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Reactive Foil Ignition Threshold Dependence on Laser and Foil Properties

R.D. Murphy[1], R.K. Grubbs[2], R.V. Reeves[1], J.P. McDonald[3], E. Jones[2], and D.P. Adams[1]

[1]Sandia National Laboratories, Albuquerque, NM USA
[2]Private
[3]Dow Corning Corporation, Midland, MI USA

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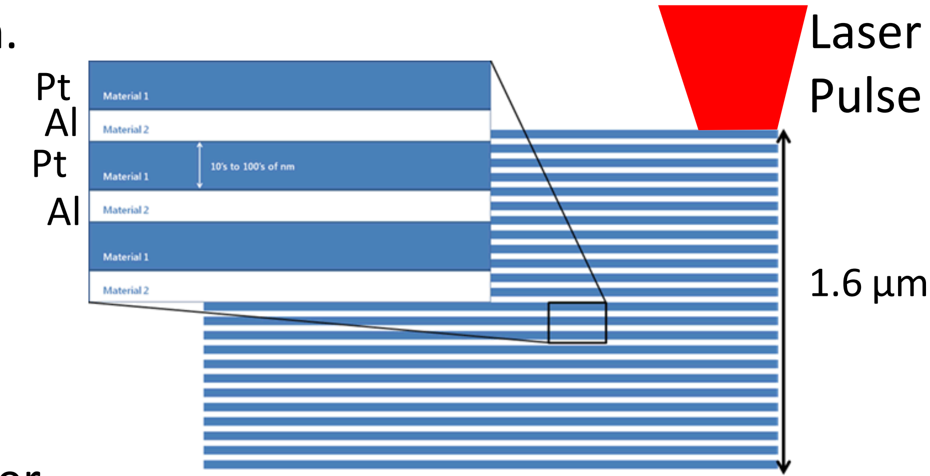
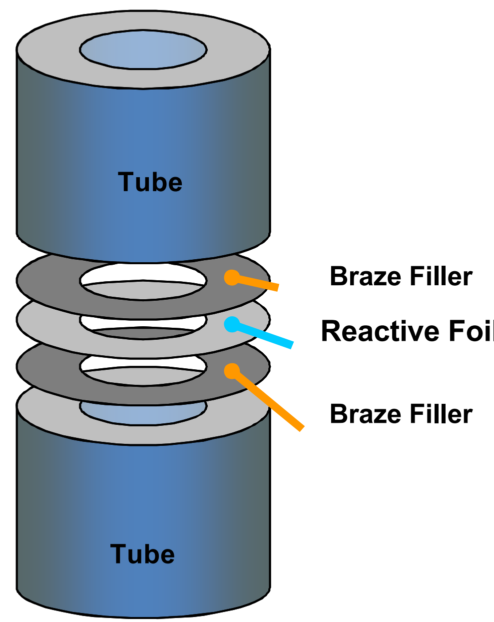
Motivation

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

- 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.



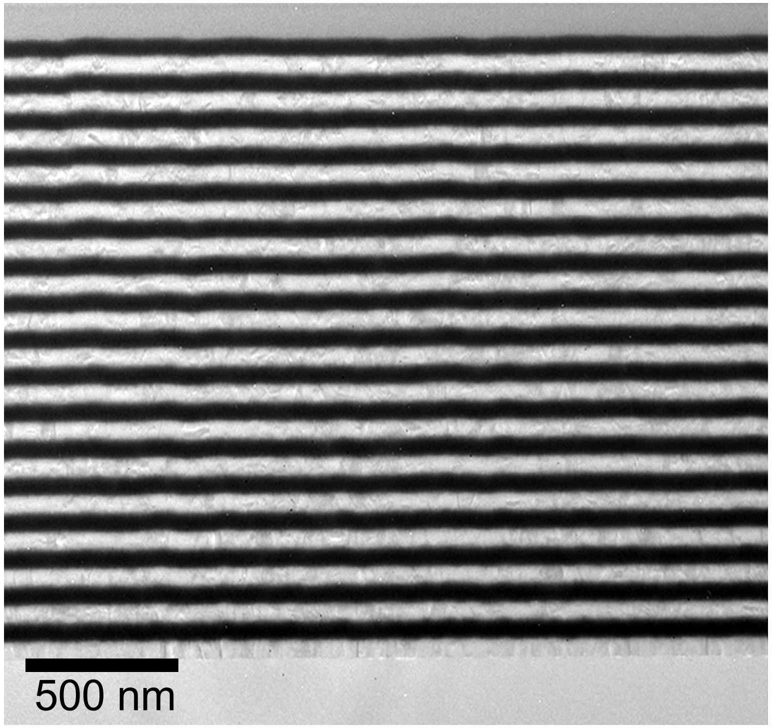
Applications: Joining, Soldering



Reactive Multilayers

Al + Pt → AlPt (intermetallic phase)

Al/Pt multilayer
TEM Cross-section

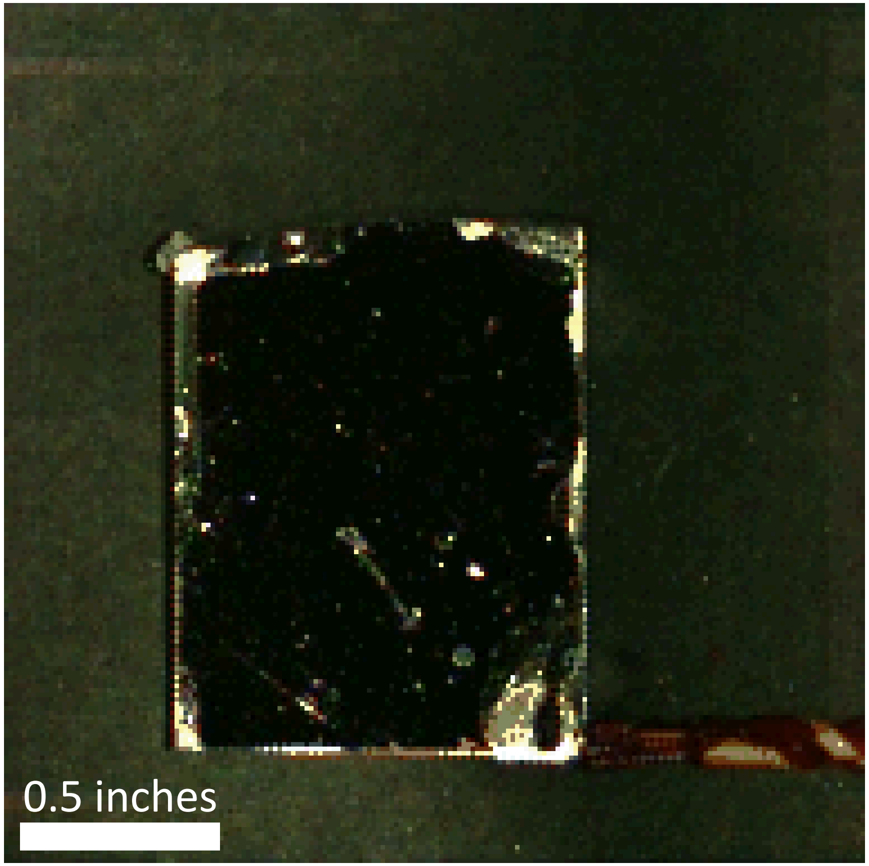


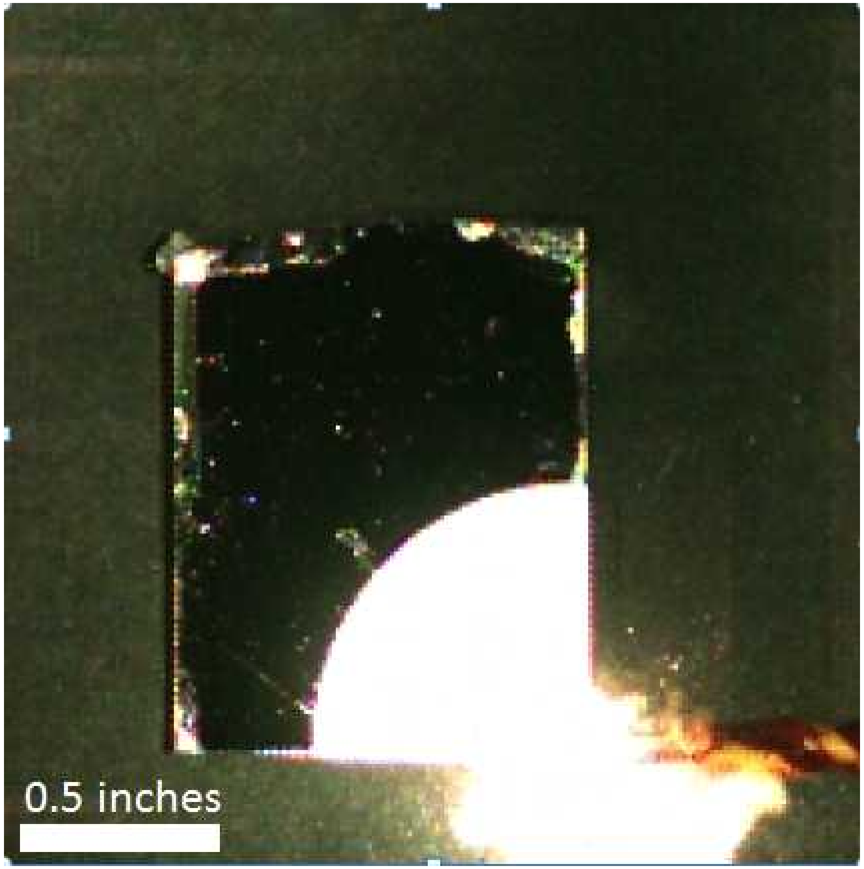
- DC Magnetron sputtered layers
- 10 - 15 Å thickness variation
- 1 to 1 Al/Pt ratio
- Heat of reaction = - 100 kJ/mol
- Adiabatic reaction temperature = 2798 °C
- Reaction onset temperature = 136 °C
- <u>Melting not required for ignition</u>

Ignition and Reaction Propagation

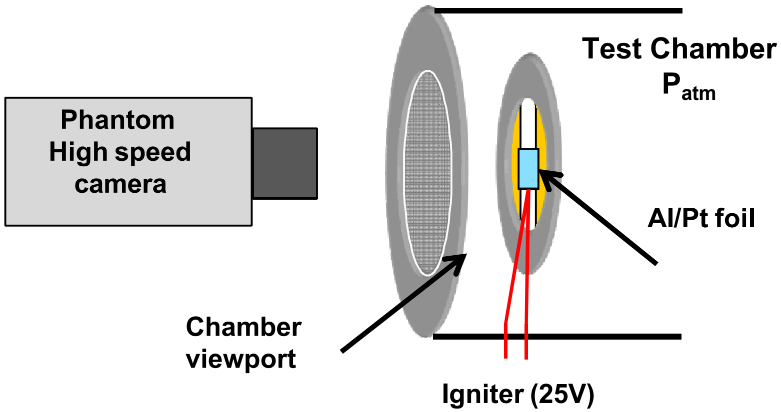
<u>Ignition by capacitive discharge</u>

~ 600 microseconds after ignition

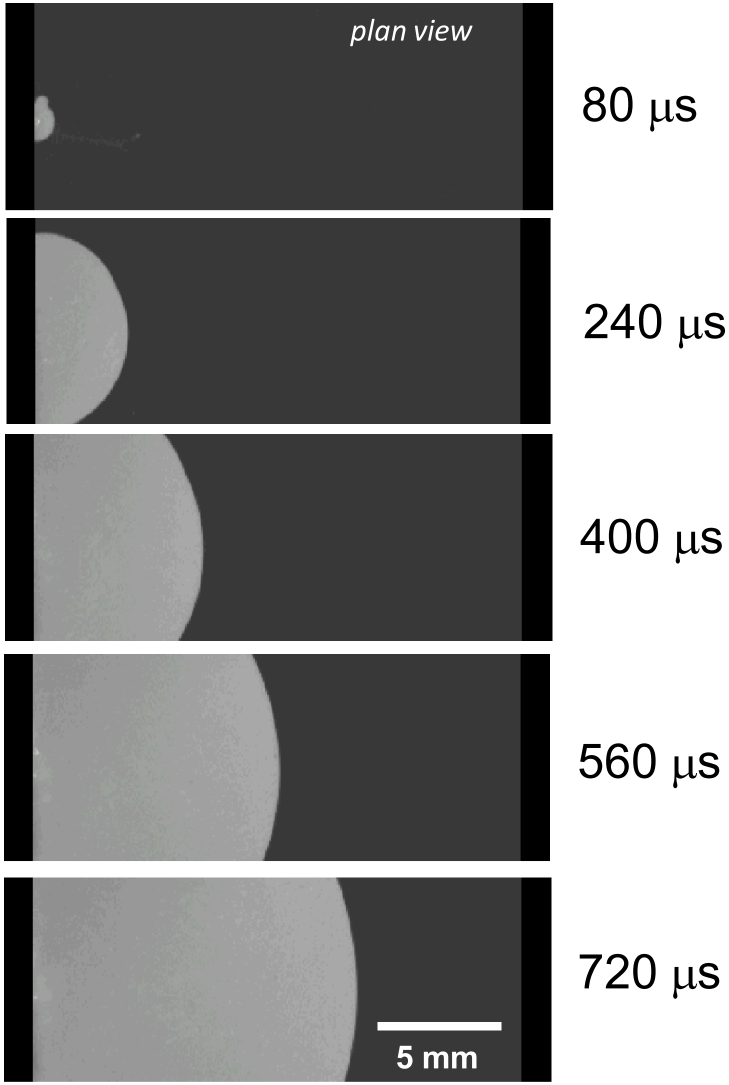




Imaging Reaction Propagation

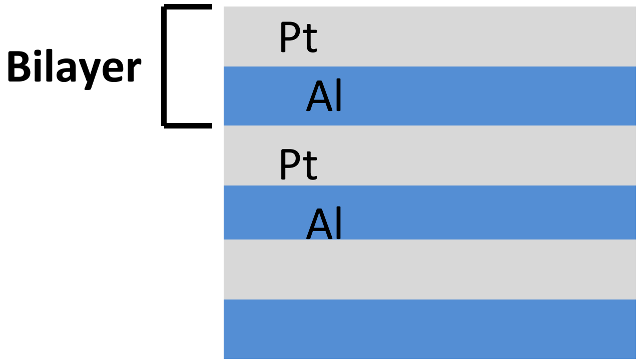


Equiatomic Al/Pt, bilayer thickness = 50 nm

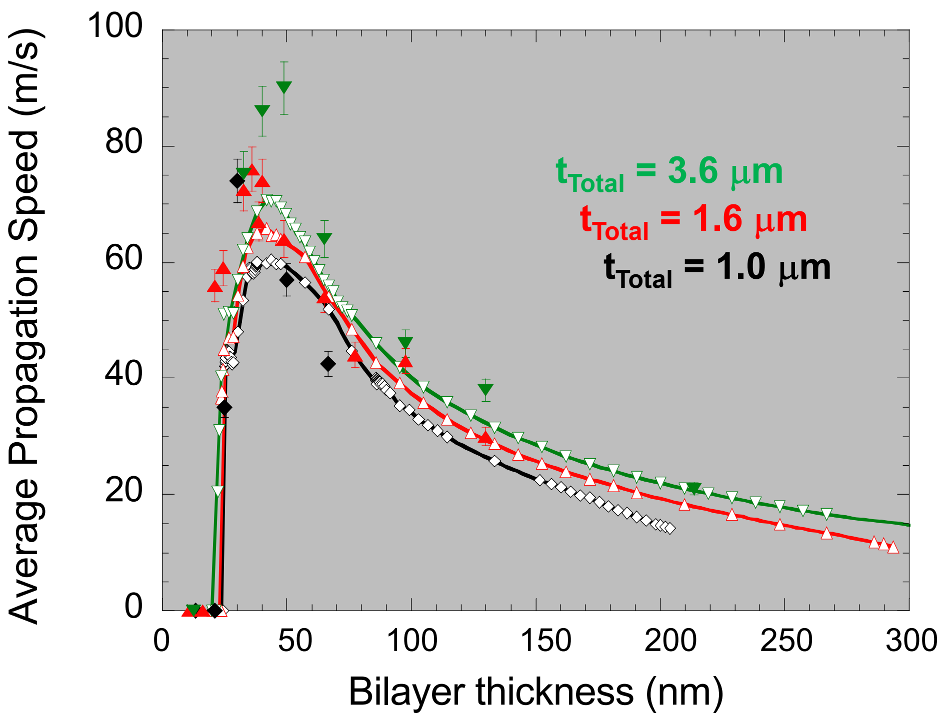


- Point ignition in air.
- Tested as freestanding foils.
- Room temperature.
- High speed photography of steady-state propagation.

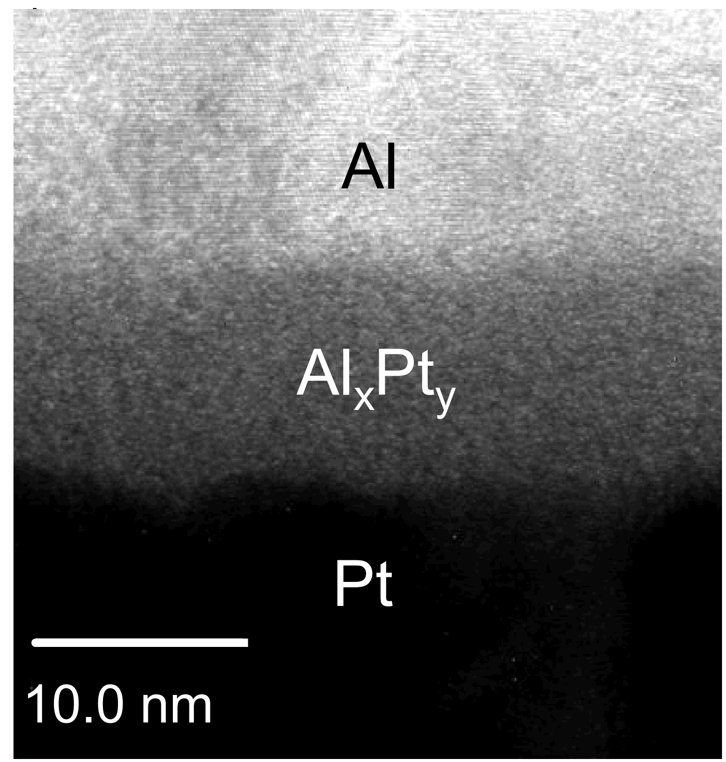
Bilayer Dependence



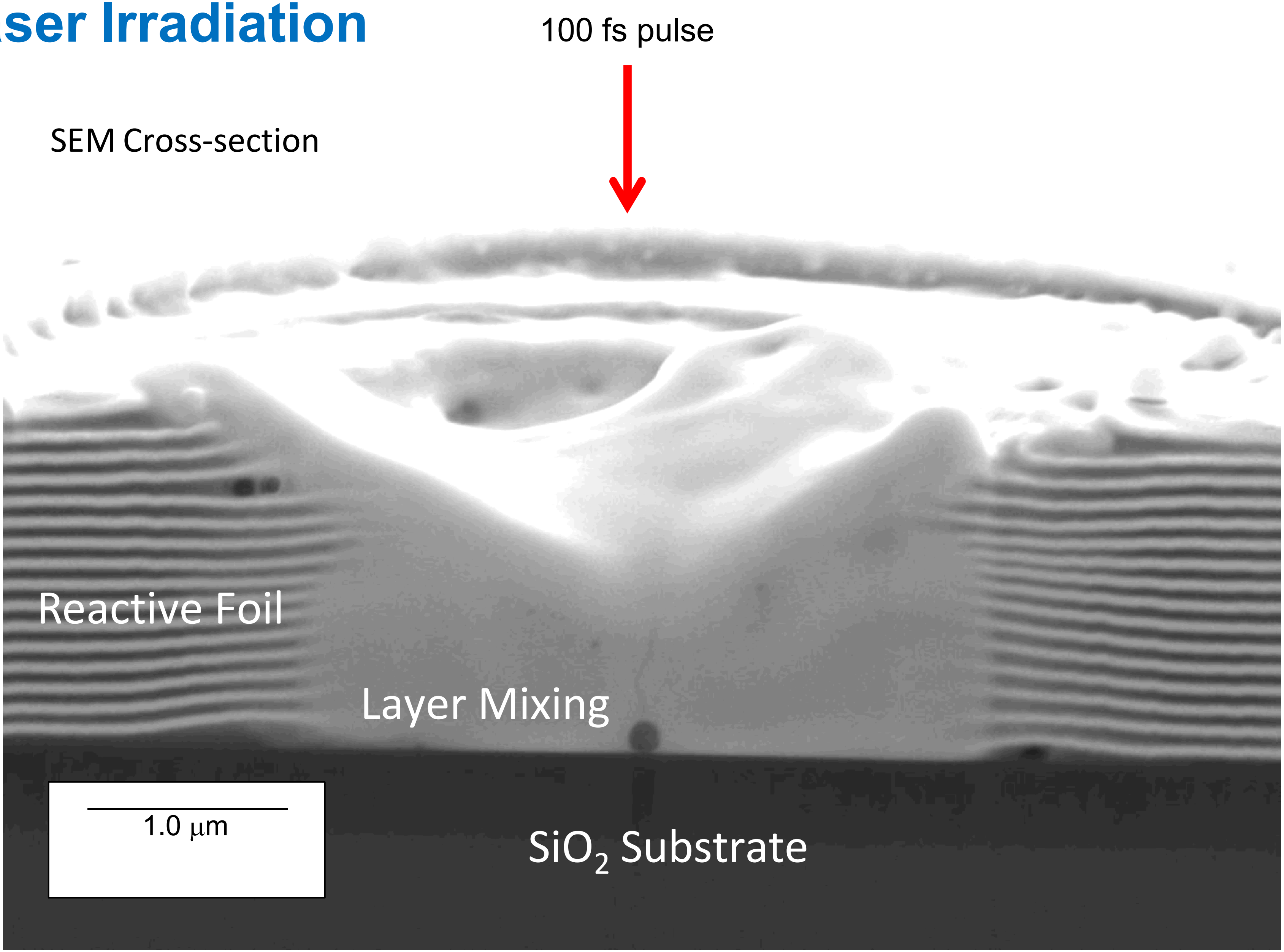
- Propagation speed increases with decreasing bilayer thickness.
- Shorter diffusion distances lead to shorter reaction times.
- Pre-mixing affects propagation speed of thinnest bilayers.



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



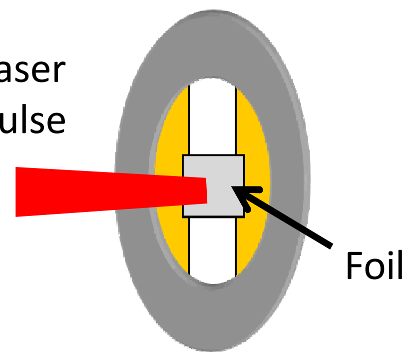
Laser Irradiation



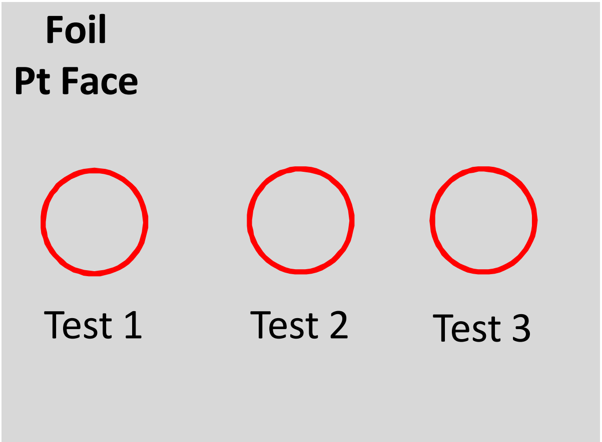
Al/Pt Irradiated at 80% ignition threshold

Determining Laser Ignition Threshold

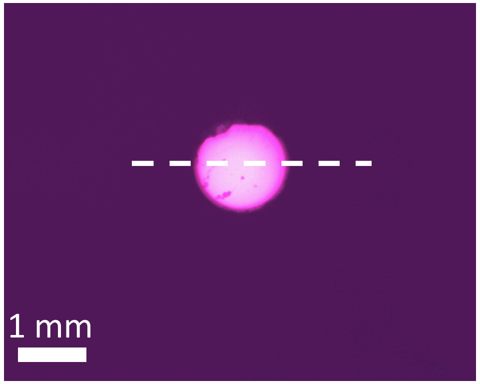
- Foil not on substrate
- Single Pulse Irradiation
- Flat-top Beam Profile
- Irradiate Pt side



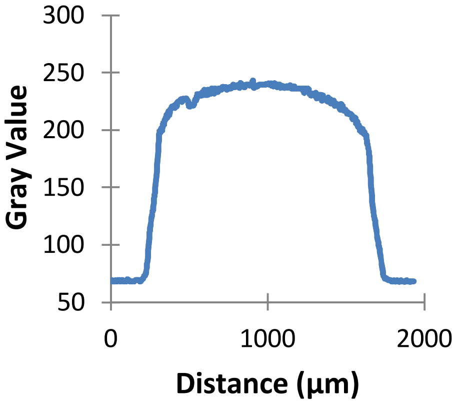
- Laser energy is increased until foil ignites.
- Non-irradiated region of sample is used for each test.

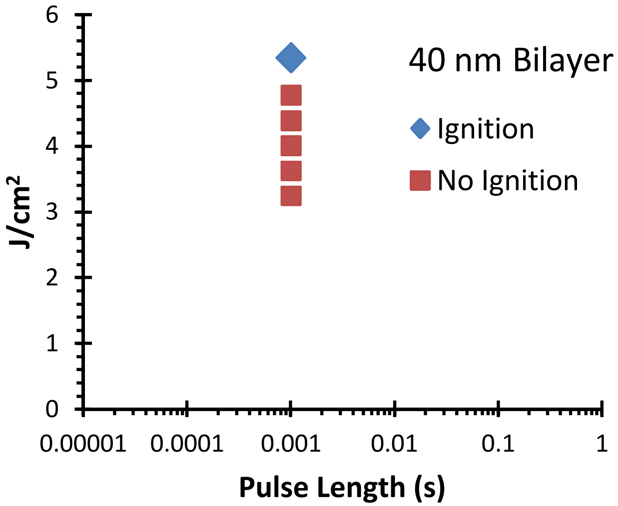


Focused Beam



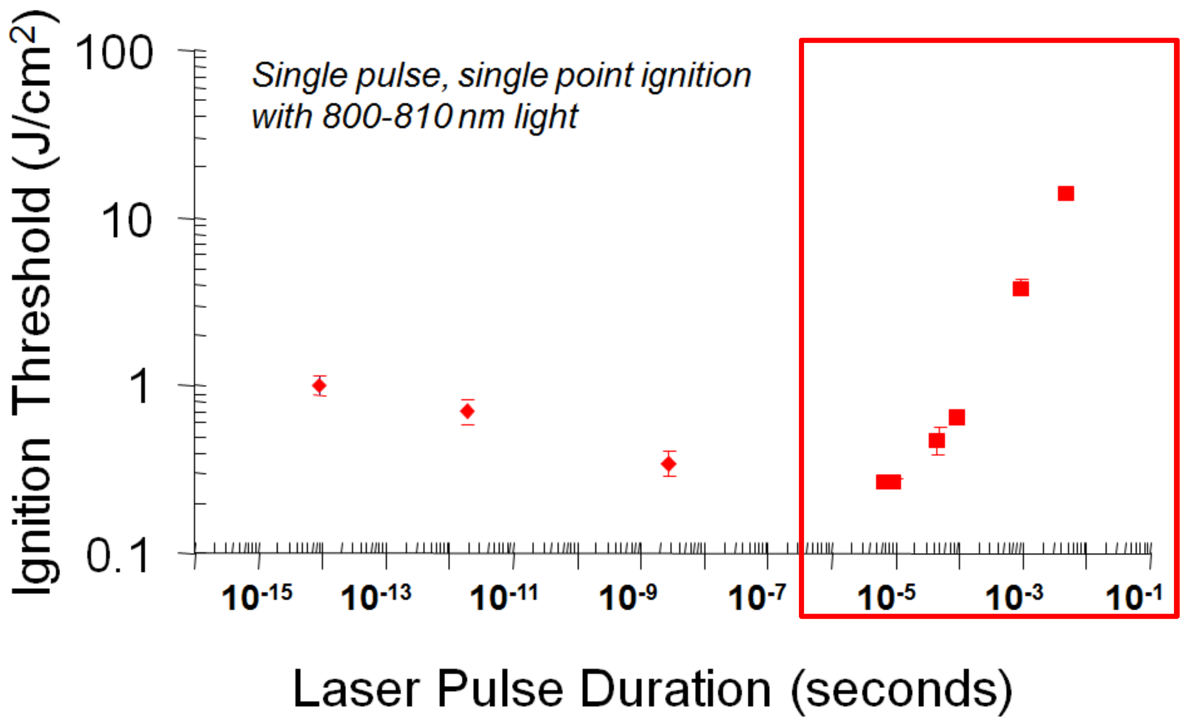
Beam Profile



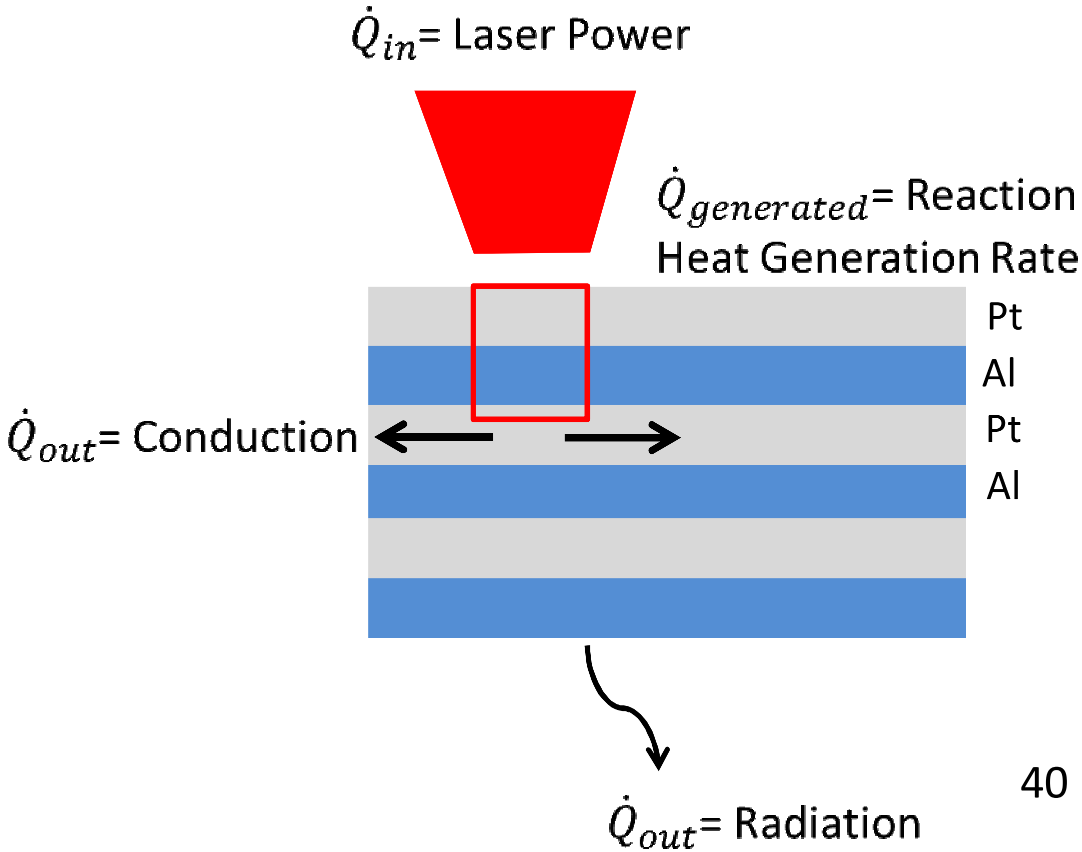


Laser Ignition Threshold

- 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

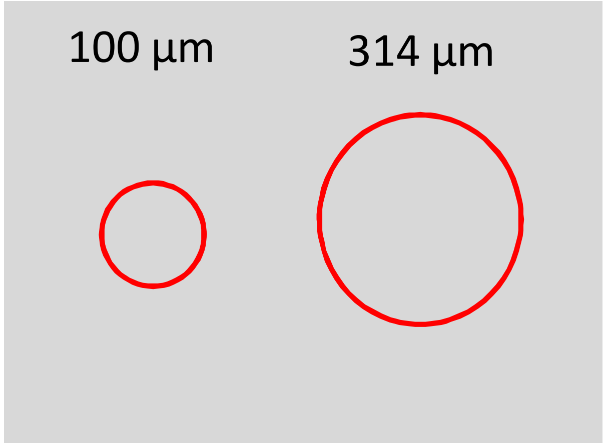


Heat Flow and Interaction Volume



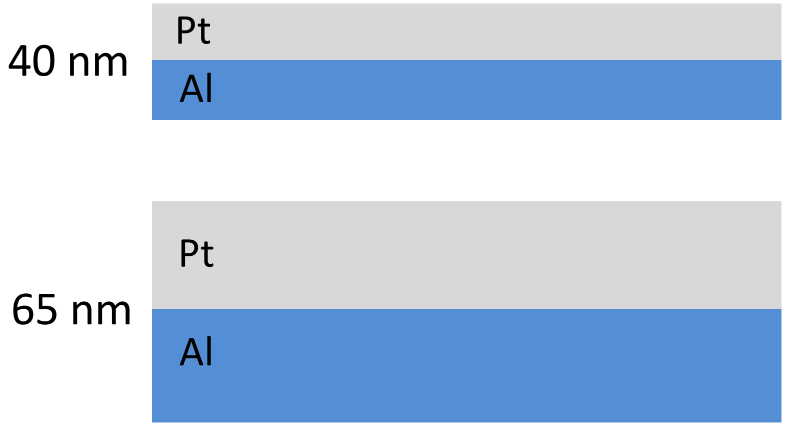
Change interaction volume

Laser Spot Size



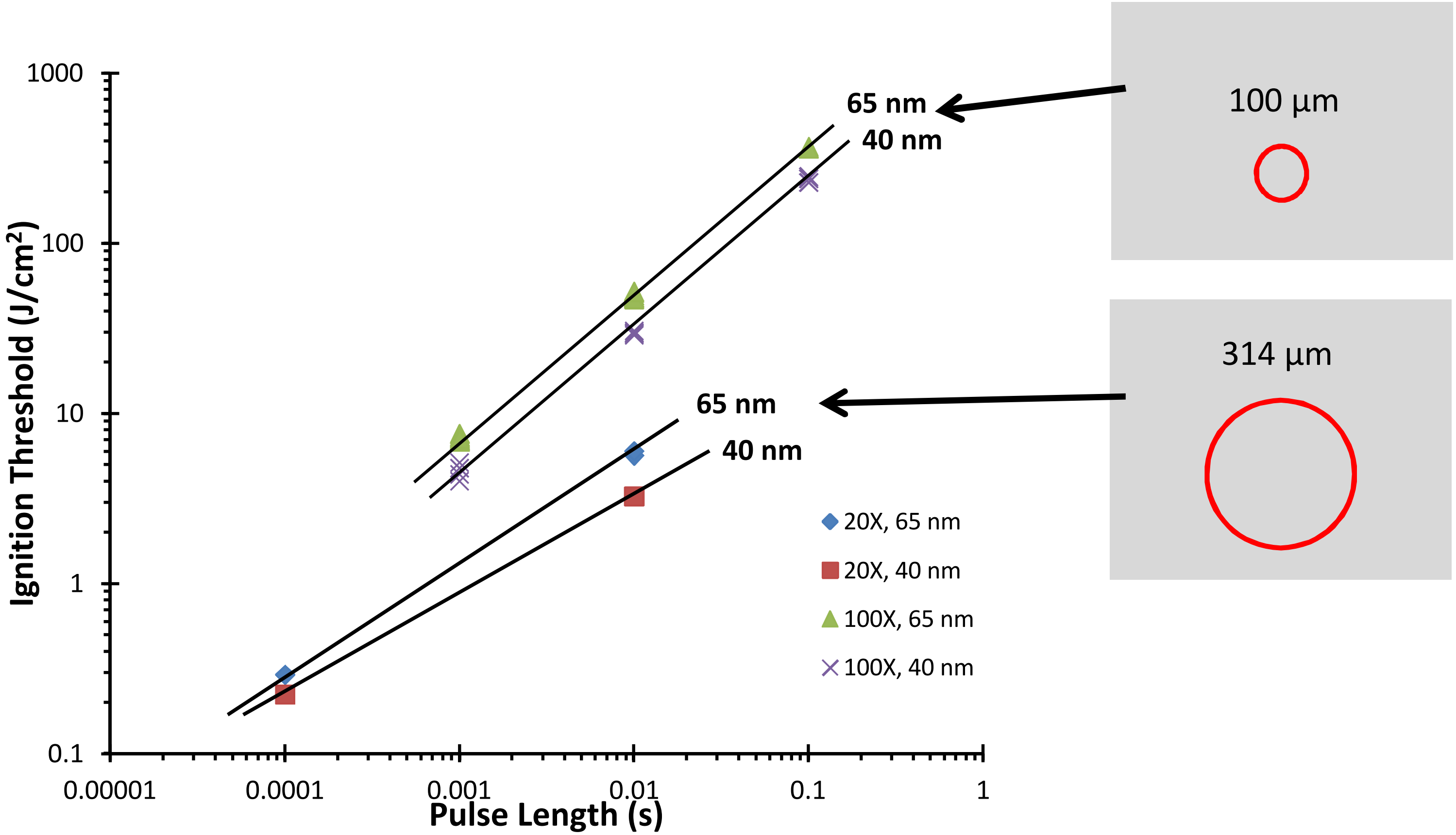
Total thickness = 1.6 µm

Bilayer Thickness



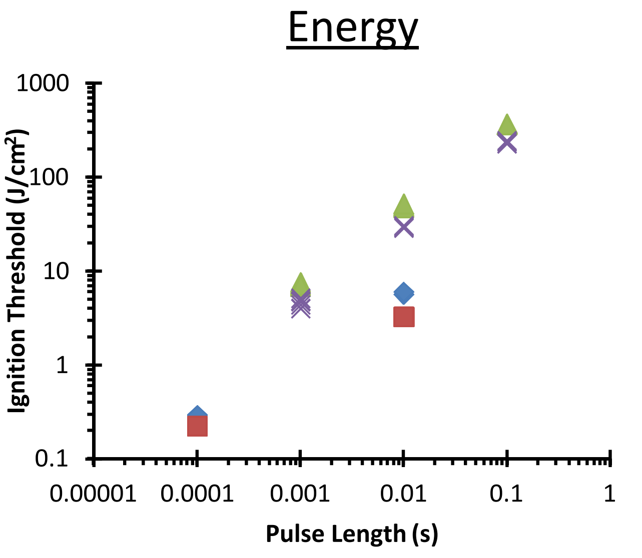
Energy Density Threshold

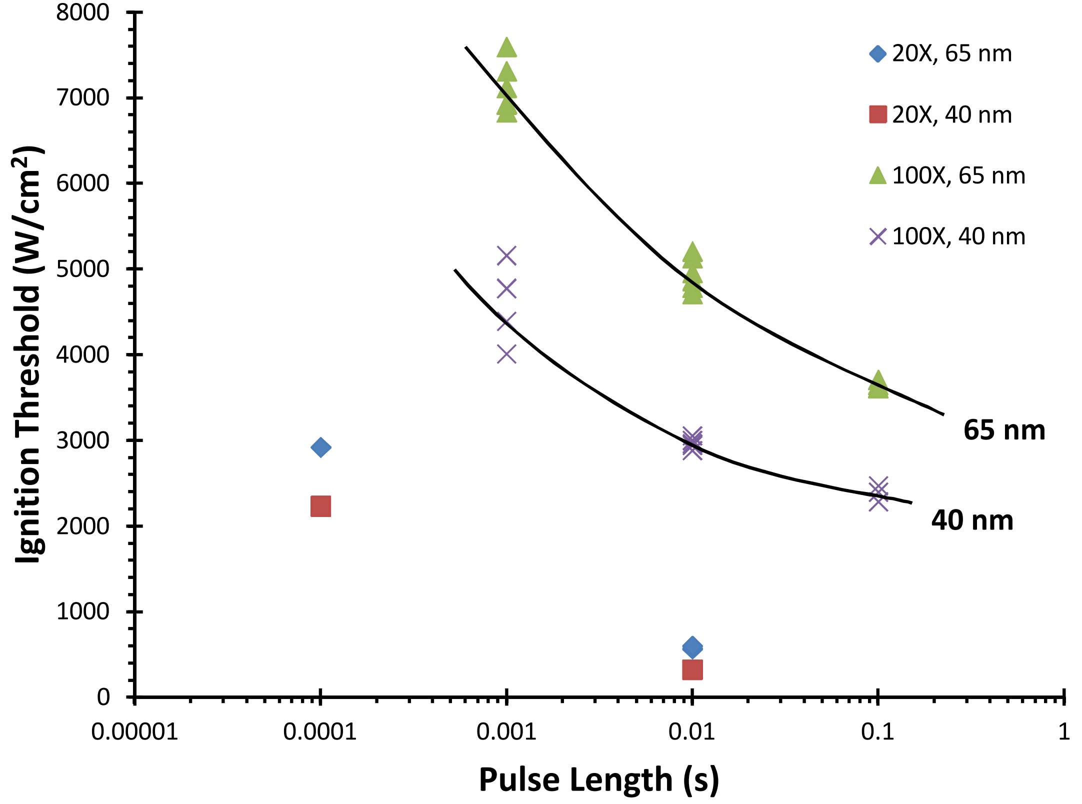
- Energy density (J/cm^2) calculated using total laser pulse E and focused laser area.
- Ignition threshold depends on laser spot size and bilayer thickness.
- Larger interaction volume and larger volume-specific interfacial surface area lower the threshold.

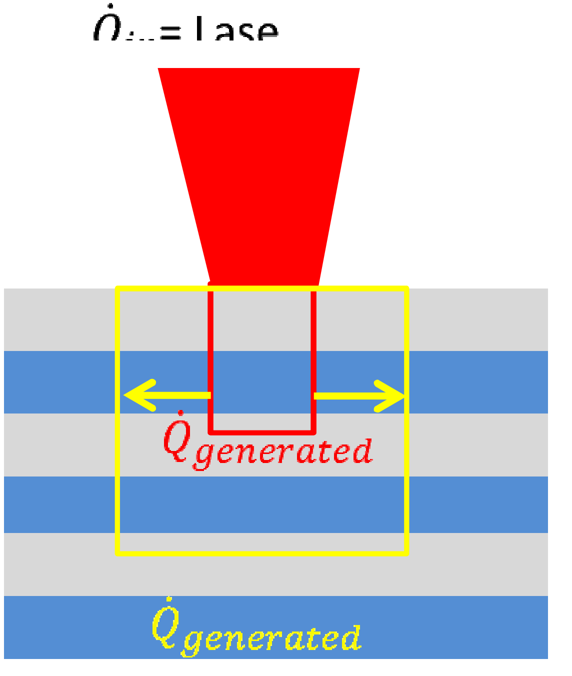


Intensity Threshold

- 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.







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.