Observations on the use of large scale laser facilities

Presented by:

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Outline

I. Overview of the laser facilities we use with some example science
   
   A) Z-Beamlet - Sandia National Lab
      1) Spallation of shocked metals
      2) Radiative blast waves
   
   B) Titan laser - Lawrence Livermore National Lab
      1) Isochoric heating with MeV protons
   
   C) Janus laser - Lawrence Livermore National Lab
      1) Optical and x-ray diagnosis of shocked materials

II. Salient aspects of performing experiments on large scale lasers

III. Important factors for successful use of large scale laser facilities

IV. Differences between large laser- and synchrotron-type experiments
We have performed a campaign of experiments on Z-Beamlet at Sandia to examine issues of spall in Al.

Z-Beamlet is a Nd:Glass laser with a multi-pass amplifier design.
Energy: 1.2 kJ at 527 nm
Pulse Length: 1-1.8 ns
Beam Profile: Square and Top-Hat without phase plate
Spot Size for Experiments: 2 mm-10 mm

VISAR probe beam:
532 nm, 8 ns FWHM, ~5 mJ

A phase plate has recently been added to produce more beam homogeneity.
We have constructed a target probing area for blast wave research on the Z-Beamlet laser at Sandia.

Overview schematic of Z-Beamlet laser

The main beam can be diverted to a local target area when not firing on Z.

Z-Beamlet can fire >1000J of 2\textsuperscript{nd} harmonic light in a 1ns pulse on target

Main 4-Pass Amplifiers
Z-Beamlet and Z-Petawatt are closely linked with the Z-machine at Sandia
Z-Beamlet and Z-Petawatt now have a devoted target area bay

- Stand alone long pulse target chamber
- Petawatt vacuum compressor chamber
- Walk in chamber for combined Petawatt/Z-Beamlet experiments
- Shielding wall
- Compact x-pinch
- 2 kJ long pulse beam line
- 0.5 kJ Petawatt beam line
- 10 TW high intensity probe laser
- Pulsed power supply for magnetic field generation
Laser driven shocks offer a unique method to study 1D high strain rate material failure.

200-500 μm Aluminum foil

ZBL Pump beam

Ablation

Shock Wave

Rarefaction wave from reflection of shock from back surface

Rarefaction wave from decrease of drive pulse

Spall

We collect shot targets to determine the material fracture morphology.
We have performed materials analysis of spalled Al targets on the Sandia Z-Beamlet laser.

Picture of the spalled area of an AL target shocked by the square Z-Beamlet beam.

SEM image of the spalled surface of a high-purity annealed aluminum target.

The dimpling is indicative of ductile fracture.

SEM image of the spalled surface of a Al+ 3% Mg target that has been slightly cold-worked.

The sharp edges and score marks indicate that the fracture is less ductile.
Laboratory study of radiative blast waves can have an impact on astrophysical models

Radiative blast waves are very important in many astrophysical phenomena.

15,000 years ago, the explosion of a supernova created...

Radiative shocks in the Cygnus Loop

In 2D, radiative shocks lead to thin shell instabilities

Astro models (Blondin et al.)

In experiments, shock waves are produced on the LLNL Janus and Sandia Z-Beamlet lasers.

Shock wave data taken by UT/LLNL collaboration on the LLNL Janus laser.

Observation

Laser pulse in

Blast wave

Shock wave in N₂ passing over a pin

Shot 37: 300ns
We study the laser generated blast wave with two, simultaneous optical probes.

**Optical layout on the Z-Beamlet laser**

- 1 kJ, 1 ns @ 527 nm
- Focusing lens
- Chamber backfilled with 5-10 torr gas
- Dark Field Imaging leg
- Mach Zender Beam Leg
- Mach Zender recombinatic
- Periscope

**Conceptual layout of the experiment**

- Blast Wave
- Pin Target
- 10-1000 J, ~1 ns Drive Beam
- Beam Block
- Temporally delayed probe beam
- Plasma with electron density gradients
- Imaging telescope

Schlieren Imaging

*Only light which is deflected will make it through.*
We have used the Z-Beamlet laser at Sandia to study the hydrodynamic perturbations on a radiative shock.

1 kJ, 527 nm pulse from Z-Beamlet

Exploding shock in nitrogen gas with induced perturbations

Radiative precursor

Increasing time

Shot 36: 150ns, 4mm Spacing

Shot 37: 300ns

Shot 38: 600ns

$A/r \sim t^{-0.9}$

$0.020$

$0.010$

$0.010$

$0.000$

$0.000$

$200$ $300$ $400$ $500$ $600$ $700$

Time (ns)
Titan is a multi-hundred terawatt laser in LLNL Jupiter laser complex.

West beam line
~ 500 J short pulse

New vacuum grating compressor

Existing Janus long-pulse TC

Existing Janus laser bay

Titan Target Chamber

Switchyard mirrors

New CPA front-end

East beam line
~ 1 kJ long pulse

Short pulse beam: 300 J in 500 fs
Long pulse beam: 1 kJ in 3ns at 527 nm
The Titan Laser at LLNL will be used for HED science and fast ignition R&D preparing for larger scale experiments at Omega EP and NIF.

Compressor & Optics Installation

World's largest MLD gratings

New multi-beam target chamber

Janus intense short pulse (JISP) - Titan
Two beams 350J, 1 ps, 1kJ, 1 ns
Titan has installed a very large, multi-use target chamber.
A short pulse laser can isochorically heat materials to high temperature and pressure.

Short laser pulse or burst of particles heats material

Heated Sample
Near solid density

Measure temperature from blackbody radiation

Measure reflectivity and expansion

Short pulse of optical or x-ray radiation
- interrogates the heated material before it can expand (<100 fs)

Time resolved emission

Aluminum ρ - T diagram

Target expands

\[ \sim \frac{d}{c_s} \]

\[ \sim 1 \mu m / 5 \times 10^6 \text{ cm/s} \]
(for 100 eV Al)

\[ \sim 20 \text{ ps} \]
We have implemented this proton heating EOS experiment on the LLNL Titan laser.

Titan laser pulse: 100J, 600fs

I ~3e20 W/cm²

MeV proton isochoric heating

Streaked optical pyrometry

Chirped-pulse interferometry

Proton spectrometer

Source: 17µm Al

Sample: 2µm Al

Partialy chirped probe pulse reflected

• Single shot time resolved thermal measurement (SOP)
• Single shot time-resolved expansion measurement (CPI)

Titan target design

Source foil pulled across window
gap etched from Si wafer
sample vapor-deposited on 50 nm SiN₃
The time history of the temperature and expansion of the heated Al slab was measured on every shot.

**SOP: Time-resolved temperature**

- Peak temperature \( \sim 25 \text{ eV} \)
- Optical transition radiation signal at \( t_0 \)

**CPI: Time-resolved expansion**

- Fourier analysis of bending fringes → phase shift → expansion in time
We have used the Janus laser at LLNL for various shock physics experiments.

The 300 J Janus is used for plasma and shock physics experiments and as a pump for JanUSP.

**Capabilities**

- **Wavelength**: 1064 nm, 532 nm, 366
- **2 beams**: 300 J (10)
- **Probe beam**: Visar, interferometer
- **Pulse width**: 100 ps to ~6 ns
- **Spot size**: 17 μm
- **Rep Rate**: 3/hr
- **2 target chamb.**: Beam smooth (FY 99)
  - 1000 J per beam
We have implemented an optical scattering diagnostic on shocked materials experiments at Janus.

With time, light scatters into streak-camera objective!
We have performed experiments devoted to dynamic x-ray diffraction of laser shocked Fe and Bi on Janus.

- Single crystal samples are shock-compressed when irradiated by laser with typical parameters: pulsewidth~1ns, energy~200J, spot diameter~3mm, yielding intensity~$10^{12}$ W/cm$^2$.
- The dynamics of the shock-compression are investigated using DXRD in Bragg (and Laue) configuration and VISAR.
We have developed a novel x-ray diffraction geometry at Janus
Salient aspects of working on large scale high energy laser facilities:

0) Early use of the facility (first 6 months) is extremely challenging for experimentalists

1) Laser time usually allocated in 2 - 4 week slots

2) Laser facility team is responsible for diagnosing the performance of the laser

3) Data is single shot (with 3 - 10 shots per day)

4) Experiments are often performed by a modest-sized team, fielding multiple diagnostics

5) The target chamber is generic and not designed for any specific experiment

6) Principal diagnostics are often developed off line at the home institution (eg the UT line VISAR at Z-Beamlet)
We have developed a velocity interferometer (VISAR) on the 1 kJ Z-Beamlet laser at Sandia to study shock induced melting in Aluminum at pressure up to 2 Mbar.

Low pressure shock in Al (~ 800 kbar)

High pressure shock in Al (~ 1.5 Mbar)
Factors important for success on high energy laser facilities:

1) A target area technical team is available for interface with the experimentalists

2) The target chamber is large and can accommodate various diagnostics

3) Small scale lasers for diagnostic development are available at the home institution

4) Students adequately prepare for shots (at low rep rate) so that none are lost

5) Shot schedule includes up to 1 week of set up and 2 to 4 weeks of shots
Facility use of Z-Beamlet and Z-Petawatt has been determined by a self-organized user group

1) Southwest Laser Consortium formed in 2005
   - Sandia National Lab
   - University of Texas
   - UC San Diego
   - General Atomics
   - Ohio State University
   - MOU and governance plan presented and approved by Sandia management in 2006

2) Sandia allocates 25% of shot time to Consortium
   - 1 x 3 week run each quarter on Z-BL and Z-PW

3) Consortium members allocate shot time among members at a semi-annual meeting

4) Facility management holds a readiness review with the shot team roughly 1 month prior to shot time.

5) NNSA has implemented a shot time peer reviewed system for Z-BL and Z-PW in FY08
Access to Titan and Janus has recently become more formal

1) For FY09 LLNL implemented a Jupiter Laser Facility Use Program

2) 70% time allocated to programmatic research; 30% allocated to basic science

3) On April 30 2008, proposals for FY09 use were due ≤ 5 p. proposal submitted to LLNL

4) Proposals are reviewed by a committee of internal LLNL scientists representing the various programs
   - Laser time allocated in 2 to 3 week slots.
   - Each proposal could receive one or more shot slots in FY09 depending upon programmatic need

5) As in the past, readiness reviews will be held
There are some clear contrasts between experiments at a large laser facility and at a large light source facility.

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<thead>
<tr>
<th><strong>High Energy Laser</strong></th>
<th><strong>Synchrotron light source</strong></th>
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<tbody>
<tr>
<td>Rep rate is very low</td>
<td>Source is essentially continuous</td>
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<td>Single experimental team on the machine at any one time</td>
<td>Numerous users conducting experiments at the same time</td>
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<td>Experiment chamber is large and suited for multiple uses</td>
<td>Experiment chambers tend to be customized for a specific experiment</td>
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<tr>
<td>Targets are single use and often expensive per shot</td>
<td>Targets are continuous use or easily replenishable</td>
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<tr>
<td>Multiple diagnostics (including “ride-alongs”) are common</td>
<td>One, well focused, diagnostic is common</td>
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