SAND2014-2971C

Pulsed Laser Interactions with Reactive Foils

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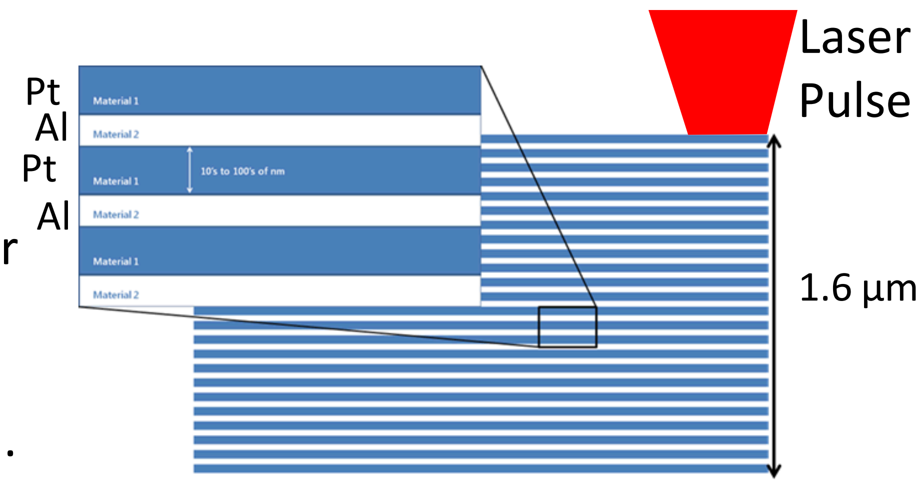
Background

- Exothermic heat generation upon ignition.
- Self-propagating reaction.
- Reactive foils may be ignited using shock waves, static discharge, and heating.
- Laser irradiation leads to more control over energy delivered to foil.
- Laser irradiation allows for remote ignition.
- Study effects of ignition on rate of heat input.
- Vary pulse length from femtosecond to millisecond to study effects of heating rate on ignition.

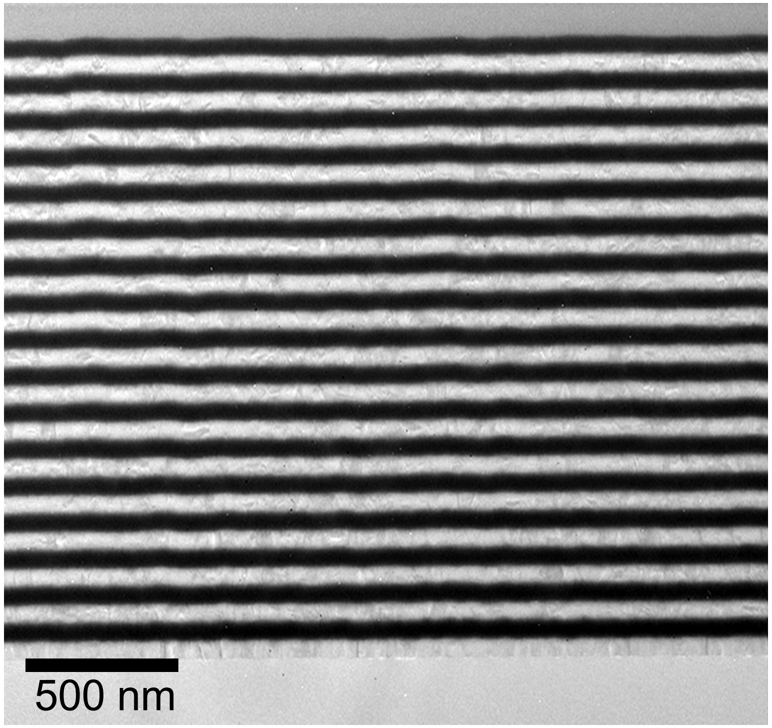
$Al + Pt \rightarrow AlPt$ (intermetallic phase)



Reactive Multilayers

Al + Pt → AlPt (intermetallic phase) + 200 kJ

Al/Pt multilayer
TEM Cross-section

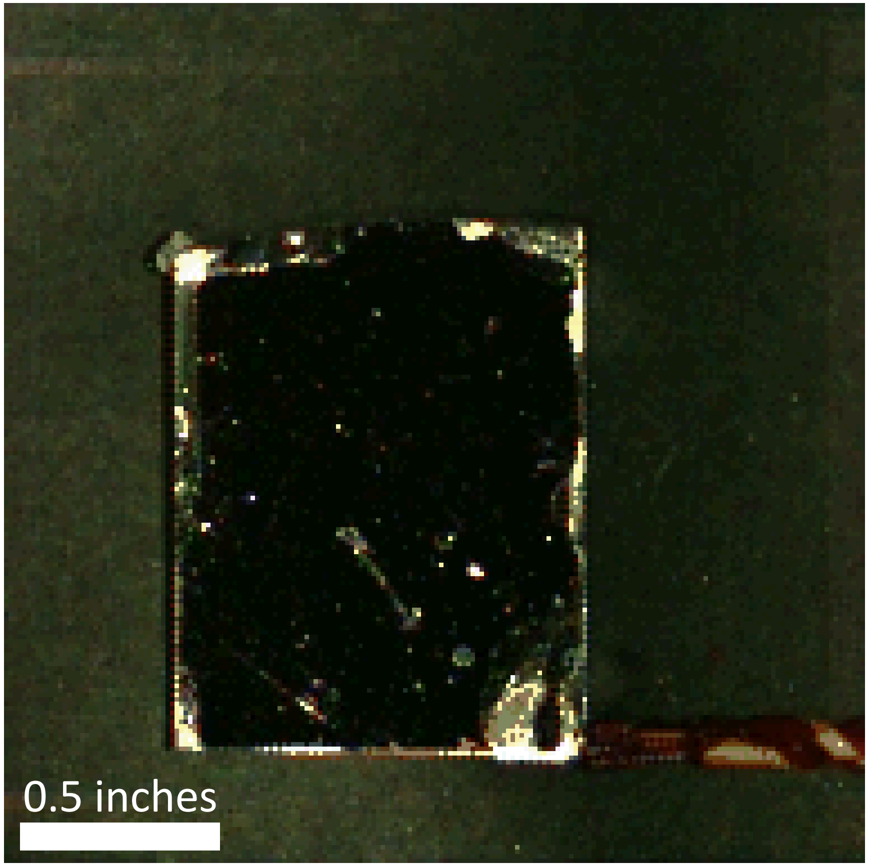


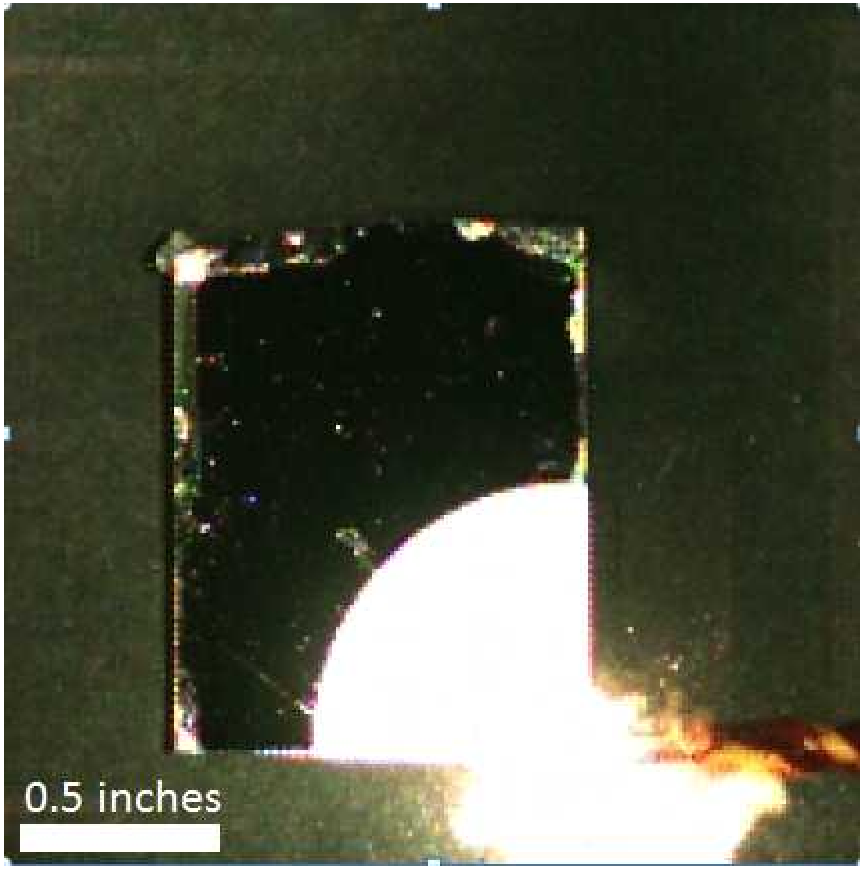
- DC Magnetron sputtered layers
- 10 - 15 Å thickness variation
- 1 to 1 Al/Pt ratio
- Adiabatic reaction temperature = 2798 °C
- Reaction onset temperature = 136 °C
- <u>Melting not required for ignition</u>

Ignition and Reaction Propagation

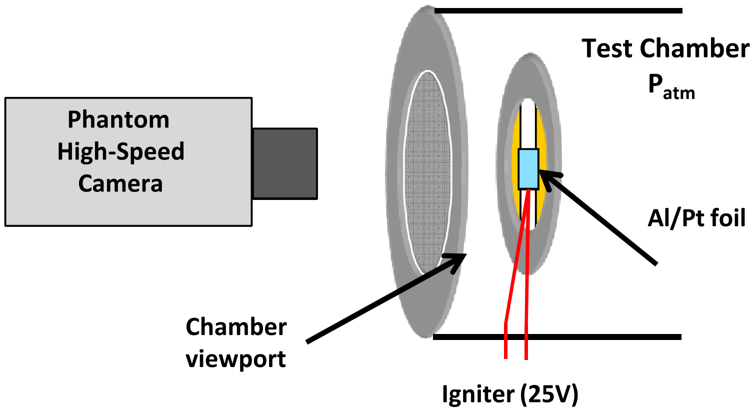
<u>Ignition by capacitive discharge</u>

~ 600 microseconds after ignition

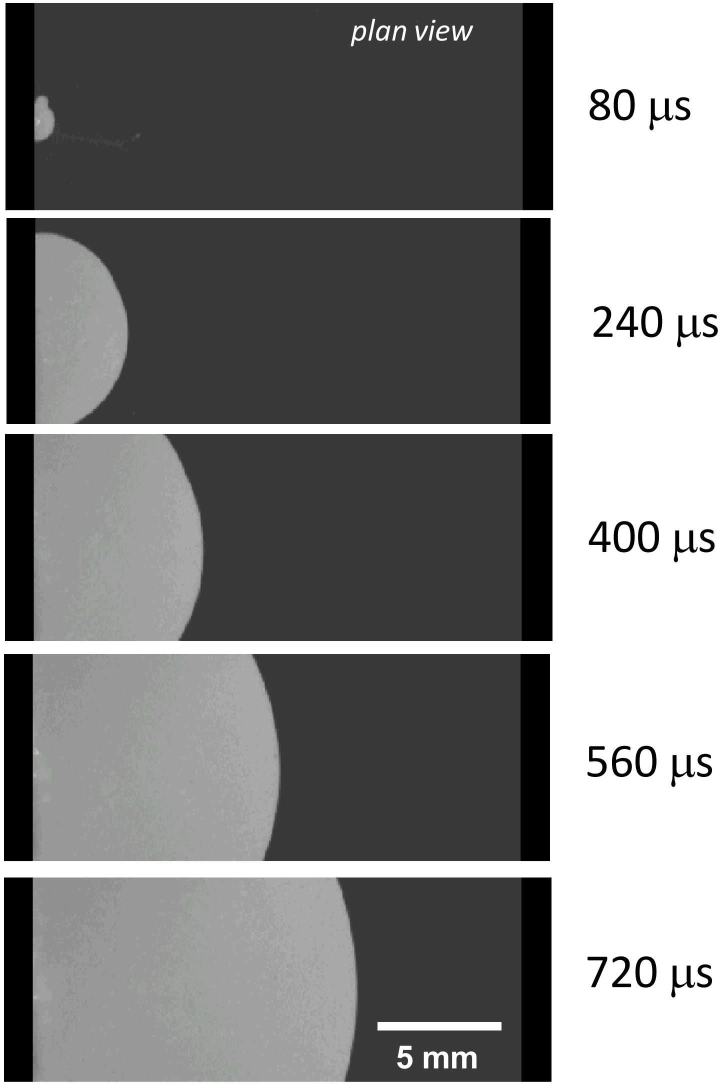




Imaging Reaction Propagation

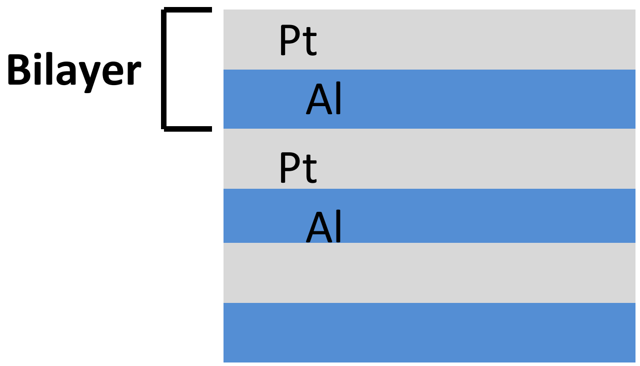


Bilayer thickness = 50 nm

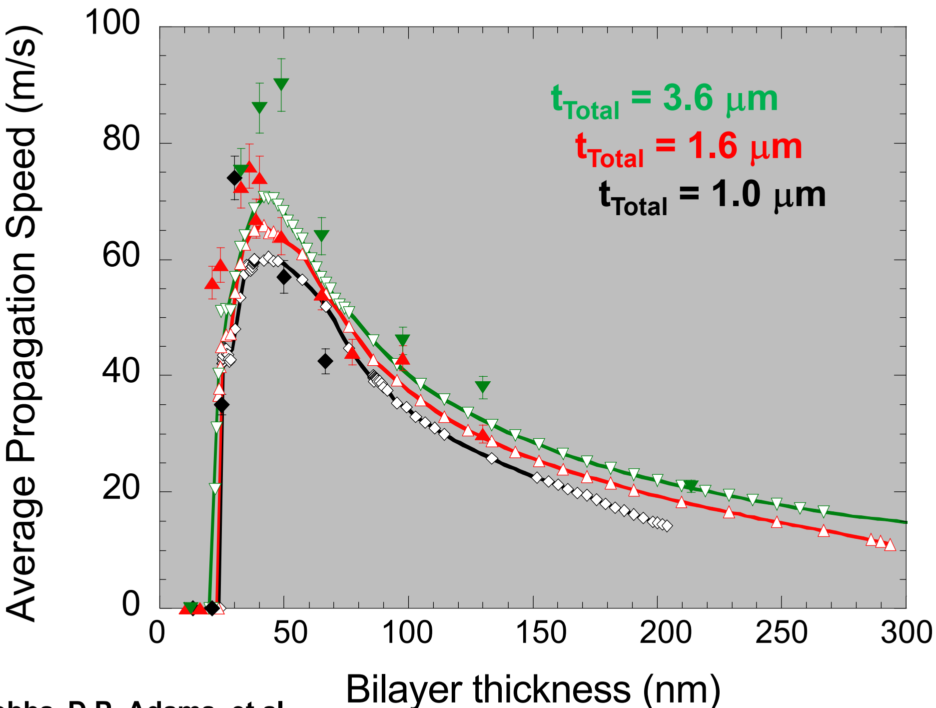


- Point ignition in air.
- Tested as freestanding foils.
- Room temperature.
- High speed photography of steady-state propagation.

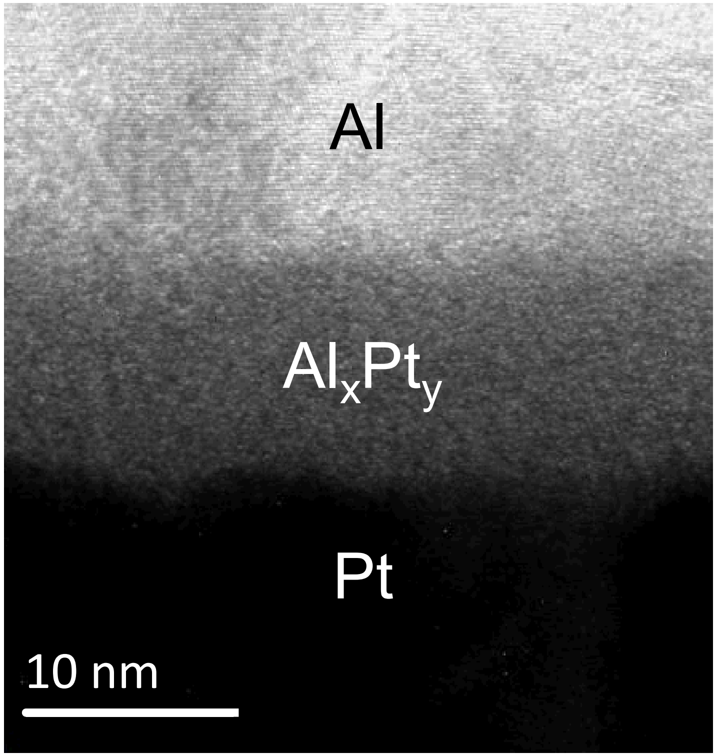
Bilayer Dependence



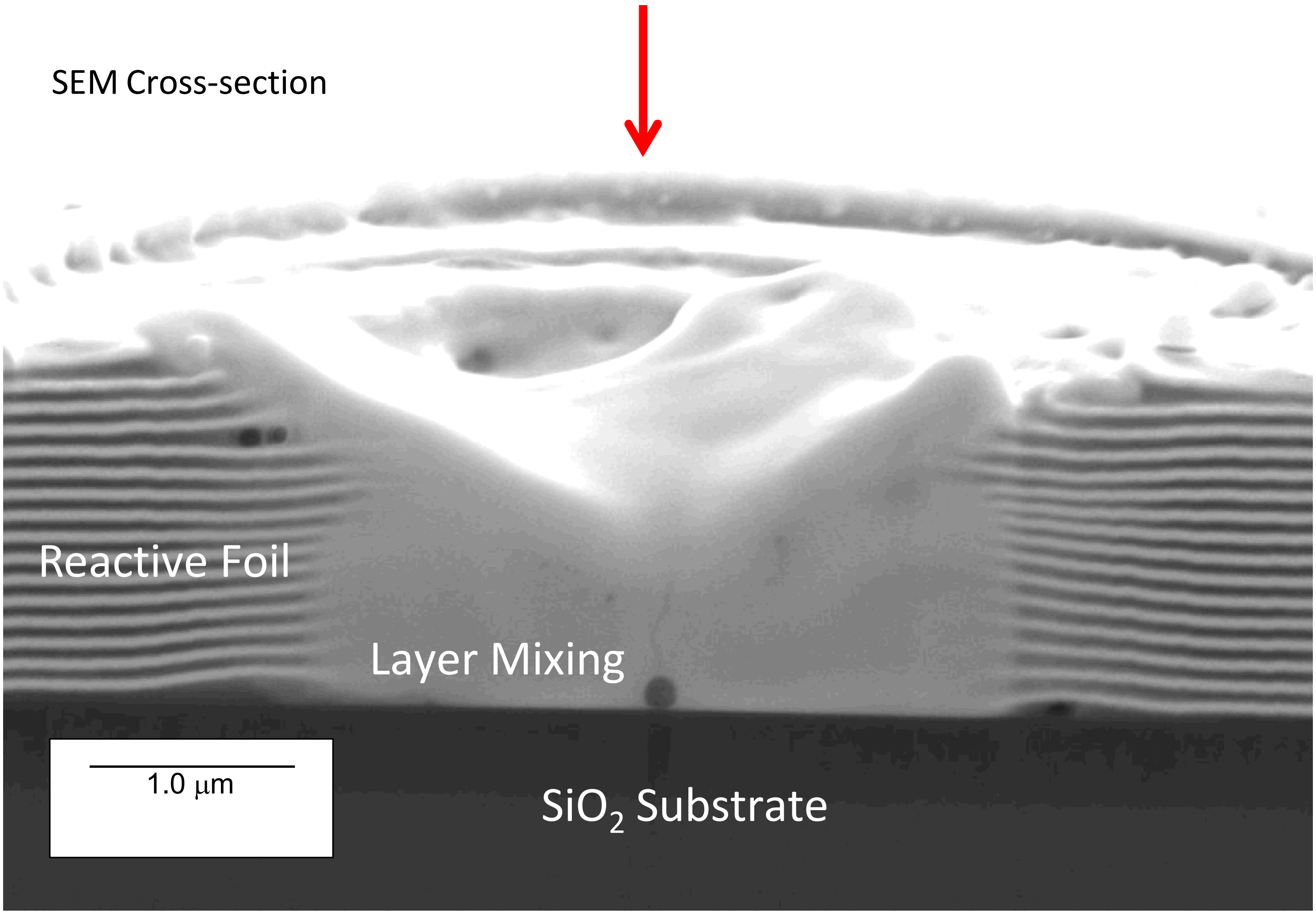
- Propagation speed increases with decreasing bilayer thickness.
- Shorter diffusion distances lead to shorter reaction times.
- Pre-mixing affects propagation speed of thinnest bilayers.



M. Hobbs, D.P. Adams, et al. 8th World Congress Comp. Mech. (2008).



Laser Irradiation

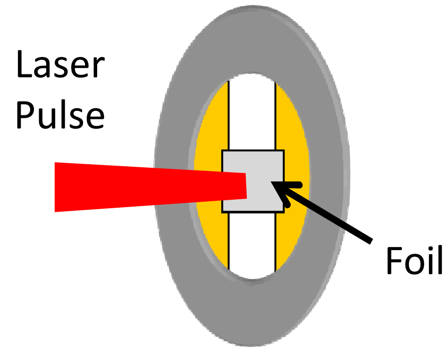


Picard, Yoosuf N. Ph.D. thesis University of Michigan, 2006.

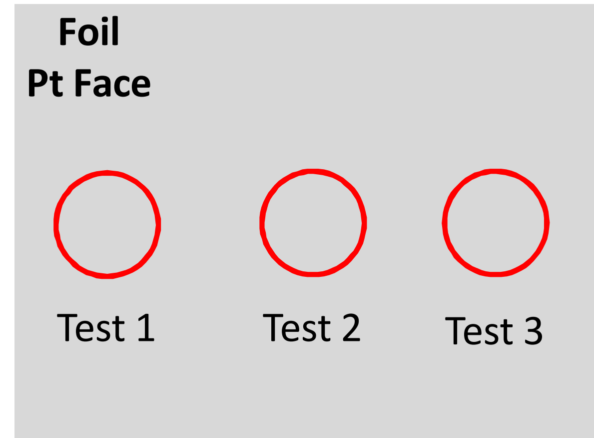
Al/Pt Irradiated at 80% ignition threshold

Determining Laser Ignition Threshold

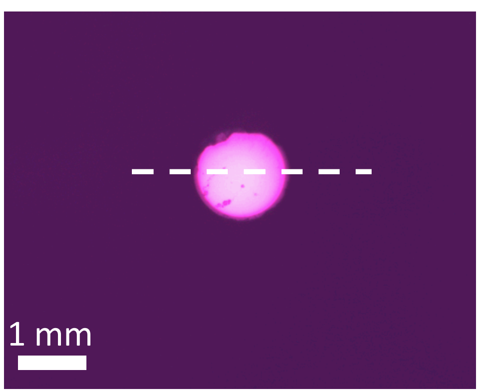
- Foil not on substrate
- Single Pulse Irradiation
- Flat-top Beam Profile
- Irradiate Pt side



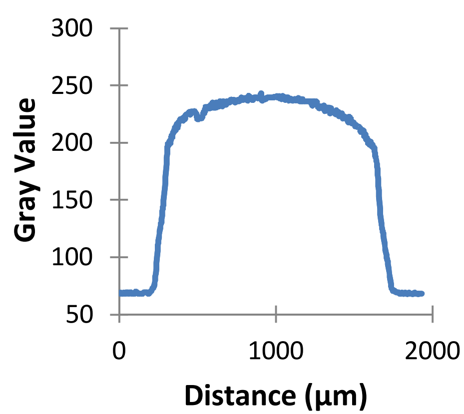
- Laser energy is increased until foil ignites.
- Non-irradiated region of sample is used for each test.

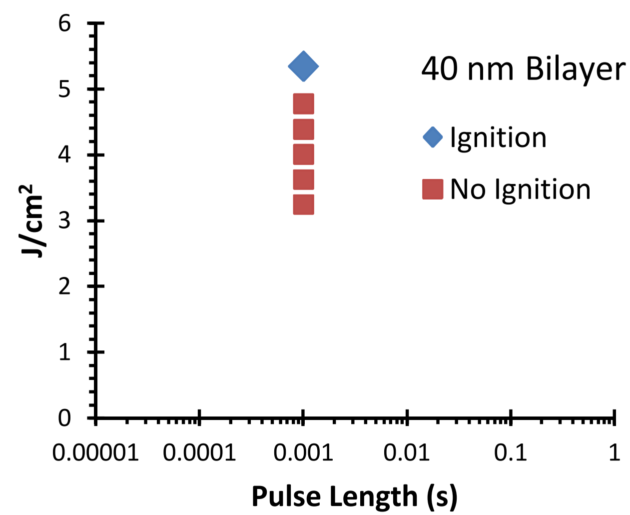


Focused Beam



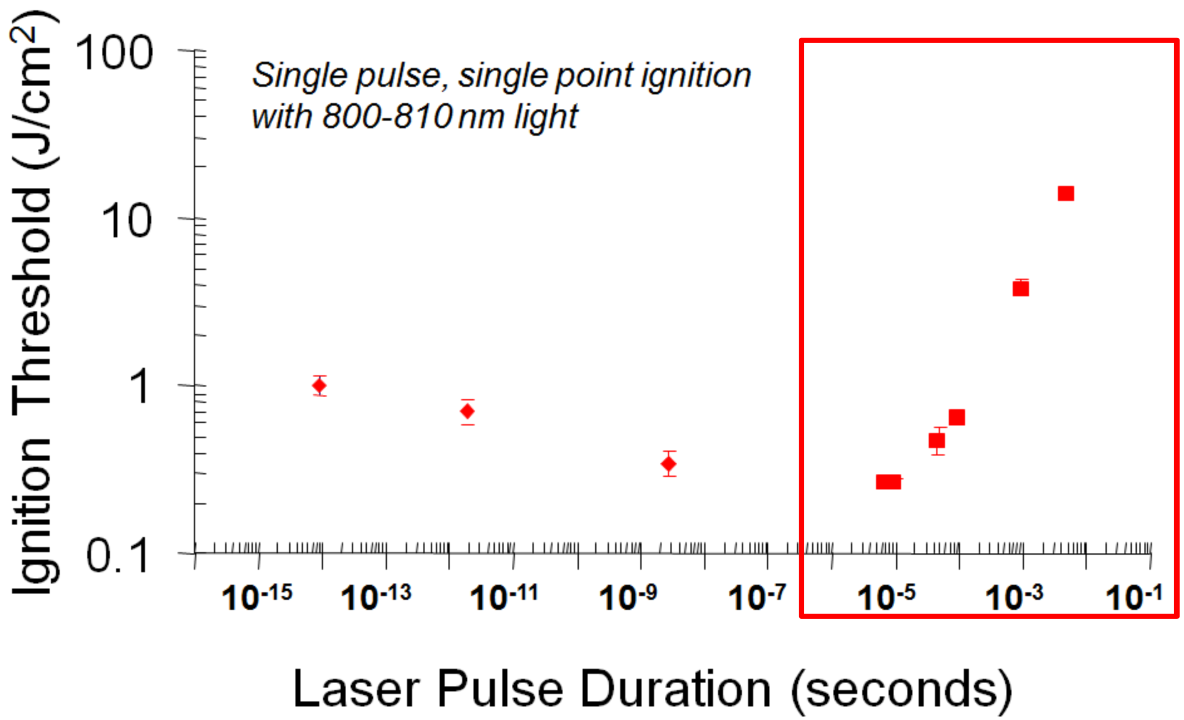
Beam Profile



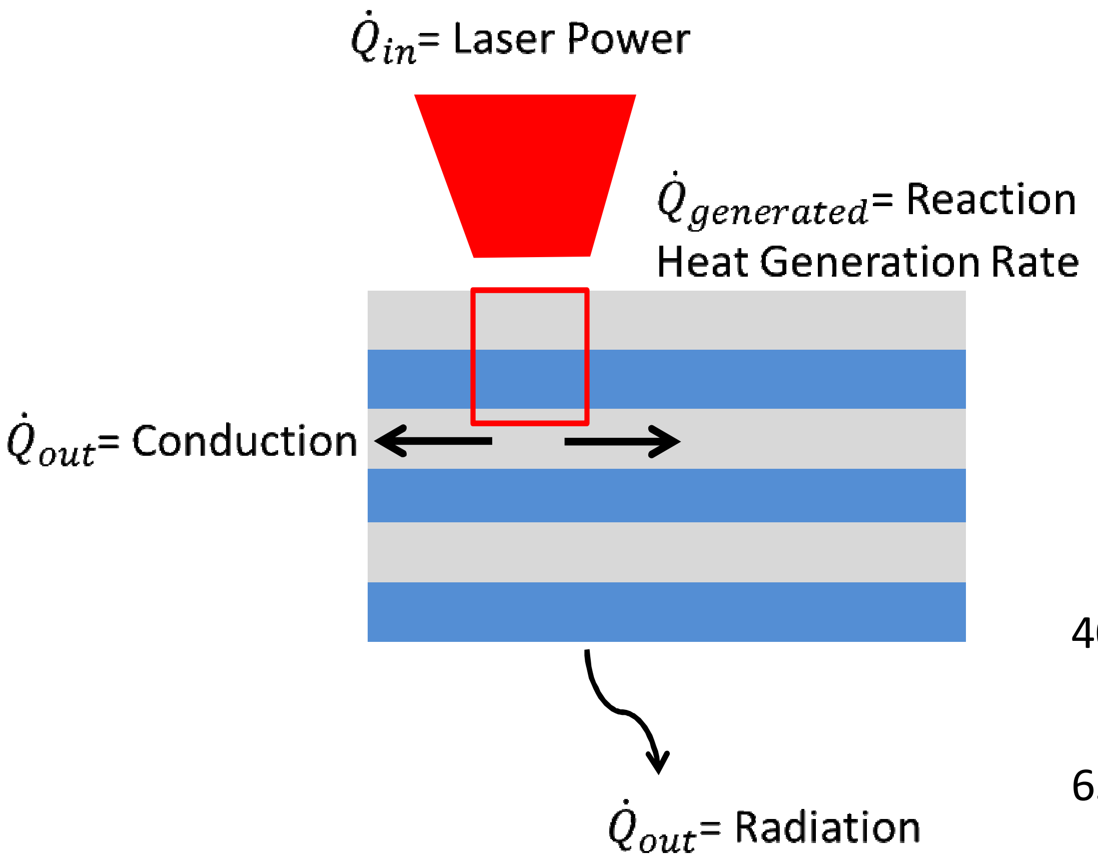


Laser Ignition Threshold

- Foil laser ignition threshold depends on pulse length.
- Laser-material interaction mechanisms depend on pulse length.
- Femtosecond and nanosecond thresholds may be strongly affected by material ablation.
- Bilayer thickness = 123 nm

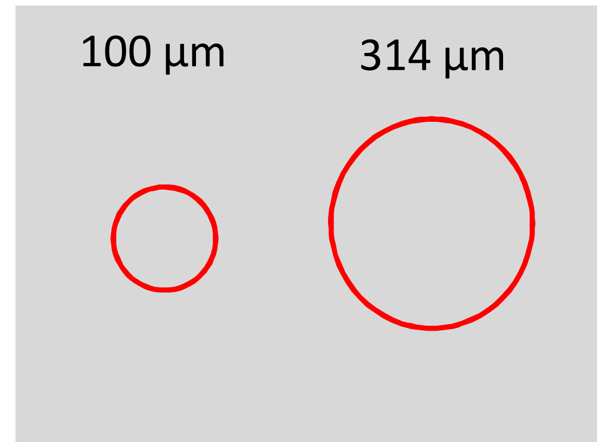


Heat Flow and Interaction Volume



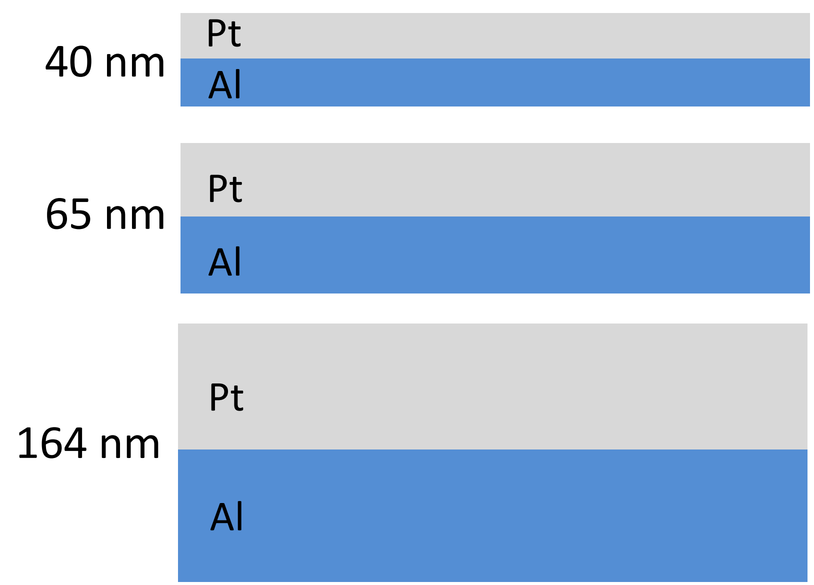
Change interaction volume

Laser Spot Size



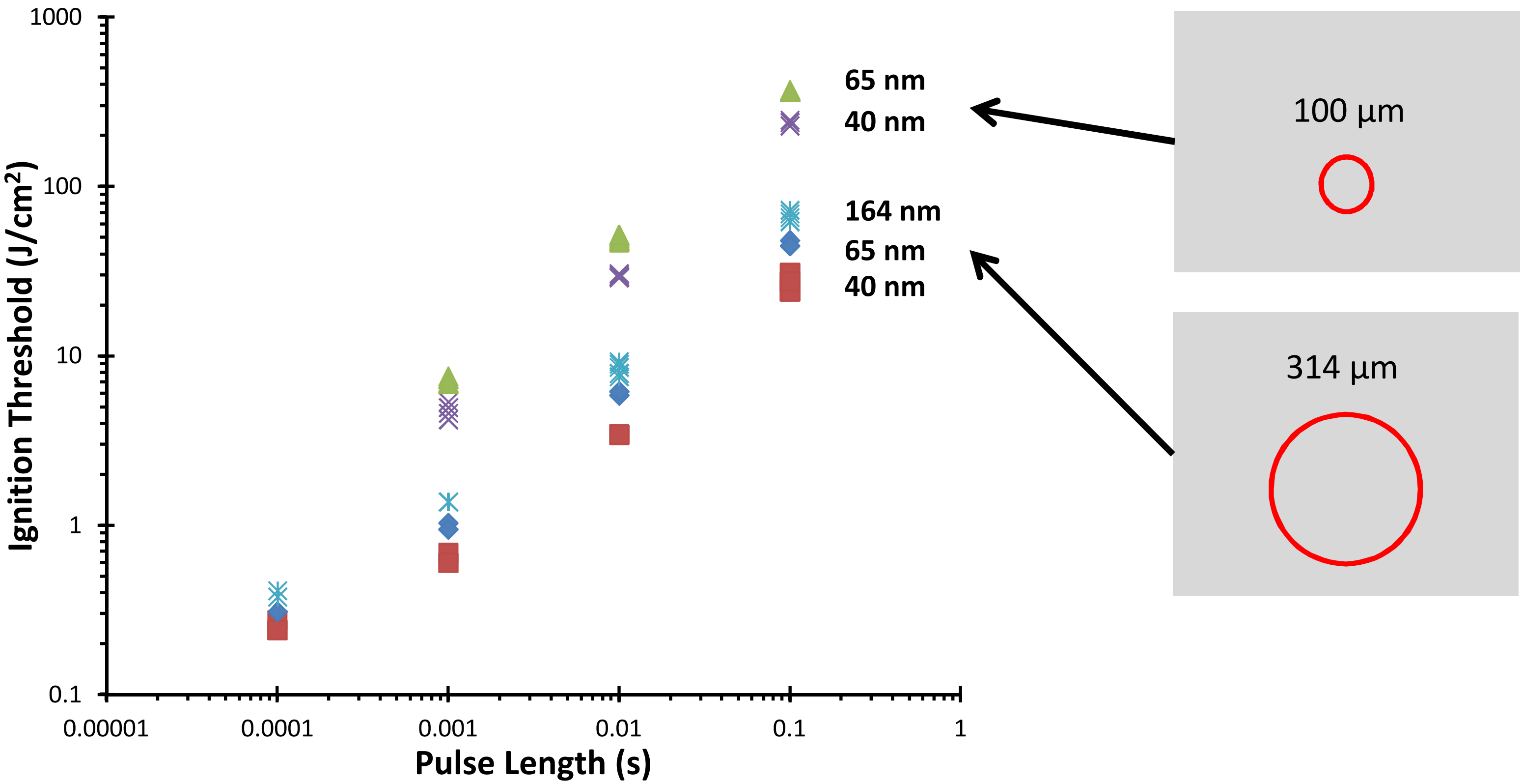
Total thickness = 1.6 µm

Bilayer Thickness



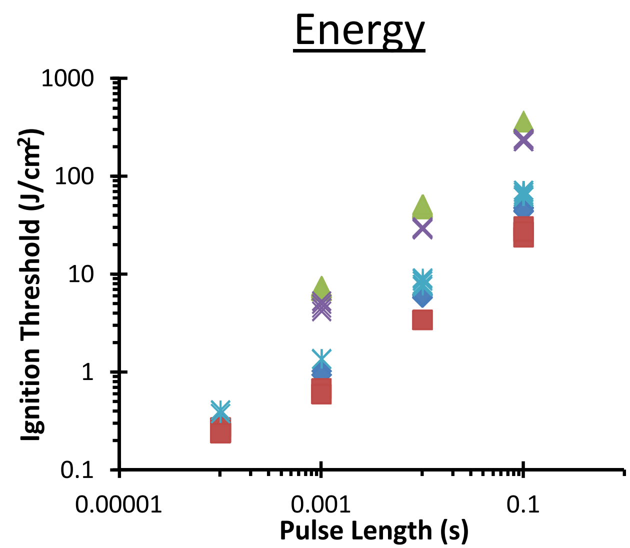
Energy Density Threshold

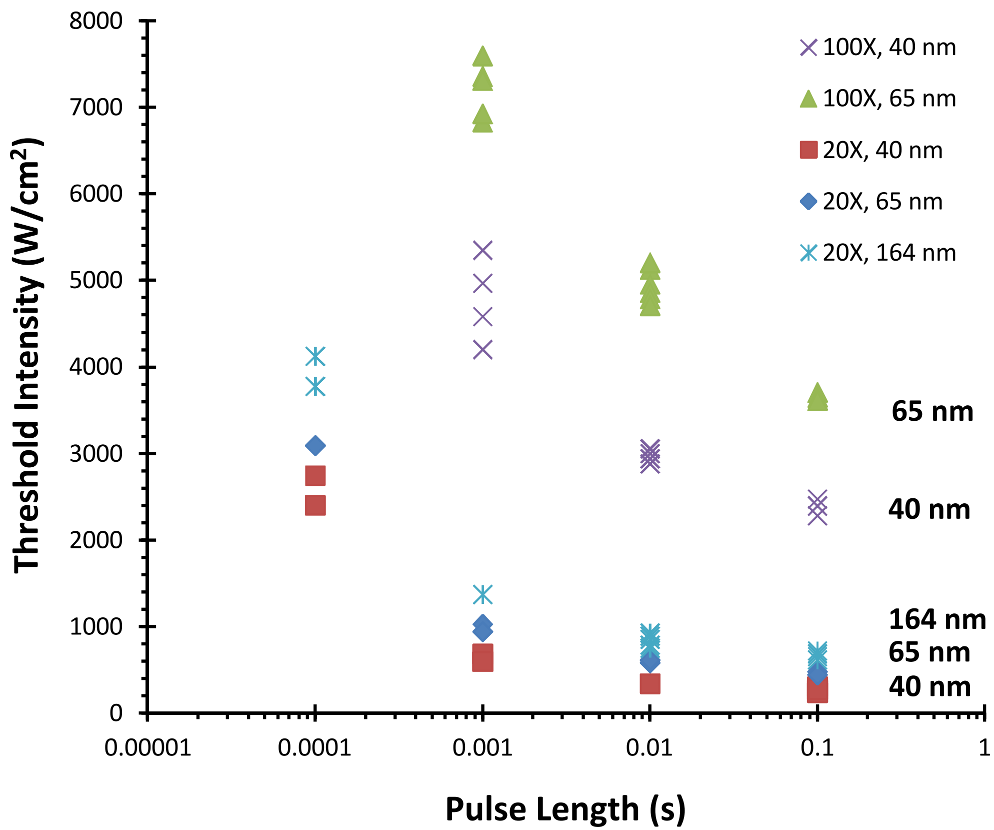
- Energy density (J/cm^2) calculated using total laser pulse E and focused laser area.
- Ignition threshold depends on laser spot size and bilayer thickness.
- Larger interaction volume and larger volume-specific interfacial surface area lower the threshold.

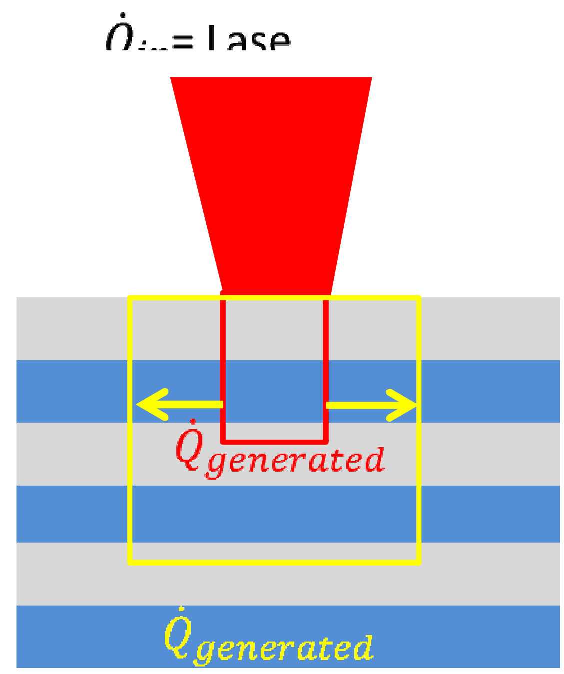


Intensity Threshold

- Intensity (W/cm^2) calculated using energy density and pulse length.
- Ignition threshold depends on intensity.
- Longer pulse lengths lower the intensity threshold.
- Longer pulse length may increase interaction volume via conduction.

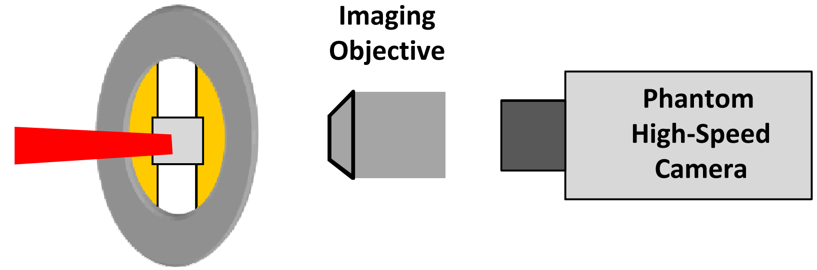






Ignition Starts Before Laser Pulse Turn Off

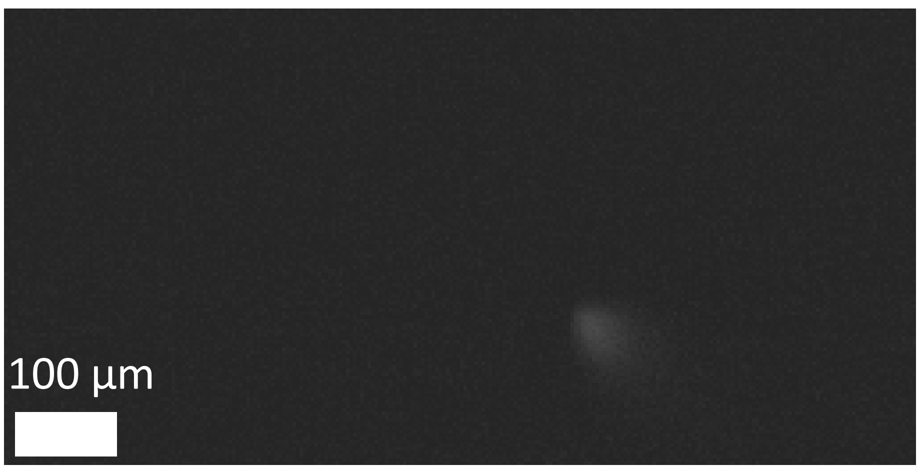
High-speed imaging of Al/Pt foil from the Al side



10 ms Pulse

65 nm Bilayer

10 µs/frame



Foil Ignites ~ 2.88 ms after laser turns on

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Laser Penetrates Foil ~ 2.91 ms after laser turns on

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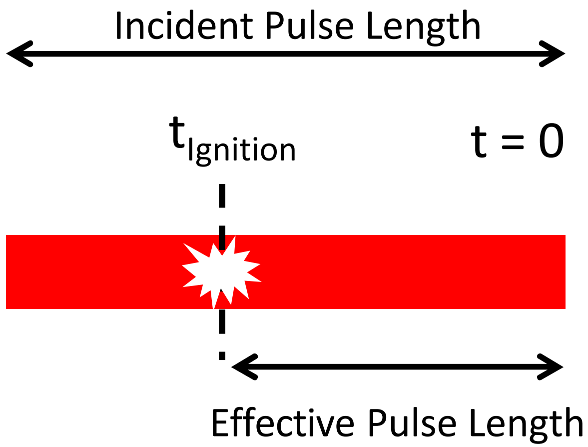
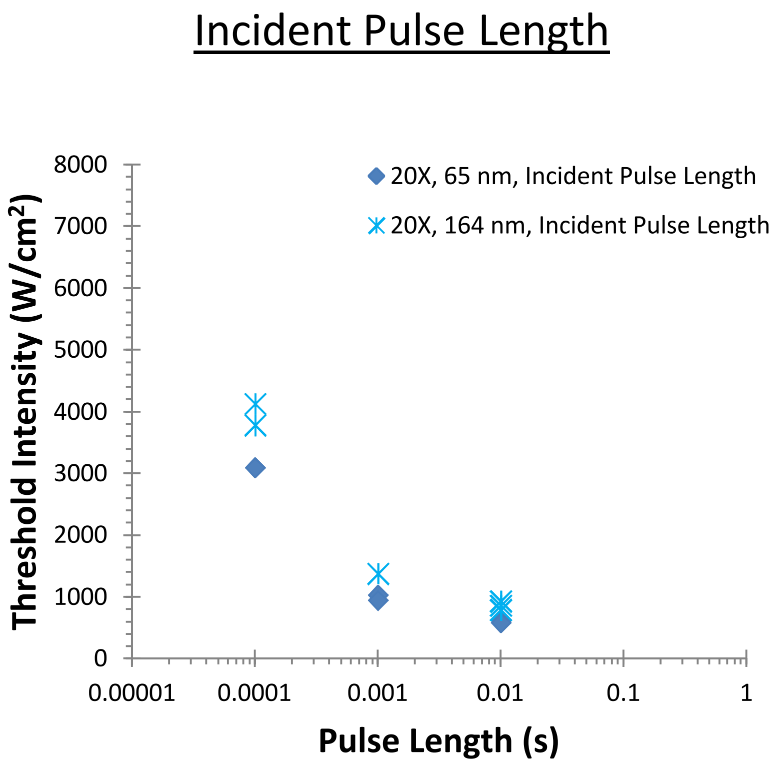
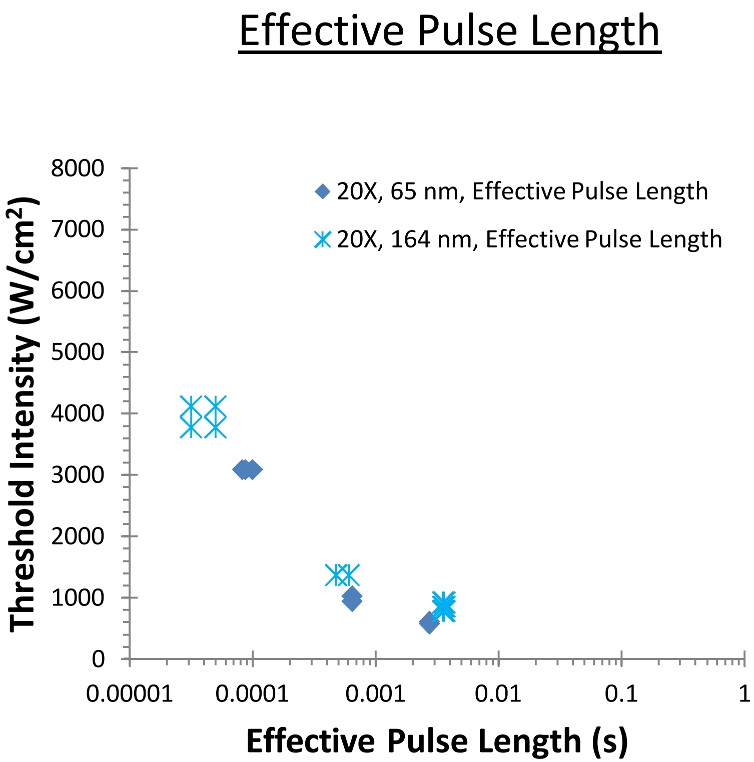
Laser-Foil Interaction Time



- Effective pulse length calculated by observing when ignition begins.
- Effective pulse length is usually shorter than incident pulse length.
- *Shorter pulses require energy to be delivered at a higher rate (power).*

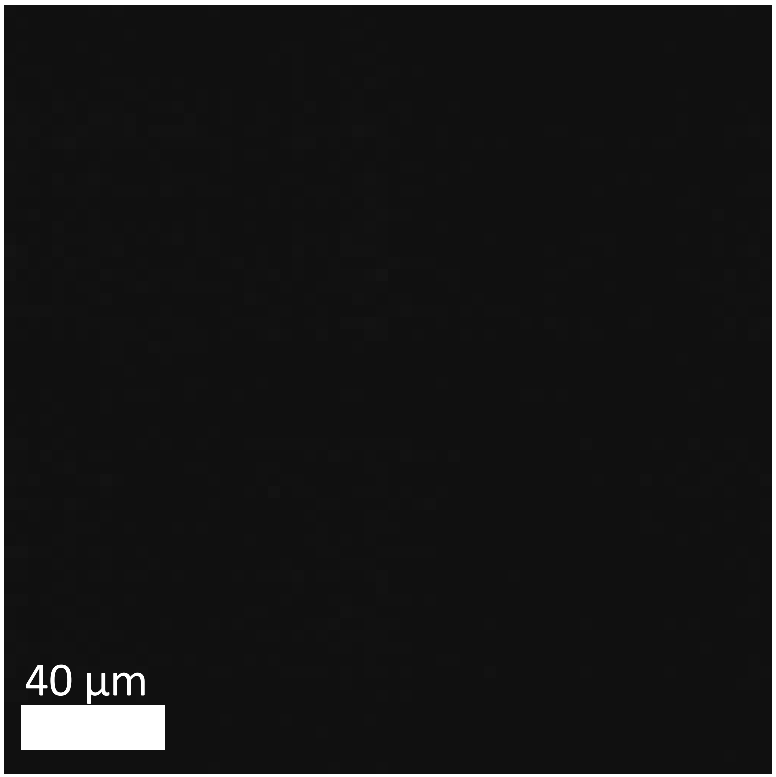




Self-Propagating Reaction after Ignition

10 ms Incident Pulse
164 nm Bilayer

4 µs/frame



Ignition ~ 3.500 ms after pulse turn on

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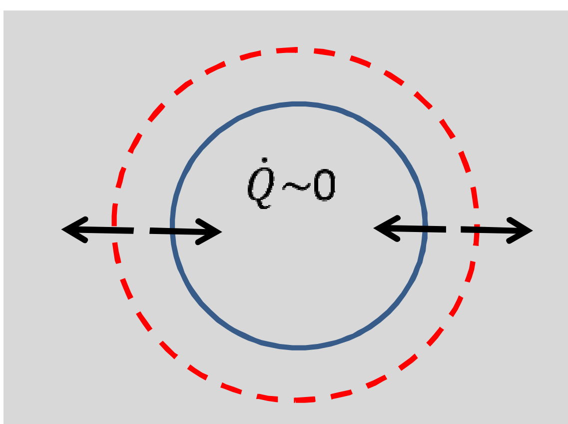
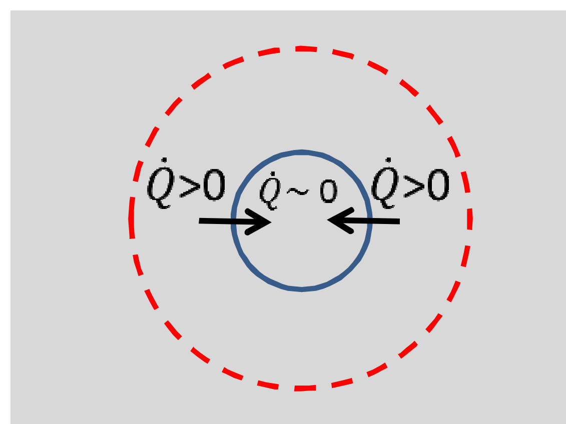
Diffusion Zone vs. Self-Propagating Reaction

- Dark center suggests ignition begins as a slow, non-propagating reaction.
- Bright annulus suggests these regions are hotter than surrounding regions.





Conclusions

- Reactive foils are ignited using single laser pulses.
- Laser pulse lengths ranging from femtoseconds to milliseconds can ignite foils.
- Laser ignition threshold depends on pulse duration, laser spot size, and foil bilayer thickness.
- Increasing laser spot size and decreasing bilayer thickness increases the volume-specific interfacial surface area, leading to decreased ignition threshold.
- Dependence of threshold on laser pulse duration likely due to competition between rate of heat input delivered by laser pulse and heat conductive losses.
- High-speed photography shows ignition usually occurs during laser irradiation.
- Separate reaction zones are observed during laser irradiation and ignition.