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ABSTRACT

A large aperture, kJ-class, multi-wavelength Nd-glass laser system has been constructed at Lawrence Livermore National Lab which has unique capabilities for studying a wide variety of optical phenomena. The master-oscillator, power-amplifier (MOPA) configuration of this "Optical Sciences Laser" (OSL) produces 1053 nm radiation with shaped pulse lengths which are variable from 0.1-100 ns. The output can be frequency doubled or tripled with high conversion efficiency with a resultant 100 cm^2 high quality output beam. This facility can accommodate prototype hardware for large-scale inertial confinement fusion lasers allowing for investigation of integrated system issues such as optical lifetime at high fluence, optics contamination, compatibility of non-optical materials, and laser diagnostics.

INTRODUCTION

Laser-induced damage to optical components is a limitation of high-fluence laser systems such as the National Ignition Facility (NIF). Such optical components on NIF range from the absorbing glass that contain stray laser light, to the KDP and DKDP crystals that generate second (2ω) and third (3ω) harmonic light (respectively), to the fused silica lenses that focus the ultraviolet light onto the target. Although much of the concern has centered on the third harmonic UV light, damage due to first and second harmonic light has not been overlooked. While some damage experiments are carried out with small Gaussian laser beams (diameter ~1 mm) by rastering over the sample surface at high repetition rate, NIF conditions are more appropriately simulated by using large-beam lasers that can cover many square millimeters in a single shot of uniform fluence. The OSL facility provides such large-beam capabilities. Recently, the existing Optical Laser Sciences facility[1,2,3,4] has been upgraded[5] to provide the capability of handling large (~ 40-cm) optics in a fully integrated environment. Large aperture and integrated testing capabilities are key to providing adequate statistical data for probability studies.

LASER CHARACTERISTICS AND ARCHITECHTURE

The Optical Sciences Laser facility has been upgraded to produce 1.5 kJ of 1.053 μm radiation. The current OSL system and the OSL Upgrade are both operational and share a common front-end. Performance features of both systems are displayed in Table 1.

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Table 1. Key performance parameters of the Optical Sciences Laser and its Upgrade.

Parameter	OSL	OSL Upgrade
Pulse length	0.1 – 100 ns	0.1 – 100 ns
Pulse shapes	Gaussian, Shaped 0.5-10 ns	Gaussian, Shaped 0.5-10 ns
Beam diameter	3.5 cm	13 cm x 11 cm
Wavelength	1053 or 527 or 351 nm	1053 and 527 and 351 nm
Bandwidth	25 GHz	25 GHz
Maximum Energy 1 mm 0.53 mm 0.35 mm	150 Joules 100 Joules 100 Joules	1500 Joules 1000 Joules 1000 Joules
Vacuum test chamber	12" chamber	24" chamber on 30-ft vessel
Shot Rate	30 min	60 min
0.35 mm Fluence Contrast	< 15 %	< 15 %
Maximum Sample Size	15 x 15 cm^2	45 x 45 cm^2

The key features provided by the Upgrade laser are the large beam size, large sample size, and fully integrated environment. The large beam size and large sample size allow us to test large areas in a reasonable amount of time, essential for adequate statistical studies of optical performance. The fully integrated environment allows for all relevant damage mechanisms to come into play. These include multi-wavelength interactions (when frequency conversion is included), non-linear effects, ghosts, fratricide (whereby damage from one optic can spoil its neighbor), and contamination. An example test cell is shown below in Figure 1.

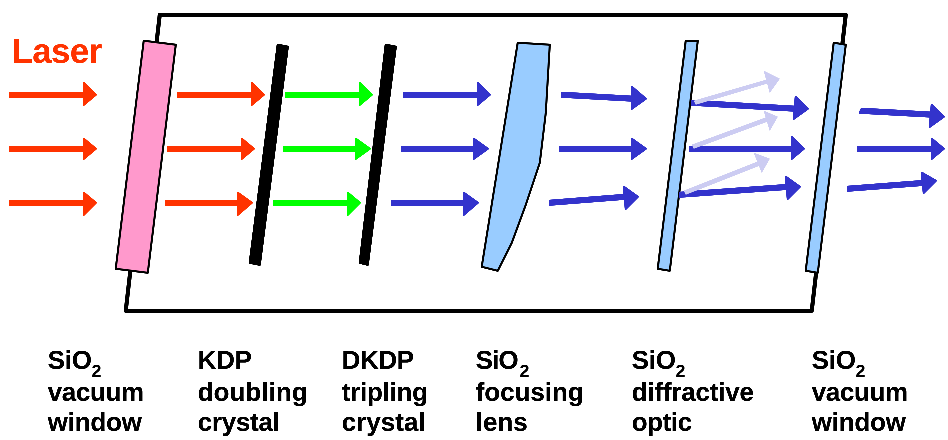

Figure 1. Example test chamber (also referred to as an Integrated Optics Module, or IOM) showing multiple optics subjected to multiple wavelengths for integrated performance testing.

The OSL facility uses a MOPA architecture. The common front-end shared by OSL and the Upgrade is shown in Figure 2a. This front-end is comprised of two Nd:YLF oscillators (one for short pulse-0.1 to 1-ns, and one for long pulse 1 to 100 ns), a pulse shaping system, four 1-cm rod amplifiers, a 2.5-cm rod amplifier, and a 5-cm rod amplifier. A milli-Joule level seed pulse from the master oscillator is temporally shaped and then amplified to the Joule level at the output of the 5-cm rod. This front-end output pulse can then be directed to either the original OSL system or the Upgrade by an insertable mirror. The original OSL system architecture is shown in Figure 2b, and the Upgrade architecture in Figure 2c.

The OSL path double passes a 9.4-cm disk amplifier (6 Brewster-angle disks per amplifier), then single passes another 9.4-cm disk amplifier (6 disks per amplifier) to reach the 100 Joule level before encountering the converting crystals. Both unconverted 1-µm and residual 0.5-µm light are dumped (for 0.35-µm operation) with dichroic mirrors before the beam is spatially filtered and imaged to the test chamber (the beam is imaged relayed from the output of the conversion crystals to the sample plane of the test chamber.

The OSL Upgrade path double-passes four 20.8-cm disk amplifiers (3 Brewster-angle disks per amplifier) before being spatially filtered and directed to the IOM test chamber. At maximum pump energy, the net small signal gain of the system is 900. Currently, the test chamber houses the conversion package that generates the 0.35-µm light.

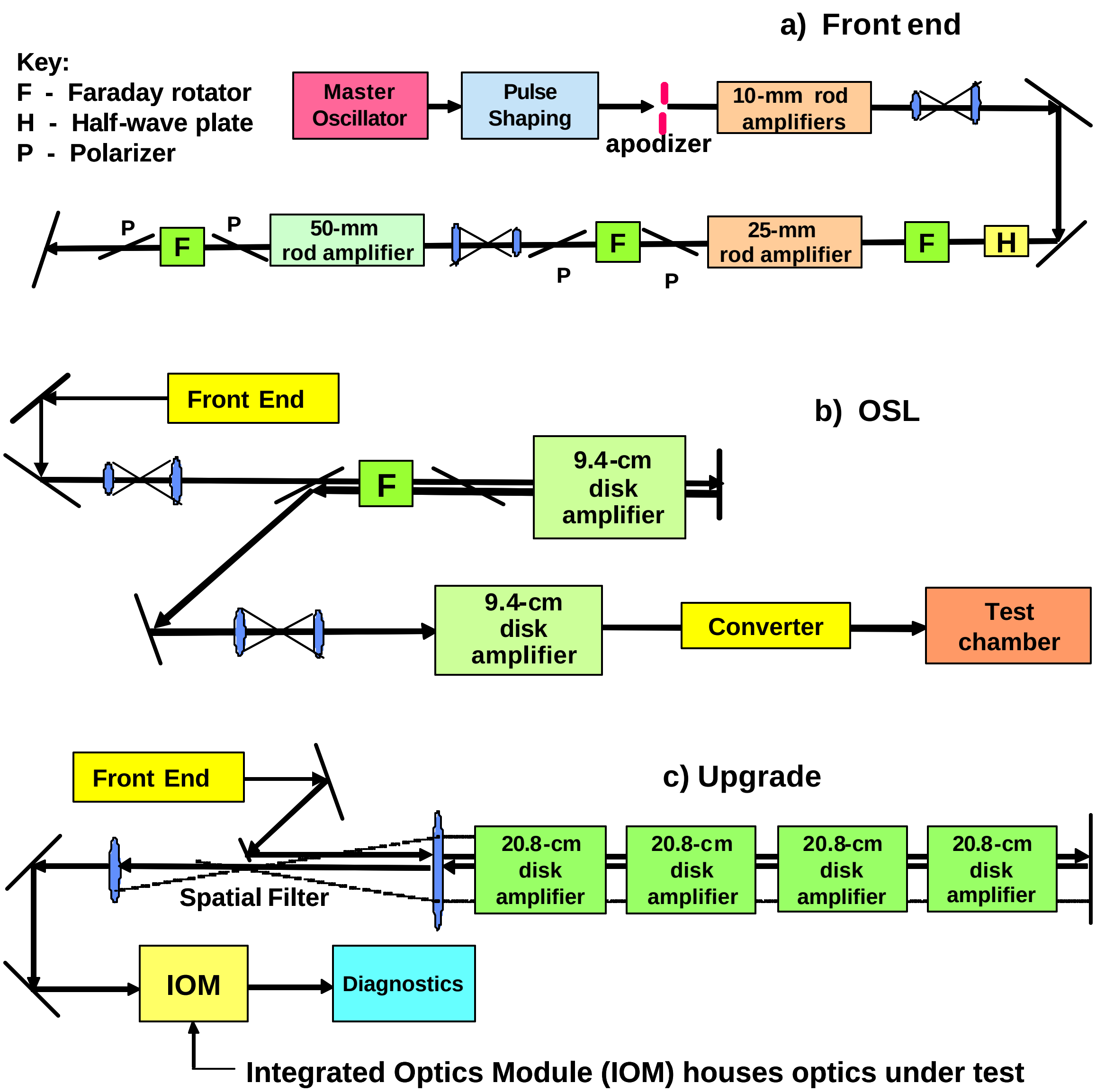

Figure 2. (a) Schematic view of the shared front-end for both OSL (b) and OSL Upgrade (c). A kinematic mirror is used to direct the front end output to either OSL or the Upgrade.

An OSL Upgrade floor-plan is shown in Figure 3. The original OSL laser sits in room to the right in this Figure, while the capacitor bank for both facilities sits in a room to the left in this Figure.

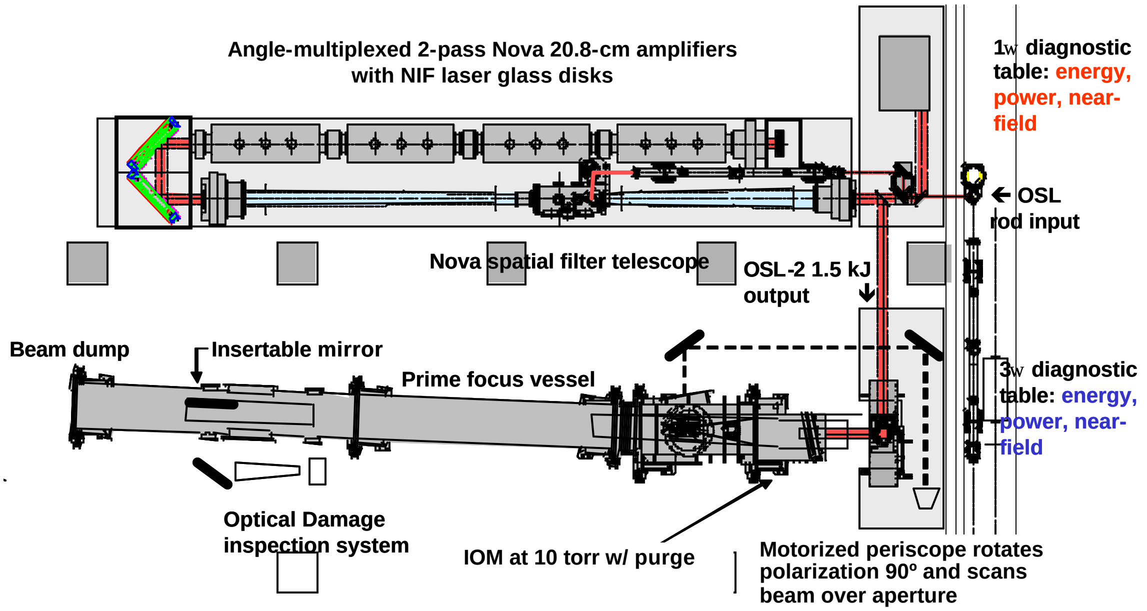

Figure 3. Floor-plan of OSL Upgrade laser.

Since the beam size is much smaller than the typical sample size in each system, the beam needs to be rastered on the sample for maximum coverage. The strategy each system employs is shown in Figure 4. OSL moves the sample relative to the stationary incident laser beam, while OSL Upgrade uses a periscope to move the laser beam relative to the stationary sample(s).

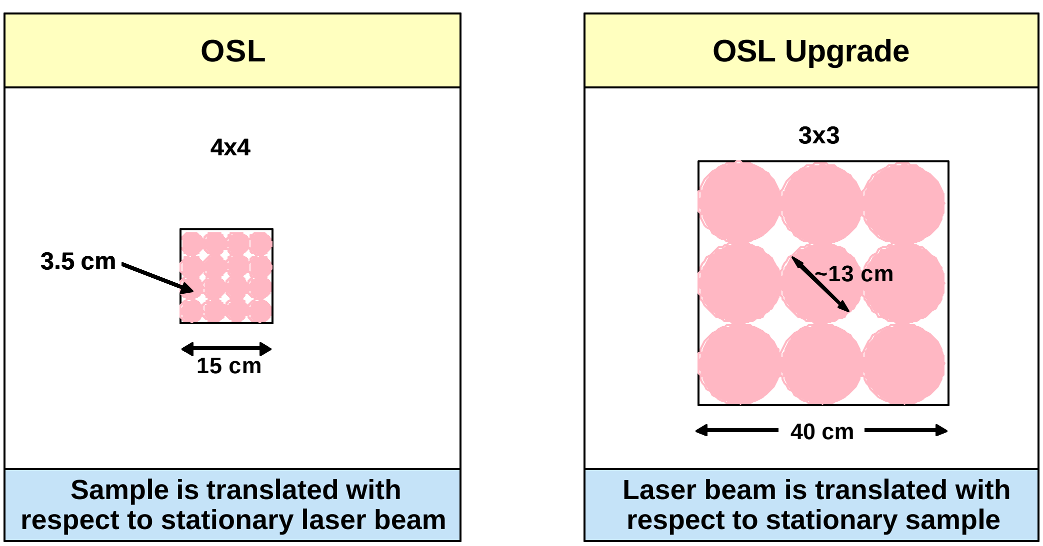

Figure 4. (a) OSL can cover a 15-cm sample with the 3.5-cm beam by moving the sample relative to the beam. (b) OSL Upgrade can cover the 40-cm sample with the ~13-cm beam by moving the beam relative to the sample. Nine sub-apertures are used to cover the full aperture of the optic.

The elliptical shape of the OSL Upgrade beam arises from the double-pass amplifier geometry, see Figure 5. Each 20.8-cm amplifier (from NOVA laser) contains three "octagonal" Nd:glass (4 wt.%) disks with epoxy bonded edge cladding. Pt-free Schott LG 770 laser glass allows 50% more energy and 10% higher gain than the LG 750 used in NOVA. The elliptical shape of the OSL Upgrade beam maximizes the fill of the beam in the amplifiers, thus maximizing the gain.

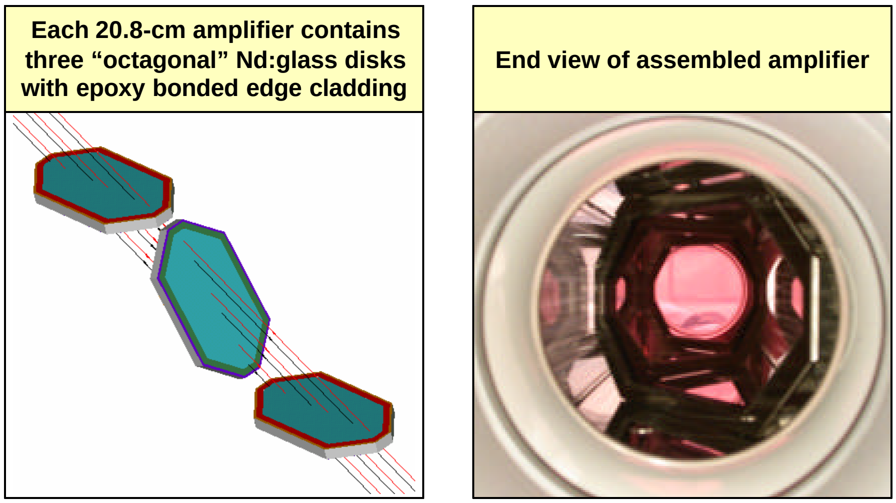

Figure 5. Schott LG 770 laser glass is used in the OSL Upgrade double-pass amplifiers.

DIAGNOSTICS

The OSL and OSL Upgrade are fitted with a full suite of high-resolution diagnostics to monitor 1-µm and 0.35 µm output. NIST-traceable 1-inch calorimeters monitor the energy and fast-photodiodes (60-ps rise time) monitor the temporal pulse shape on each shot (one for each wavelength). A streak camera is also available for higher-resolution temporal data 1-µm. Near-field images are recorded on each shot with scientific-grade CCD cameras (175-µm/pixel resolution for 1-µm and 570-µm/pixel resolution for 0.35-µm). The far-field is currently only monitored for pre-shot alignment. The 1-µm diagnostic in the OSL Upgrade takes light from a leaky mirror after emerging from the spatial filter, while the 0.35 µm diagnostic is fed by a 40-cm $Si0_2$ beam splitter located beyond the tripling crystal and focusing lens (see Figure 3). Optical damage in this splitter limits the use fluence (at the location of the test optics) to about 4 J/cm^2 at 0.35 µm, 3-ns. For fluences greater than 4 J/cm^2, a different set of 0.35-µm energy, power, and near-field diagnostics (lower resolution) are fed by a diffractive optic placed in the beam beyond the focusing lens which samples a small portion of the main 0.35-µm output.

The test optics in the IOM are also monitored for damage after each shot. This is accomplished using a Schlieren imaging system called ODI, for Optical Damage Inspection, shown schematically in Figure 6. Each sub-aperture is illuminated with collimated CW 1-µm light, which is then focused by the lens in the test chamber. A dark stop (Schlieren ball) is located at the focus to block un-scattered light. Scattered light from damage, scratches or other defects can bypass the dark stop and make its way into a collection lens (Nikon 600-mm f/4) and onto a scientific-grade CCD camera. By changing the z-location of the CCD relative to the collection lens, each optic in the test chamber can be imaged (and thus inspected for damage). By changing the x-y location of the CCD camera, each sub-aperture within each optic can be imaged. The onset of damage in determined by comparing ODI images taken before and after a shot and looking for an increase in scattered intensity. Spatial resolution of our system has been measured to be

165 µm/pixel using a calibrated grid at the 1-µm input plane, which agrees well with the calculated value of 166 µm/pixel (de-magnification = 12.3, CCD pixel spacing = 13.5 µm).

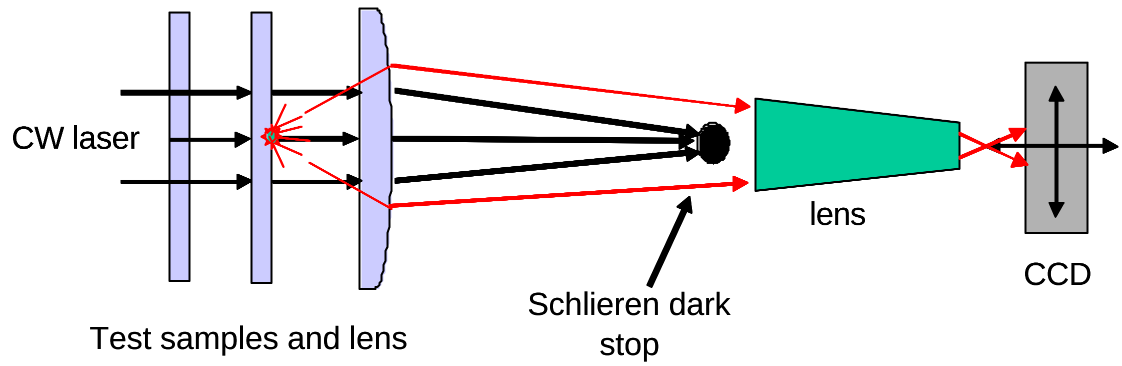

Figure 6. Schematic of Schlieren imaging system. High-frequency scattered light (due to damage or other defects) is imaged at the CCD. Different test samples are imaged by moving the CCD in the z-direction, while different sub-apertures are accessed by moving the CCD in the x-y direction.

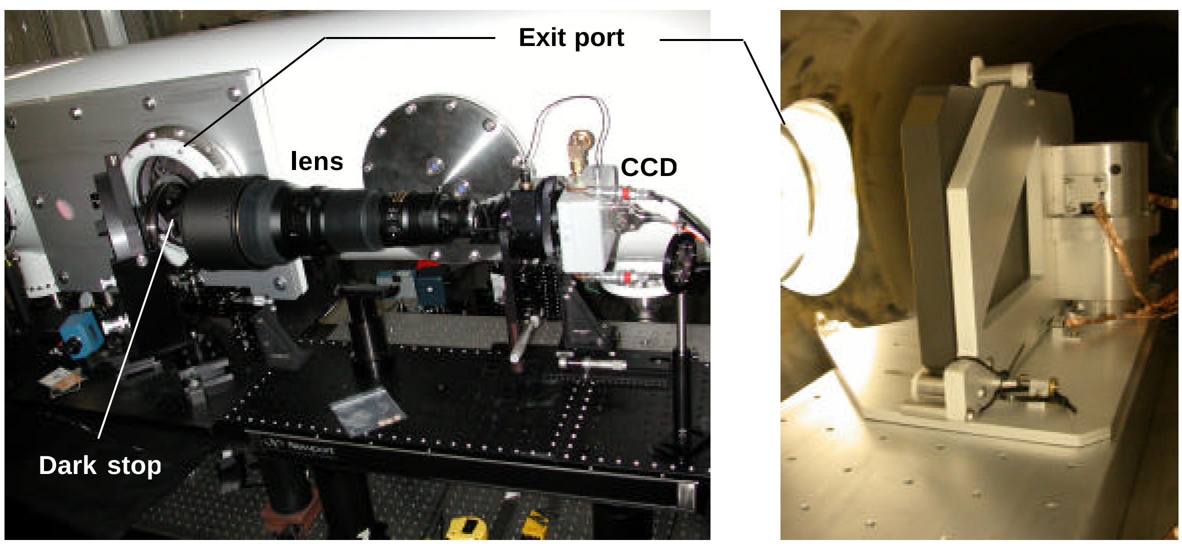

Figure 7. The Optic Damage Inspection system on the OSL Upgrade (left) is fed by an insertable mirror located inside the prime focus vessel (right).

1-MICRON LASER OUTPUT PERFORMANCE

To date, over 500 shots have been fired on the OSL Upgrade with reliable, high-performance output. Figure 8 shows 1-µm gain data plotted with a Franz-Nodvik model prediction. 1-µm near-field performance is shown in Figure 9, along with analysis showing 1-µm beam contrast is less 10%. 0.35-µm contrast is typically below 15%. Here, contrast is defined as the standard deviation of the fluence inside a patch encompassing the majority of the beam (shown), divided by the average fluence in the same patch.

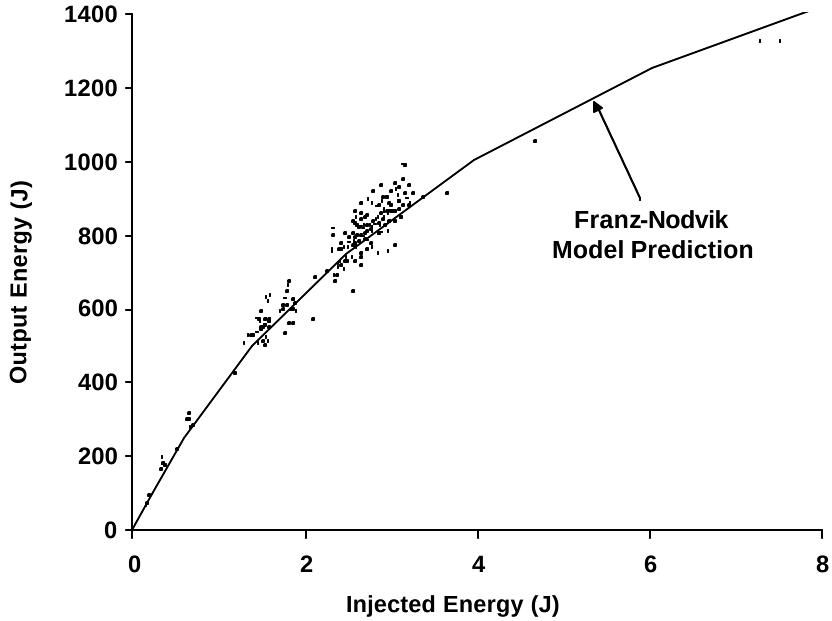

Figure 8. Gain data and model prediction for 1-μm output of the OSL Upgrade.

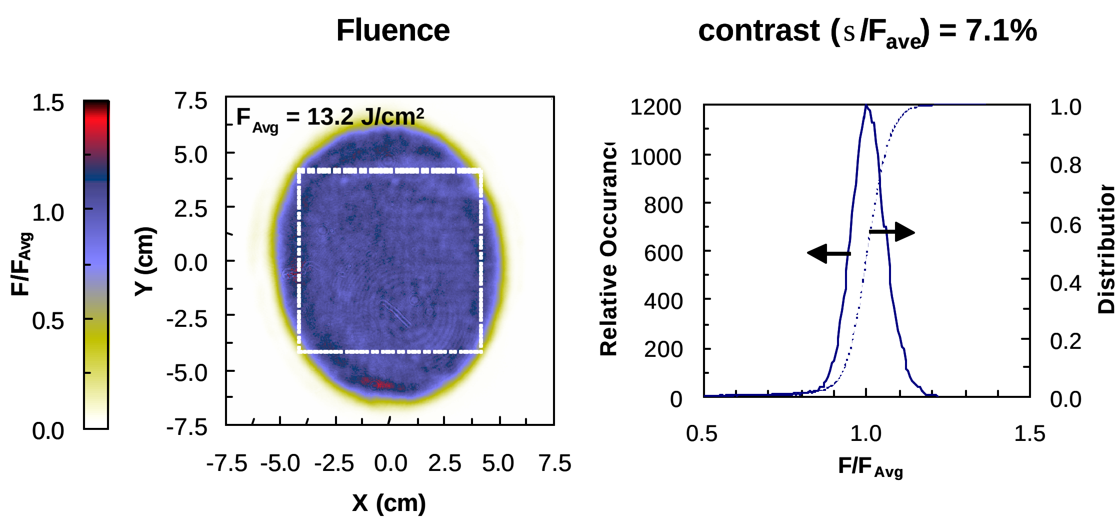

Figure 9. OSL Upgrade 1-μm output typically has a contrast of less than 10%. The contrast (right) was calculated for the square patch of fluence data, shown at left.

CONCLUSIONS

The Optical Sciences Laser Upgrade allow for high-fluence, large aperture testing of optical components in a fully integrated environment. This laser presents unprecedented capabilities for a laser devoted to optical performance testing, including shaped pulse lengths which are variable from 0.1-100 ns. A full suite of energy, power, and near-field diagnostics, as well as over 500 shots of reliable, high-quality output make this an invaluable tool in optical performance testing of optic and optical performance.

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