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Near-Failure Detonation Behavior of Vapor-Deposited Hexanitrostilbene (HNS) Films

Robert Knepper, Ryan R. Wixom, Michael P. Marquez, and Alexander S. Tappan

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NNSA National Nuclear Security Administration

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Motivation

- Investigate mechanisms that cause explosives to fail at small scales
- Mechanisms that control explosive initiation and propagation typically have a strong dependence on microstructure
- Physical vapor deposition provides ability to manipulate microstructure by varying deposition conditions
- Preparation-Structure-Property relationships

Physical Vapor Deposition - HNS

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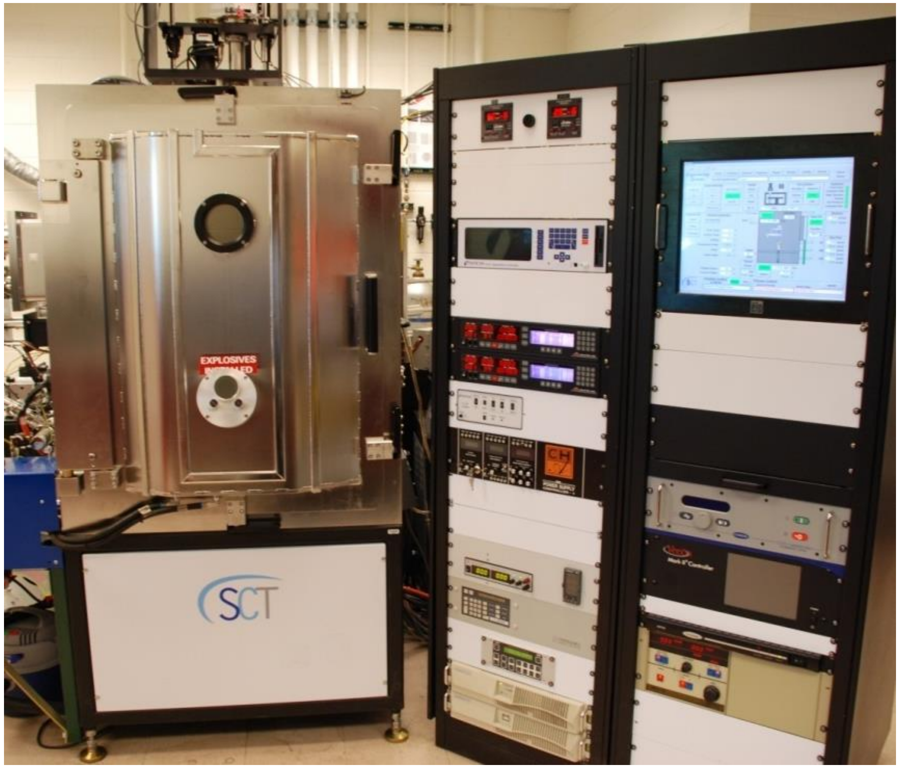
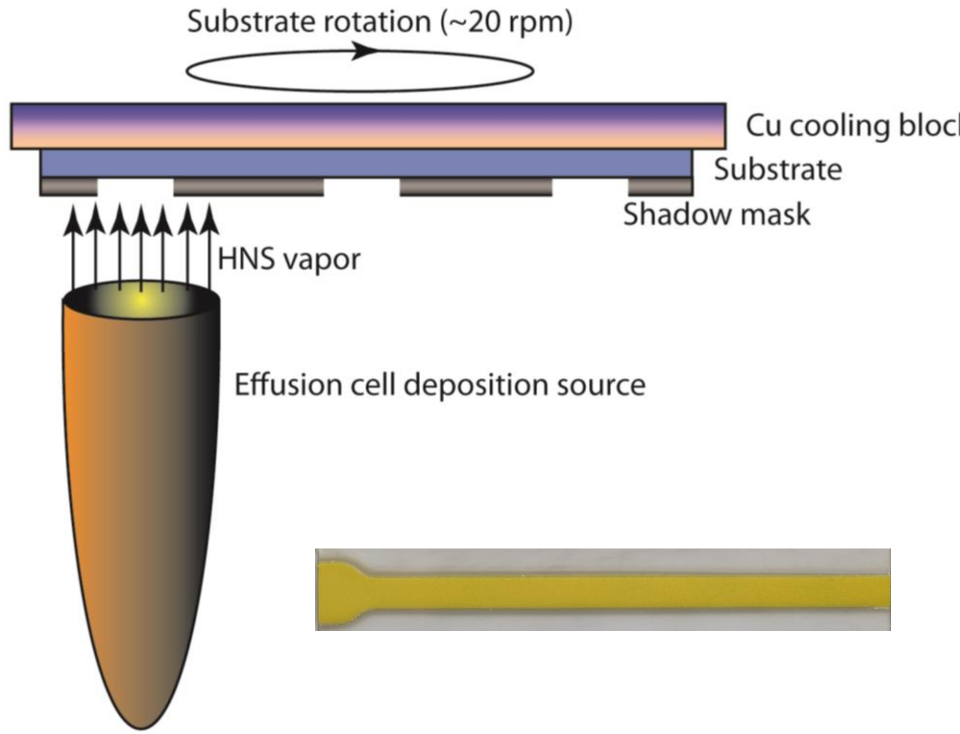
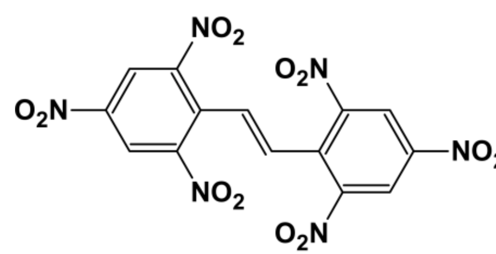


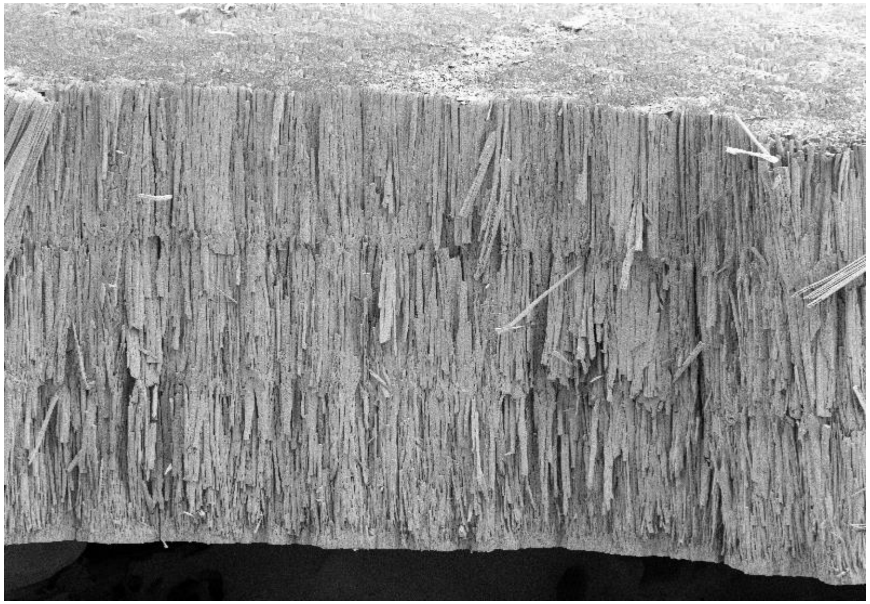


- Melting temperature: 315 ºC
- Decomposition onset: at melt or earlier
  - ⇒ Lower vapor pressures, slower deposition rates
- Maximum Deposition Rate: ~ 10-20 μm/hr

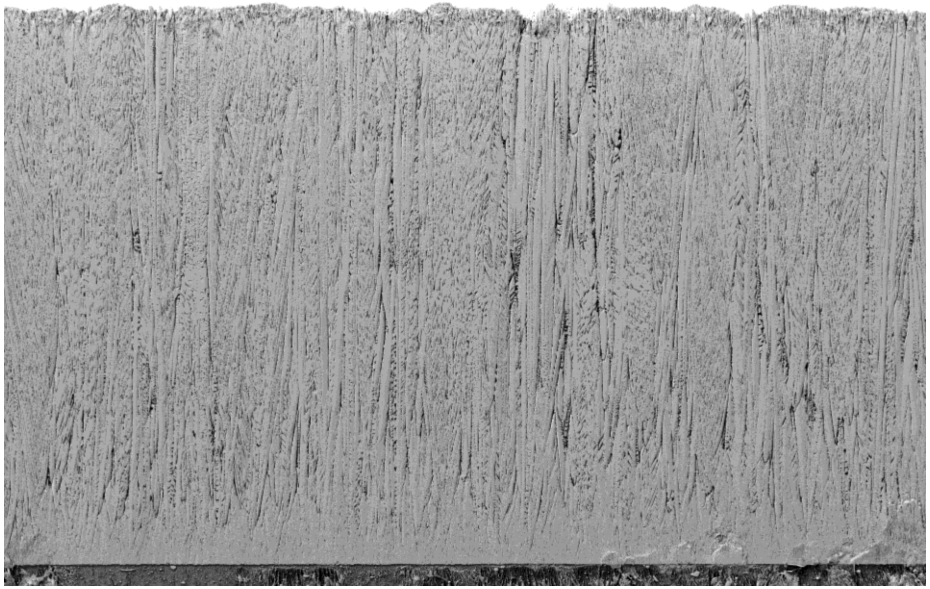


HNS

HNS Film Microstructure



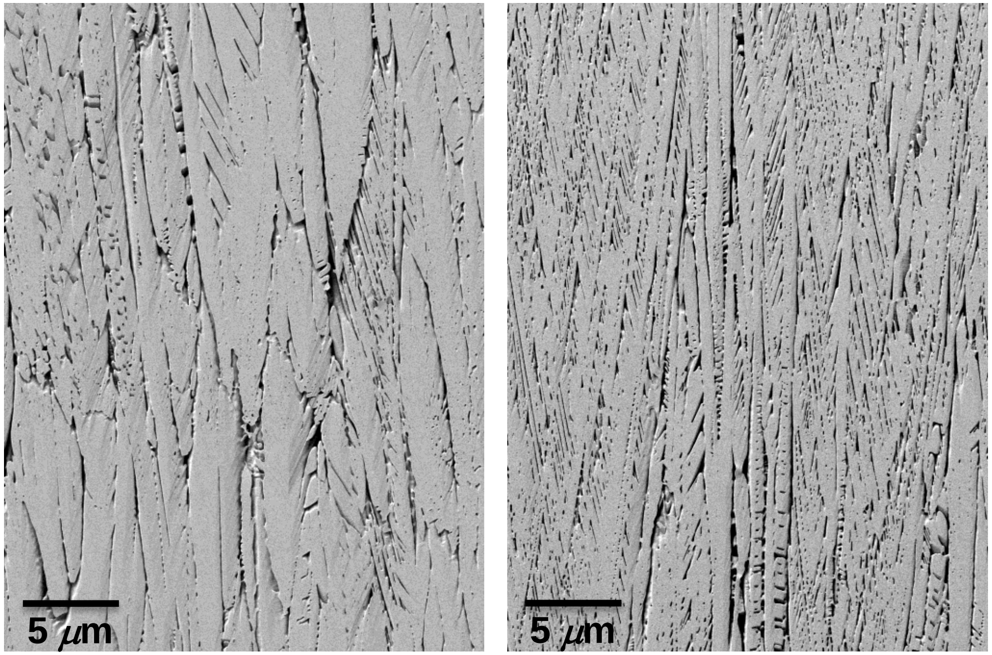
Fracture cross-section of an HNS film.



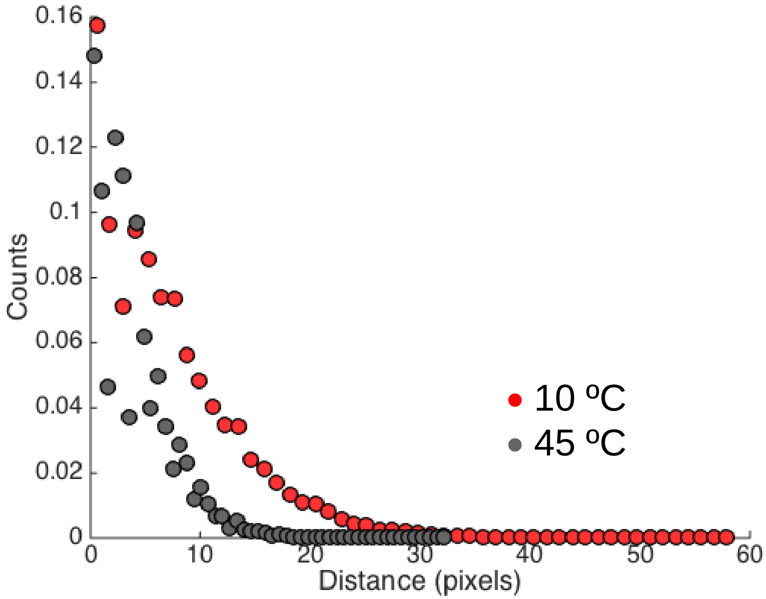
Ion-polished cross-section of an HNS film.

- Vapor-deposited HNS exhibits a columnar microstructure oriented perpendicular to the substrate with column widths on the order of 1 μm
- Density and porosity distribution are dependent on deposition conditions

HNS Film Microstructure



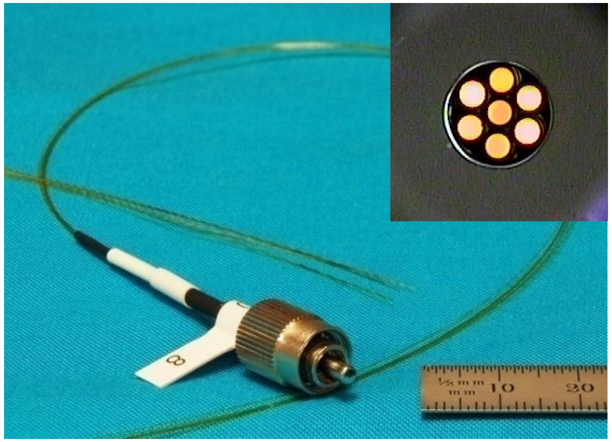
Ion-polished cross-sections of HNS films deposited at 10 ºC (left) and 45 ºC (right). Each image is 25 μm across.



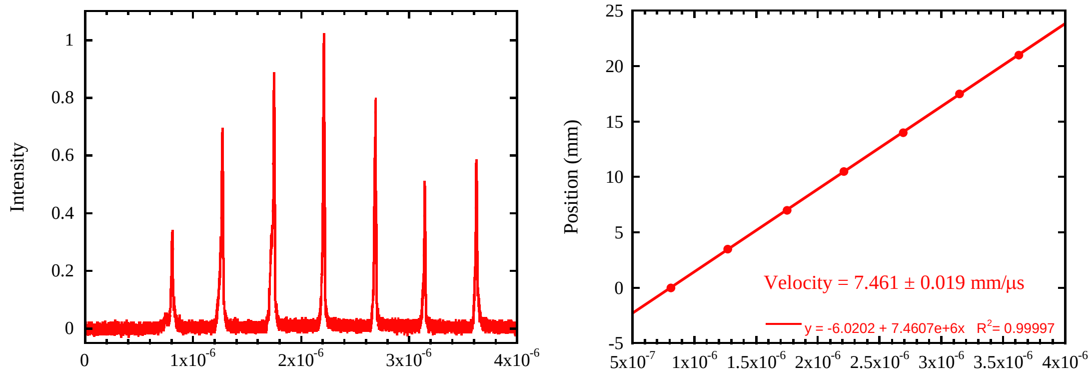
Histogram of a Euclidean distance map indicating distances from any pixel to a pore in HNS films deposited at 10 ºC and 45 ºC.

- 2-D sections indicate that average film density decreases with increasing substrate temperature from ~ 91 %TMD at 10 ºC to ~ 86 %TMD at 45 ºC
  - ⇒ Getting new FIB capability online to better quantify 3-D porosity distribution and density
- Spacing between pores decreases as substrate temperature increases

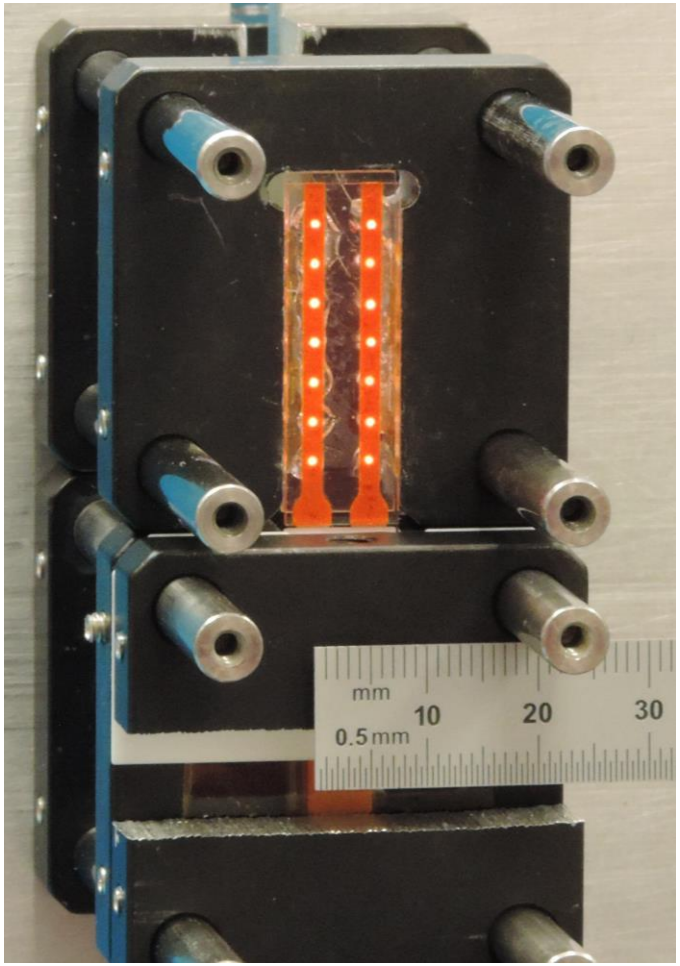
Thin Film Detonation Experiments



Photograph of an optical fiber probe with inset showing a six-around-one connector.

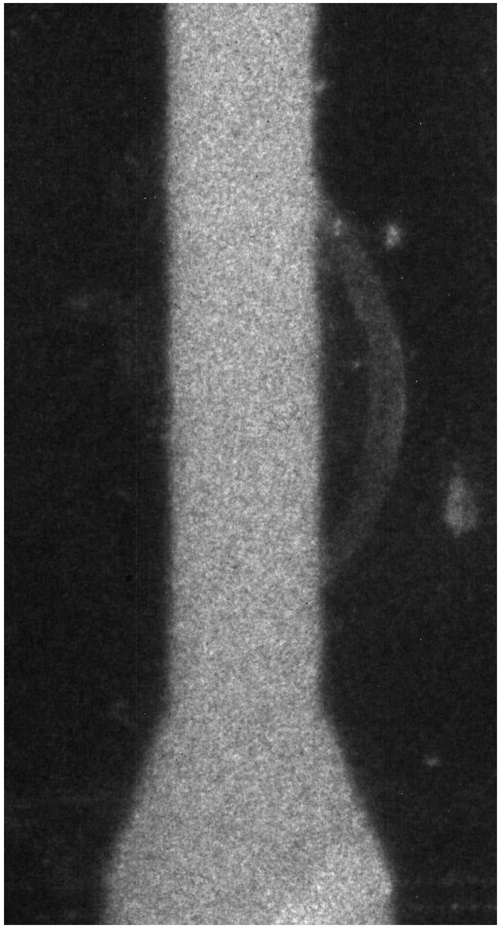


Example oscilloscope data and resultant position vs. time plot used to determine detonation velocity.



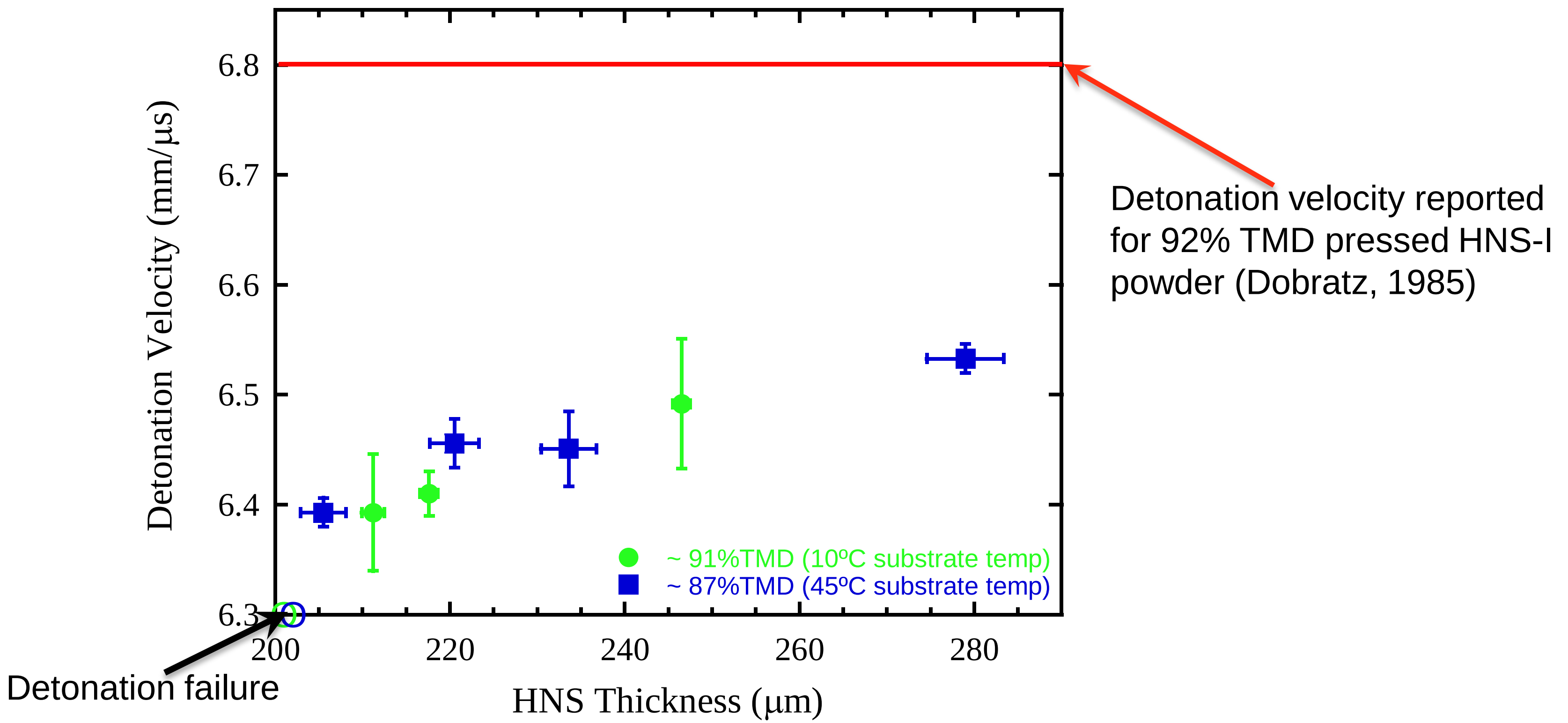
Photograph of an optical fiber probe lid on a deposited explosive film. Fibers are illuminated to show their locations.

HNS Critical Thickness Experiments



Framing camera image of a 1.6 mm wide HNS line (left) and a video (15 ns exposure, 135 ns interframe time) showing detonation propagation (right).

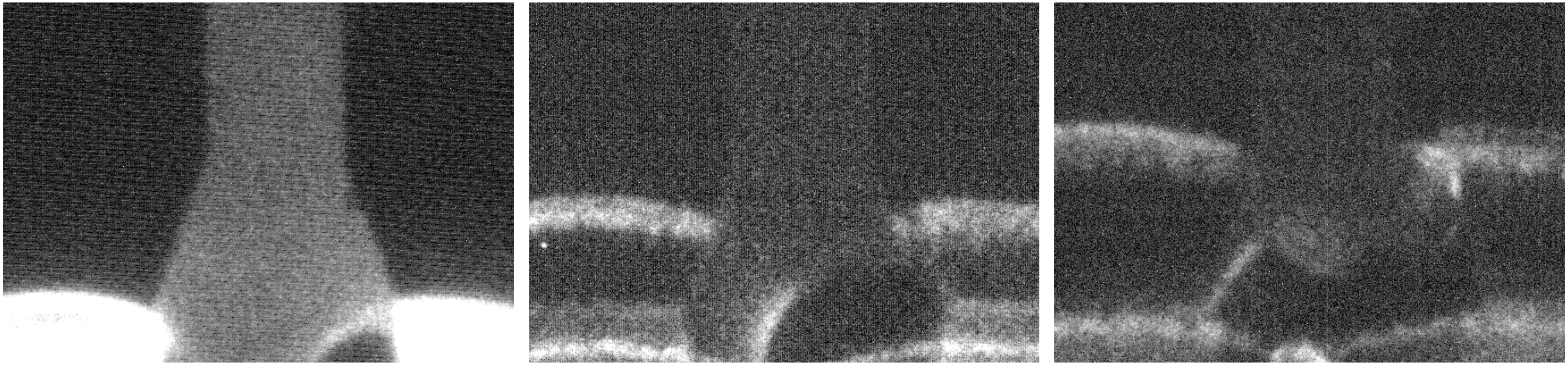
HNS Critical Thickness Experiments



Detonation velocity vs. thickness for HNS films deposited with different substrate temperatures.

- Detonation does not propagate in HNS films thinner than ~ 200 μm
- Low detonation velocities compared to pressed powders at similar densities
  - ⇒ Suggests that these tests are in the "velocity deficit" region of the critical thickness curve
- Despite differences in density, similar detonation velocities and failure thicknesses are observed for the two different microstructures

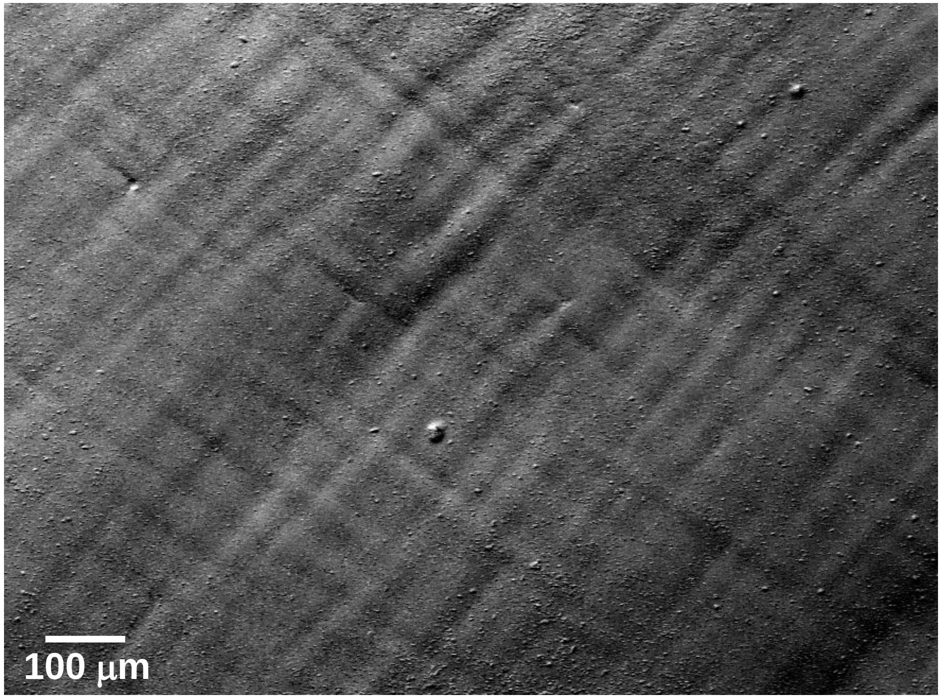
HNS Corner Turning



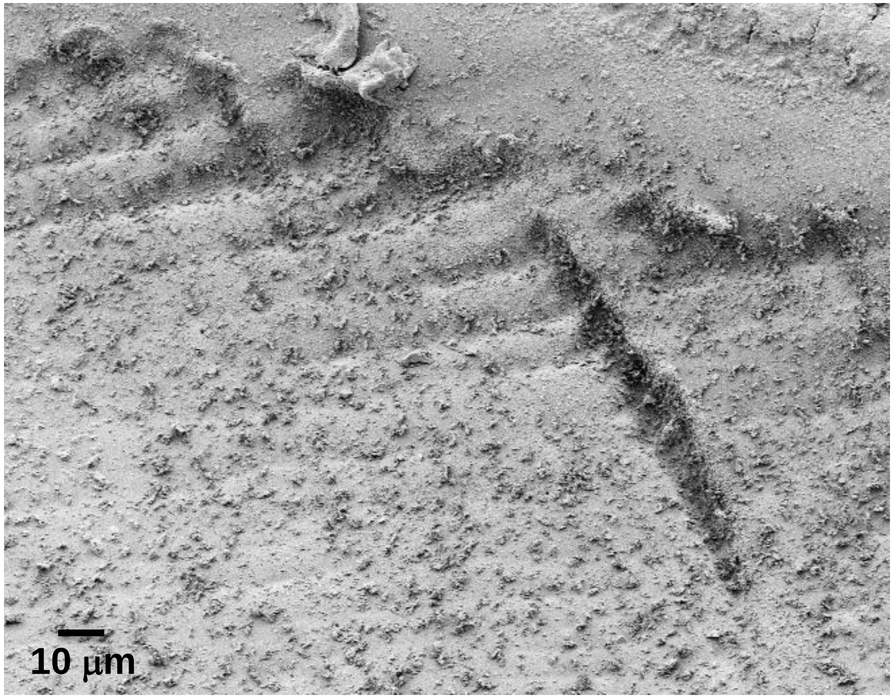
Framing camera images (15 ns exposure, 165 ns interframe time) from an HNS critical thickness test that did not ignite properly. The detonation front's failure to propagate along the length of the line demonstrates the poor corner-turning ability of HNS.

- Early experiments were ignited from the edges of the pad at the end of the HNS line; occasionally detonation only initiated on one side of the pad
  - ⇒ Likely due to contact issues between PETN initiation increment and the HNS pad
- When ignited from only one side, the detonation front was unable to turn the corner and propagate along the length of the line.
  - ⇒ Prompted a redesign of the initiation geometry

Near-Threshold Detonation Instabilities



Dent track from a near-failure HNS detonation experiment showing cross-hatching patterns throughout the track.



Dent track from a near-failure HNAB detonation experiment showing cross-hatch patterns only near the edge of the dent.

- Dent tracks in the polycarbonate substrates record instabilities in the detonation front at near-failure conditions
- “Cell size” in dent tracks from HNS films is several times larger than seen in similar experiments with HNAB films

Conclusions

- Altering substrate temperature during deposition changes resultant density and porosity distribution in the film
  - $\Rightarrow$ Lower film density and smaller average spacing between pores with increasing substrate temperature
- Detonation fails to propagate in HNS films thinner than ~ 200 μm
- Detonation velocities and failure thicknesses are similar in these HNS films, despite the differences in microstructure
- Cross-hatch patterns in dent tracks indicate instabilities in detonation front at near failure conditions

Acknowledgements

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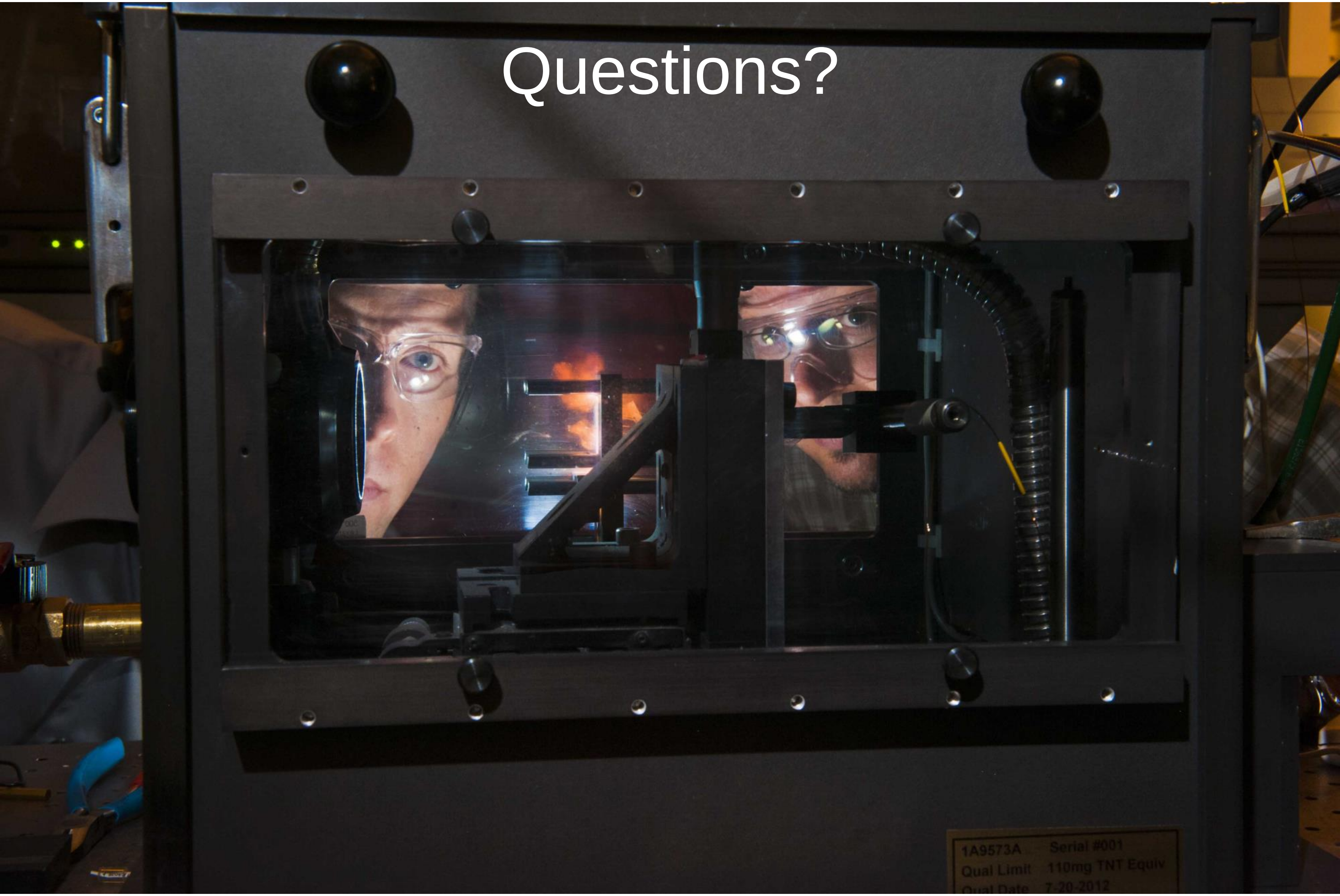
M. Barry Ritchey

Questions?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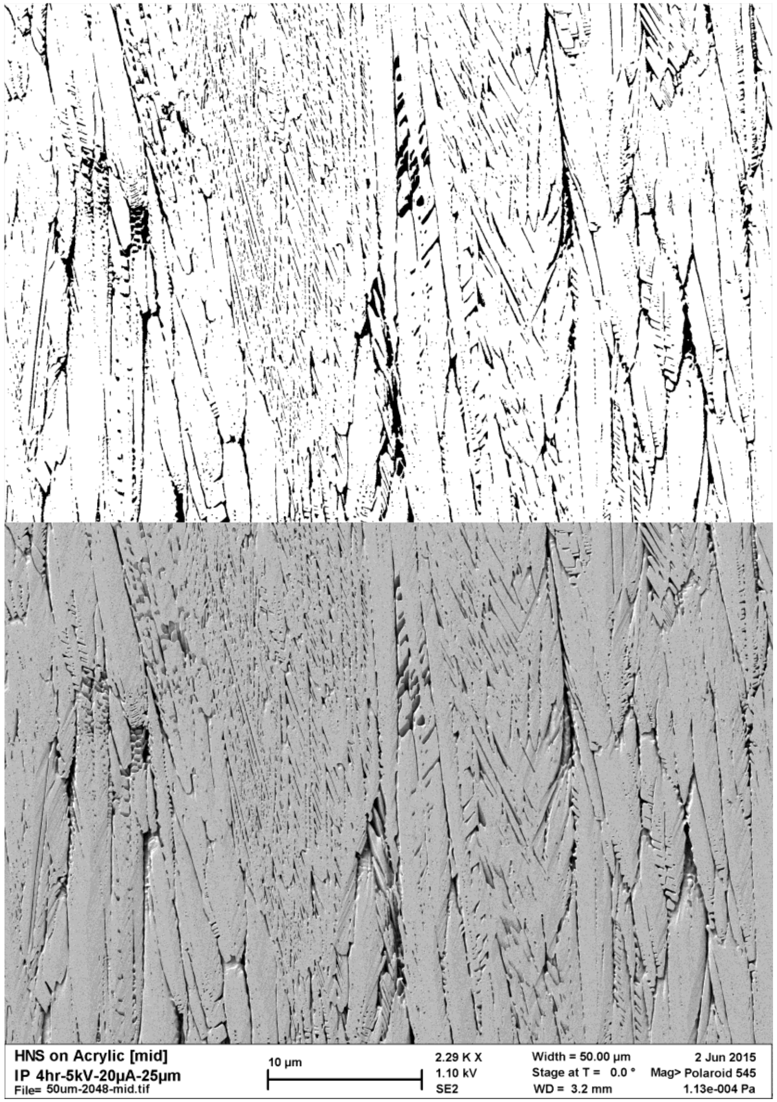
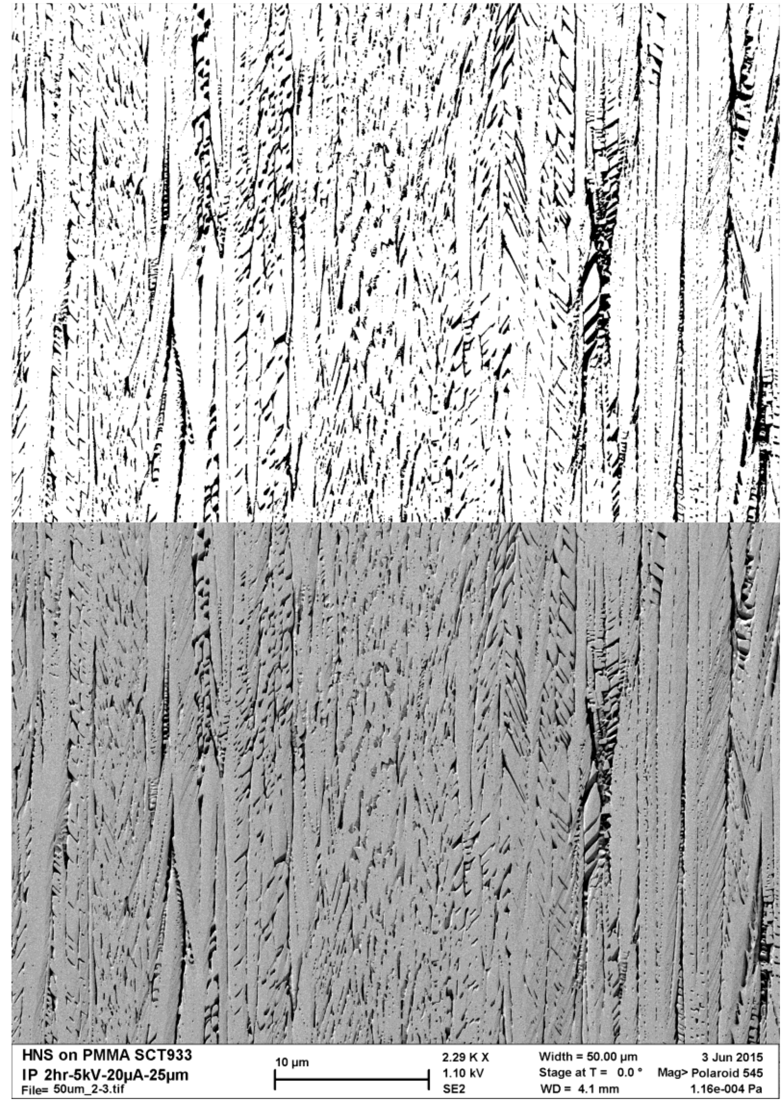
Backup Slides

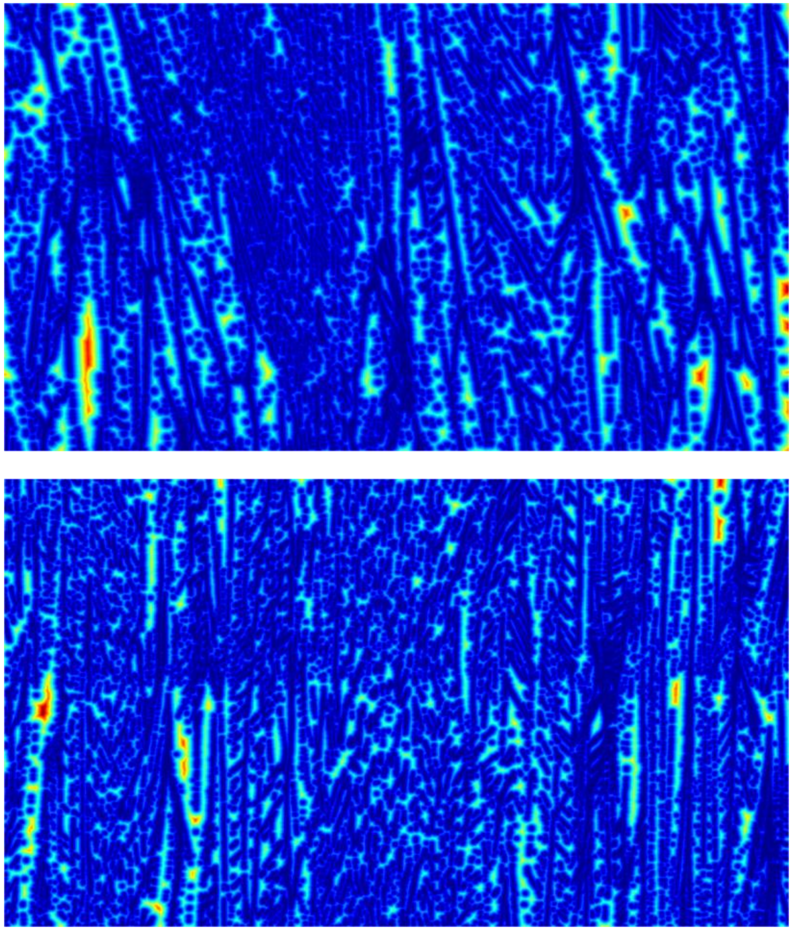
Thresholding SEM Cross-sections



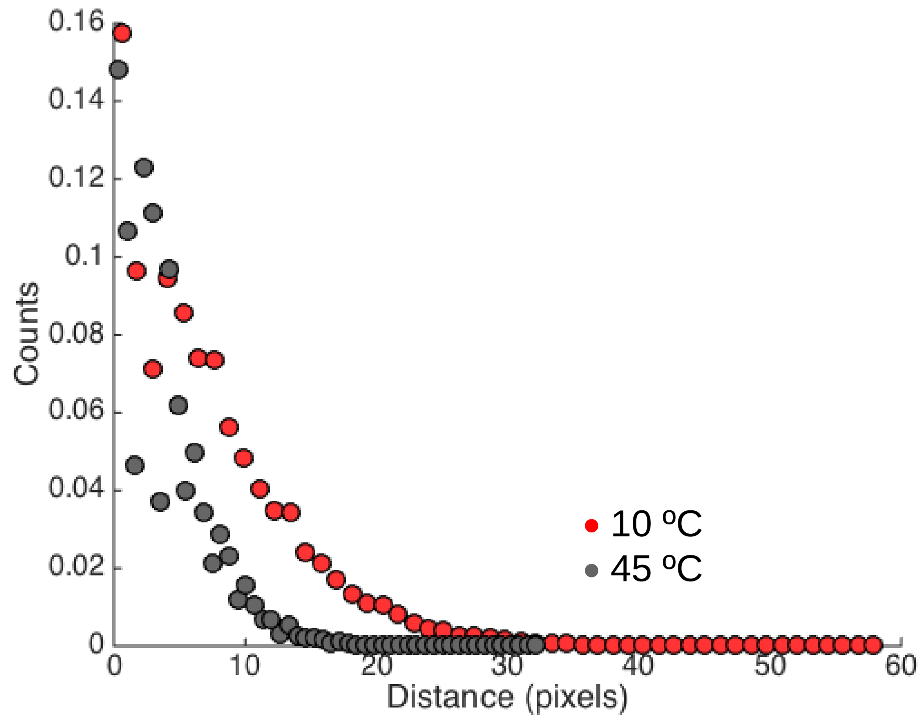


Raw and binarized SEM images of HNS films deposited at 10 ºC (left) and 45 ºC (right)

Euclidean Distance Maps



Euclidean distance maps depicting the distance from any given pixel to the nearest pore for HNS films deposited at 10 ºC (top) and 45 ºC (bottom).



Histogram showing distributions of the distances depicted in the Euclidean maps. Note that the higher counts at larger distances for films deposited at 10 ºC indicates a larger average spacing between pores.