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LASEM-420 System Operating Manual

by Catherine A. M. Dillier and Jennifer L. Gottfried

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DEVCOM Army Research Laboratory

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14. ABSTRACT
LASEM (laser-induced air shock from energetic materials) is a microscale method for prescreening energetic material performance. This instruction manual is intended as a user guide for operating and troubleshooting the LASEM-420 system. It briefly describes sample preparation, the various hardware components, operating instructions, helpful tips and tricks for troubleshooting issues, as well as considerations for designing a new or upgrading the current LASEM system. As new equipment is added and additional troubleshooting wisdom arises, this manual will be updated.

15. SUBJECT TERMS
laser-induced air shock from energetic materials, LASEM, LASEM-420 system, diagnostics, Weapons Sciences

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Contents

List of Figures

1. Introduction

LASEM (laser-induced air shock from energetic materials) is a microscale experimental technique developed at the U.S. Army Combat Capabilities Development Command Army Research Laboratory to rapidly prescreen the explosive performance of novel energetic materials.[1] This method uses hundreds of micrograms of material per test compared to the tens of grams of material conventional testing requires and incorporates a variety of time-resolved diagnostics to evaluate and understand the chemical reactions taking place. The LASEM-420 system is a higher time-resolution modification of the original LASEM-84 system[2,3]—where the numerals refer to the frame rate of the high-speed camera used to image the laser-induced shock waves in thousands of frames per second (kfps), either 420 or 84 kfps. The operating mode can be switched between the LASEM-84 and LASEM-420 settings by selecting the appropriate camera configuration (i.e., saved resolution and frame rate settings). As currently configured, the LASEM-420 system also includes additional diagnostic equipment not incorporated in the original LASEM-84 setup, as shown in Figures 1 and 2. This report provides operating instructions for the LASEM-420 setup, including details on sample preparation, the start-up and shutdown sequences, directions for running a test and saving data, data collection tips, helpful hints for troubleshooting and calibrating diagnostics, and considerations for building a new or upgrading the current LASEM system.

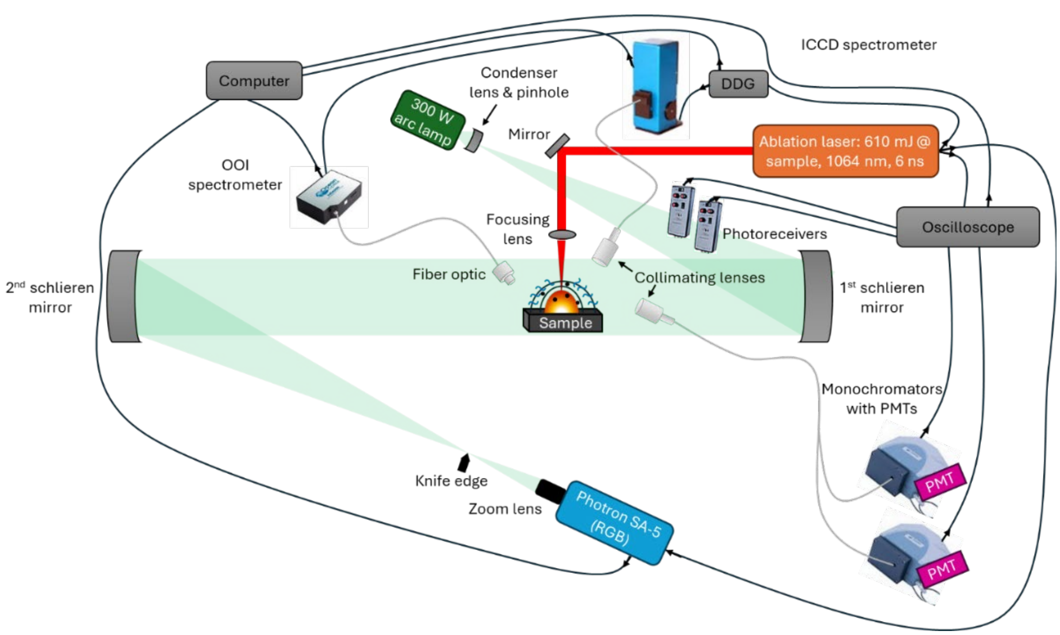

Figure 1. Schematic of the LASEM-420 setup.

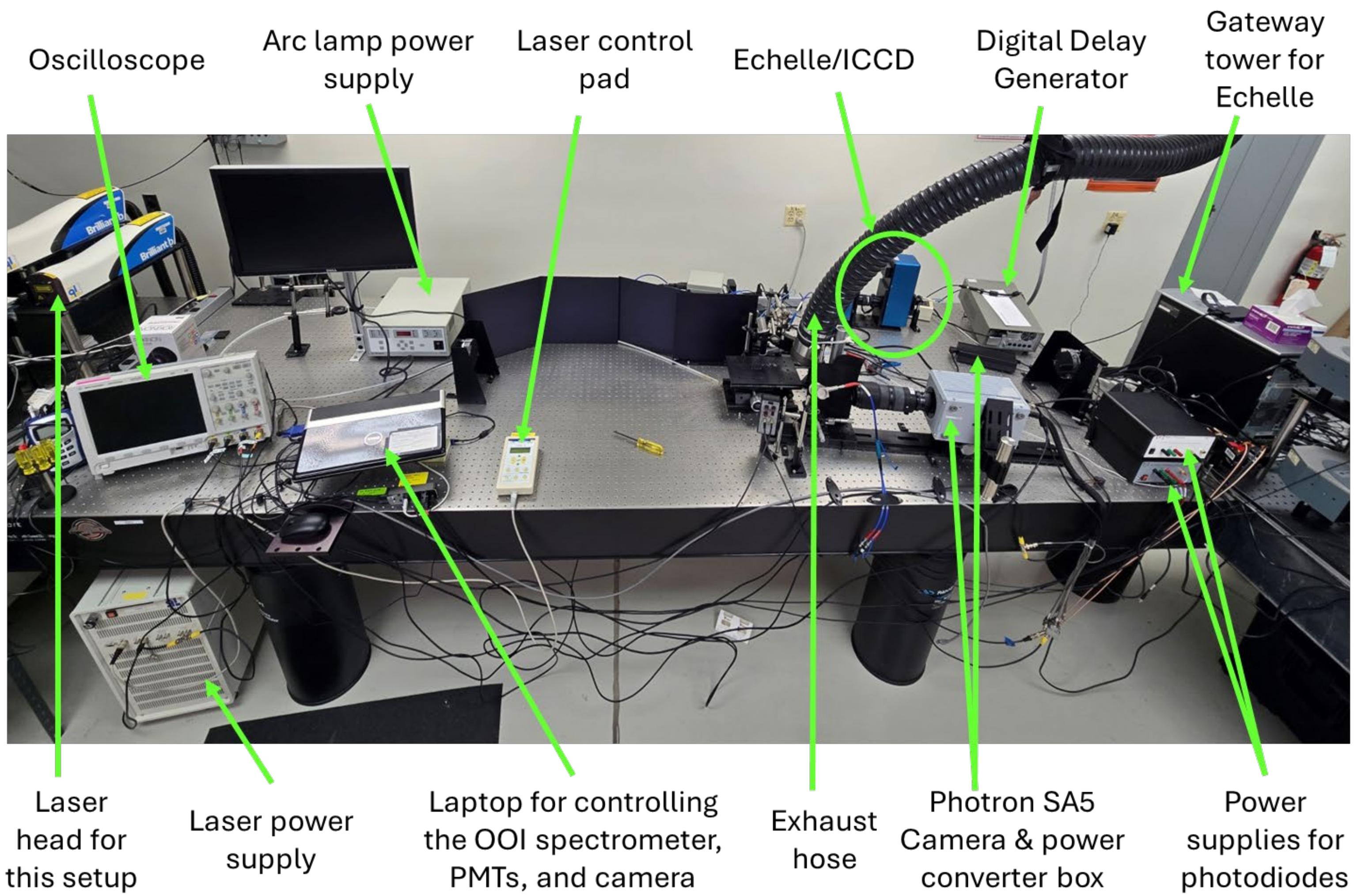

Figure 2. LASEM-420 setup with key diagnostics and hardware pointed out.

2. Sample Preparation

- Use a spatula to firmly and evenly spread and press approximately 10 mg of the powdered sample onto double-sided tape affixed to a glass microscope slide (75 × 25 mm).
  - Start with a small pile of material on one end of the tape and then spread it across. As you spread the material, press it firmly into the tape to avoid any air bubbles.
  - Completely cover the tape with material and gently scrape or tap off any excess material. See Figure 3 for an example.

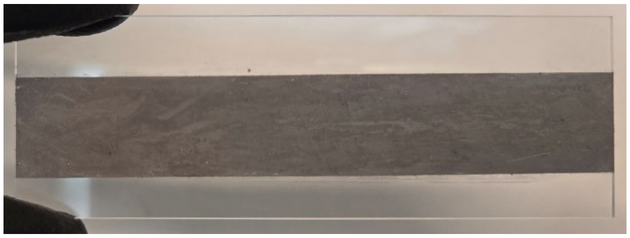

Figure 3. Example of proper sample preparation where the material has been evenly spread across the tape and the excess material been removed without leaving streak marks.

  - Verify that the tape is completely covered and there are no obvious streaks. If all or part of the focused laser pulse contacts bare tape it will be ablated into the laser-induced plasma and contribute to the plasma dynamics and spectroscopic signal (Figures 4 and 5).

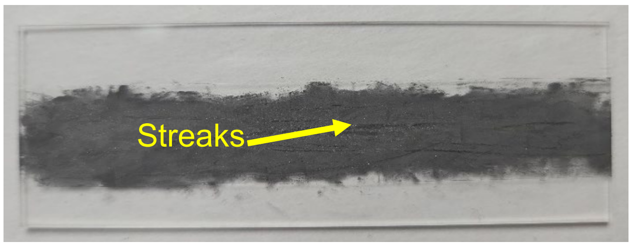

Figure 4. Example sample preparation where the slide has not been completely covered and there are streak marks, indicating uneven material coverage.

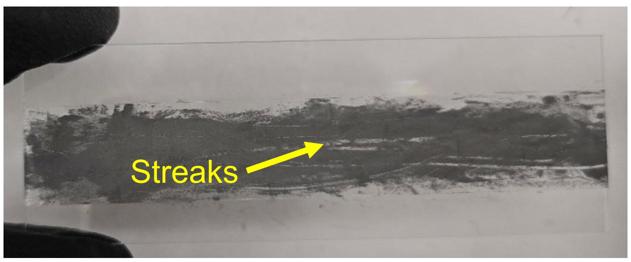

Figure 5. The same slide from Figure 4 but held up to the light to more clearly show the uneven coverage and streak marks where the material has been accidentally scraped off.

- For highly combustible materials where one shot can ignite part or all of the material on the slide, use multiple slides and spread small spots of material across slides instead of covering the entire tape. An aiming device such as a visible laser pointer may be necessary to ensure that only the prepared sample is hit by the laser (Figure 6).

Figure 6. Example slide with material spread in small spots rather than covering the entire slide.

3. Brief Description of Hardware

Sections 3–7, 9, and 10 apply to the 2025 ARL LASEM-420 System. Some of the hardware may be similar for other LASEM systems and the alignment tips might be helpful; however, the detailed instructions on running the system and diagnostics are specific to the 2025 ARL LASEM-420 System. Operating instructions and guidelines will vary for other LASEM systems.

- Sample Stage
    - Purpose: adjustable vertical stage to set the sample microscope slide on. The sample stage height is set to 4.8125 inches to ensure the laser breakdown in air occurs just below the sample surface (as currently aligned).
- Laser
    - Purpose:
        - Ablate, ionize, and excite material (forming a laser-induced plasma)
    - Program/controller:
        - Use control pad to set lamp voltage, q-switch delay, enable flashlamps, and fire
- Dell Laptop
    - Purpose:
        - Control the Ocean Optics spectrometer, high-speed camera, and photomultiplier tubes (PMTs)—and to save all video and diagnostic data except the Echelle (including pulling data off the oscilloscope)
- Digital delay generator (DDG)

- Purpose:
    - Set the gate width and delay for the Echelle and Ocean Optics spectrometers
  - Program/controller:
    - Triggered off the laser pulse (external Q-switch signal from the laser power supply)
- Oscilloscope
  - Purpose:
    - Capture data from PMTs and photodiodes
  - Program/controller:
    - Triggered off the laser pulse
  - Use "RunIntuiLink Data Capture" on laptop to pull and save data from oscilloscope
- Gateway Tower
  - Purpose:
    - Operate KestralSpec 5.18 for the Echelle
- Arc lamp
  - Purpose:
    - Light source for schlieren imaging
    - Power supply used to set the wattage (brightness)
- Photron SA5 camera
  - Purpose:
    - High-speed videos
  - Program/controller:
    - Triggered off the laser pulse
    - Use PFV4 software on laptop to control camera settings
      - IP address: 192.168.0.12
      - Subnet: 255.255.255.0
- Echelle/intensified charge-coupled device (ICCD)
  - Purpose:
    - Measure gated, spectrally resolved emission produced from reactions taking place during the laser-induced plasma or subsequent post-plasma combustion reactions
  - Program/controller:
    - Triggered using DDG
    - DDG also used to set the gate width (integration time) and delay
    - Intensifier controller used to set the gain
- PMTs and monochromators
  - Purpose:

        - Measure early time (microsecond timescale), time-resolved emission at specific wavelengths
            - Currently set to 486 and 656 nm to look at AlO (or H_{β}) and H_{α} (or background) emissions, respectively
    - Program/controller:
        - Use PMT2100 software on laptop to set gain and turn on
        - Oscilloscope used to record data
- Ocean Optics USB4000 (OOI Spectrometer)
    - Purpose:
        - Measure gated, spectrally resolved broadband emission on the millisecond timescale
    - Program/controller:
        - USB powered
        - SpectraSuite on laptop used to record data
- Photodiodes (PDs)
    - Purpose
        - Measure time-resolved visible and infrared (IR) emission (primarily on the millisecond timescale)
    - Program/controller:
        - Oscilloscope used to record data

4. LASEM-420 Start-up Sequence

- Interlock (Figure 7)
    - Turn on laser interlock (switch on the black power supply box and then turn the interlock key and press button to engage the interlock)

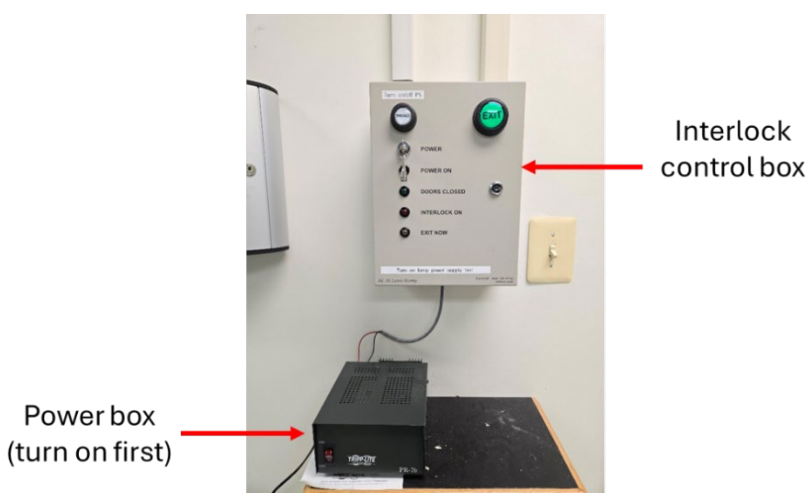

Figure 7. Interlock box and power supply.

- Exhaust (see Figure 2)
  - Carefully take off exhaust cap (cap on large black hose above sample stage)
  - Then, turn on exhaust system (Figure 8)

Figure 8. Switch to turn on exhaust system located toward the end of the lab by the double doors.

- Laser
  - Turn key switch (key is located in lock box next to the interlock box in Figure 7), let warm up approximately 5 min (Figure 9)
  - Verify on control pad that flashlamp voltage is set to 1760 V
  - Start flashlamps (will fire 80 times, may need to warm up more to next temperature interlock setpoint)
  - Press "single shot" to fire and trigger diagnostics

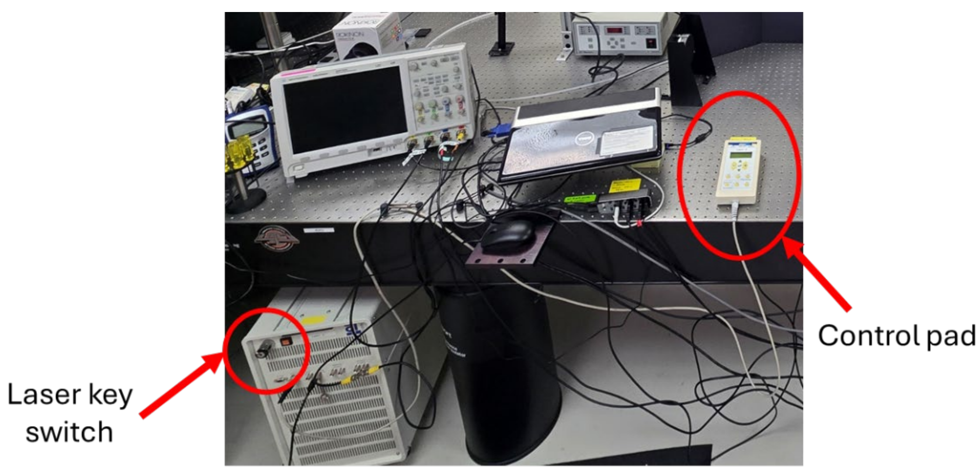

Figure 9. Laser power supply and control pad.

- Dell Laptop (see Figure 2)
  - Plug in power cord

  - Turn on and open programs as directed below
- DDG (see Figure 2)
  - Turn on, double-check settings:
    - External trigger, trigger threshold = 1.01 V, slope = +, impedance = 50 Ω
    - Output: AB, impedance = 50 Ω, TTL
- Oscilloscope (see Figure 2)
  - Turn on
  - Set x-axis scale (approximately 1 ms/div for nano-Al, up to 10 ms/div for strongly combusting materials)
  - Double-check that PMT channel impedances are set to 50 Ω, y-axis = 1 V/div, trigger threshold = 1.66 V
  - Open "Run IntuiLink Data Capture" software on laptop
    - Double-check that the number of data points saved is set to one million and that all four channels are selected
      - Instrument menu at the top→Agilent 7000 series
- Echelle/ICCD (triggered using DDG)
  - Plug-in camera (fan will turn on)
    - DO NOT BUMP the fiber optic cable; if you do, you will have to recalibrate the system (Figure 10)
  - Turn on intensifier control (gain = 900, pulse mode)
  - Turn on Gateway tower
  - Open ICCD version of KestralSpec 5.18 for Echelles
  - Select defaults for all prompts
    - Apogee Alta/AP/KX/SPH series
    - SE 100/200 Spectrographs from Optomechanics Research (OMR)
    - Always display this prompt at start
    - USB
  - Allow to cool to –10 °C (this will take approximately 10 min)
  - Set/check timing on DDG
    - First (10) shots use A = 10-µs delay, B = 490-µs gate
    - Second (10) shots use A = 1.5-µs delay, b = 10-µs gate
  - Open camera shutter (under acquire menu → open camera shutter)
  - Double-check under setup menu → acquire that exposure time is 0.0005 s, 1 accumulation, no delays
  - Acquire one dark spectrum
  - Select "XY" to re-scale
  - Set as background blank
  - Set auto background subtraction (use set background blank)
  - Press "acquire"

- Fire test shot to ensure spectrum appears (first shot is usually noise); look for H 656 nm, Al 394/396 nm, O 777 nm (depending on sample)
    - If not triggering or you encounter intermediate triggering, wiggle USB cord going into the camera (Figure 11). The camera port is loose, so you need to adjust the cord until it triggers every time. Also verify that you are getting the appropriate counts (they should be around 60,000). If you are not, double-check the alignment (Section 10.1). If that is not an issue, then you need to wiggle the cord again until you get both the proper counts and eliminate any intermittent triggering.
        - Ensure it properly triggers at least 20 times prior to continuing testing (need 20 shots per sample)
- Clear all curves before starting data acquisition

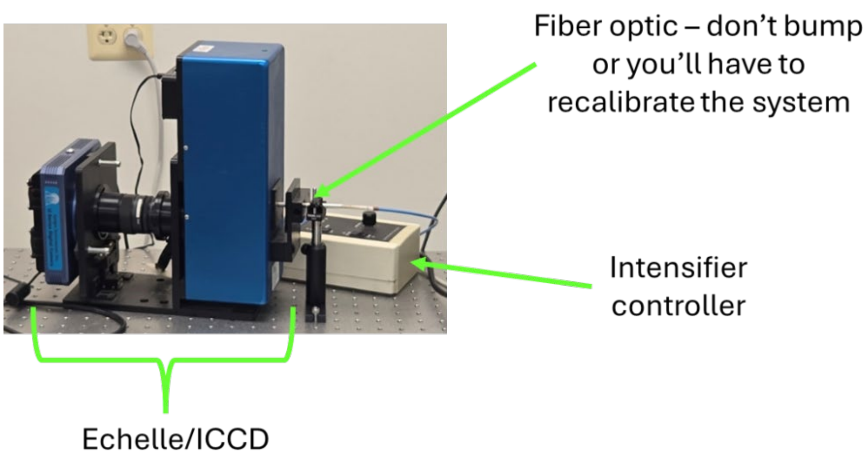

Figure 10. Echelle spectrometer and ICCD camera and intensifier controller used to set the gain.

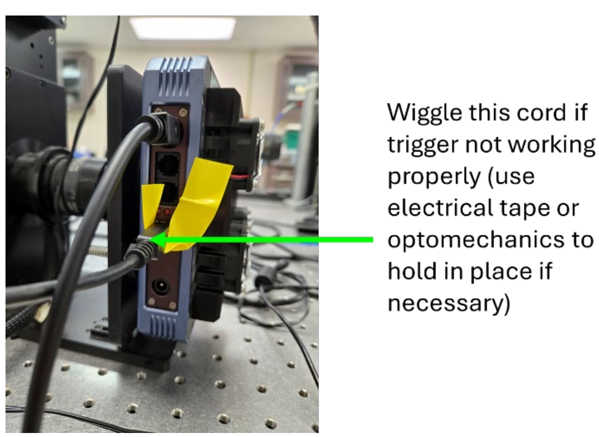

Figure 11. USB cord that connects the ICCD camera to the computer.

- Arc lamp (see Figure 2)
  - Turn on power supply (flip switch)
  - Press “lamp start” (set at 200 W for 84 kfps, 300 W for 420 kfps)
  - Let warm up for several minutes
- Photron SA5 Camera (see Figure 2)
  - Plug-in power converter box (a.k.a., power supply box)
  - Turn on camera (button on back); try not to bump
  - Let warm up for a few minutes
  - Open PFV v351 on Dell laptop
  - Choose the saved variable setting you want (84 or 420 kfps)
  - Rotate image 90° (should see mirror clip in upper right)
  - Click “fit” to fill screen
  - Set trigger mode to “manual,” three preframes suggested
  - Verify the recording option is set to “Direct Start” (this gives you the single-press trigger)
  - Take a snapshot of the 9.5-mm thread height screw (use either 6- or 2-μs shutter depending on frame rate; example shown in Figure 12)—snapshot saves in folder labeled “snapshot shortcut” on desktop. The screw threads must be clearly visible so you can use the thread height to measure the pixel distance later.
  - Set shutter exposure to 1 μs for 84 kfps or 359 ns for 420 kfps
  - With lens cap on, select “shading”

Figure 12. Example snapshot of 9.5-mm thread height screw (yellow line) used to convert pixel size to millimeters. The image has been cropped for clarity and space.

- PMTs (Figure 13)
  - Monochromators currently set to 486 and 656 nm to look at AlO (or H_β) and H_α (or background), respectively (Figure 8)
  - Open PMT2100 software on Dell laptop
  - Set gains (three is a good place to start), default bandwidth is 2.5 MHz
    - ***PMTs saturate at 2 V, be sure to look at all relevant timescales for evidence of saturation (typically <10 µs for laser-induced plasma emission, approximately 10–200 µs for peak post-plasma emission)
  - Check boxes for PMT1 and PMT2
  - Press play
  - Let warm up for a few minutes
  - Note: if the computer cannot find the PMTs, unplug the USB cable and re-plug in

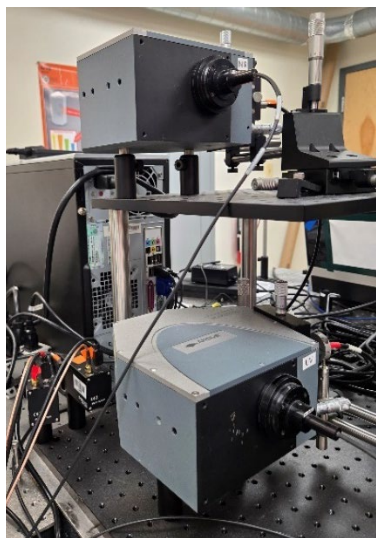

Figure 13. Monochromators and PMTs.

- OOI Spectrometer (Figure 14)
  - Set timing on DDG (default: C = 500-µs delay, D = 10-ms gate width)
  - Open SpectraSuite on Dell laptop
    - If frozen, end in task manager and unplug/plug-in USB, restart
  - Make sure spectrometer is recognized, close top two windows (you just want the plot)
    - If not recognized, then unplug/plug in USB
  - Set trigger to external hardware
  - Check to make certain it is triggering
    - If not triggering/no signal, wiggle black and red wires on back of spectrometer until it triggers (Figure 14)

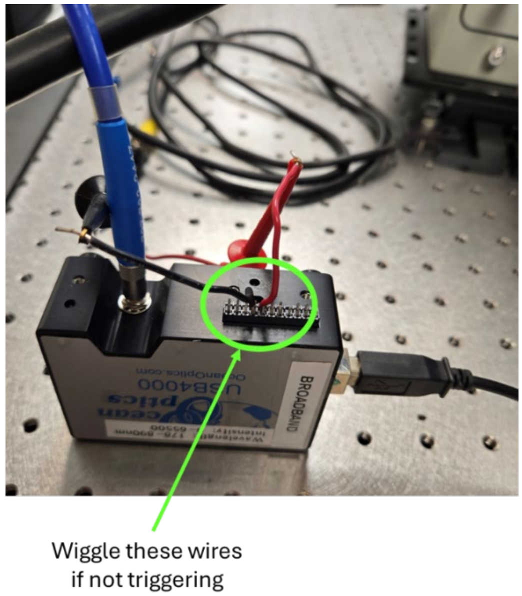

Figure 14. Wires for triggering the OOI spectrometer.

- Photodiodes (see Figure 2)
  - Turn on both power supplies
  - Set/check IR PD gain (1×10^2 for micron-Al and 1×10^3 for nano-Al is a good starting point)
  - Visible/AlO PD gain fixed at 3×10^4 with the AlO bandpass filter in place

5. Detailed Procedure for Running a Test and Saving Data

- Prior to firing the laser:
  - Create a folder to save the data (recommend using the current date as the folder name)
  - Ensure oscilloscope is set to "Run" or "Single"
  - Double-check all gains on diagnostics
  - Clear all previous Echelle spectra (except background submission) in KestralSpec (Echelle software on tower)
  - Ensure "Acquire" has been selected on KestralSpec
    - Will say "waiting for trigger" if already done
  - Press "Record" in the high-speed camera software just before firing (will time out)
    - Will say "Trigger In" if already done
- Firing the laser:
  - Press "single shot"

        - DO NOT PRESS “start” (will cause the laser to continuously fire at 10 Hz). If pressed by mistake, press stop immediately to cease firing
- Post firing (not necessary to complete in this order, but most efficient if you do):
    - To save video:
        - Go to the save tab
        - Change frame range
            - Frames –1 to 13 for 84 kfps
            - Frames –1 to 69 for 420 kfps
        - Press “save”
            - Save as PNG images (see Data Nomenclature for recommended naming convention)
    - Load/get oscilloscope channels (PMTs and PDs data)—will take a moment for everything to load
        - Click “Get Data” icon at the top of the IntuiLink Data Capture software (looks like a mini-oscilloscope)
    - Move sample into position for next laser shot (using wide spacing for first five shots, closer spacing is ok once all combustion diagnostic data acquired; see Figure 15)
    - Press “Acquire” on KestralSpec (will save all the data at the end)
        - At the END of each set of 10 shots:
            - To save data: export file as text, make sure to select “Export all curves”
            - Change settings on DDG for next set of 10 spectra
                - First (10) shots use A = 10-µs delay, B = 490-µs gate
                - Second (10) shots use A = 1.5-µs delay, B = 10-µs gate
    - Save oscilloscope data
        - To save: close each window—prompt asking if you want to save the data will pop up—select yes and save each file
            - Save each channel as a text file, no x-axis (see Data Nomenclature for recommended naming convention)
    - Save OOI spectra
        - To save: floppy icon, select tab delimited format, click on dialog box then press “save” (see Data Nomenclature for recommended naming convention)
    - Press “Run” or “Single” on oscilloscope to reset and wait for next trigger signal

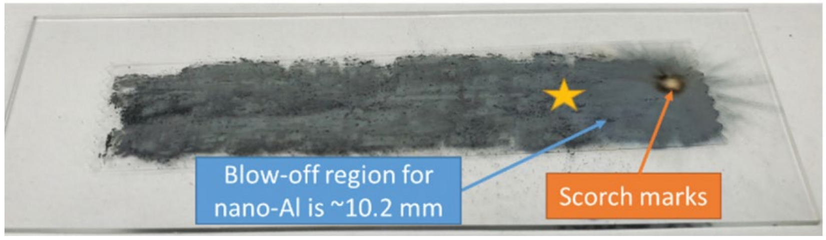

Figure 15. Photo of a prepared sample of nano-Al on double-sided tape affixed to a standard glass microscope slide (75 mm long, 25 mm wide).[4] The orange arrow is pointing toward a previous laser shot position and the gold star indicates an appropriate location for the next shot.

6. Summarized Order of Operations

- Save video
- Load/get oscilloscope channel data onto laptop
- Move sample
- Press "acquire" on Echelle (tower)
- Save oscilloscope channel data
- Save OOI spectra
- Press "single" or "run" on oscilloscope
- Press "record" on camera
- Fire laser

  change the DDG settings for the echelle after you take the first (10) shots

7. Data Collection and Nomenclature for Saving

- 20 shots total per sample
  - Save all (20) videos
    - Samplename-#
  - Save the data for the first (5) shots of the following (get at least five shots with the same gain settings and no saturation):
    - Oscilloscope
      - Ch. 1: IRPDsamplename-#
      - Ch. 2: AlOPDsamplename-#
      - Ch. 3: AlOPMTsamplename-#
      - Ch. 4: HPMTsamplename-#
    - OOI Spectrometer
      - OOIsamplename-#
  - Echelle
    - Save (10) shots at each of the following DDG settings:

        - A = 10-μs delay, B = 490-μs gate
            - ICCDsamplename490us-
        - A = 1.5-μs delay, b = 10-μs gate
            - ICCDsamplename10us-
- Other: Igor code used to process data cares if you skip a number in the sequence (so, do not)
- Other: do not add extra special characters (e.g., another "-") or MATLAB code will not run without being modified
- Data processing information can be found elsewhere[5–8]

8. Tips for Quality Data

- Watch for saturation of data
- AlO PD and PMT: looking for hump (there may be multiple maxima)
- Try to limit changing PD gains between samples when you are comparing things since the gain settings affect the response time of the PD (unless you are only interested in millisecond timescale events)
- Can change PMT gains as needed between samples (keep constant for a given sample)
- Videos
    - Make certain that the shock wave is centered. The initial shock wave (first frame or two) will be slightly curved, so you want the center of the curve in the center of the frame.
        - To check this, shade at a higher frame rate (smaller resolution) and then switch to a lower frame rate (higher resolution) and record a shock wave video. Shading at the higher frame rate will leave an artifact (looks like a shadow) of that resolution on the lower frame rate image which can then be used to align the center of the shock wave (Figure 16).

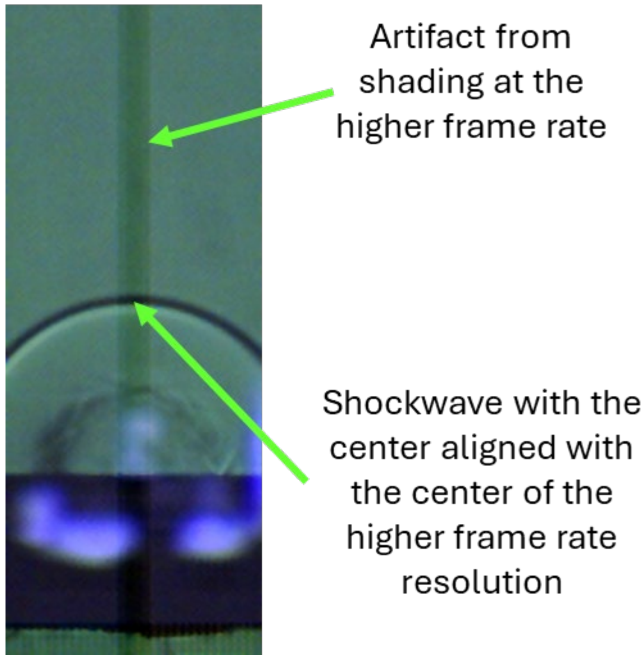

Figure 16. Example snapshot from a high-speed video taken at a lower frame rate and higher resolution (84,000 fps, 640 × 64) with an artifact of the higher frame rate resolution (420,000 fps, 640 × 16), so it is easy to verify the center of the shock wave is aligned with the center of the higher frame rate resolution.

- White band behind shock front should go all the way across (Figure 17)
  - If it does not, check camera focus (should be 33 cm in front of laser focus for optimal shock-wave imaging; see black line on laser table) and lighting
    - Adjust amount of light passing through (razor blades—see schlieren alignment section for further details)
  - For better visualization of the shock wave/quick quality check, you can shift the image a bit (one of the round buttons in the row of icons at the top)

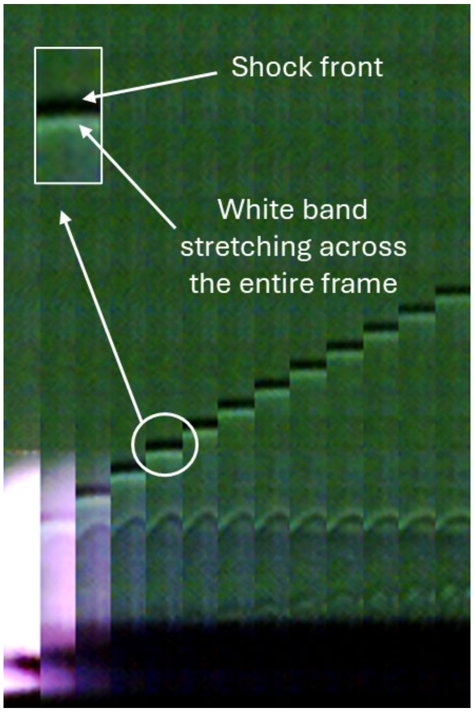

Figure 17. Example snapshots from the high-speed schlieren imaging video of laser-excited PBXN-5. The images have been cropped and the brightness increased by 70% for easier visualization of the shock wave.

9. LASEM Shutdown Sequence

- Exhaust
  - Turn off exhaust system
  - Then put on exhaust cap (failure to cap the exhaust line could lead to condensation buildup and rust on a humid day)
- Laser
  - Stop flash lamps
  - Turn off key switch
  - Return key to lock box
- Echelle/ICCD
  - Exit software
  - Do not disable temperature control
  - Let fan run a few minutes
  - Turn off intensifier control box (tan box)
  - Unplug camera so fan turns off (says digital camera on box in front)
- DDG
  - Turn off
- Arc lamp
  - Press "lamp off"

    - Let fan run a few minutes
    - Turn off power supply (flip switch)
- Photron SA5 camera
    - Exit software
    - Turn off camera
    - Disconnect power converter (brick)
    - Put lens cap on
- Oscilloscope
    - Turn off
- PDs
    - Turn off both power supplies
- PMTs
    - Press stop
    - Exit program
- OOI Spectrometer
    - Stop waiting for trigger (press "II" pause)
    - Exit program by going to "File" and "Exit"
    - Unplug USB if freezes
- Turn off Gateway tower (after saved data is retrieved)
- Turn off laptop and unplug power cord (after saved data is retrieved)

For extended time out of lab (i.e., over holidays or furlough), unplug lasers and power strips from the wall and ensure cords are off the floor.

10. Alignment and Calibration

10.1 Diagnostics

- Echelle
    - To align:
        - Use the red diode laser with small black power box (Figure 18)
        - Point diode laser through back of collimator (Figure 19) to center the collimator at the laser focus (spot marked on sample stage)

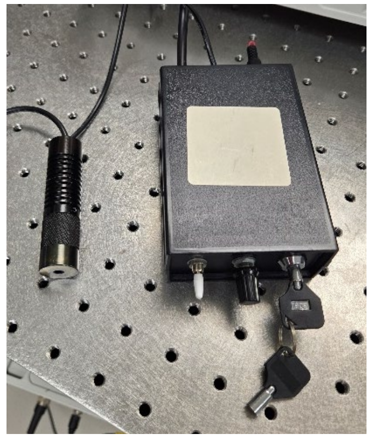

Figure 18. Red diode laser used to align diagnostics.

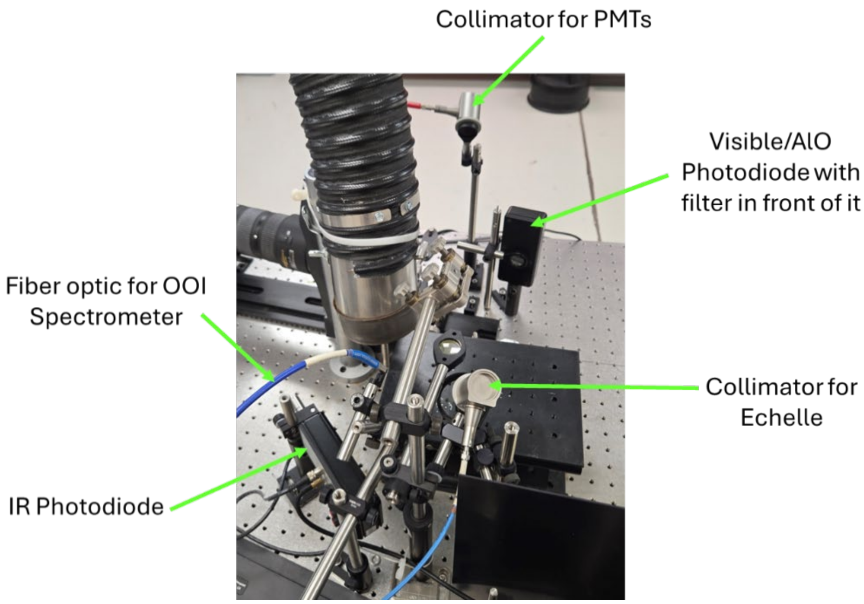

Figure 19. Collimators, fiber optics, and PDs used to collect diagnostic data.

- To calibrate:
    - Make certain the fiber optic is seated correctly and completely
    - Multiple ways to do it, one option:
        - Set gain to 700 on the intensifier controller
        - Set the gate width for the echelle on the DDG to 2 ms (B = 2 ms)
    - Disconnect the fiber optic cable from the collimator and connect it to the Hg–Ar lamp
    - Open camera shutter (under acquire menu → open camera shutter)
    - Double-check under setup menu, acquire, that exposure time is 0.0005 s, one accumulation, no delays
    - Acquire one dark spectrum
    - Select "XY" to re-scale

- Set as background blank
- Set auto background subtraction (use set background blank)
- Switch to “Active Image” under the “Window” menu at the top
- Add the calibration toolbar by going to the same “Window” menu→Spectrograph Setup→Calibrate x-axis
- Press “acquire”
- Trigger using laser (normal procedure for firing)
- Double-check that the image is not saturated—one pixel should be brighter than the others
- Follow the calibration instructions in the KestralSpec for Windows Software manual to select the correct pixel locations (see pages 59–60; Figures 20 and 21 below)
- Redo several times to hone in on the correct calibration
- Reconnect fiber optic cable to collimator (without affecting the collimator alignment)
- Switch view back to spectrograph (“Window” menu → spectrum plot) and check calibration using known wavelengths and dummy sample
    - H = 656.27, 656.28
    - O = 777.194, 777.417, 777.539
    - N = 742.364, 744.229, 746.831
- Important: save the calibration by selecting File→Update INI File

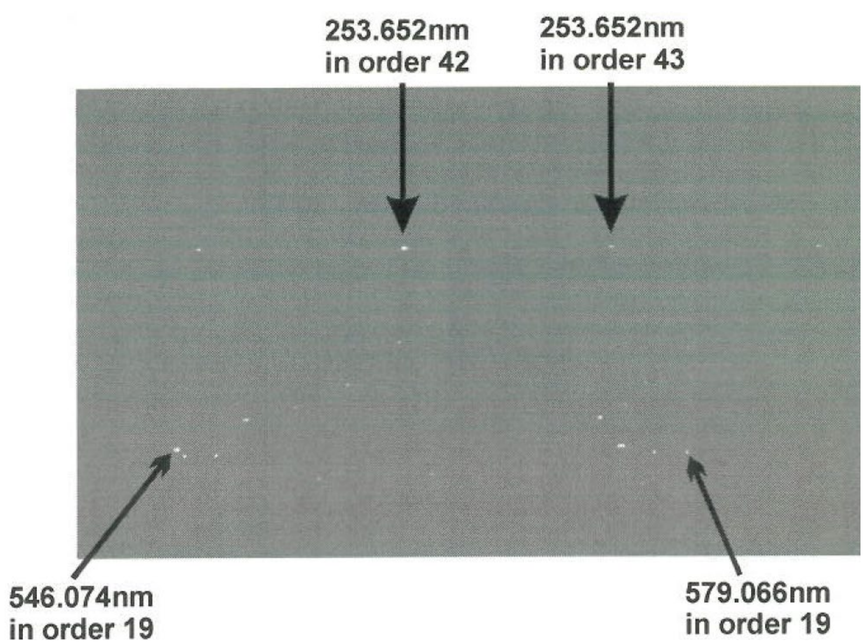

Figure 20. Pixel locations and their corresponding wavelengths for calibration.

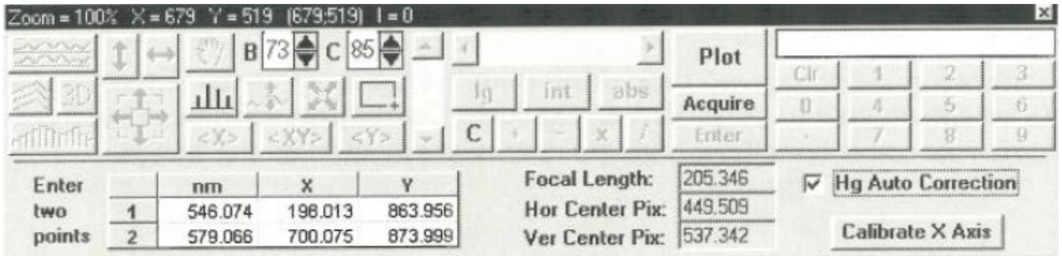

Figure 21. Enter the pixel location of each wavelength into the "X" and "Y" boxes and then click "Calibrate X Axis."

- OOI Spectrometer and PMTs
  - Point red diode laser through end of fiber optic cable (Figure 13) to overlap with laser focus
- PDs
  - Aim receptors (Figure 14) toward laser focus (slightly above sample stage) as best as possible (do not adjust position between samples you want to compare)

10.2 Focusing the Camera

10.2.1 Shock-Wave Videos

- Use flashlight with ring of LEDs to fix the focus of camera at the set position (Figure 22)
- Line up the flashlight with the black line on the table

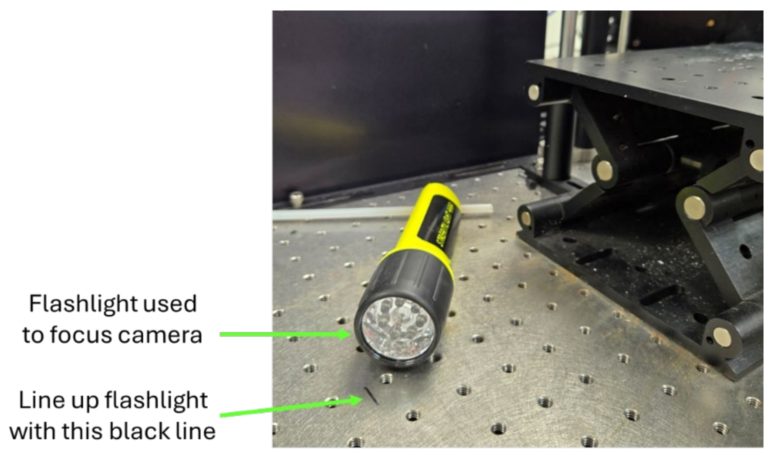

Figure 22. Flashlight and black line used to focus the camera.

10.2.2 Plasma, Post-Plasma, and Self-Sustained Combustion Videos

- Use flashlight with ring of LEDs (Figure 22) to focus the camera at the laser focal position on the sample surface instead of the black line on the table
- Adjust the resolution to narrow the field of view to better capture the desired phenomena
  - Recommended settings (tweak as necessary):
    - 128 × 144 for plasma
    - 320 × 360 for post-plasma combustion
    - 1024 × 1024 for self-sustained combustion
- Adjust the frame rate: need greater visual resolution rather than timing
  - Recommended settings (tweak as necessary):
    - 232,500 fps for plasma
    - 54,250 fps for post-plasma combustion
    - 7000 fps for self-sustained combustion
- Adjust the lighting—this will depend on the sample and how much light is produced during combustion. Two options to do so:
  - Lower the wattage on the arc lamp
  - Change the shutter exposure time in the camera settings
- Example images for each regime (Figures 23–25) have been cropped to better visualize the event taking place:

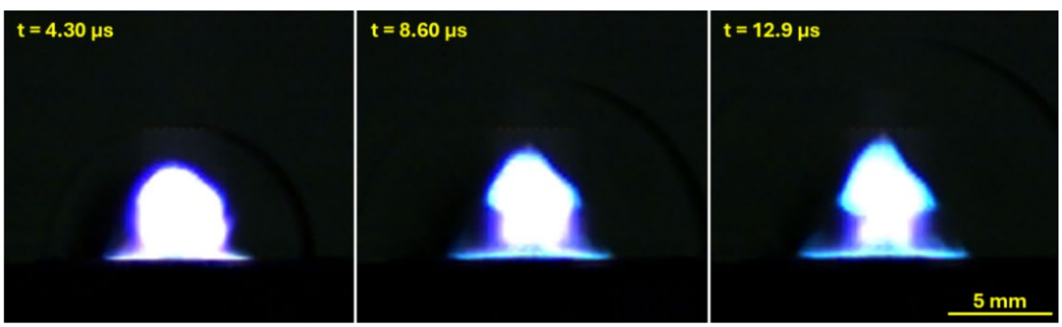

Figure 23. Example snapshots from a high-speed video of the laser-induced plasma for micron-sized aluminum.

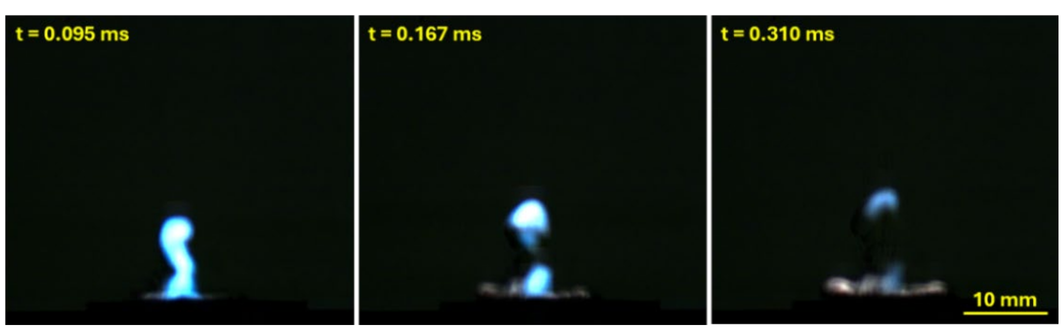

Figure 24. Example snapshots from a high-speed video of the post-plasma combustion for micron-sized aluminum.

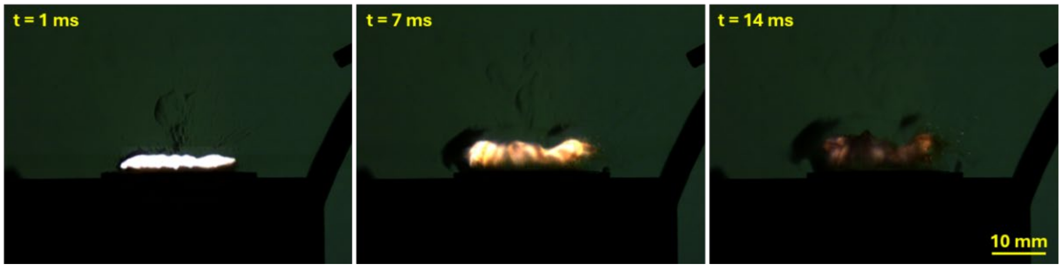

Figure 25. Example snapshots from a high-speed video of the self-sustained combustion for micron-sized aluminum.

10.3 Laser Alignment

- Check energy directly out of the laser head. If it is lower than anticipated (< approximately 685 mJ), increase the lamp voltage until the energy exiting the laser head is back to approximately 685 mJ. Note: decreasing energy out of the laser head indicates the flashlamp may be nearing the end of its lifetime or, in the worst-case, that the neodymium-doped yttrium aluminum garnet (Nd:YAG) rod inside the laser is being damaged and the laser will eventually need to be replaced.
- Check laser energy directly below the focusing lens to ensure alignment
  - If the energy is significantly lower than anticipated (approximately 600 mJ, check laser log book for most recent measurements), then it is possible the beam is clipping something or is misaligned and coming down diagonally instead of straight.
- To re-align the laser, you will need to use two parallel and centered irises to realign (Figure 26)
  - Place the iris setup underneath and in line with the second laser mirror, directly above the sample stage (remove the laser focusing lens while aligning the laser beam) (Figure 27)
  - Use the first turning mirror (closest to the laser head) to get the laser through the top iris (Figure 27)
  - Use the second turning mirror to get the laser through the bottom iris (Figure 27)
  - Remove the iris setup and reinsert the focusing lens such that the laser beam hits the center of the lens
  - Re-check the energy directly below the focusing lens and repeat the alignment process until the energy is restored to the expected level

Figure 26. Two-iris setup used to align the vertical laser pathway.

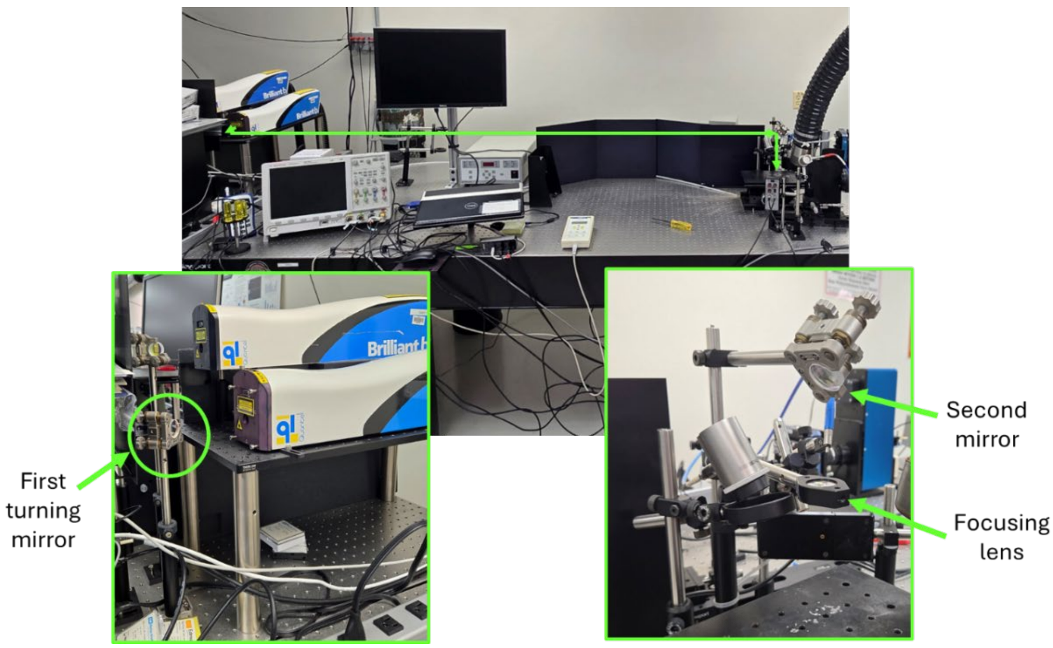

Figure 27. Top: Laser path indicated by the green lines. Bottom left: First turning mirror used to direct the laser onto to the second mirror. Bottom right: Second mirror used to direct the laser down through the focusing lens onto the sample.

10.4 Schlieren Alignment

- Concept: visualize changes in refractive index that cause the light to bend due to density changes in the region between the two schlieren mirrors[9]
  - Use the knife edge to cut off some of the light that is bending, resulting in dark lines in the schlieren video
- Size of the image is dictated by the aperture in front of the lamp (Figure 28)
- Position of the image on the second mirror is dictated by the first mirror

   - Adjust the position of the first mirror to position the image on the center of the second mirror
   - You want the image to completely fill, but not exceed, the second mirror
- Use the second mirror to direct the image into the center of the camera
- Adjusting the knife edge—the goal is to get the same image gradient (brightness) all over
   - Must use both micrometer knobs to adjust the gradient
      - Helpful tip: move the knife edge in and out of the light path to clearly see where the gradient is off (i.e., is the image getting brighter on the left or right side first?)
   - After that, adjust only one razor blade till the shock wave looks the best. Figure 17 in Section 8 provides example snapshots of how the shock wave should look.

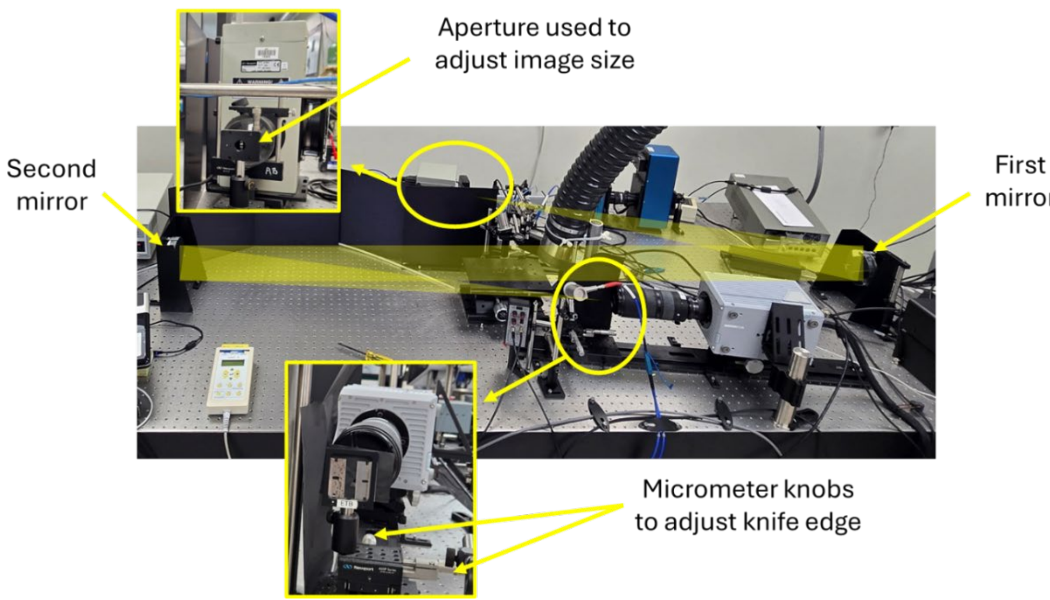

Figure 28. Top: Schlieren setup. The yellow shaded areas represent the light pathway.

11. Recommendations for Designing a LASEM System

In the event a new LASEM system is required, or the current facility is upgraded, there are several factors that need to be considered:

1) Purpose
2) Sample type (metals, neat explosives, explosive formulations, etc.)
3) Material properties of samples being tested

LASEM at its core consists of a high-energy, short-pulse laser; a schlieren imaging system; and a high-speed camera. If the purpose of the LASEM system is singularly to measure the shock velocity, then these are the only necessary components.

However, if additional diagnostic information is required, sample type (metals, neat explosives, explosive formulations, etc.) and material properties (e.g., emission wavelengths) need to be considered. The following are general recommended considerations for both the essential components and the diagnostic equipment included in the system described herein and broken down by laser–material interaction time regimes. For other diagnostics of interest see Gottfried and Wainwright.[1]

Essential LASEM components:

- Laser: high-energy, short (nanosecond) pulse
    - Considerations: energy, pulse duration, wavelength; see Gottfried and Wainwright[1] for more details
    - High-energy, short nanosecond-pulse duration is recommended to minimize laser–material interaction time (i.e., minimizing the effects of the optical absorption of the sample)
    - 1064 nm recommended for maximum obtainable laser pulse energy and minimal laser–material interaction (most of laser pulse is absorbed by the plasma)
    - Example: Lumibird Q-Smart Model PMBX0001
        - Specifications: 850 mJ, 1064 nm, 10 Hz
- Schlieren system: two parabolic mirrors or lenses and a light source
    - Considerations for parabolic mirrors: experimental setup will determine the mirror focal length needed and size of the parabolic mirrors or lenses
    - Considerations for light source: heavily depends on the sample type. Neat explosives will produce less light than metals so while a Hg-Xe arc lamp will work for explosives, an alternative lighting system is necessary to visualize the shock wave at early times for metals.
        - Example for neat explosives and formulations: Newport Arc Lamp Model 6290
            - Specifications: Hg-Xe, 200 W, ozone-free
            - Higher wattage arc lamp (e.g., 1000 W) recommended for enclosed sample chambers with windows that may have reduced light transmission
        - Example for metal-based reactive materials: Spoiled-coherence imaging SILUX640 laser (Specialized Imaging, 640 ± 6 nm)
            - Specifications: 10 ns to 30 µs pulse width, pulse frequency up to 10 MHz, up to 400-W lighting power, 640-nm wavelength
- High-speed camera
    - Considerations: frame rate, exposure time, spatial resolution, buffer size (i.e., maximum number of frames), color versus monochromatic, sample being studied—metal-based reactive materials have brighter

emissions at early times, so may want a higher frame rate for greater time-resolution

    - For short exposure times, a monochromatic camera (i.e., without a Bayer filter) will be more light sensitive

- Example: Photron FASTCAM Nova Model S9
    - Specifications: color, max frame rate of 900,000 fps, megapixel resolution at 9000 fps, 8-GB memory

Optional diagnostic equipment for early, middle-, and late-time regimes that are included in the LASEM system are described herein:

Laser-induced plasma (early, microsecond-timescale)

- Equipment: Spectrometer with microsecond-gate capabilities
    - Uses: high-resolution, time-resolved emission spectroscopy, calculating plasma temperatures and electron densities
    - Considerations: wavelength range (sample dependent—*What species are you expecting to see, or are you interested in?*), time-resolution (need to gate down to us), high-resolution (clearly distinguish between various lines)
    - Example: Catalina Scientific OWL Spectrograph customized to the desired wavelength region (high-resolution spectra from the UV to NIR regions [200–900 nm] provide the most flexibility for all sample types).

Plasma-ignited combustion (middle, µs-ms timescale)

- Equipment: monochromators in conjunction with PMTs
    - Uses: time-resolved species emission and temperature calculations
    - Considerations: wavelengths of emitted species (sample dependent—*What species are you expecting to see, or are you interested in?*), wavelengths needed for temperature measurements, time-resolution (µs)
    - Example PMTs: Thorlabs model PMT1001
        - Specifications: 230–920 nm wavelength range
    - Example monochromator: wide range to choose from, highly recommend researching options to find one that best meets your sample needs
        - e.g., monochromator (or bandpass filter) can be selected to observe AlO or BO_2 emission for Al- or B-containing materials, respectively

Self-sustained combustion (late, ms-timescale)

- Equipment: Spectrometer with ms-integration time capabilities to investigate self-sustained combustion reactions (corresponds to the fireball expansion, 1–200 ms timescale)
  - Considerations: wavelengths of emitted species (sample dependent—*What species are you expecting to see, or are you interested in?*), time-resolution (ms)
  - Example: Ocean Optics, model HR2
    - Specifications: 190–1100 nm wavelength range, integration times from 1 μs to 2 s, customize grating and slit width to fit needs (sample dependent—*What species are you expecting to see, or are you interested in?*)
- PDs to investigate time-resolved emission—can add bandpass filters to look at specific species such as AlO for aluminum-based samples
  - Considerations: Wavelength range of interest (sample dependent—*What species are you expecting to see, or are you interested in?*)
  - Example: New Focus Model 2053
    - Specifications: 900–1700 nm, 10-MHz sampling rate
  - Example: New Focus Model 2051
    - Specifications: 300–1050 nm wavelength range, 10-MHz sampling rate

Other miscellaneous things needed to set up a LASEM system:

- Exhaust outlet to remove ablated species and combustion gases
- Sample stage
- Focusing lens and mirrors for aligning laser
- Instrument controllers for high-speed camera and diagnostics
- Optomechanics for setting up diagnostics
- DDG to set timing delays and gates for diagnostics
- Oscilloscope to record data
- Collimators to collect light for diagnostics
- Fiber-optic cables
- Bayonet Neill–Concelman (BNC) cables
- If an arc lamp (or other fan-cooled equipment) is used, shielding may be required to block the exhaust from entering the schlieren imaging region

12. Summary

LASEM is a microscale method for prescreening energetic material performance. The LASEM-420 system—the numeral referring to the frame rate of the high-speed camera used to image the laser-induced shock waves in thousands of frames per second—involves multiple diagnostics, each of which has their own method of operating. This instruction manual is intended as a user guide for operating and troubleshooting each component of the LASEM-420 system. It provides brief descriptions for the various hardware along with operating instructions and helpful tips and tricks for troubleshooting issues as well as recommendations for designing a new system or upgrading the current system. As new equipment is added and additional troubleshooting wisdom arises, this manual will be updated.

13. References

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7. Gottfried JL. Automated shock wave measurement and fitting for the LASEM-420 system, part III: influence of pixel rounding errors. DEVCOM Army Research Laboratory (US); 2023 Dec. Report No.: ARL-TN-1184.

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List of Symbols, Abbreviations, and Acronyms

ARL	Army Research Laboratory
DDG	digital delay generator
DEVCOM	U.S. Army Combat Capabilities Development Command
ICCD	intensified charge-coupled device
IR	infrared
kfps	thousands of frames per second
LASEM	laser-induced air shock from energetic materials
LED	light-emitting diode
Nd:YAG	neodymium-doped yttrium aluminum garnet
OMR	Optomechanics Research
OOI	Ocean Optics USB4000 (spectrometer)
PD	photodiode
PMT	photomultiplier tube
TTL	transistor–transistor logic
USB	Universal Serial Bus

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