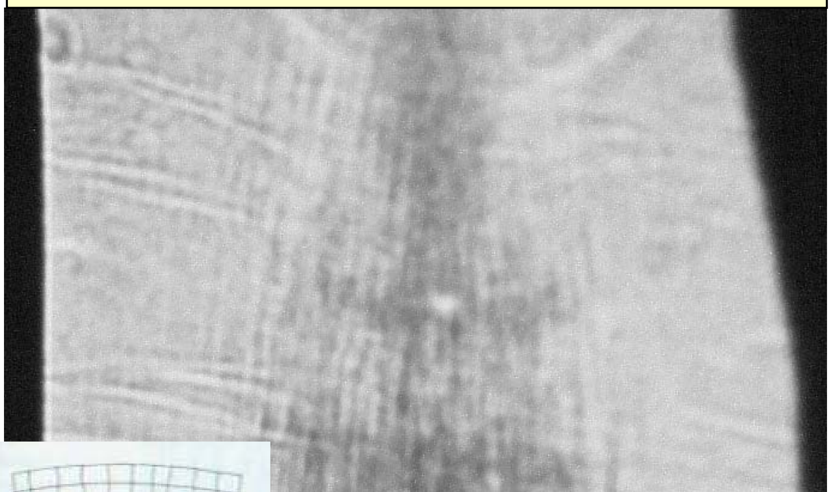
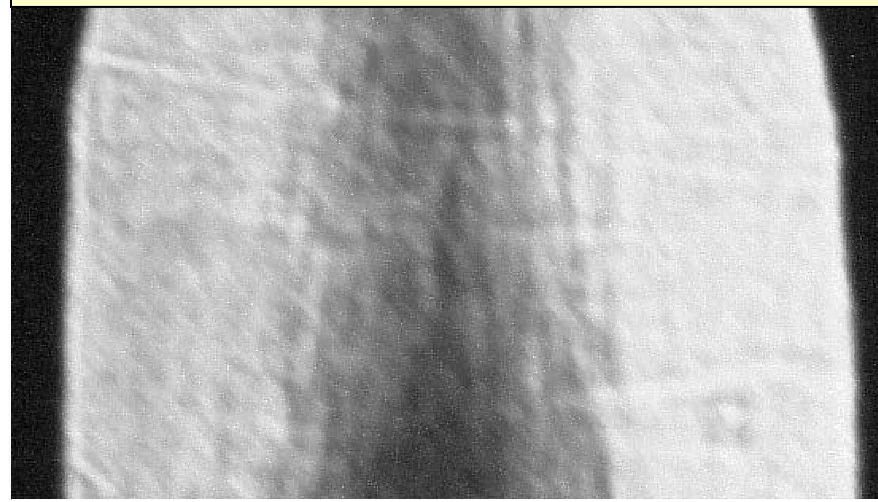
There are 20 slabs in fabrication to provide spares and higher quality parts

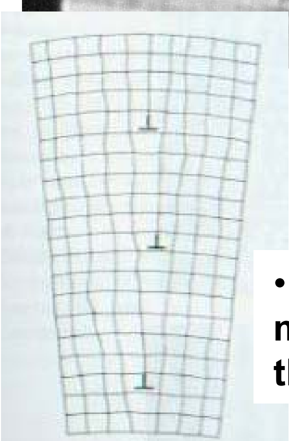
Growth	Cut/Shape	Polish/Shape	Assemble
			
4	6	9	2

Spare Slabs:

We are now focused on improving crystalline quality and growth options that allow IRE scale parts

Grain boundaries have been reduced in recent boules in full diameter section

Previous growth	Recent boule
	

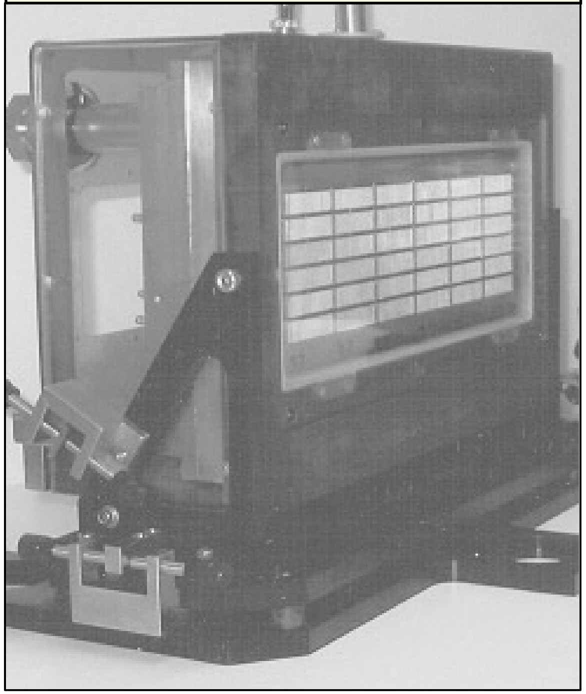
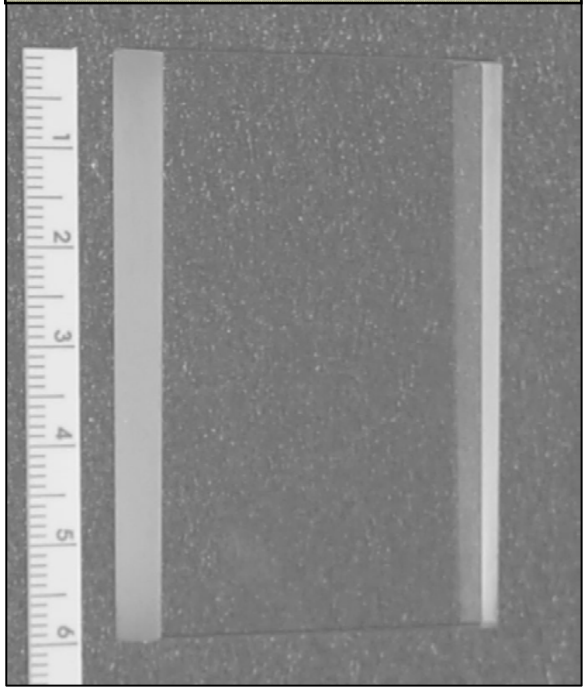
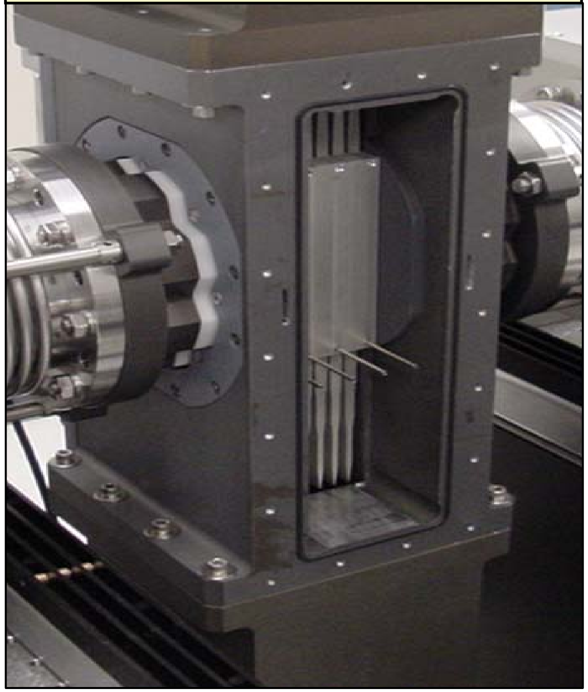


Reduction

- Formed when defect sites migrate together to relieve thermal stress

Stress induced grain boundaries have been reduced by controlling the cooling profile of the crystal during growth

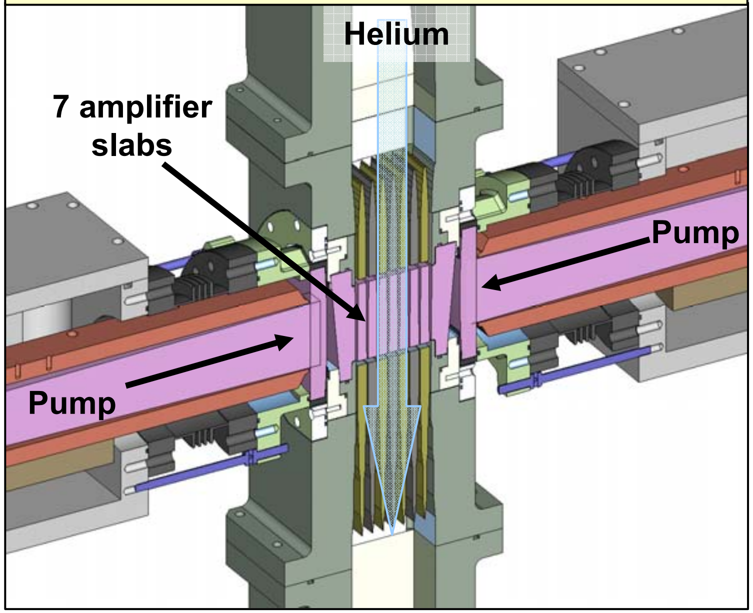
Progress in cooling performance

Diode pump arrays	Solid-state gain media	**Helium gas cooling**
		

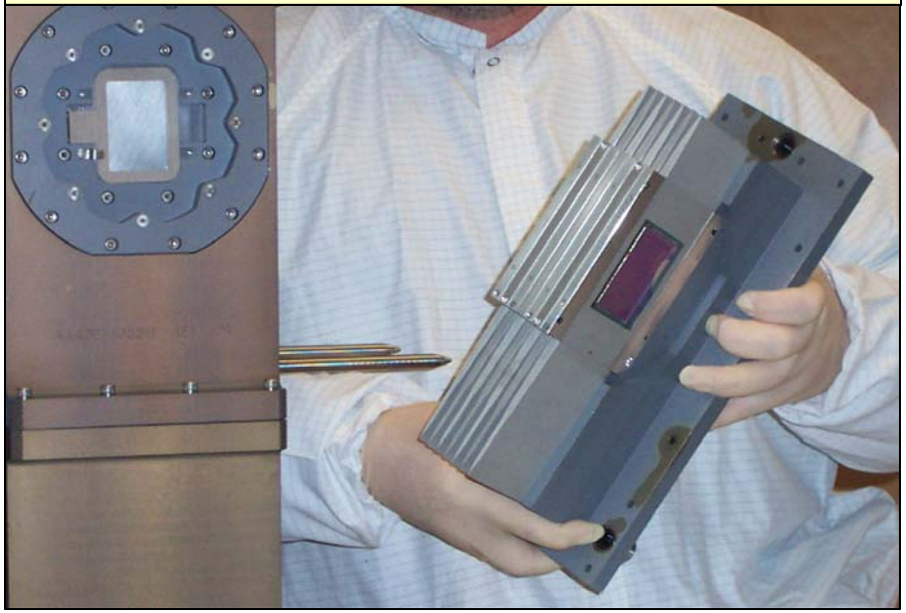
Both helium amplifiers have been characterized for beam wavefront and meet expectations

The measured wavefront of both amplifiers is close to thermal modeling in shape and magnitude

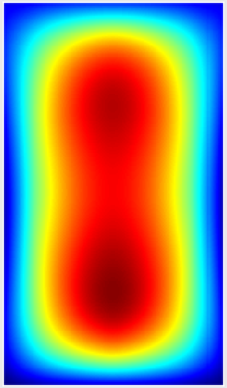
Mach 0.1 helium gas cooling



Amplifier Assembly



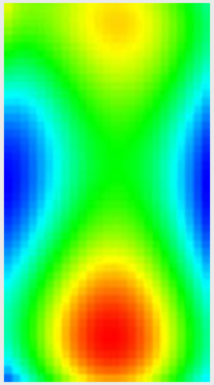
Thermal Model - 7 slabs only



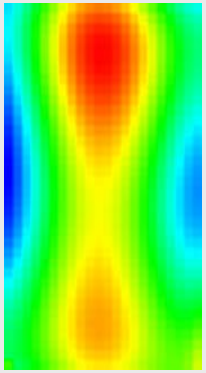
Amp
1.4 waves

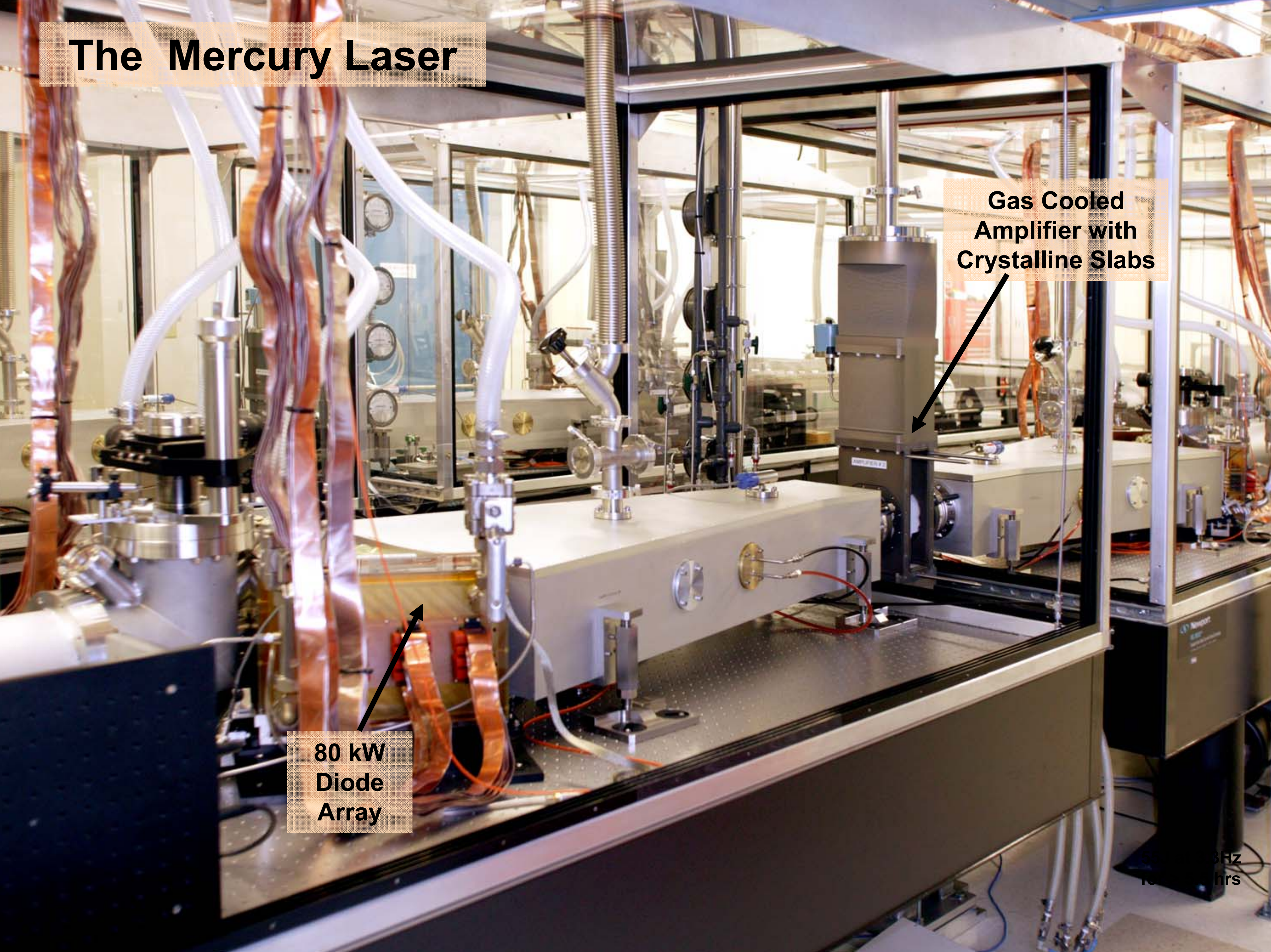
Experimental Data - includes all optics

Amp 1
1 wave

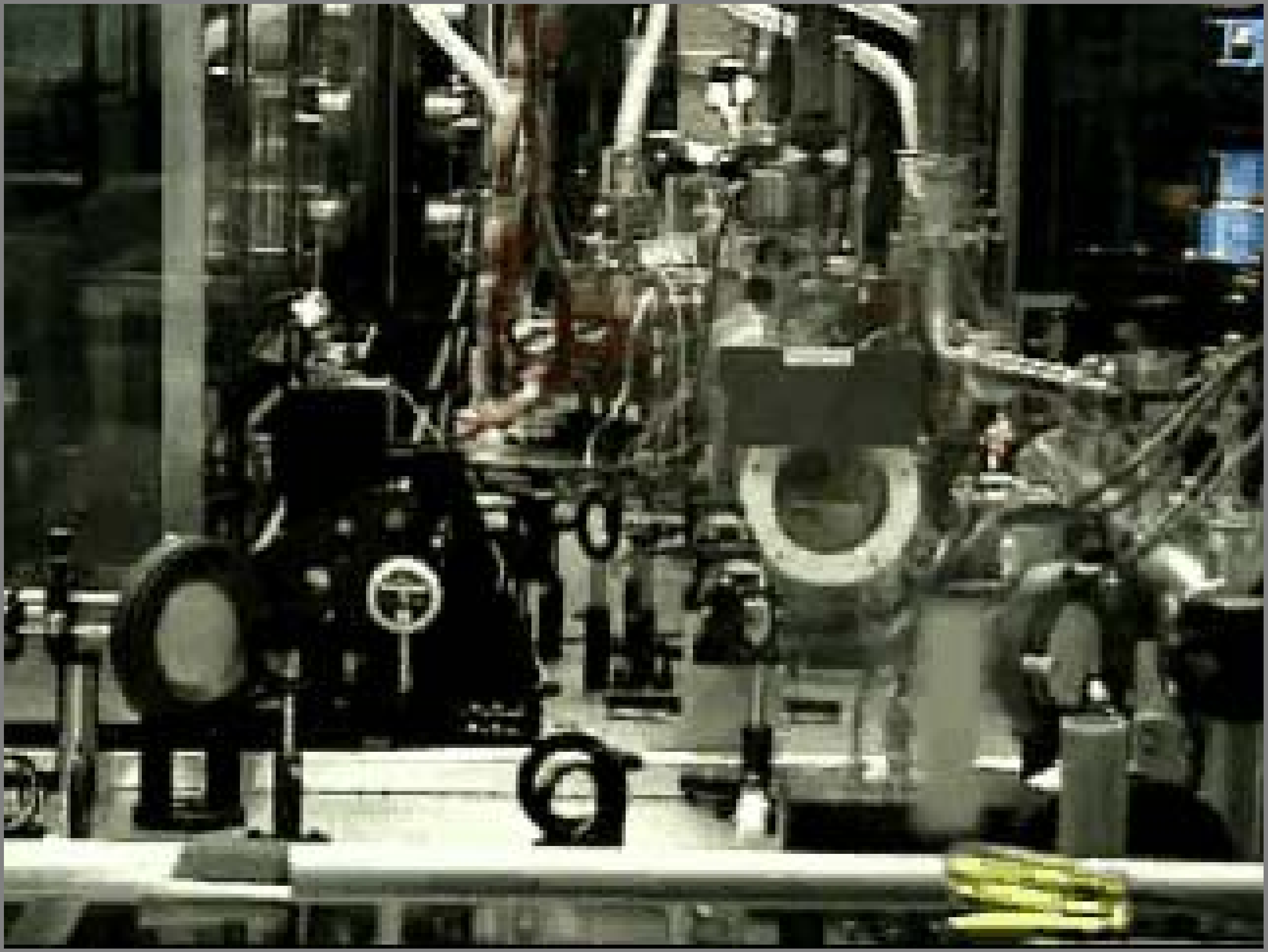


Amp 2
1.17 waves




The Mercury Laser
Gas Cooled Amplifier with Crystalline Slabs
80 kW Diode Array

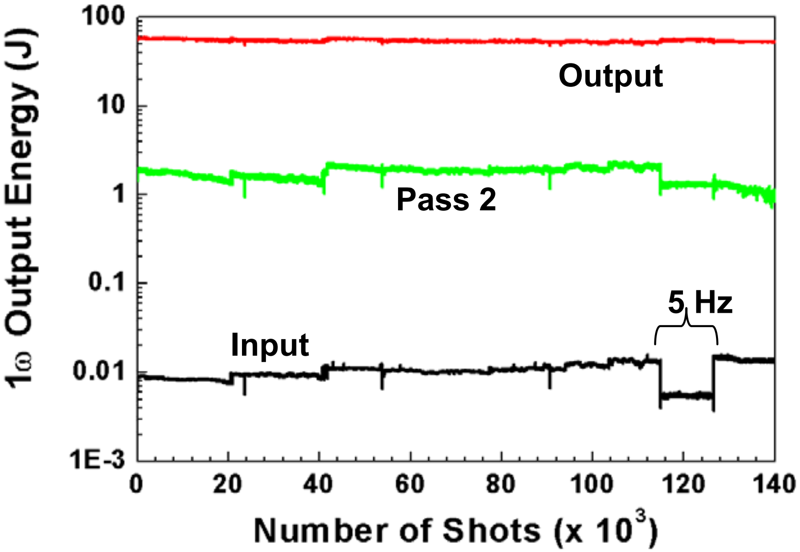
Mercury laser operations movie
of 550 W, at 10 Hz, for several 1 hour runs



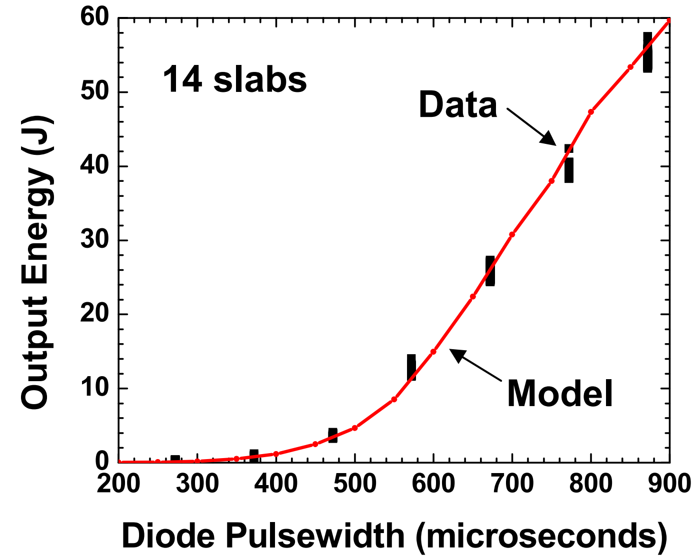
May 20th 2005

The Mercury was operated for 55J at 10 Hz for >10^5 shots producing 0.55 kW of average power

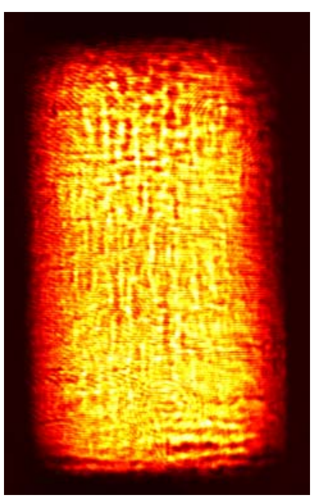
Average Power (Three 1 hr runs)

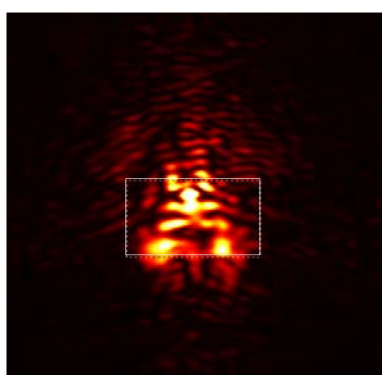


Single Shot Energetics



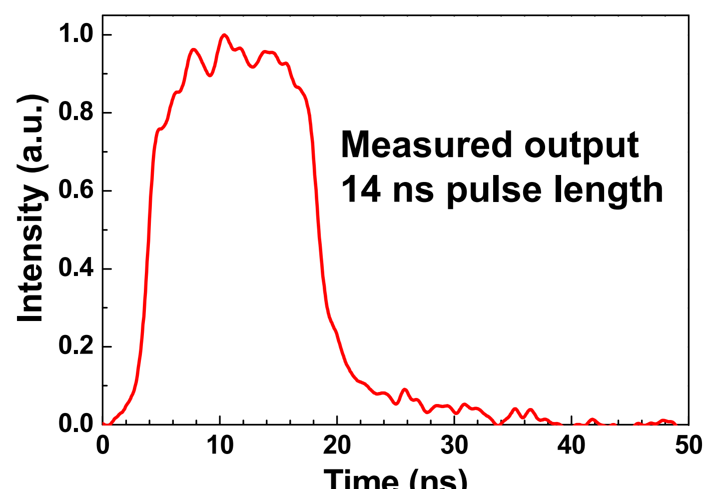
Beam Images





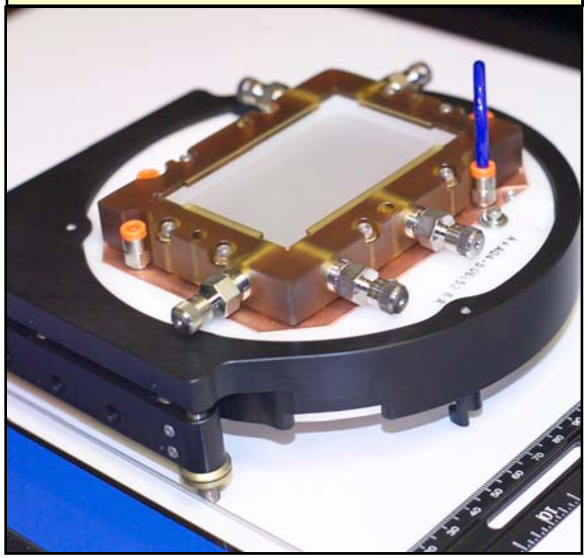
80% energy in a 10X DL spot

Temporal Pulse

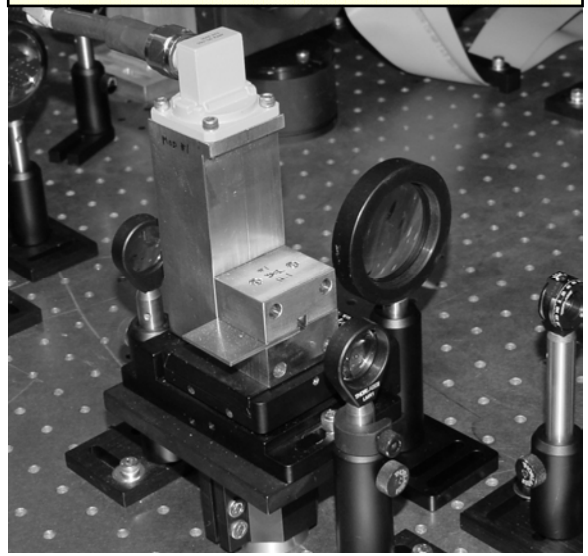


Progress on wavelength conversion

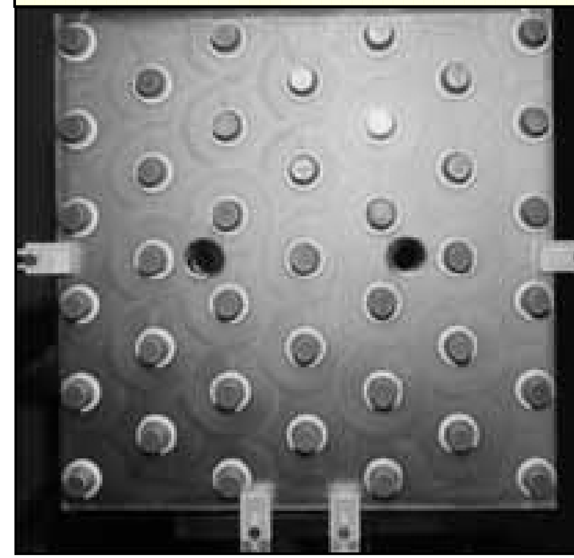
Wavelength



Bandwidth



Wavefront

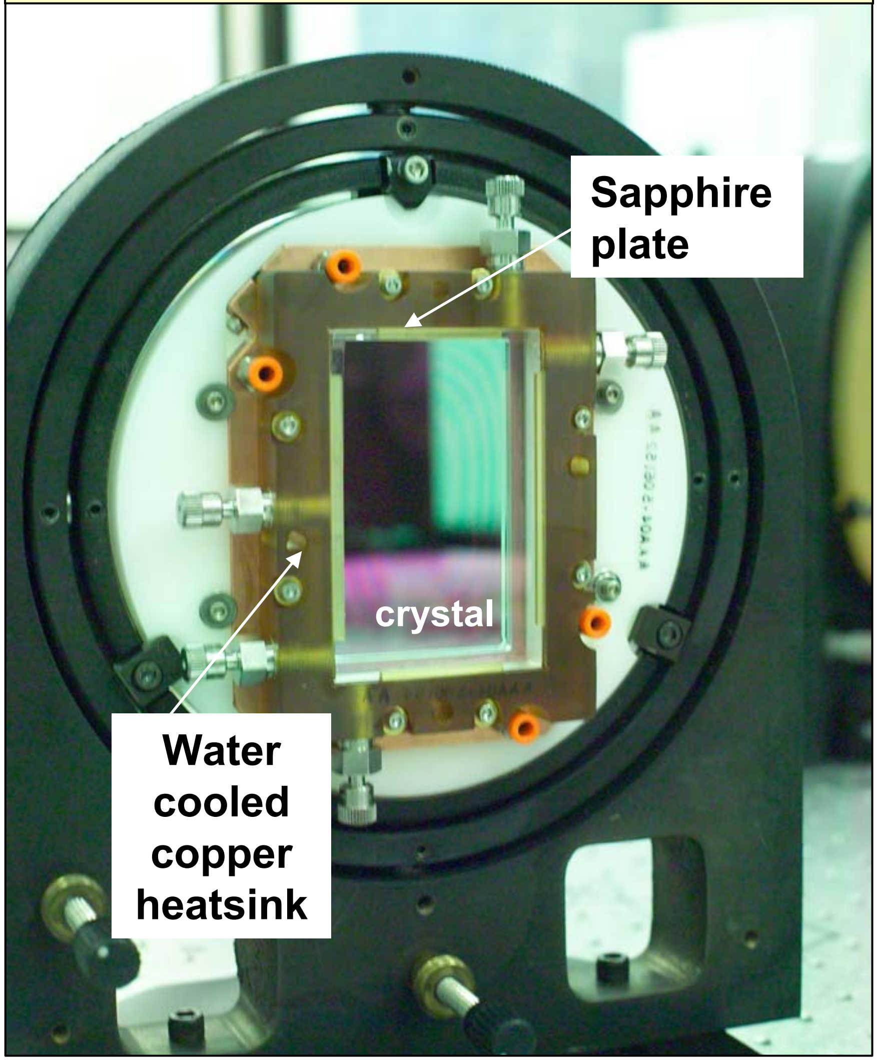


Using advanced materials such as YCOB, we have generated over 200 W in average power output

Experiments were performed with one plate of YCOB

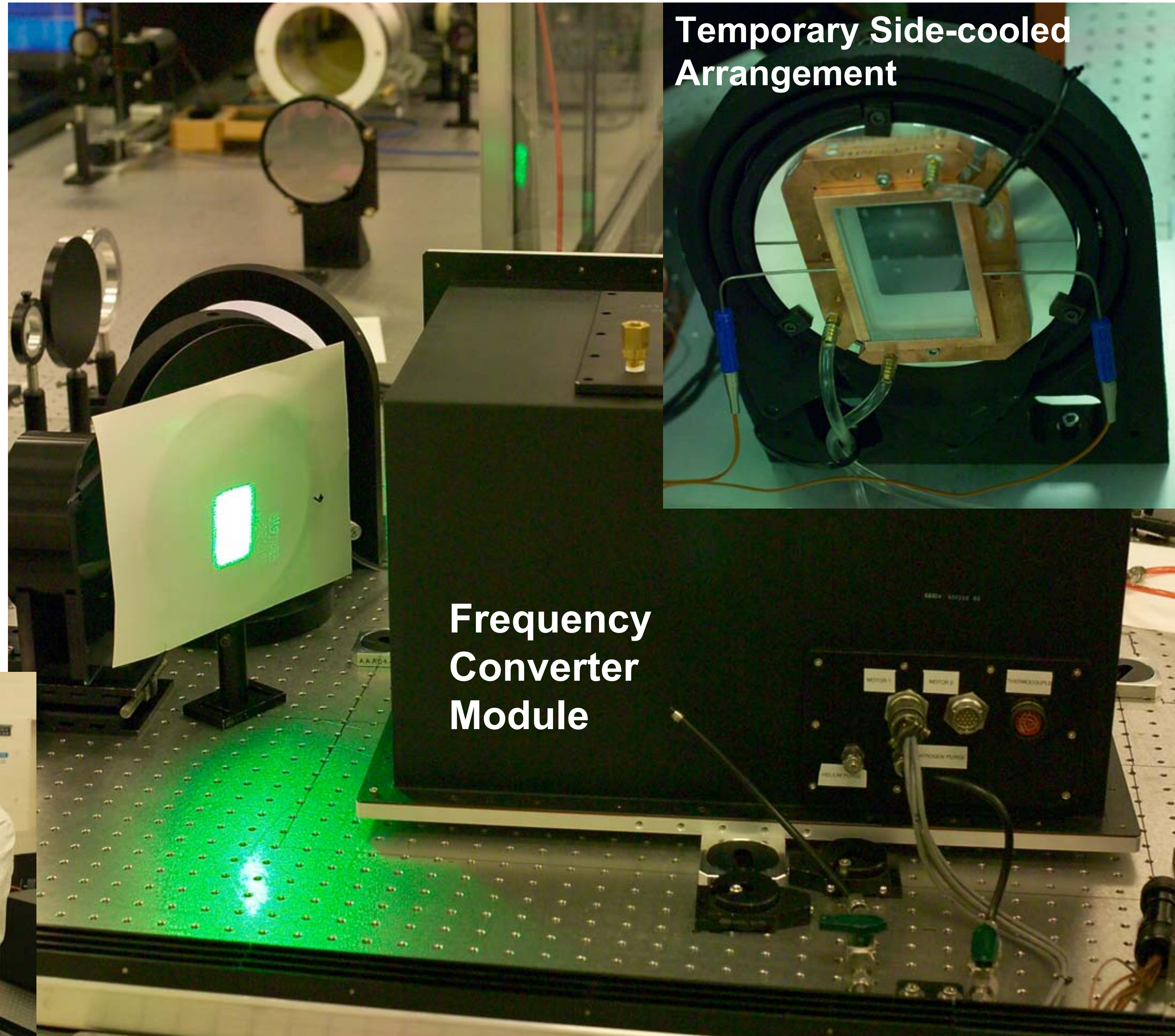
Within 9 months of R&D, a company is producing world's largest YCOB

Face cooled 2ω converter hardware



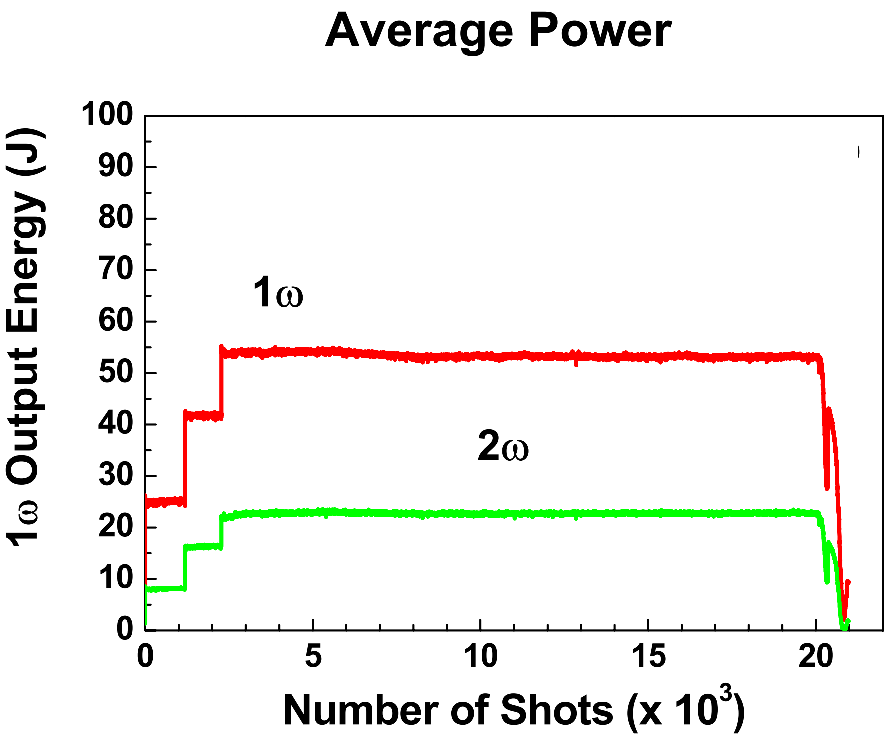
We have demonstrated *first* 2ω light at *10 Hz* repetition rates

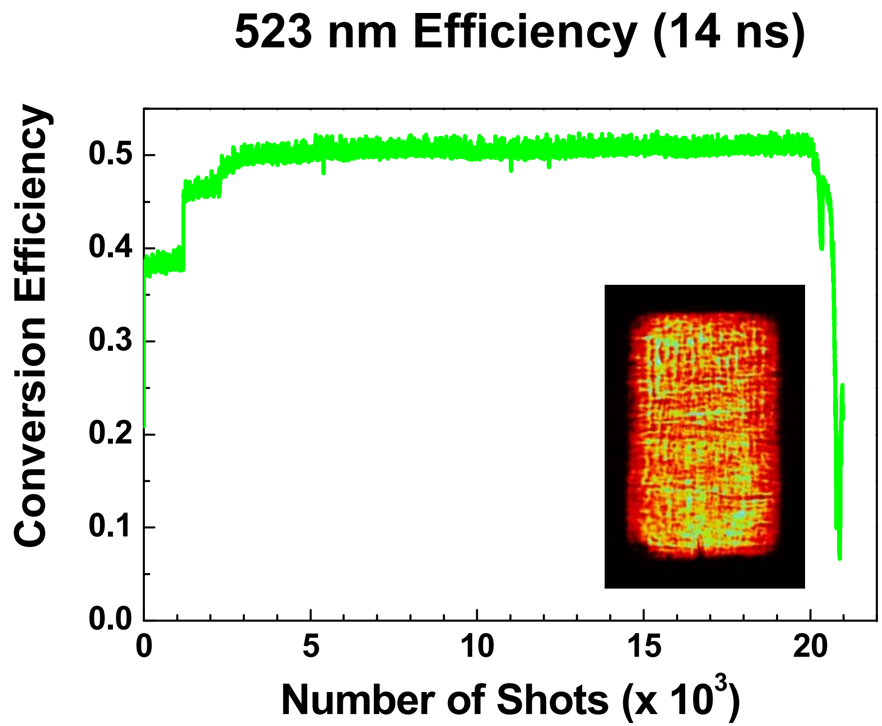
YCOB
1.6 x 5.5 x 8.5 cm slab



Zhi Liao and Chris Ebbers basking in the green glow of success

We operated system for >10^4 shots with YCOB and produced 22.7 J at 10 Hz or 227 W of average power at 523 nm



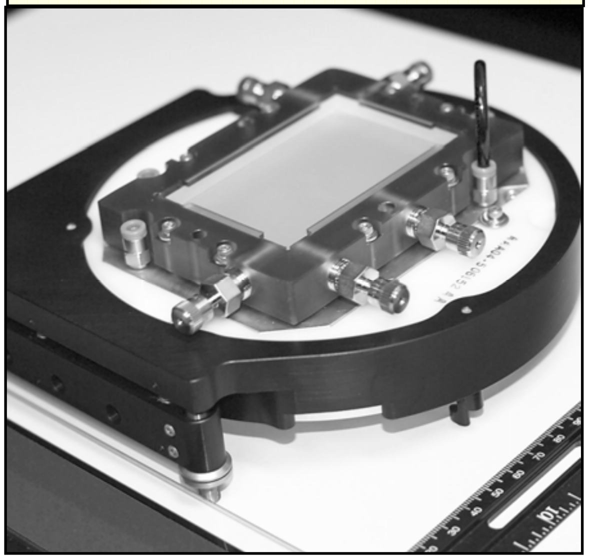


With YCOB we have reached world records in both material apertures and high average power performance at 10 Hz rep- rates

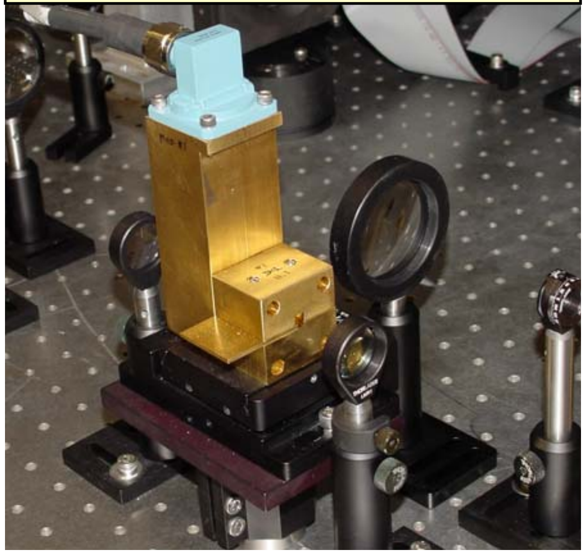
Poster: C. Ebbers and Z. Liao

Front-end laser progress

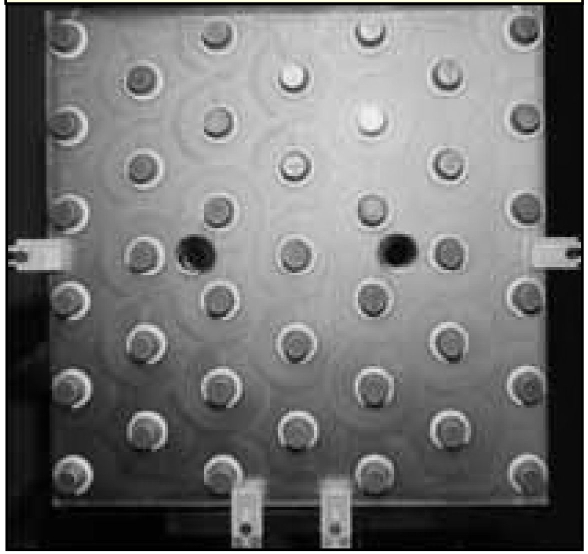
Wavelength



Bandwidth



Wavefront



The advanced front end laser is nearly complete with installation scheduled for next year

The front end design for the Mercury laser is based on fiber amplifier technology to provide a stable and robust system

Energy stability and beam quality are required for reliability and ignition pulses

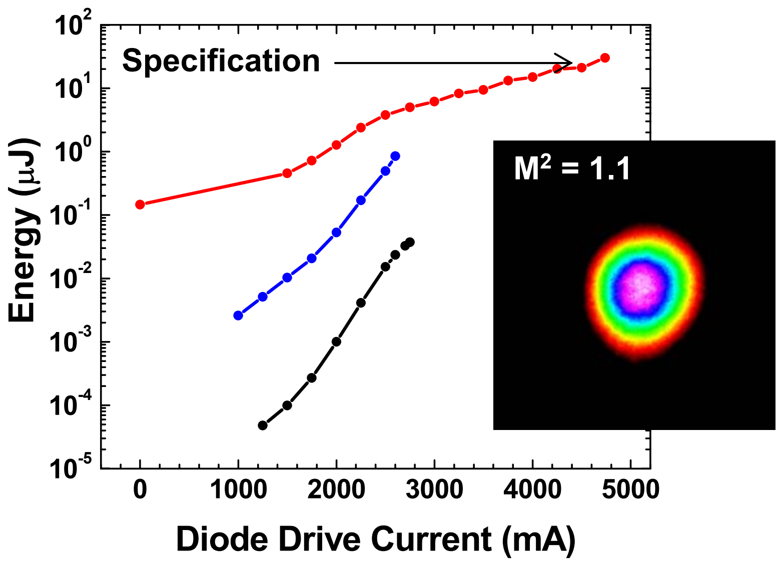
- 500 +/- 2.5 mJ @ 10 Hz
- 10,000:1 signal to noise
- Beam quality: $M^2 < 1.5$

Temporal shaping is required for gain distortion compensation and ignition pulses

- < 5% amplitude fluctuations
- > 250 ps jitter
- 20:1 contrast

Spectral Bandwidth is required for beam smoothing on target

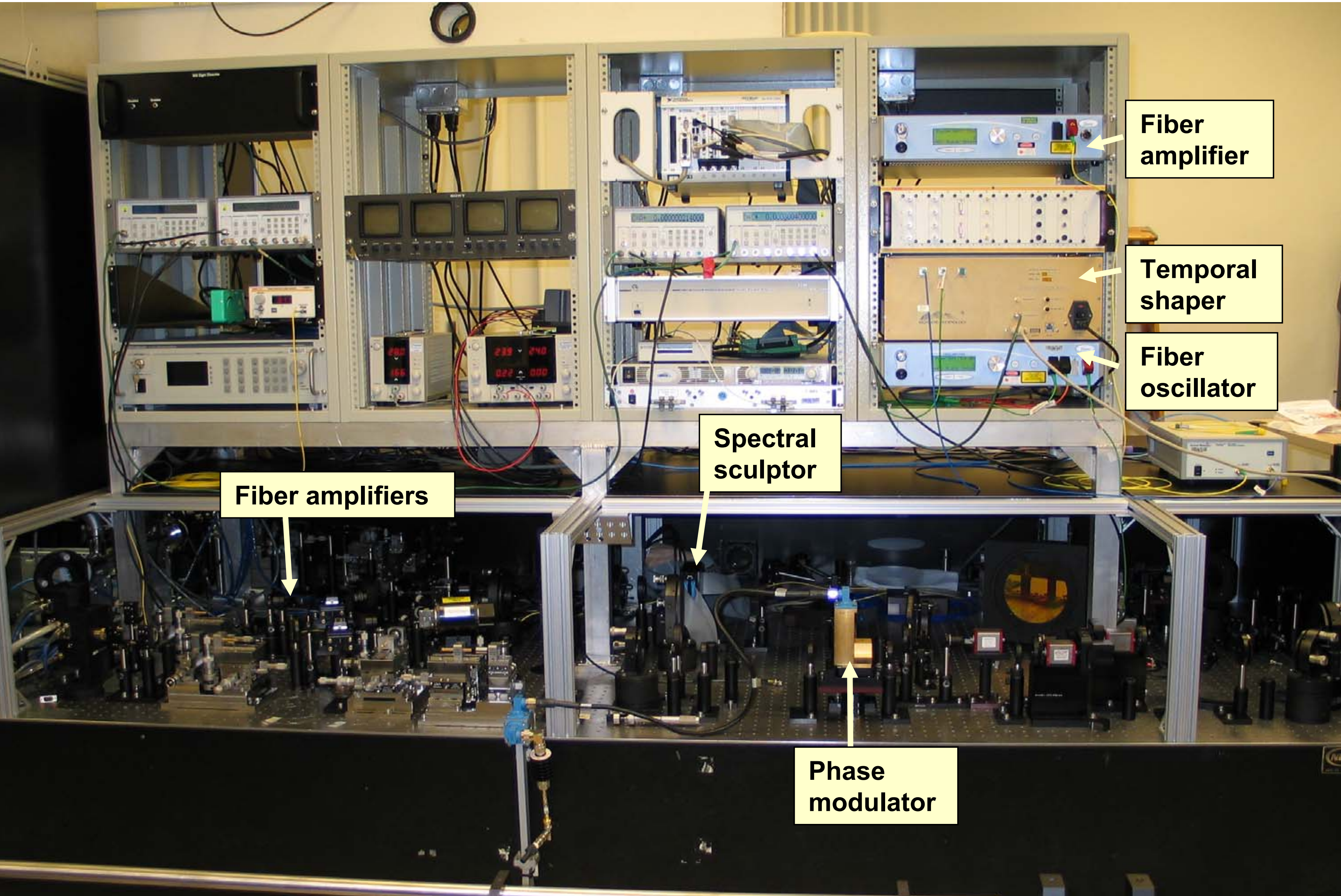
- 3 GHz stability
- >150 GHz bandwidth
- 100:1 contrast



We have demonstrated that the fiber-based section of the front end meets energy and beam quality requirements

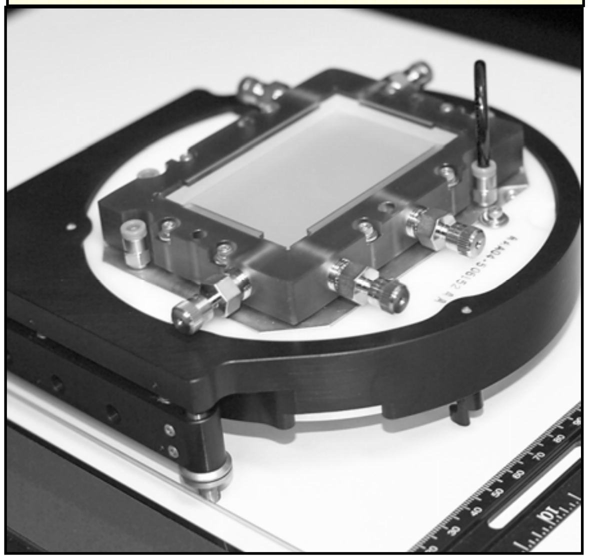
Poster: P. Armstrong

Fiber osc – Temporal shp – Fiber amp – RF bandwidth – Spectral sculpt – Fiber amp – S-FAP Ring

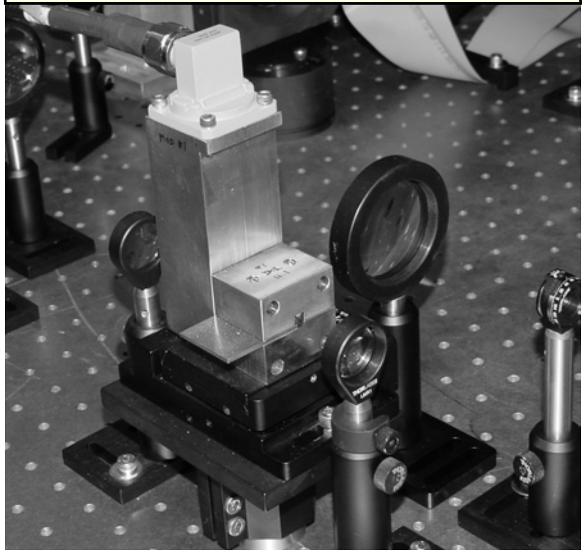


Wavefront correction progress

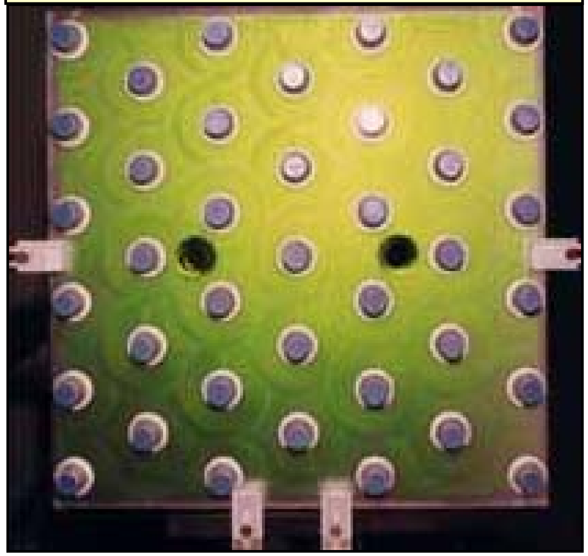
Wavelength



Bandwidth



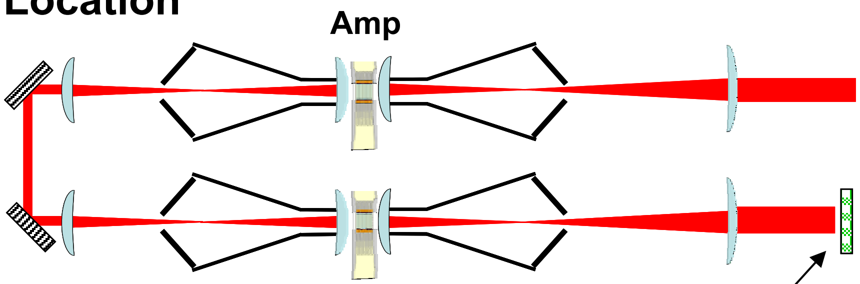
Wavefront



- **MRF is being regularly used to smooth phase profiles of Yb:S-FAP slabs**
- **Phase plates are being used to correct low order thermal distortions**
- **The adaptive optic has been designed and is in procurement**

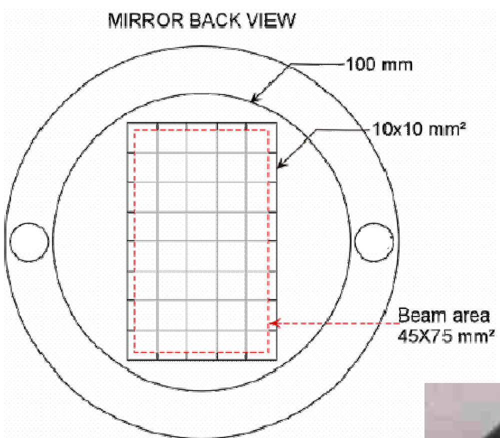
Recent tests on wavefront control substrates indicate that average power specifications will be met

Location

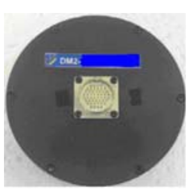


Active wavefront control

Design



Prototype Hardware



Specifications

Mercury Laser AWC Specfication	
	minimal
Physical	
Active Aperture [mm]	45x75
Surface Flatness (P-V) [um]	0.1
Surface P-V correction [um]	4.00
Max spatial frequency [1/cm]	0.5
Laser	
Wavelength [nm]	1047
Energy [J]	35
Pulse width [ns]	3
Avg. Power @ 10Hz [W]	300
Peak Intensity [GW/cm^2]	2.6
Fluence [J/cm^2]	1.04
Controls	
Resolution [points]	128 x 128
Rep. Rate [Hz]	3
close loop operation	yes
sensitivity [waves]	0.05
dyanmic range [waves]	0.01 -10

We are successively meeting our performance goals

		Goal	Present	End FY05
Components	Amplifier slabs	14	14 ✓	28
	Diode tiles	288	307 ✓	324
	Amplifiers	2	2 ✓	2
	- Cooling uniformity (rms)	<1%	0.12% ✓	0.12%
	Wavefront control	DM	On order	Offline demo
Laser Performance	Energy (J)	100	63	100
	Rep-rate (Hz)	10	10 ✓	10
	Efficiency (%)	10	4.5	10
	Diode reliability (shots)	10^8	10^8 ✓	10^8
	Laser reliability (hrs)	8	8	> 10
	Beam quality (xDL)	5	10 @ 55J	10
	Pulse-shaping (ns)	3-10	3-15 ✓	3-15
	Bandwidth (GHz @ 1ω)	>150	250	Offline demo
	Conversion	$2\omega/3\omega$	2ω ✓	2ω

✓ Completed

On schedule

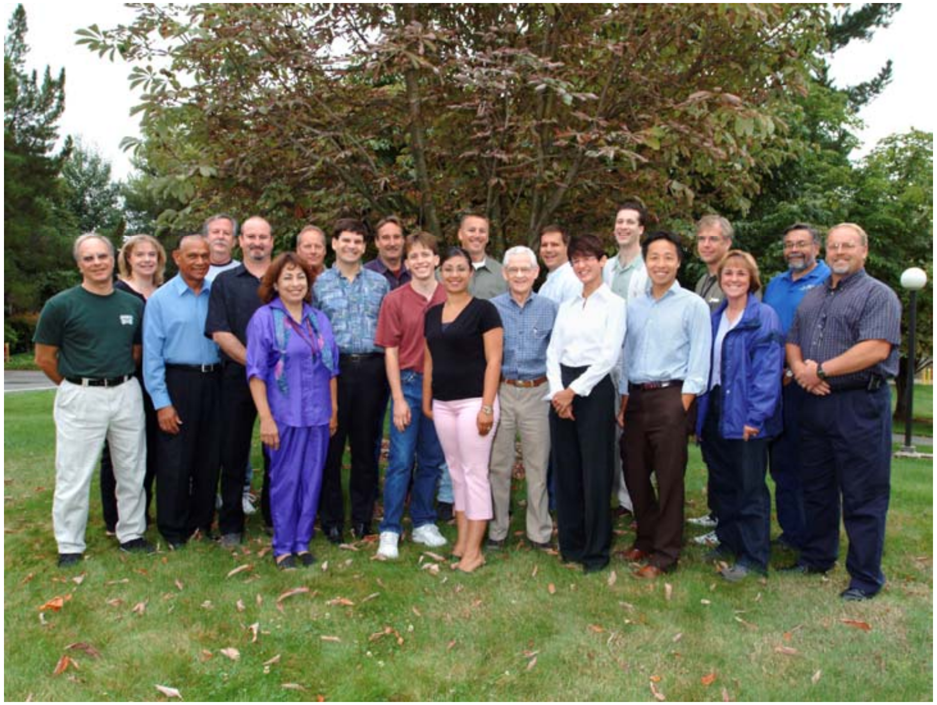
Summary

- ✔ **Project Overview**
  - International/National DPSSL Programs are pushing technology envelopes

- ✔ **System Performance**
  - Mercury Laser performance goals are on track
    - 1ω: 550 W average power at 14 ns for > 10^5 shots (55 J at 10 Hz)
    - 2ω: 227 W average power at 14 ns for > 10^4 shots (22 J at 10 Hz)

- ✔ **Component Performance**
  - Pump diode arrays (Commercial prototypes meet specs)
  - Crystalline gain media (20 spare slabs in queue)
  - Gas cooled amplifiers (Thermal wavefront agrees with model)
  - Front end (System 80% complete)
  - Adaptive optics (Commercial vendor engaged)

- **Next Generation Design Considerations (R. Beach)**
  - System engineering with statistics in mind
  - Out-of-the box thinking to push efficiencies
  - Leveraging NIF engineering



Mercury Team

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Schott Glass Technologies
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Photonic Crystals
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