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Progress Towards A Benchtop Energetics Capability (BRIEFING CHARTS)

Mario E. Fajardo
William K. Lewis (NRC)

Air Force Research Laboratory
Munitions Directorate
AFRL/MNAC
Eglin AFB, FL 32542-6810

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William K. Lewis (NRC)

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14. ABSTRACT

The incorporation of nanometric (sub-micron size) metal fuel and oxidizer particles into energetic materials is a promising approach to increasing significantly the systems-level performance of munitions. …

See full Abstract on the second chart

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Mario E. Fajardo and William K. Lewis (NRC)
AFRL/MNME, Energetic Materials Branch
Ordnance Division, U.S. Air Force Research Laboratory
2306 Perimeter Road, Eglin AFB, FL 32542-5910
mario.fajardo@eglin.af.mil

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Abstract

The incorporation of nanometric (sub-micron size) metal fuel and oxidizer particles into energetic materials is a promising approach to increasing significantly the systems-level performance of munitions. We propose to exploit the phenomenon of laser driven shock initiation of energetic materials to enable bench-scale testing of initiation mechanisms and energy-release reaction kinetics of nanometric energetic materials using methods which utilize a minimum of often rare and expensive energetic materials, and which routinely yield rapid repetitive energetic events. Direct laser initiation of energetic materials involves a complicated combination of shock, electronic, and thermal effects which are very difficult to relate to real-world chemical-explosive-driven initiation processes. We will use laser driven flyer plates to decouple the laser photon flux from the energetic material, reducing interference from direct electronic and thermal initiation mechanisms, thus greatly simplifying matters. The technology for producing laser driven flyers is advancing rapidly, thanks to efforts in a number of laboratories around the world. We will exploit as much of the state-of-the-art as feasible, including the use of advanced numerical simulation techniques to model our benchtop experiments. We will adapt the "nanoshock target array" approach, pioneered by Dlott and coworkers, for generating repetitive energetic events. In this method thin films of energetic materials are prepared on a transparent substrate "target coupon" which is rastered mechanically through the fixed focus of a pulsed laser beam. Our novel adaptation will include the laser driven flyer plate intermediate and a target-in-vacuum capability. The expansion of reaction intermediates into vacuum will quench subsequent reactions and preserve these intermediates for spectroscopic and mass spectrometric interrogation. Conversely, we will also employ buffer gases and "glass confined" experimental geometries as necessary to permit longer reaction times. The spectroscopic diagnostics will permit testing of common modeling assumptions, such as local thermodynamic equilibrium, and will be capable of measuring conditions in the reaction flow.

Introduction

"Insensitive Munitions (IM) are conventional weapons and ordnance that fulfill their <u>performance objectives</u> while <u>minimizing collateral damage</u> if exposed to stimuli including fires, impact and shock threats." (emphasis added)

"The statutory requirement for IM is set forth in U.S. Code, Title 10, Subtitle A, Part IV, Chapter 141, Section 2389..."

Department of Defense Acquisition Manager's Handbook for Insensitive Munitions
January 2004, Revision 01

bullet impact | fragment impact | fast cook-off | slow cook-off | sympathetic detonation | shaped-charge jet impact

NATO Munitions Safety Information Analysis Center (MSIAC) Website

Research Strategy

<u>Premise</u>: the rational design and evaluation of new insensitive energetic materials will require an improved *fundamental* understanding of their initiation mechanisms and energy-release reaction kinetics.

<u>Challenges</u>: (1) real world explosively driven events are extremely complex, scale-dependent phenomena. (2) current full-scale testing protocols are slow, do not yield direct information on pertinent chemistry, and novel formulations often use rare and costly ingredients.

<u>Approaches</u>: (1) mimic conditions found in a small slice of space and time within a reacting energetic material. (2) benchtop initiation of small samples combined with advanced spectroscopic diagnostics.

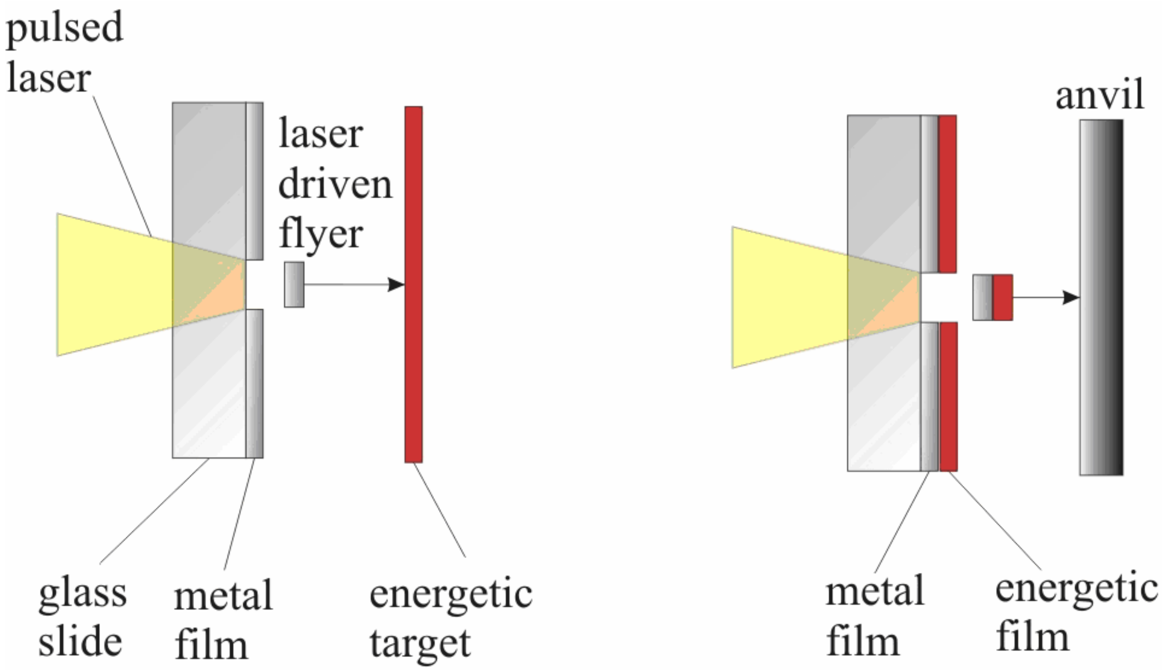
Objective / Payoff

- Develop laboratory bench-scale techniques to characterize the initiation mechanisms and reaction kinetics of candidate nanometric insensitive energetic materials.

- Enable rapid, safe, inexpensive, bench-scale testing of candidate energetic materials, including ones available only in sub-gram quantities.

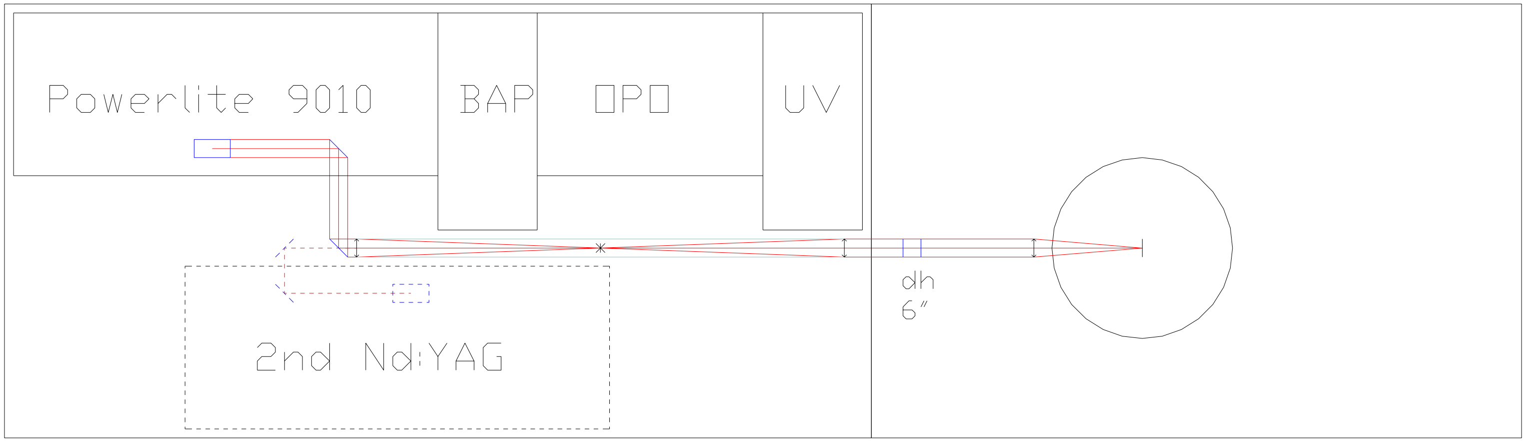
Approach: Overview

- Nanosecond (ns) pulsed laser driven shocks & flyer plates
- High speed photography using 5 ns gated ICCD camera
- NanoEnergetic material film targets or coated substrates
- Spectroscopic diagnostics to monitor reaction kinetics



Approach: Laser

relay imaging with 0.6875 m (27.1") f.l. lenses

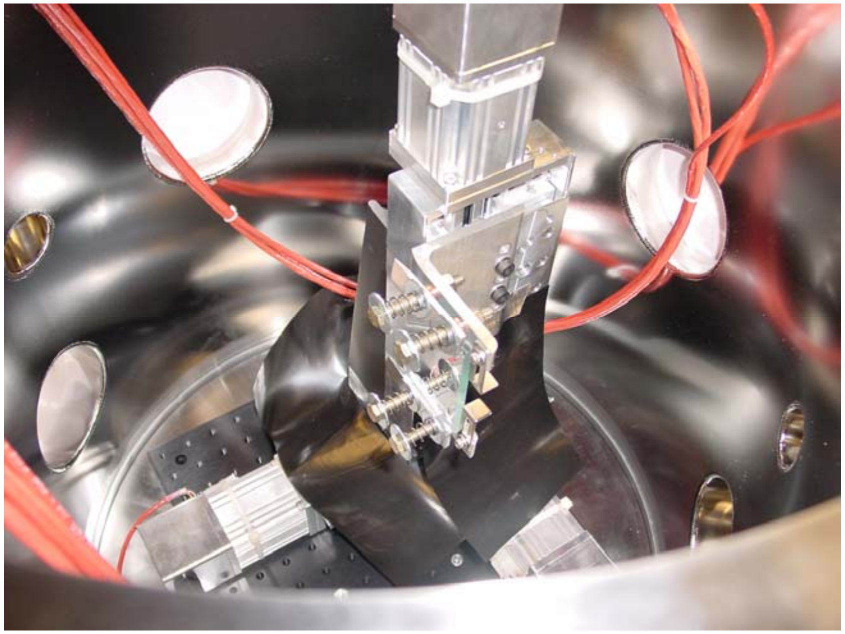


- Use relay imaging to deliver top-hat intensity profile to final focusing optics outside of vacuum chamber.

- Investigating techniques for delivering focused top-hat profile <u>at</u> target: custom aspheric lenses, telescopes, diffractive beam shapers, etc...

Approach: Sample In Vacuum

Main experimental vacuum chamber in place, assembled, and initial pump-down accomplished.



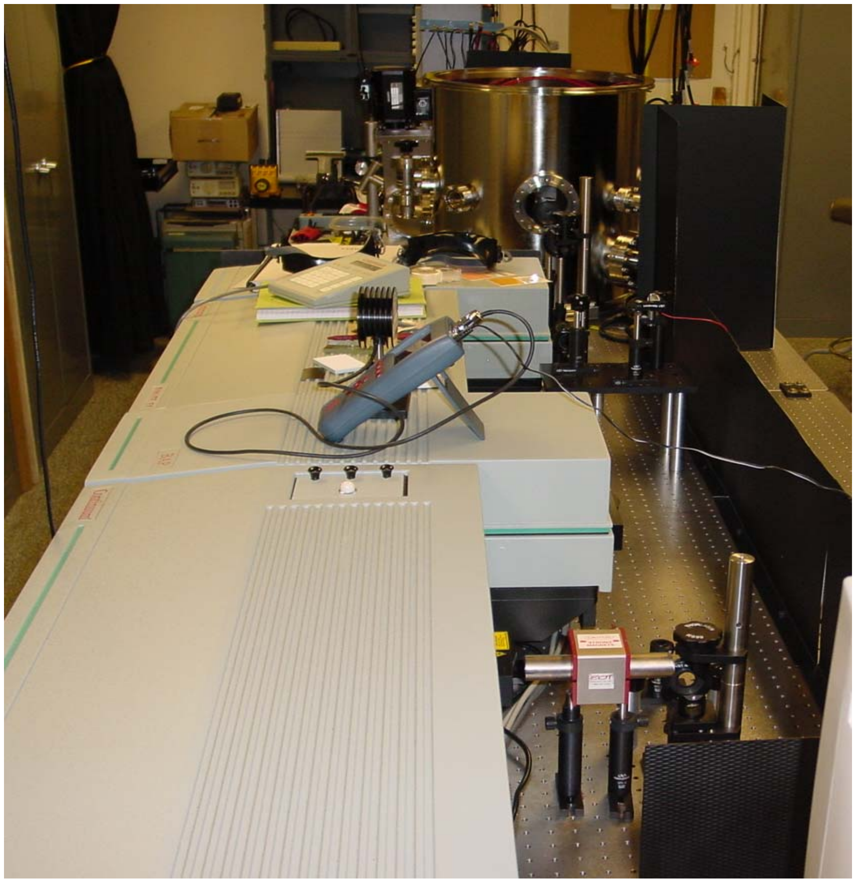
Expansion into vacuum preserves intermediates for spectroscopic interrogation.

Reflectron TOFMS on order.

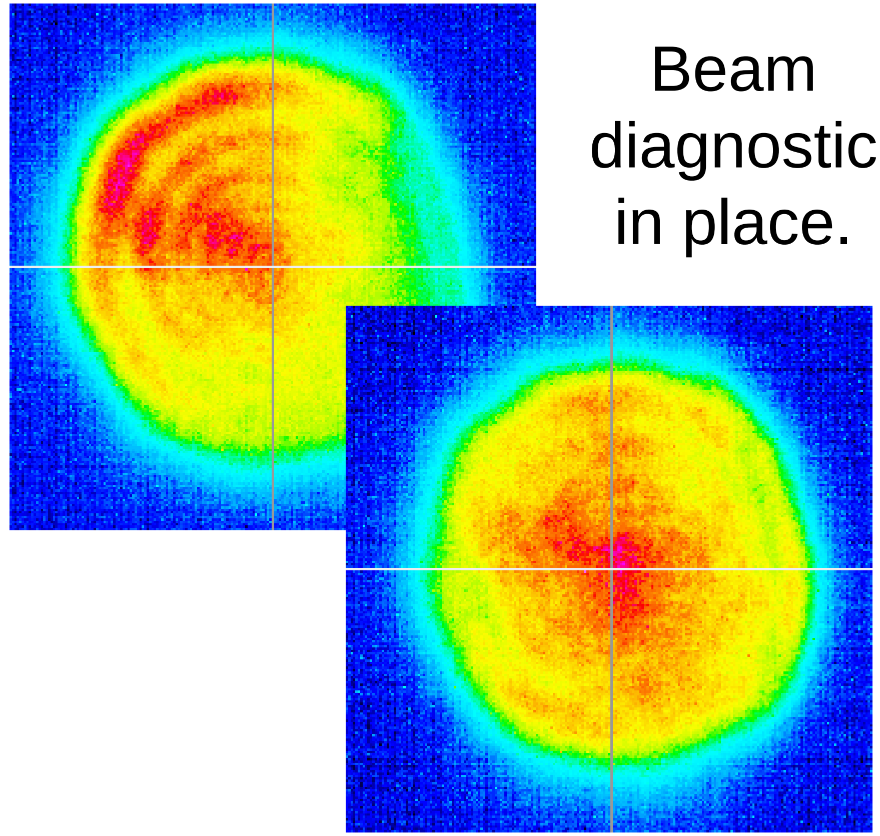
Approach: Diagnostics

- High speed photography with IgCCD camera
  - telecentric lenses
- Single-shot spectroscopies:
  - time-gated dispersed emission & LIF
  - transient absorption
  - electron-impact ionization TOFMS
- Reproducible, repetitive events:
  - LIF excitation
  - cavity ring-down
  - REMPI TOFMS
- Mechanical analysis of recovered flyers/targets

Progress: Laser



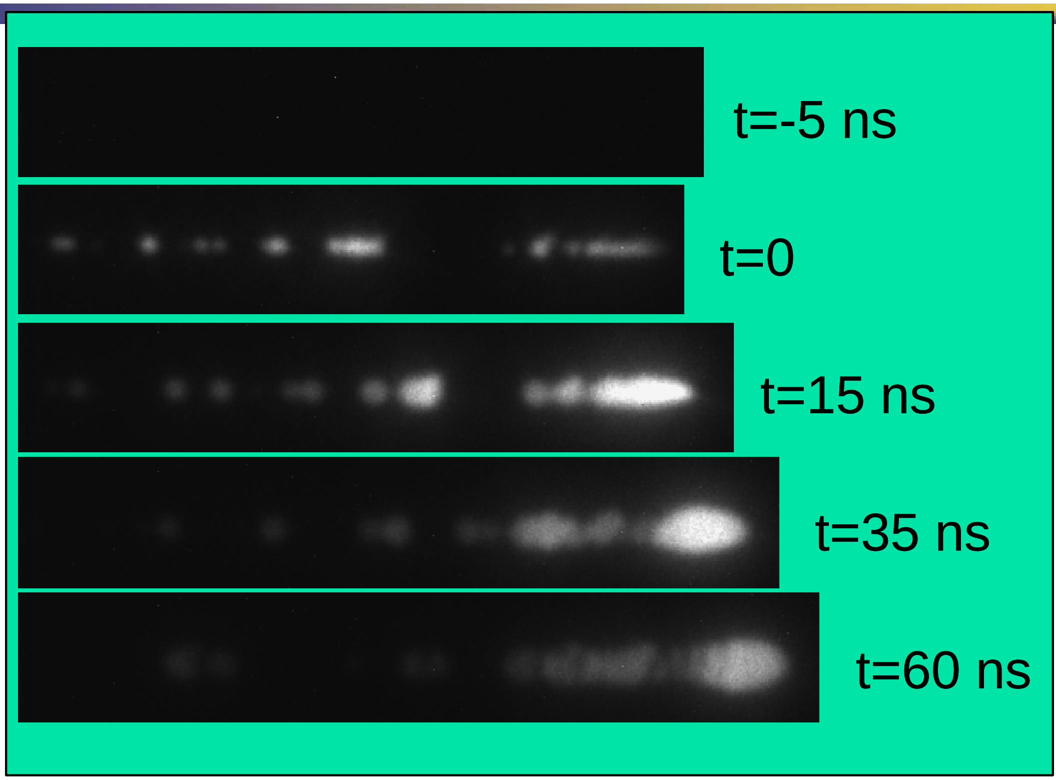
Main optical layout established.



Beam diagnostic in place.

Laser beam profile diffraction-degraded ⇒ relay imaging optics.

Progress: IgCCD Camera



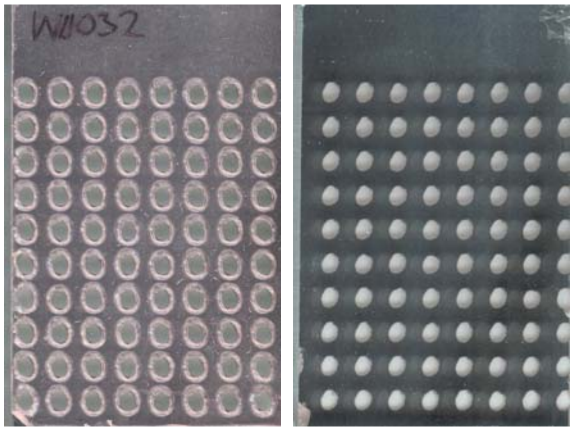
10 ns intensifier gating

Dielectric breakdown in air at laser beam waist.

Plasma expands laterally at v = 14(±3) km/s !

KE(N^+ @ 14km/s) = 14 eV.

Progress: Samples



Soda-lime glass substrates transmit >600 MW/cm^2 (!). Inexpensive, rugged target coupons.

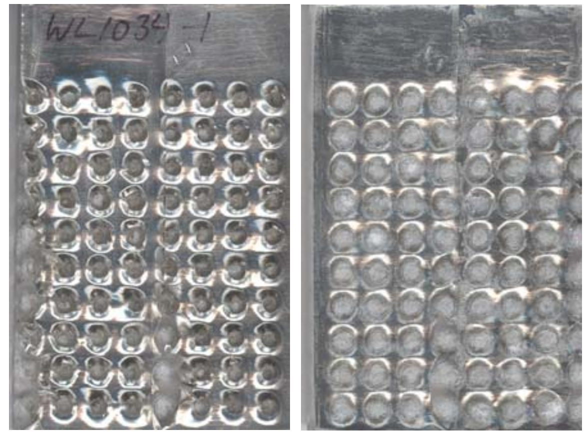
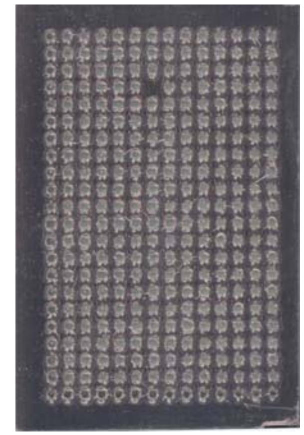


Plate-glass substrates badly damaged by dielectric breakdown; reject for further use.



14x22=308 events/coupon

@ 10 Hz $\Rightarrow$ 5 min/coupon

Progress: Launching "flyers"

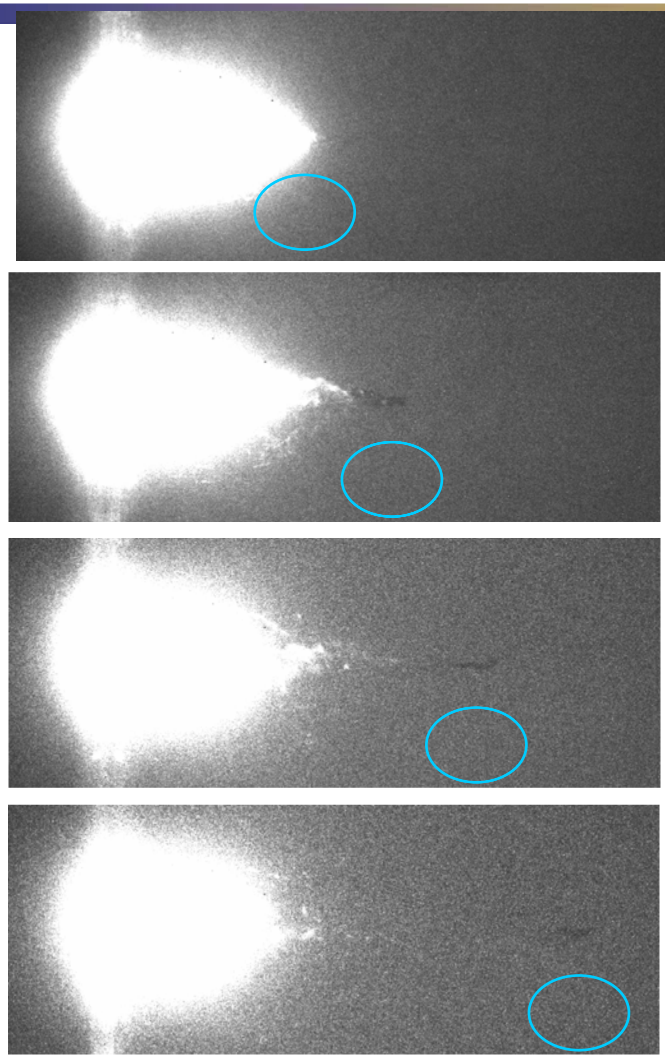
delay

10 μs

15 μs

20 μs

25 μs



Polymer-coated glass mirror in air

Laser-driven exploding foil regime:

$d_{foil} \approx \lambda_{laser} \approx 1\ \mu m$

$I_{laser} \approx 600\ MW/cm^2$

Nominally "identical," repetitive events

Reproducible enough to calculate polymer "flyer" velocity:

930±50 m/s

Badly distorted non-planar "flyers,"
must fix laser beam profile,
and relay-image beam
$\Rightarrow$ **"top-hat" profile at target**

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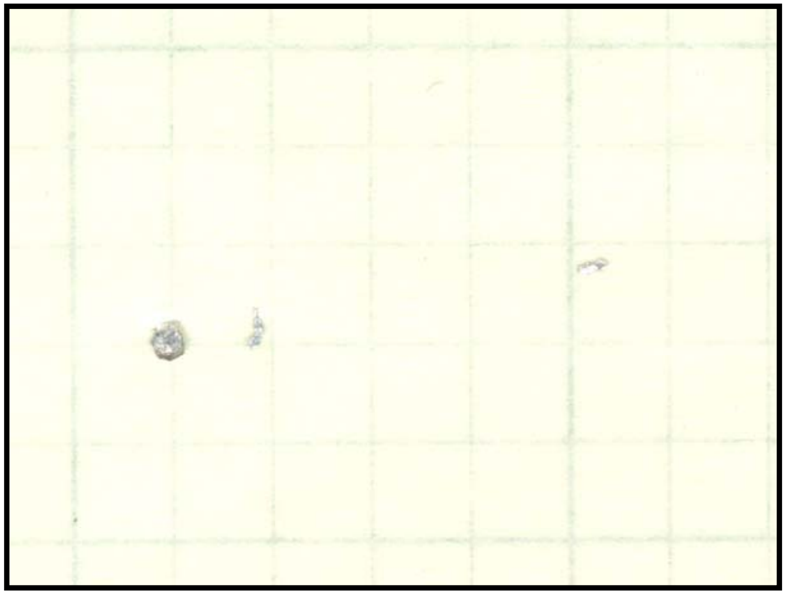
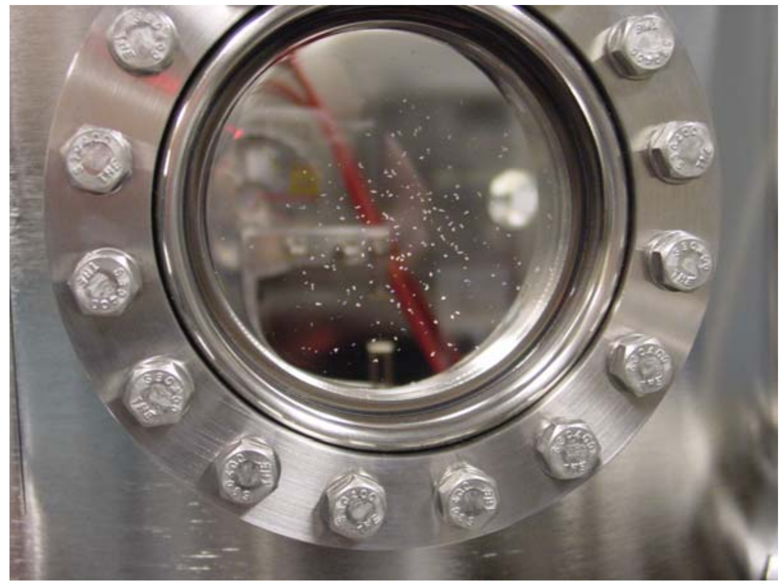
Progress: Recovered "flyers"

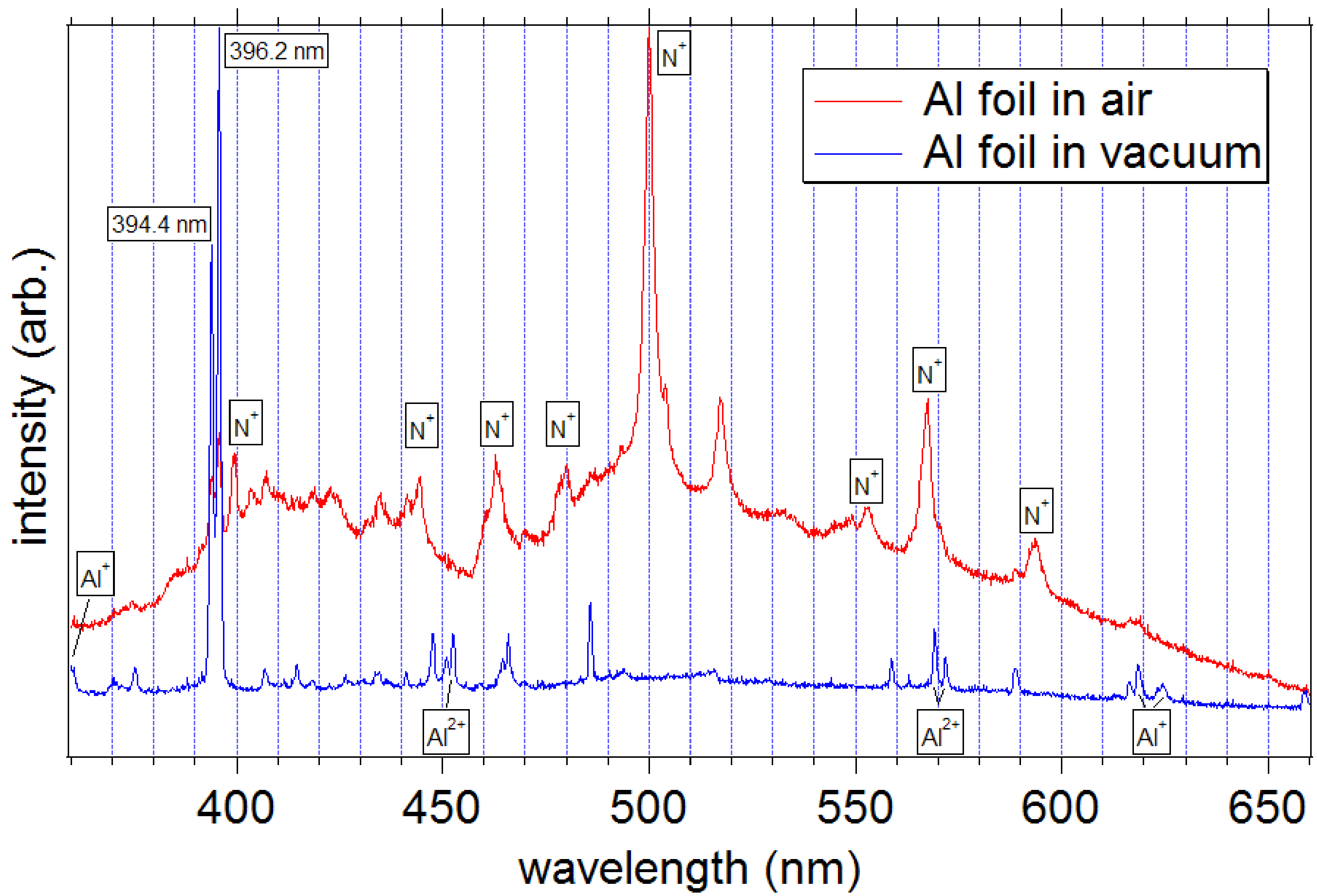


Al foil flyer recovered after transiting ≈ 5 cm in air and penetrating several pages into engineering pad.

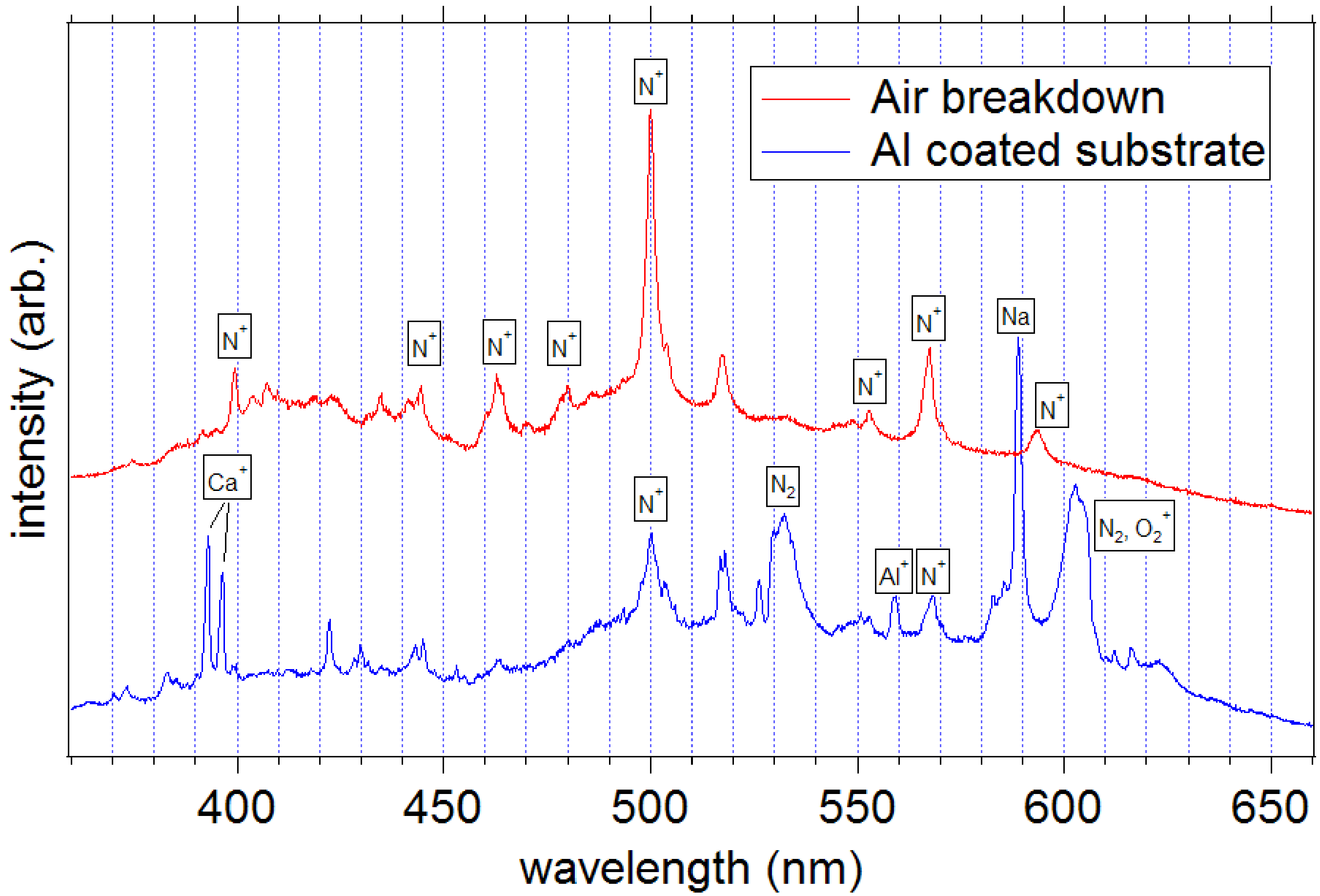


Polyethylene "flyers" stuck to vacuum chamber window after transiting ≈ 30 cm in air.

Progress: Spectroscopy



Progress: Spectroscopy



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Future Directions

- **Procure dedicated flyer-driving laser; is 2 J sufficient?**
  - demonstrate initiation of energetic material.
- **Explore laser target and sample preparation techniques.**
- **Demonstrate launch of planar flyers; photograph.**
- **Time-gated and spatially-resolved emission spectroscopy with gICCD+monochromator.**
- **Computational modeling of flyer launch process;**
  - Dr. Y. Horie (MNME) & Prof. K. Gonthier (LSU)
- **Incorporate Reflectron TOFMS.**
- **Develop advanced laser-based diagnostics;**
  - broad-band nonlinear optical mixing (e.g. CARS).