Sandia National Laboratories

Reactive Foil Ignition by Pulsed Laser Irradiation

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Abstract

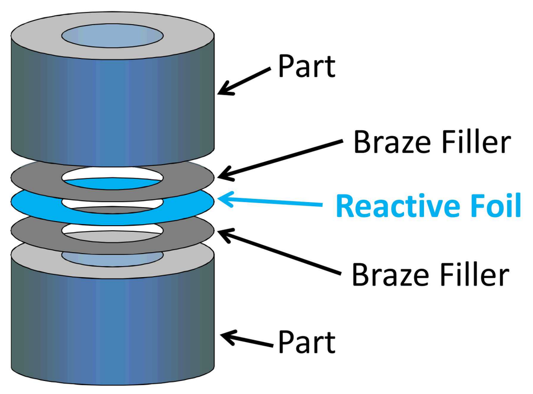
It has been shown that forced mixing of reactive layers (foils) leads to an exothermic release of energy after initiation of mixing by forced impact or pulsed laser irradiation. In order to understand the ignition of foils initiated by laser irradiation, we study the interaction of laser pulses with Al/Pt multilayer reactive foils prepared by sputter deposition. It will be shown that the single-pulse ignition threshold is dependent on the length of the laser pulse as the pulse length is varied from 100 fs to 100 ms. The dependence of the ignition threshold on pulse length is a combination of laser-material interactions such as the size of the heat affected zone, changes in reflectivity with pulse length, and the onset of ablation for ultrafast irradiation. The laser spot size is varied for each pulse length to explore the effects of heat confinement on the ignition threshold. Foil ignition kinetics is further investigated by varying the bilayer thickness for each pulse length, which subsequently changes properties such as mixing and reaction front velocity.

Applications

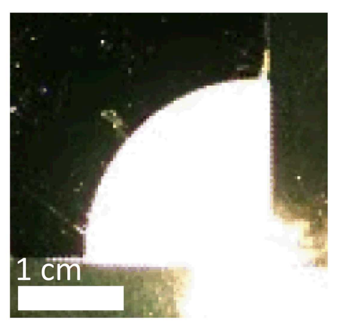
- Reactive foils typically used for joining applications
- Ignition generates heat and induces self-propagating reaction
- Adiabatic reaction temperature = 2798 °C
- Heat from reaction melts brazing material
- Laser induced ignition leads to more control over ignition
- Laser irradiation commonly used for cutting foils
- Laser ignition allows for remote ignition of foils

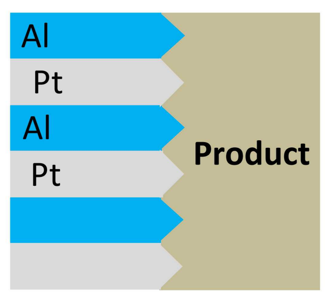
Ignition → Self-propagating reaction

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



~ 600 microseconds after ignition

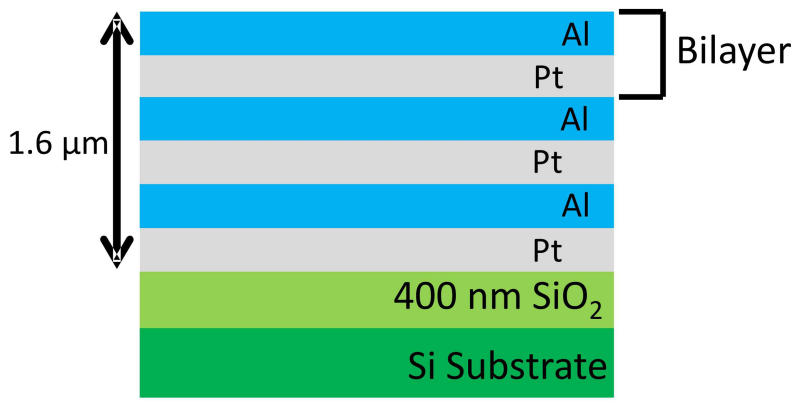




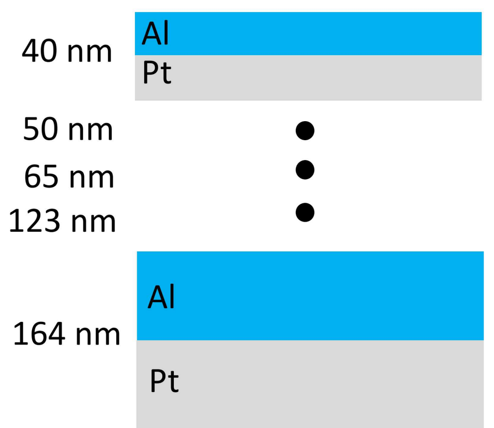
Experimental

Film Growth

- DC Magnetron Sputtering
- SiO_2 deposited first as a passivation layer
- Several bilayer designs tested
- Bilayer thickness chosen to maintain a 1-to-1 Al/Pt atomic ratio
- Foils removed from substrate before ignition

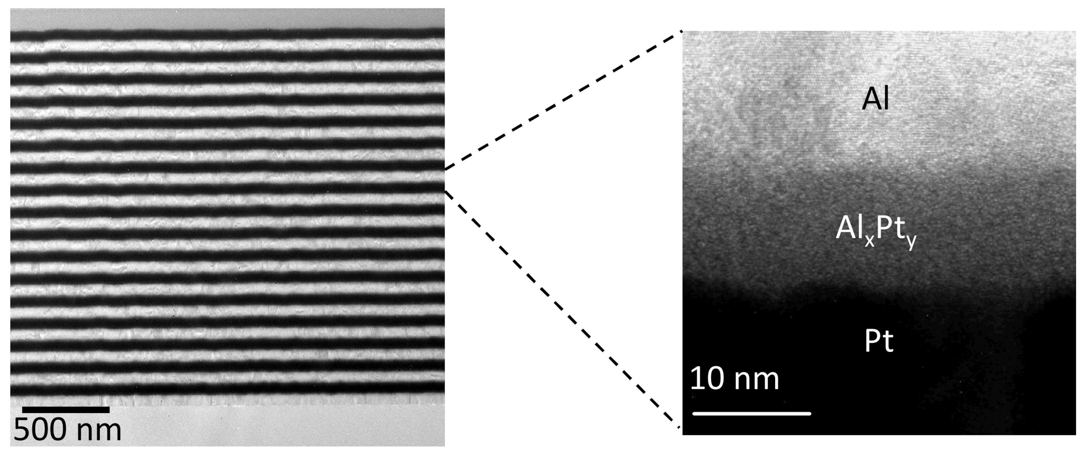


Bilayer Thicknesses Tested



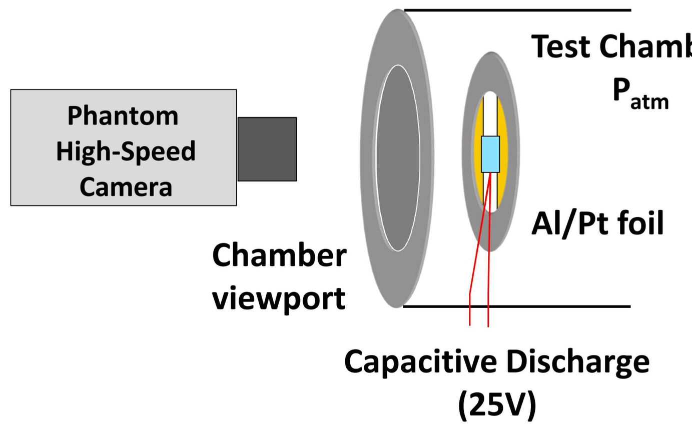
Characterization

- Bright-field transmission electron microscopy cross-section
- 10 - 15 Å layeer thickness variation
- Pre-mixing at interfaces during deposition forms layers of product phases (Al_xPt_y)

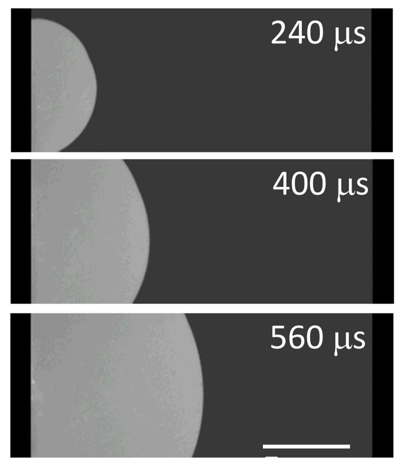


Imaging Reaction Propagation

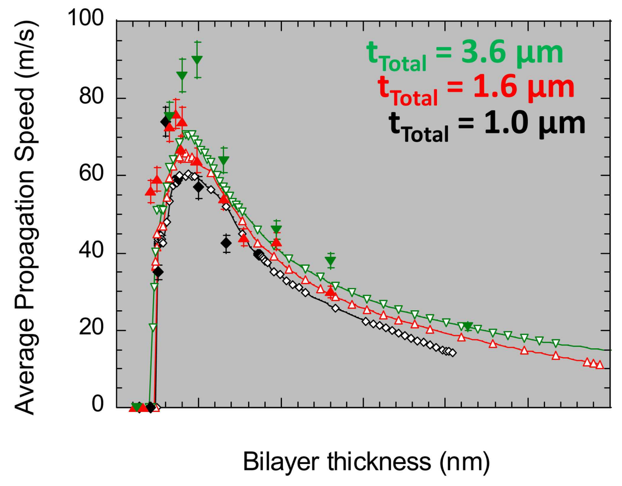
- Ignition by capacitive discharge in air
- Freestanding foils
- Room temperature
- High-speed photography of steady-state propagation



Bilayer thickness = 50 nm



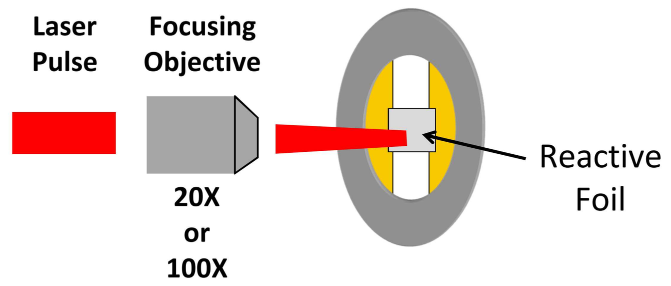
- Reaction front speed increases with decreasing bilayer thickness.
- Pre-mixed regions responsible for no propagation of thinnest bilayers.

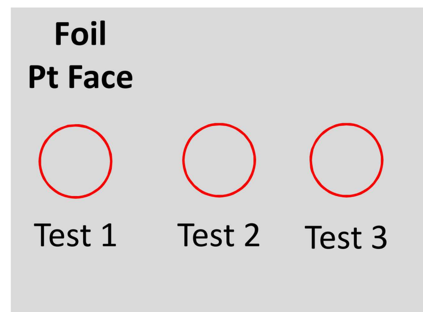


M. Hobbs, D.P. Adams, et al., 8th World Congress Comp. Mech. (2008).

Laser Ignition

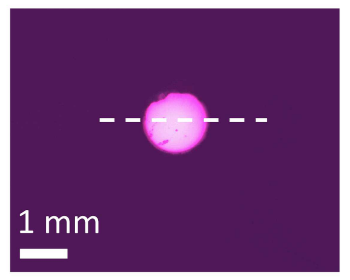
- Single laser pulses used to ignite foils
- Always irradiate Pt side first
- Flat-top beam profile



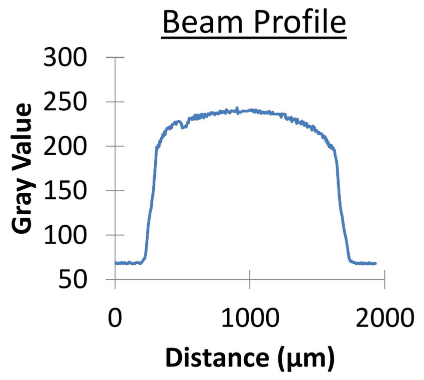


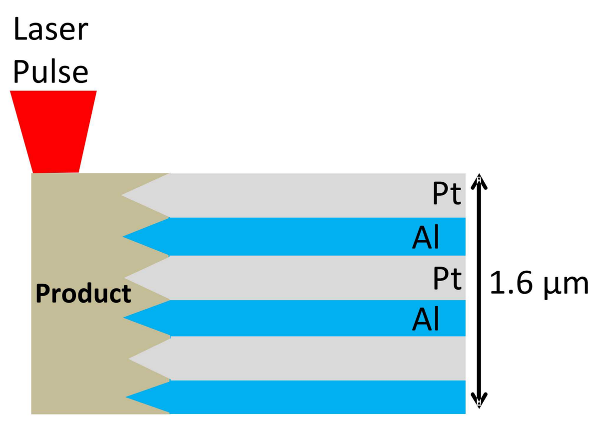
- Laser energy is increased until foil ignites
- Non-irradiated region of foil used for each test
- Laser fluence is calculated by dividing laser energy by focused laser beam area

Focused Beam

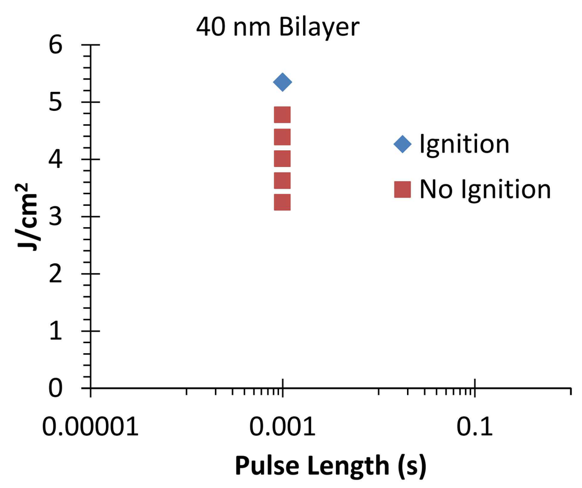


Beam Profile





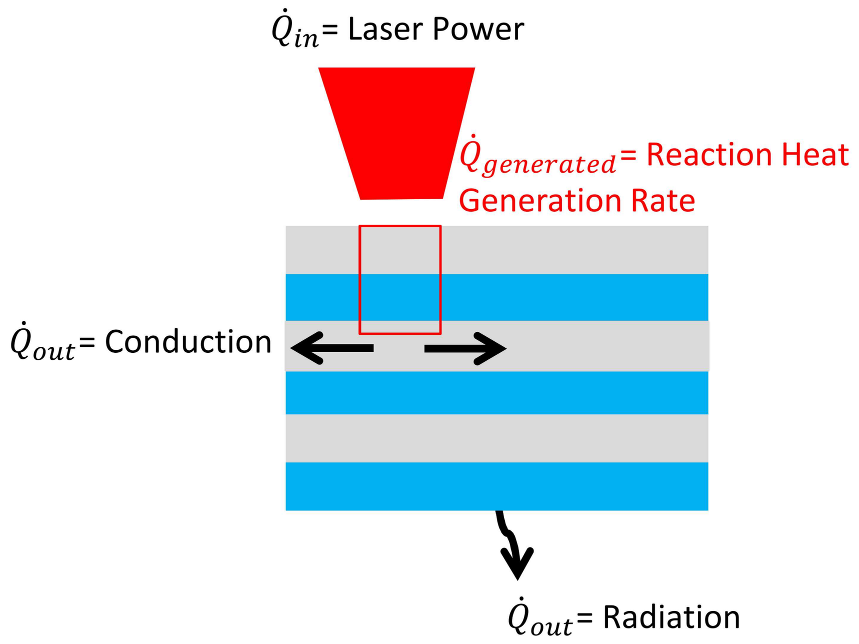
Determining Ignition Threshold



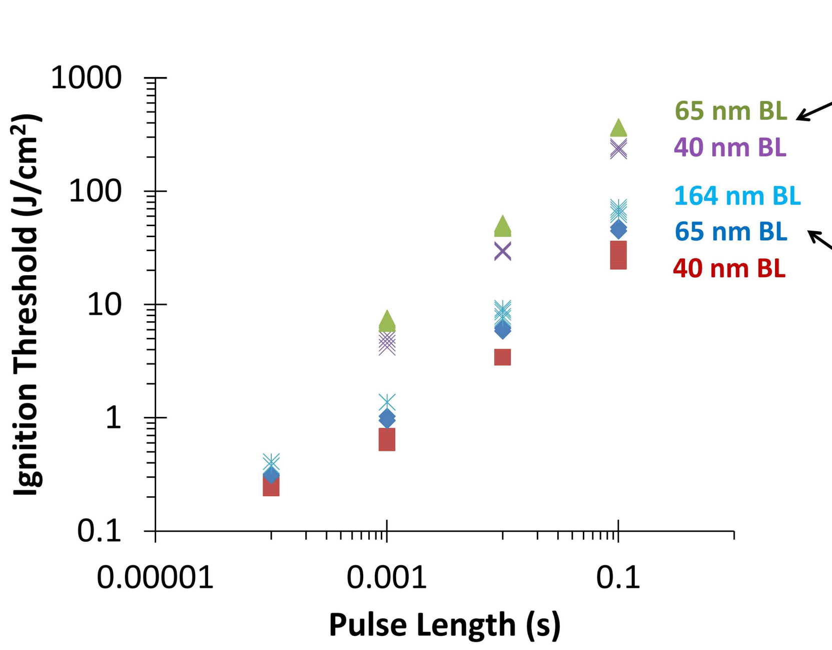
Ignition Thresholds

- Laser-foil interaction volume is initially defined by the focused laser beam diameter and the bilayer thickness
- Input heat flow is provided by laser power and heat generated by self-propagating reaction
- Heat flow away from system is main due to conduction
- Heat flow during and after irradiation changes interaction volume

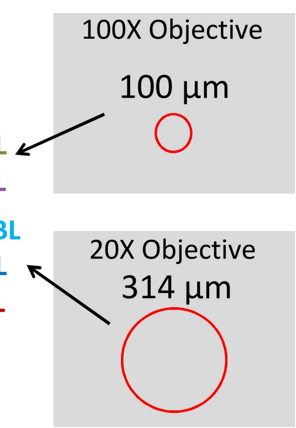
- The laser fluence required for ignition increases with increasing pulse length
- Thinner bilayers have lower thresholds
- Larger laser diameters have lower thresholds
- Larger laser interaction volumes lead to lower thresholds



Laser Fluence Threshold



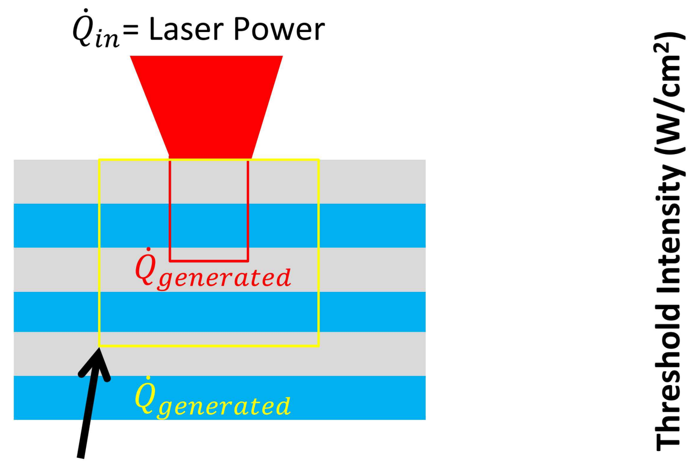
Focused Laser Diameter



Timescales

- Laser fluence does not account for incident laser pulse length
- Calculate laser intensity by dividing laser fluence by the pulse length

- Intensity threshold decreases with increasing pulse length
- Suggests conduction of heat generated by reaction during irradiation increases the interaction volume, decreasing the threshold for longer pulses

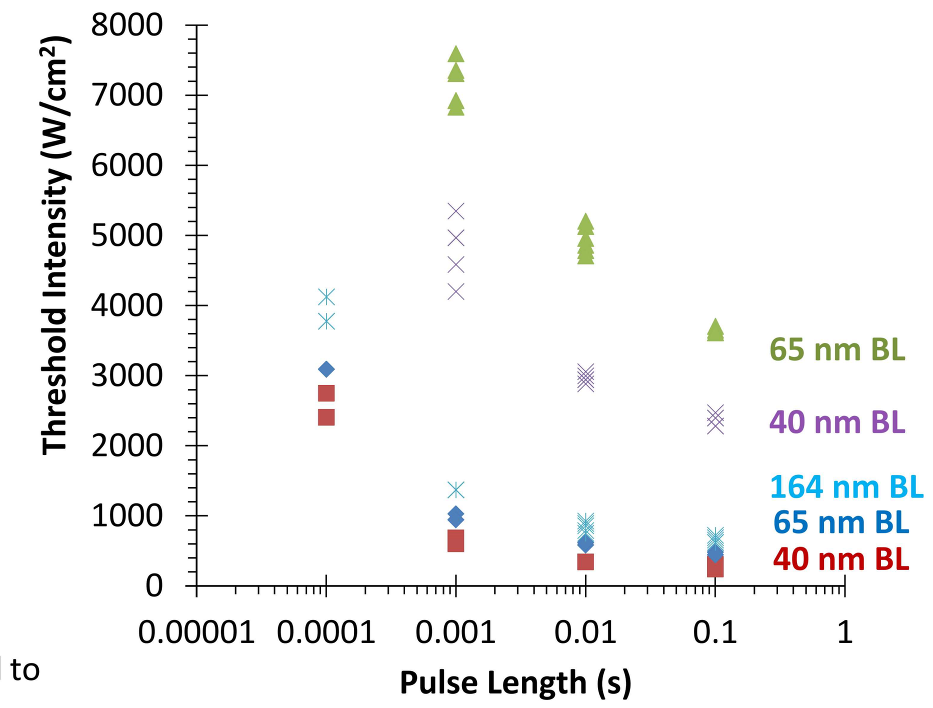


- Increasing interaction volume due to heat conduction during pulse

- At the ignition threshold for 100 µs pulses (highest intensity), Al and Pt are estimated to reach ~ 700 °C within the irradiated area.

- Diffusion length estimates for 100 µs pulses show the entire foil thickness can be heated to 700 °C in ~ 30 ns within the laser irradiated region

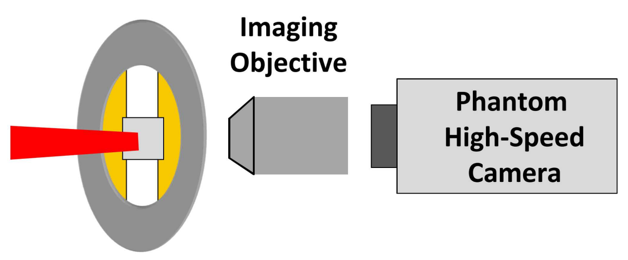
Laser Intensity Threshold

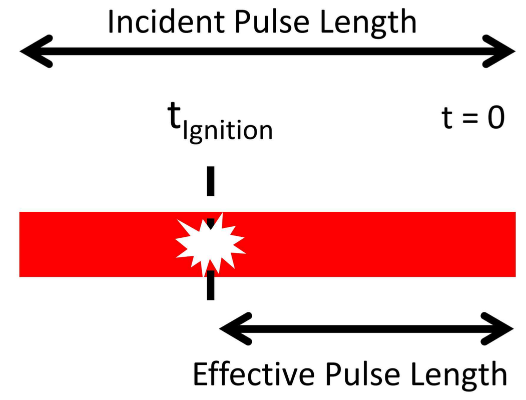


High-Speed Imaging

- Perform high-speed imaging on Al side to determine when foil ignites
- Foil often ignites before laser pulse ends
- Pulse lengths must be adjusted for laser-foil interaction time.

Imaging foil from the Al side



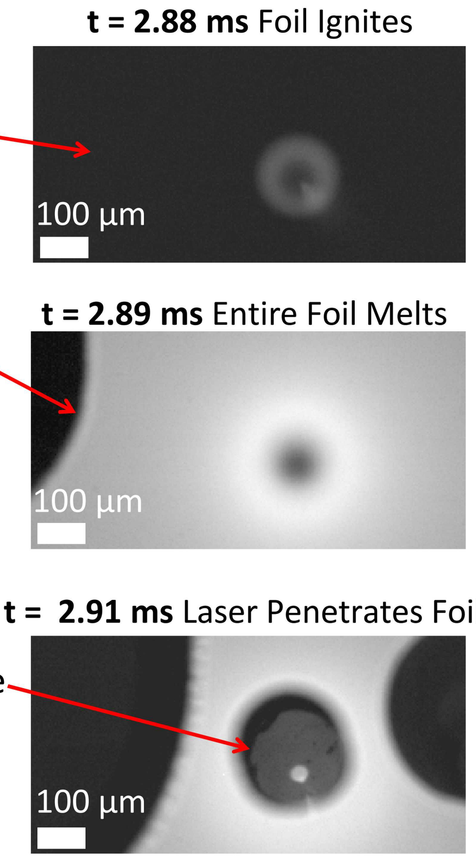


10 ms Incident Pulse
65 nm Bilayer
619 W/cm²

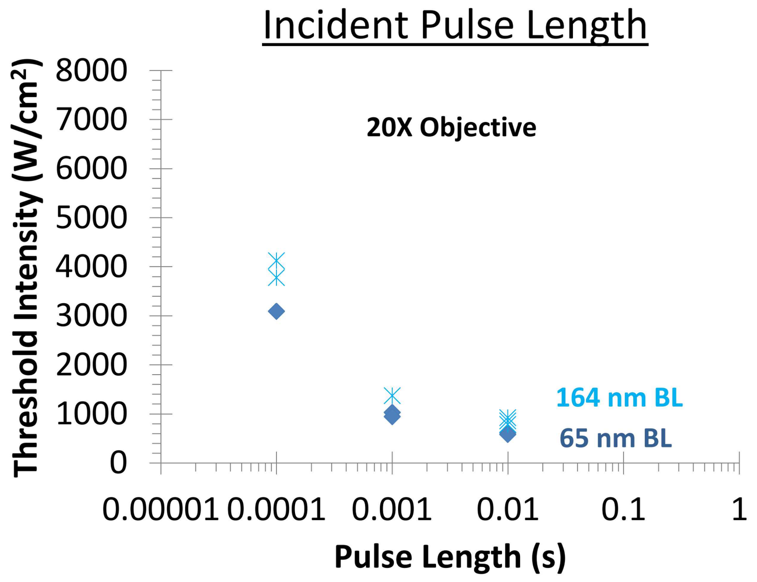
Foil dark in regions which have not ignited

Molten foil collapsing due to surface tension

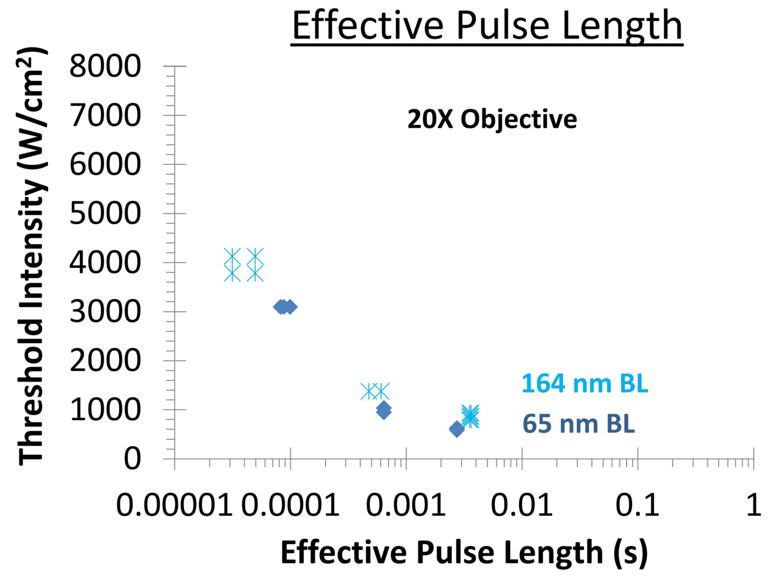
Focused laser beam visible



Incident Pulse Length



Effective Pulse Length



Conclusions and Future Work

- Reactive foils are ignited with 100 µs to 100 ms laser pulses.
- Pulse length, focused laser beam size, and bilayer thickness affect the threshold for ignition.
- Laser-foil interaction volume affects ignition threshold.
- Foils usually ignite before laser pulse ends, leading to an effective pulse length.
- Future work will involve exploring foil ignition times using ns and fs laser pulses.

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