All diode-pumped 4 Joule 527 nm Nd:YLF laser for pumping Ti:Sapphire lasers

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April 26, 2017

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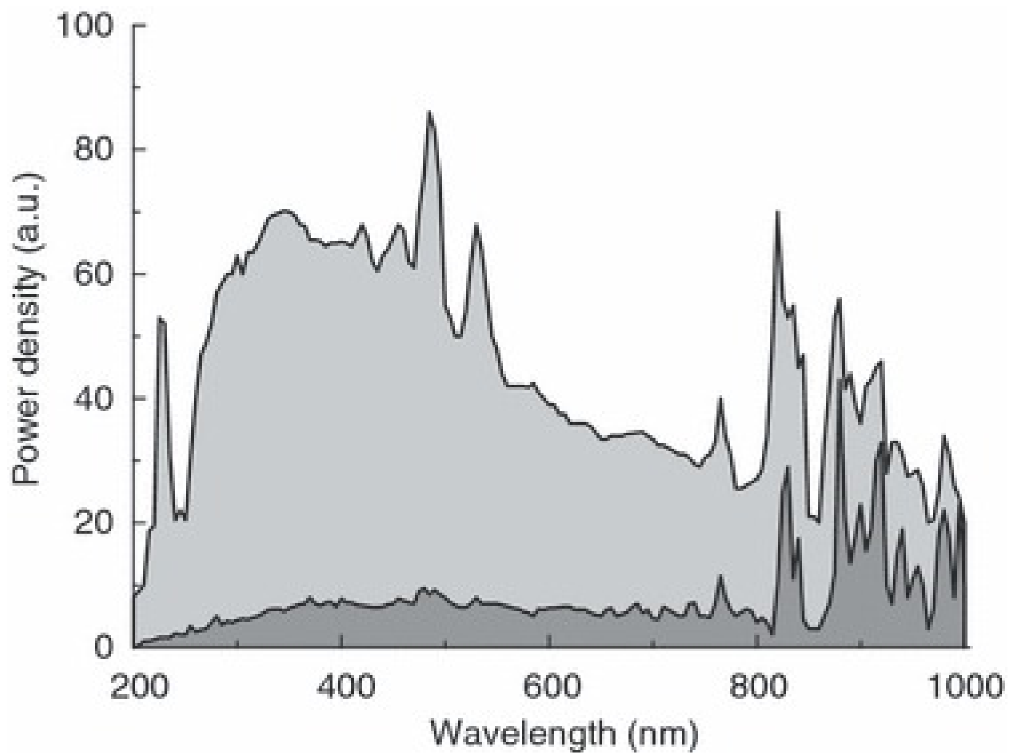
Outline

- Comparison of pump sources for high energy solid state lasers
  - Performance and lifetime of typical Xenon flash lamps
  - Reliability and lifetime data of NG CEO high peak power laser diodes used in the laser
- Gain module model and parameters
- Laser layout and performance
- Conclusions

Approved for public release; NG 17-0791 dated 4/12/17.

Typical Spectrum of Pulsed Xenon Flash Lamp



The spectrum of pulsed xenon flash lamps is dependent on the input voltage.
Source: http://www.heraeus.com

Flash Lamp Lifetime

"There is no general method available for the reliable estimation of flash lamp lifetimes.

In the high energy regime, see Figure Y it is possible to predict with reasonable accuracy the expected lifetime using equation 22. In this high energy regime lifetime is primarily determined by the mechanical strength of the quartz tubing and the amount of degradation caused within the lamp by ablation of the quartz material.

In the low energy regime of Figure Y lifetime is primarily determined by electrode effects, principally that of sputtered material from the cathode. The sputtered deposits will slowly build up on the inside wall of the lamp, reducing output."

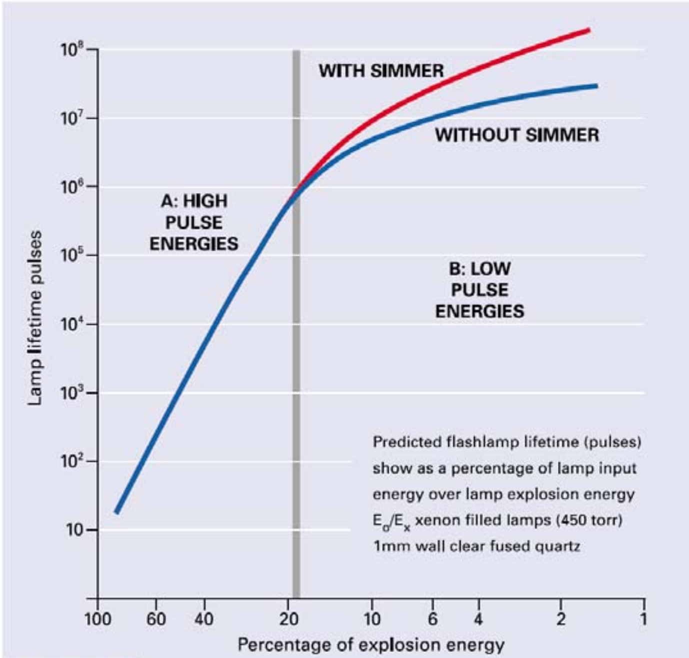


Figure Y

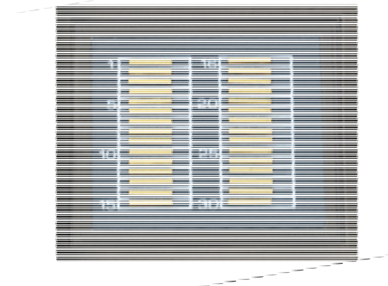
Source: High Performance Flash and Arc Lamps; Technical Information; Perkin Elmer

Advantages of All-diode Pumped High Energy Solid State Lasers

- Biggest drawback is the short lifetime of lamps.
  - The flash lamp pumping energy drops by typically 80% after tens of millions shots.
  - When the lamps are replaced, the cavity optics usually requires a slight realignment to maintain a good output mode from the laser.
  - This routine maintenance actually conceals another limitation – their optical alignment tends to drift over time and requires periodic realignment, irrespective of any lamp change
- Increase in reliability of high peak power laser diodes
  - Maturity of semiconductor material epitaxy
  - Optimization of laser waveguide structures
  - Improvements in facet coating technology
  - Gains in packaging and cooling technologies.
- Laser diodes offer a degradation rate that is 100-1000 times lower than typical flash lamps.
- ~10 time better efficiency than lamp-pumped lasers
- With the reduction in cost of high power laser diodes, diode pumped high-energy lasers have reached a very competitive position relative to flash lamp-pumped lasers.

NGCEO Product Overview

Outsourced EPI Growth → Manufacture Laser Diode Bars → Ext. Sales



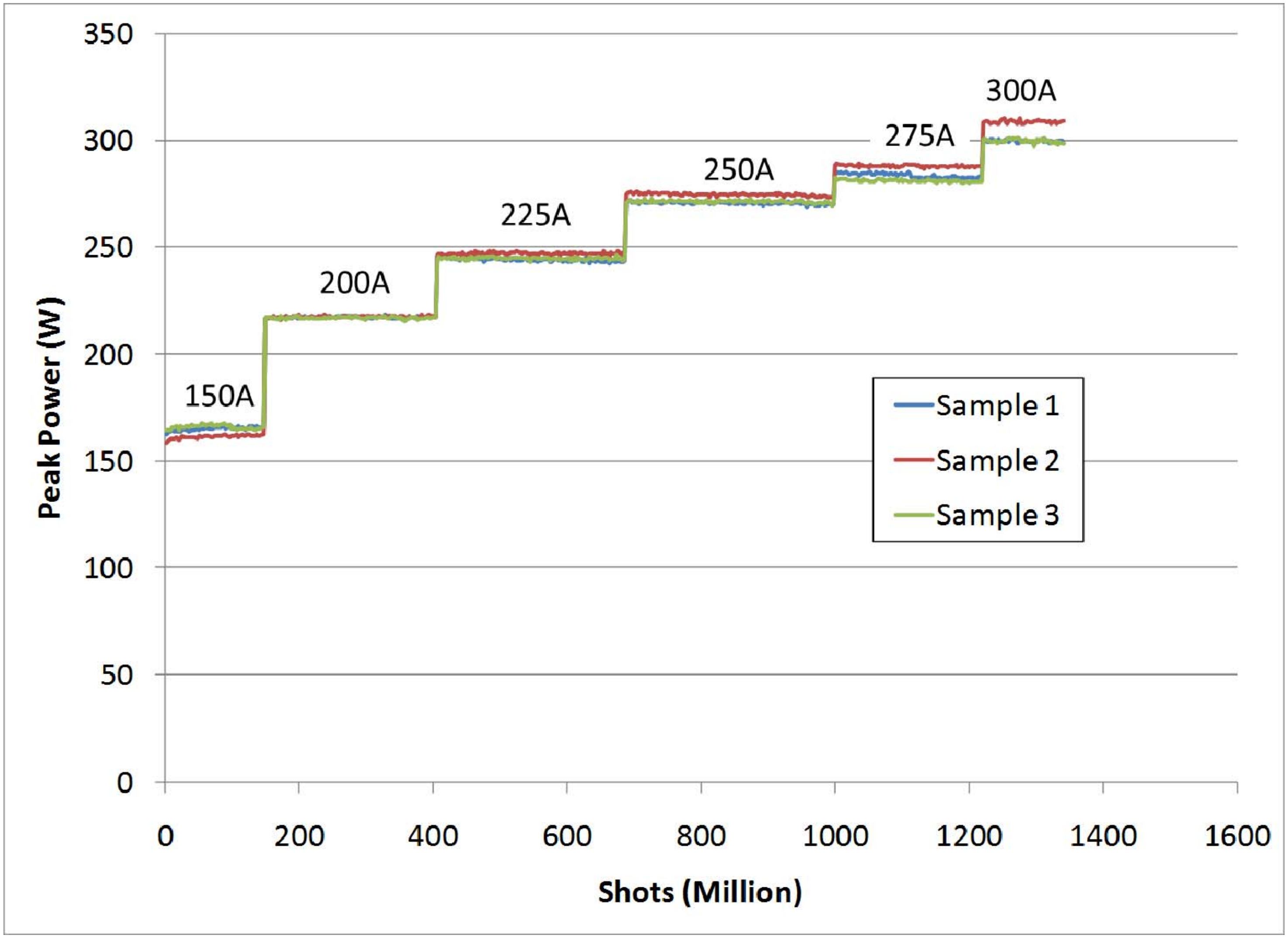
Internal or External Diode Bars → Manufacture Laser Diode Arrays → Ext. Sales

Manufacture Laser Gain Modules → Ext. Sales

Manufacture DPSS Laser Systems → Ext. Sales

NGCEO designs & manufactures OEM laser components for commercial, scientific, and military applications

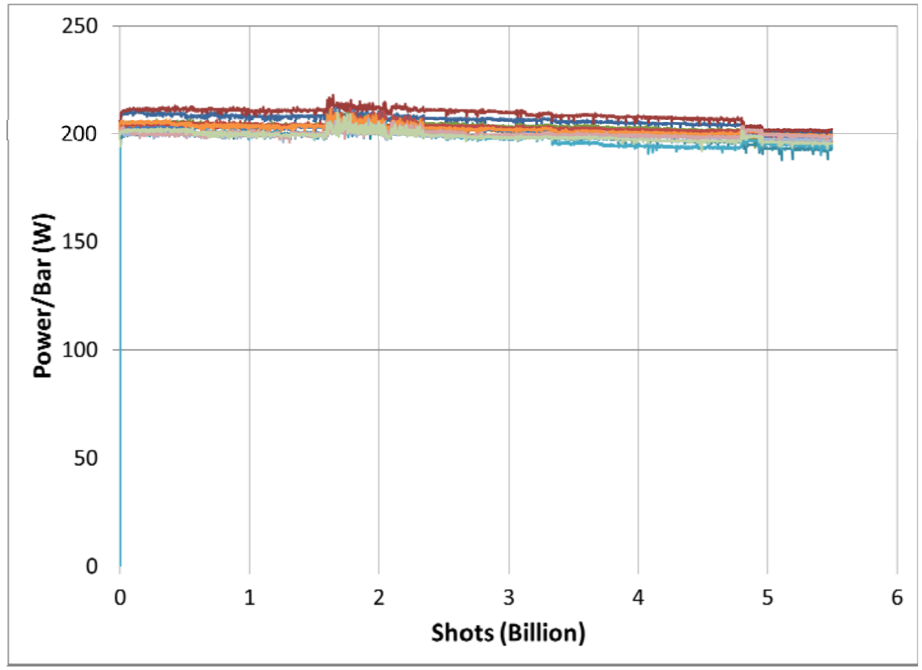
Step-stress Life Test Results of NGCEO's 80x nm QCW Bar



Operational Life Test Results

Life test conditions

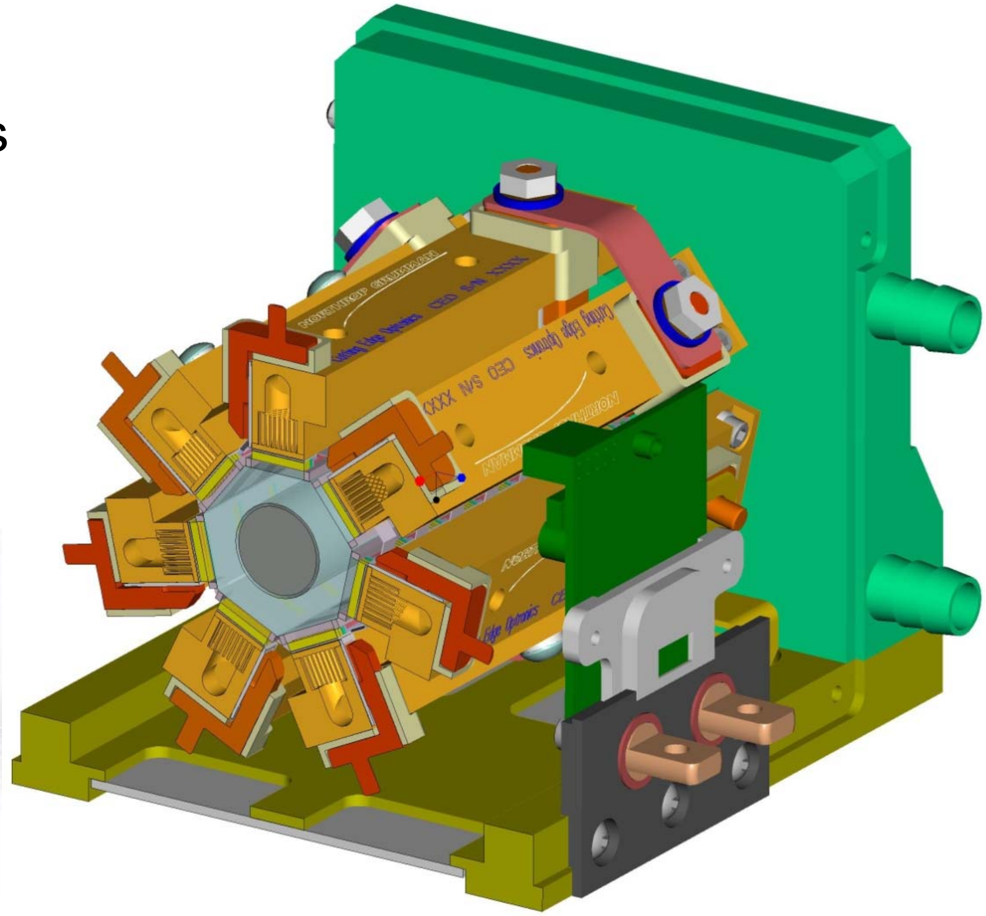
Sample type	4-bar Array
Array pitch (µm)	400
Sample Size (arrays)	15
Sample Size (bars)	60
Repetition Rate (Hz)	250
Pulse-width (µs)	150
Water Temperature (°C)	25



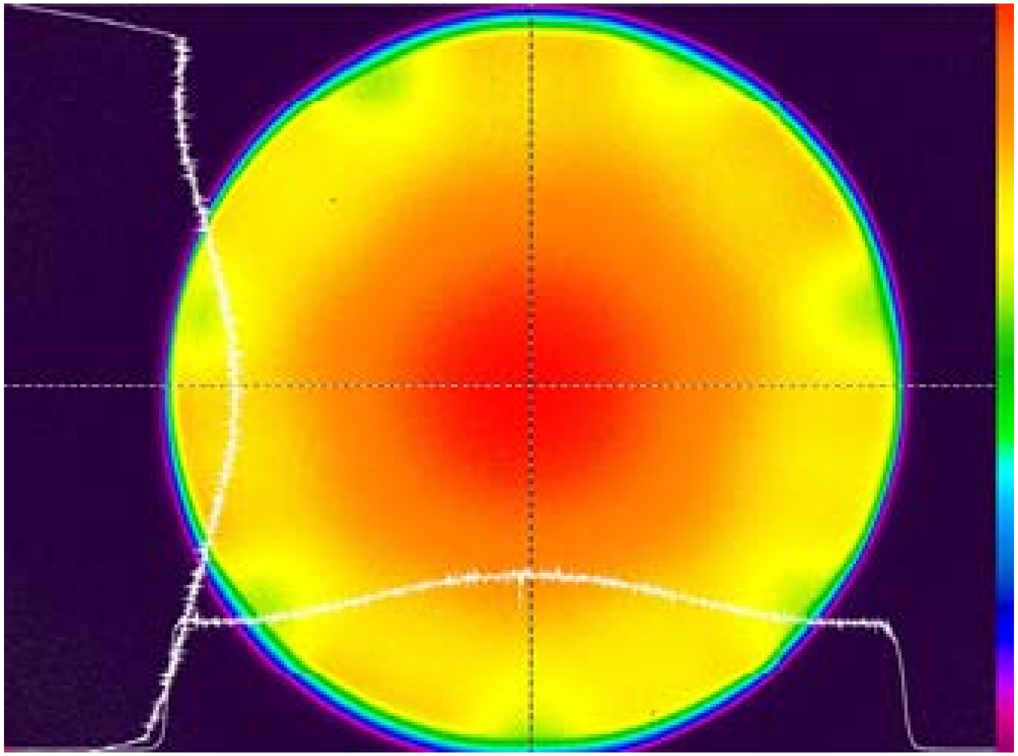
- There is minimal degradation over the course of the first 5.5 billion shots
- No statistically significant predictions of product lifetime can be made at this point.
- Approximately 255 days of continuous operation under these conditions
- The peak power and average power of the laser diode arrays in an NGCEO laser are operated at de-rated conditions for over 10 billion shots, which meets one of the key thresholds of industrial operation.

Laser Amplifiers

- All amplifiers are Diode Pumped Solid State (DPSS)
- Large selection of laser amplifiers
- Radially pumped rod geometry
- Rod aperture sizes from 2mm to 25mm
- Stored energies to 4J



Gain Uniformity of REA22 Nd:YLF Module



Fluorescence light distribution of NG CEO REA22 pump module with approximately 6 Joule stored energy.

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Franz and Nodvik Model

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The relationship between the stored energy, small signal gain, input energy fluence and gain can be accurately described by the model of Franz and Nodvik. The amplifier gain (G) for a laser pulse can be expressed in the form

$$G = \frac{E_{sat}}{E_{in}} \ln\left\{1 + \left[\exp\left(\frac{E_{in}}{E_{sat}}\right) - 1\right] G_0\right\} \tag{1}$$

G (the gain for the pulse), E_{in} (the input pulse energy per unit area), E_{sat} (the saturation energy density) and G_0 (the initial small signal gain) where G0 is defined as

$$G_0 = \exp(g_0 l) = \exp(D_{st} / E_{sat}) \tag{2}$$

In equation (2), g_0 is the SSG coefficient, *l* is the length of the active medium and D_{st} is the stored energy density.

For a 4-level system with fast lower level relaxation the saturation fluence is given by

$$E_{sat} = \frac{h\nu}{\sigma} \tag{3}$$

where h is Planck's constant, ν is the frequency of the laser wavelength, σ is the stimulated emission cross-section.

The saturation fluence is 0.67 J/cm^2 for Nd:YAG and 1.57 J/cm^2. for Nd:YLF.

To achieve the good optical-optical efficiency, the power amplifiers should be operated over the saturation fluence.

Layout of 4 J 527 nm Nd:YLF Laser

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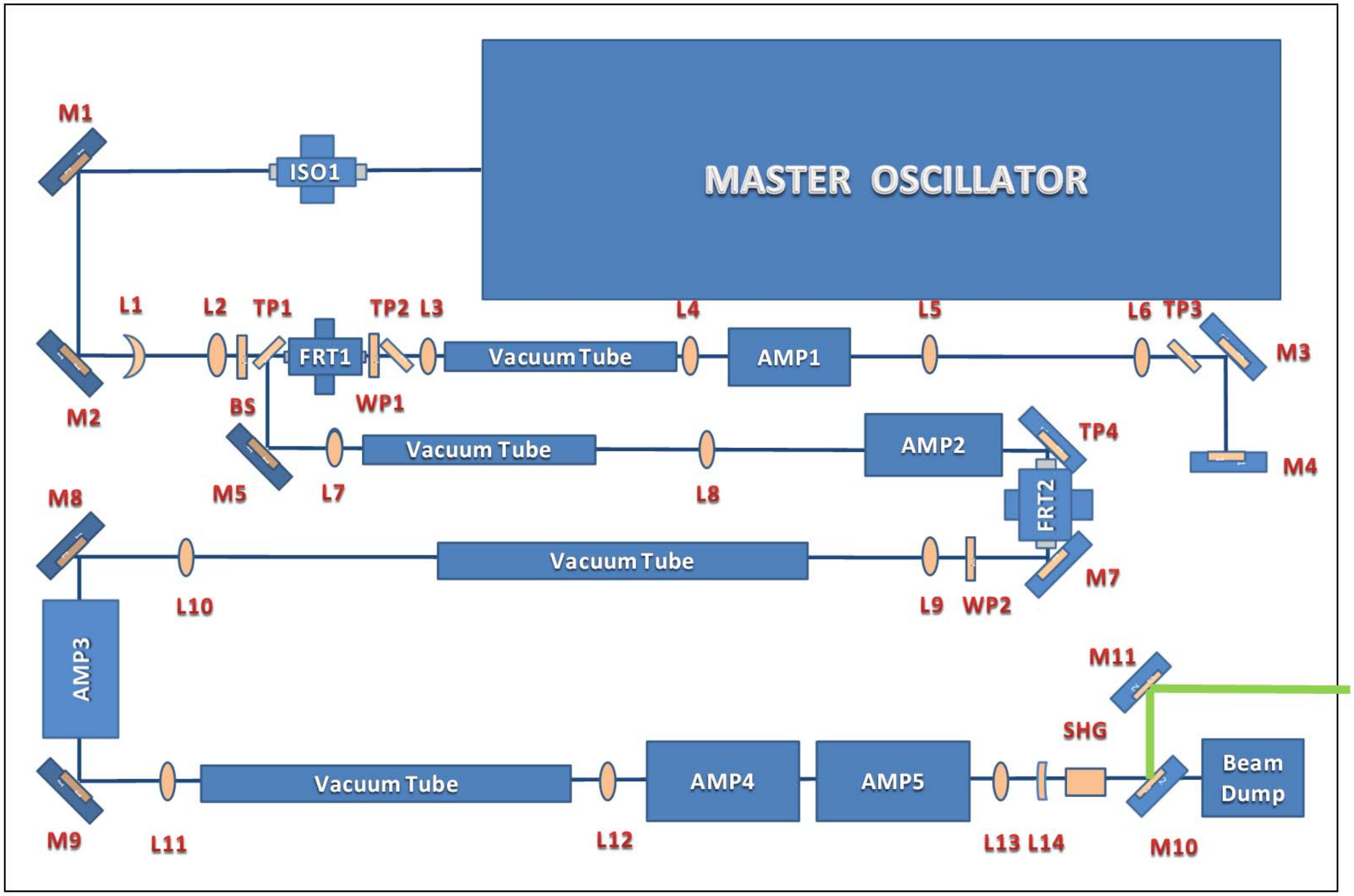
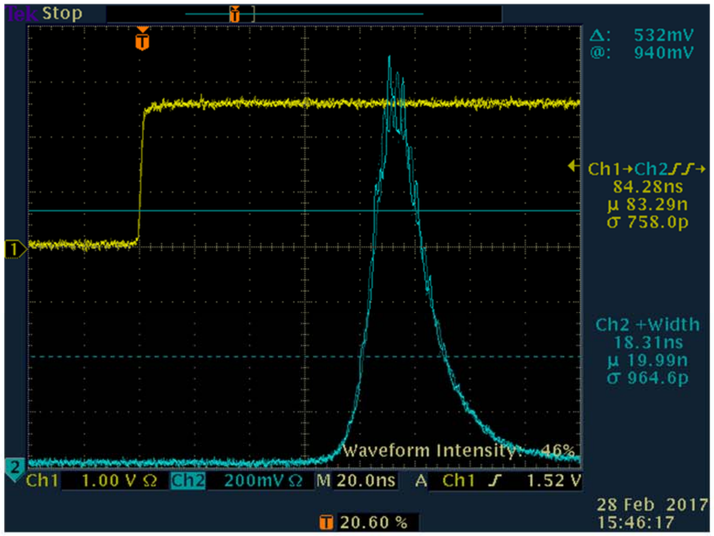
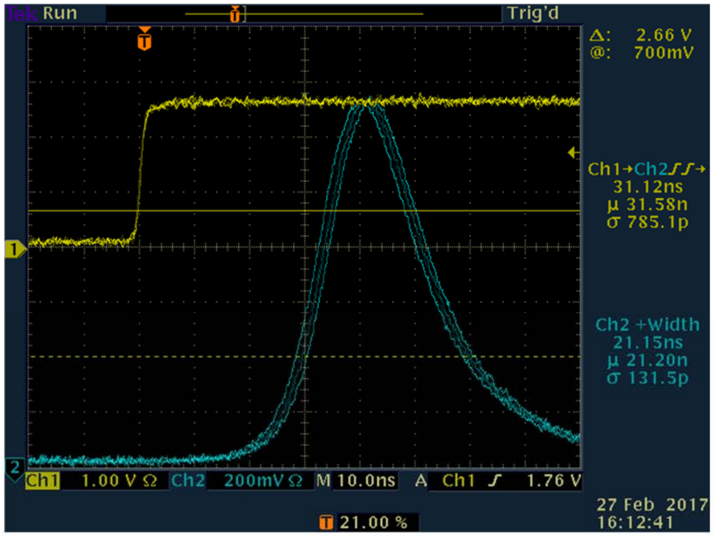


Temporal Profiles of Laser Pulses from Oscillator (~20ns; Jitter <1ns)



(a)



(b)

External trigger signal (Channel 1, yellow trace) and laser pulse temporal profile of the oscillator, (a) without seeding while (b) with seeding.

25 Hours (1.8 Million Shots) Long Term Energy Stability of the Oscillator

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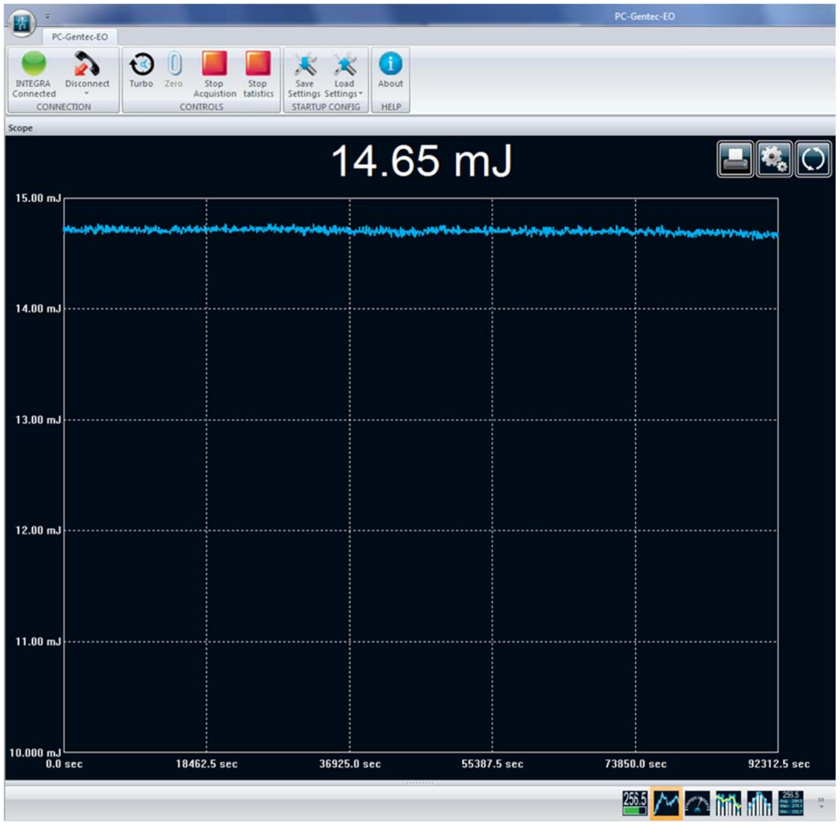
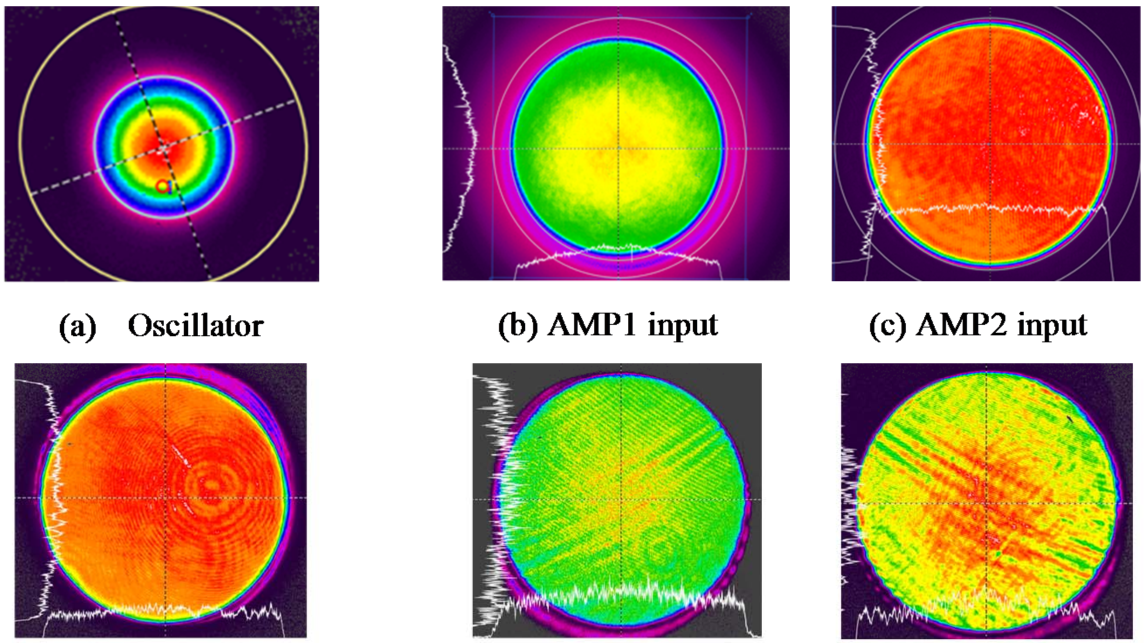


Pulse-to-pulse energy stability ~0.25% RMS

Beam Profiles at Several Locations of the Laser



(a) Oscillator (b) AMP1 input (c) AMP2 input

(d) AMP3 input (e) AMP5 output (f) Output, 527 nm

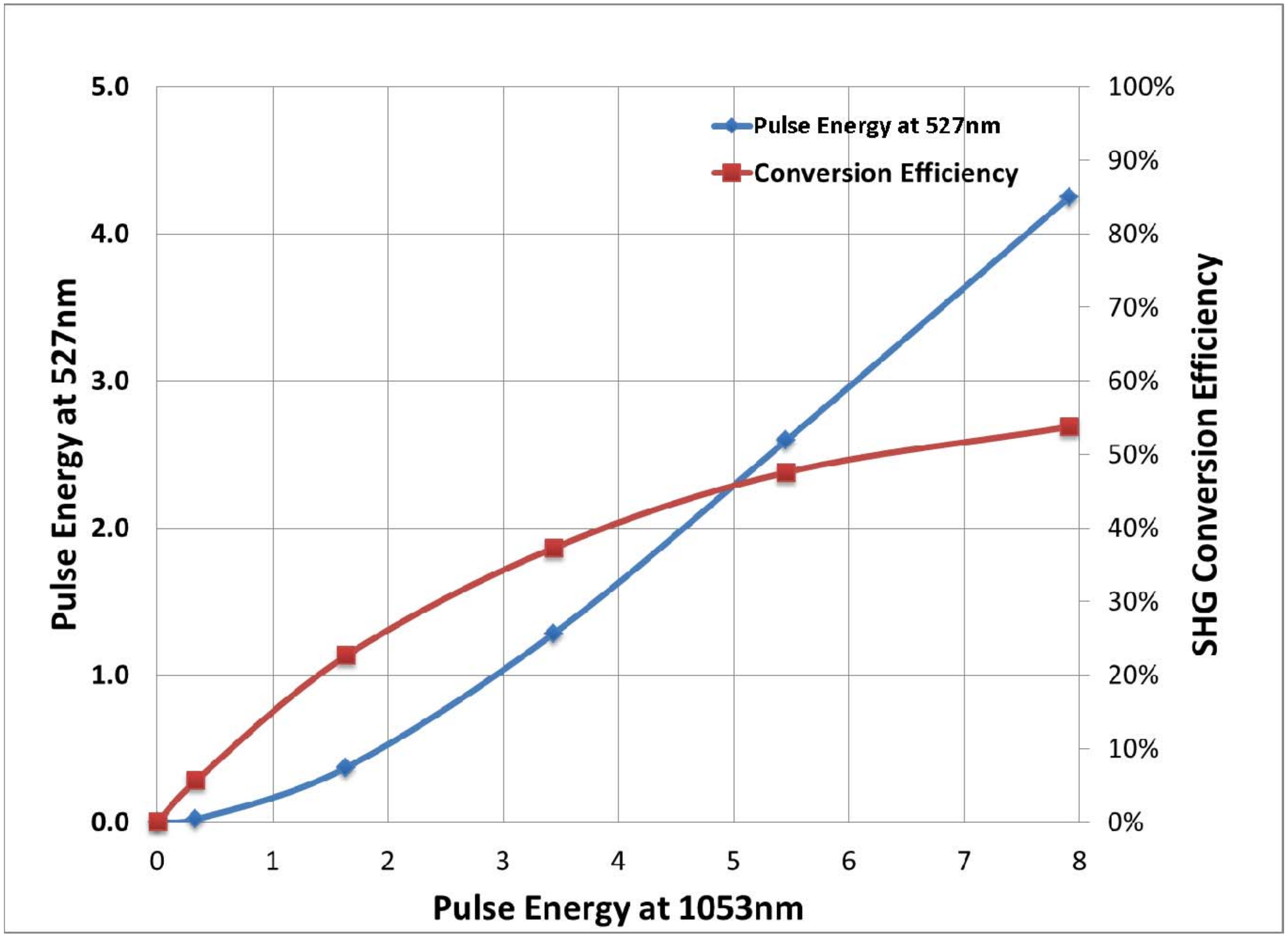
The degradation of the beam profile after AMP4 is believed to be related to the quality of that particular Nd:YLF crystal. This problem can be addressed with a better quality Nd:YLF rod.

Pulse Energy after Each Amplifier

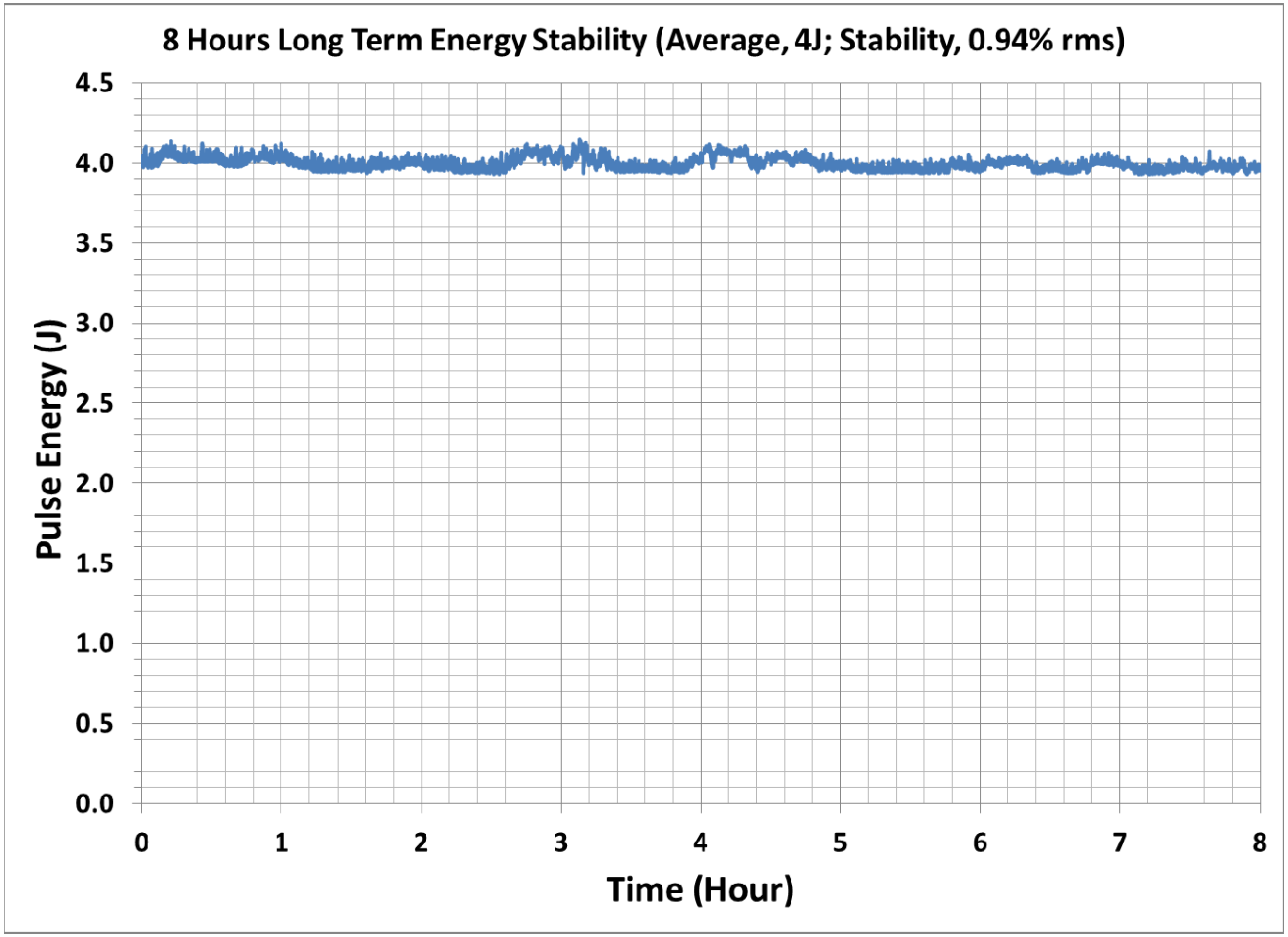
Location	Pulse energy at 1053nm
Double pass of AMP1	400 mJ
AMP2	1.8 J
AMP3	3.8 J
AMP4	6.0 J
AMP5	9.0 J

The pump current for all the amplifiers was limited to 150 A and pulse-width around 350 μs to support over 10 billion shots of lifetime

SHG Conversion Efficiency (~55%)



8 Hour Long Term Energy Stability at 527 nm



Conclusions

- An all diode-pumped 4 Joule 527 nm Nd:YLF laser was demonstrated.
  - smooth flat top beam profile is ideal for pumping Ti:Sapphire lasers
  - Smooth flat top beam profile also helps on reduction the risks of the laser damage and increase the reliability of the laser.
- The laser had overall 21% optical-to-optical efficiency at 1053 nm
- With the benefits inherited from long lifetime high peak power laser diodes as the pumping source, the laser had excellent short-term and long term stability.
- The modular design approach opens the door to affordable, customized diode-pumped high-energy lasers.

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