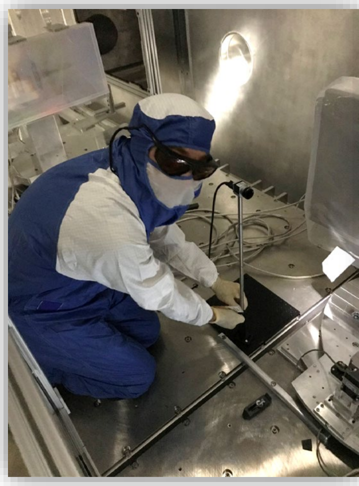
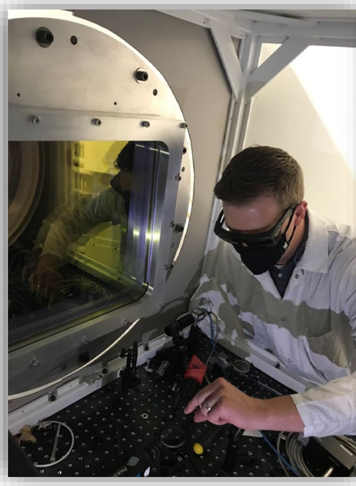
Sandia National Laboratories

Z-Petawatt Laser Highlights for FY21

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Overview

We're happy to report that the full-aperture upgrade project, started in FY18, is now complete and short-pulse target experiments are underway. The table below lists the present performance level of ZPW. Additional laser improvements are in progress to increase the laser energy and pulse contrast along with implementing a correction for achromatic aberrations to reduce the focused spot size and pulse width.

Highlights over the past 18 months

- Compressor alignment complete: June 2020
- Contamination mitigation installed in compressor chamber: Aug. 2020
- Off-axis parabola alignment complete: Aug. 2020
- Full system shots begin: Sept. 2020
- Target shots begin in Chama chamber: Oct. 2020
- Phase-I contrast improvements complete: May 2021

	ZPW 2021 Operational Data
Energy (J)	285
Pulse Length (ps)	2
OAP f/# (edge)	6
Focal Spot FWHM (μm)	15
Focal Intensity (W/cm^2)	2x10^{19}
Shot Rate (shots/day)	2

FY22 Plans

- Increase laser energy to 350 J: Q2/FY22
- Complete Phase-II contrast enhancement: Q3/FY22
- Install achromatic corrector optics: Q4/FY22
- Commission gas jet and cryogenic target systems in Chama: Q4/FY22

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Laser Commissioning

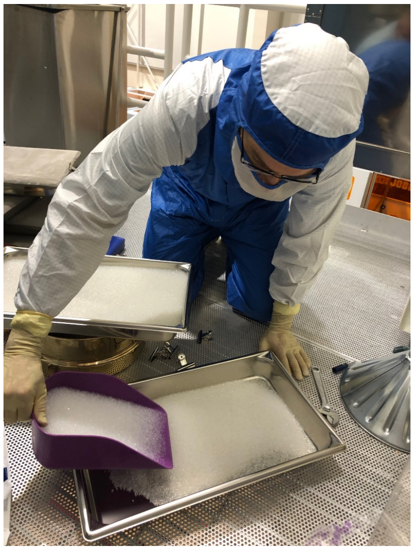

Fig. 1: Silica gel tray preparation

Since the last update report in March 2020, the full aperture compressor hardware was installed and aligned. A contamination mitigation system was implemented, similar to the system at ILE Osaka, using 50 kg of baked silica gel as a getter of hydrocarbon contaminants. The photo at left shows one of the 18 silica gel trays that are placed inside our compressor vessel.

A 400 fs pulsewidth was measured with our FROG diagnostic inside the compressor using a reduced-aperture beam to avoid the temporal broadening caused by chromatic aberrations from the meter-scale beam transport optics. The pulsewidth from the full-aperture beam is approximately 2 ps at present due to these chromatic aberrations and associated radial group delay issues. To address these, an achromatic pre-corrector was initially designed by Erhard Gaul and Sandi Bruce in Austin, Texas. The device allows us to achieve both a sub-ps pulsewidth and a smaller focal spot size with the full aperture beam, with the combination allowing nearly an order of magnitude improvement to peak intensity. Optics procurements are underway and we expect the system to be fully commissioned by the end of CY 2022.

The new off-axis parabola was also installed and aligned to the Chama target chamber over the past year. In addition to diagnosing the pre-shot Chama focal spot, a full suite of on-shot beam diagnostics has been implemented which includes near-field and far-field images, photodiode detectors to measure ns-scale contrast, wavefront sensor images, and a full-beam calorimeter energy measurement.

Ultimately, better diagnostics and continuous improvements will allow us to reach our laser system design goals of up to 420 J in 500 fs at the shortest duration and 1.2 kJ in >10 ps at the highest energy. The mentioned improvements to address chromatic aberration in conjunction with adaptive optics should allow us to reach the diffraction-limited spatial performance of 7 μm spot size. Together these will allow intensities of up to 10^{21} W/cm^2.

Contrast Improvements

Improving laser pulse contrast by an additional 2 orders of magnitude is a high priority with a goal of achieving a level of 10^{-9} – 10^{-10} over the next 18 months. We now have a Tundra cross-correlator with a 4ns scan range to improve our contrast measurements and an auxiliary front-end compressor to help identify issues causing contrast degradation.

Using the new Tundra and front-end compressor, we've been able to make rapid progress in tracking down and eliminating a large number of optical prepulses, mostly in the range of 0.25 to 1 ns before the main laser pulse. The main source of our prepulses were reflections from damaged optics and the oversight of using unwedged OPCPA crystals in the front end. The Tundra plot in Fig. 2 shows the present contrast level with nominally 4 prepulse groups still remaining. Further optimization will occur when Tundra scans are performed after the full-aperture compressor at the end of the laser chain.

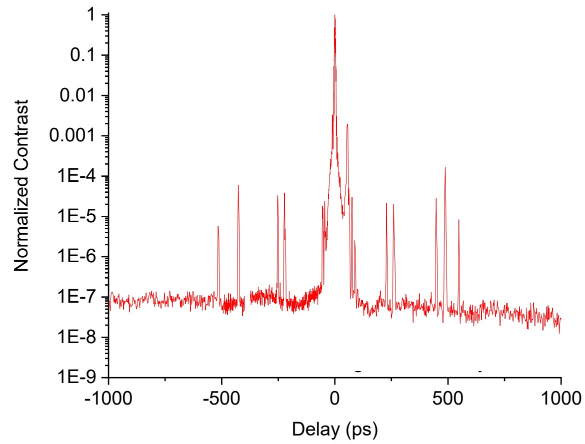

Fig. 2: Contrast measurements with OPCPA output into an auxiliary compressor

Another noteworthy achievement towards higher contrast is the successful testing of a new two-stage design modification of our picosecond-scale optical parametric amplifier (ps-OPA). The approach uses residual pump light from the 1st stage to combine with either 1st stage signal or idler output in the 2nd stage crystal. This dual stage approach offers two modes of operation denoted as the signal² and idler² modes, depending on whether the signal light at 1054nm is boosted as more signal from the 2nd crystal or whether idler from the 1st crystal interacts at the 2nd crystal to generate another idler at 1054nm along the input beam. With blocking of the 1st stage signal, the idler² mode eliminates all residual seed light along the output beam. As such, it offers significant contrast performance improvements, with preliminary measurements on a prototype system showing a contrast of $2x10^{-10}$ at -500 ps compared to $2x10^{-9}$ for the signal² operation mode. We will be incorporating this into the ZPW front end over the coming year and expect it to improve our contrast between 2-4 orders of magnitude from previously achievable levels.

Experimental Campaigns

We've resumed short-pulse laser experiments in the new Chama target chamber. The Chama chamber also has the capability for simultaneously using the multi-kJ ns-timescale ZBL laser and the Chaco laser with 2ω energies up to 40 J on a ns timescale. The photo in Fig. 3 shows the Chama chamber in the background with Sandia scientists and visiting researchers Joseph Strehlow and Mathieu Bailly-Grandvaux from UCSD's Center for Matter under Extreme Conditions (CMEC) and Center for Energy Research (CER).

A total of 40 ZPW target shots were completed in FY21. About 1/3 of calendar time is available for ZPW experiments throughout the year. The majority of staff and facility time are allocated to other commitments to support Z experiments, configuration and testing applications of the laser in long-pulse uncompressed mode, and continued laser improvements and maintenance.

The initial ZPW experimental campaigns studied particle acceleration to benchmark on-target intensity, 17-21 keV x-ray source optimization for x-ray diffraction, 17 keV x-ray radiography source development, and plasma mirror performance for a lab-directed research and development (LDRD) project on Laser Wakefield Acceleration. We measured a maximum accelerated proton energy of 40 MeV consistent with an on-target laser intensity of 10^{19} W/cm^2 and an x-ray conversion efficiency of 2×10^{-4} for 17 keV x-rays, which is near the expected maximum achievable from published results in the literature. We also obtained some initial radiograph images at 17 keV with an exposure level that should be scalable to Z experiments in the future.

Experimental infrastructure will continue to develop at Chama. Gas jet and cryogenic target capabilities are expected to be added in FY22. Probe beam improvements allowing low-jitter sub-ps duration pulses are also expected.

Fig. 3: September 2021 solid target experiments team (L to R): Quinn Looker, Patrick Rambo, Matthias Geissel, Mathieu Bailly-Grandvaux (UCSD), Joseph Strehlow (UCSD), and Benjamin Galloway.