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Effects of Confinement on Detonation Behavior of Vapor-Deposited Hexanitroazobenzene Films

Robert Knepper, Michael P. Marquez, and Alexander S. Tappan

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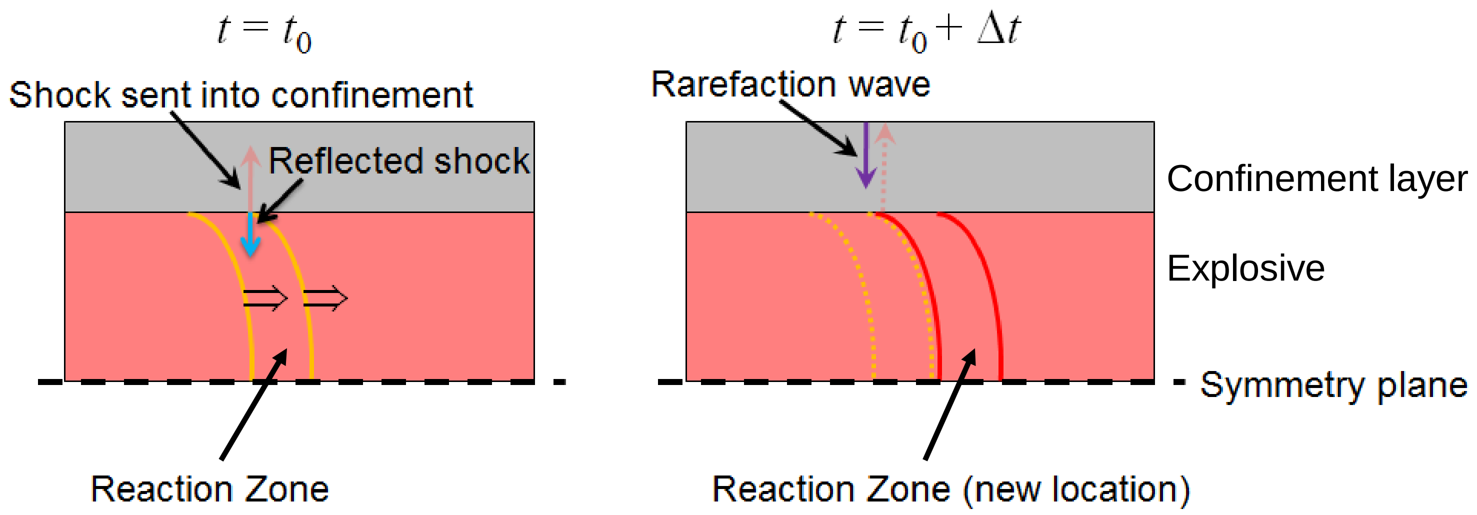
Overview

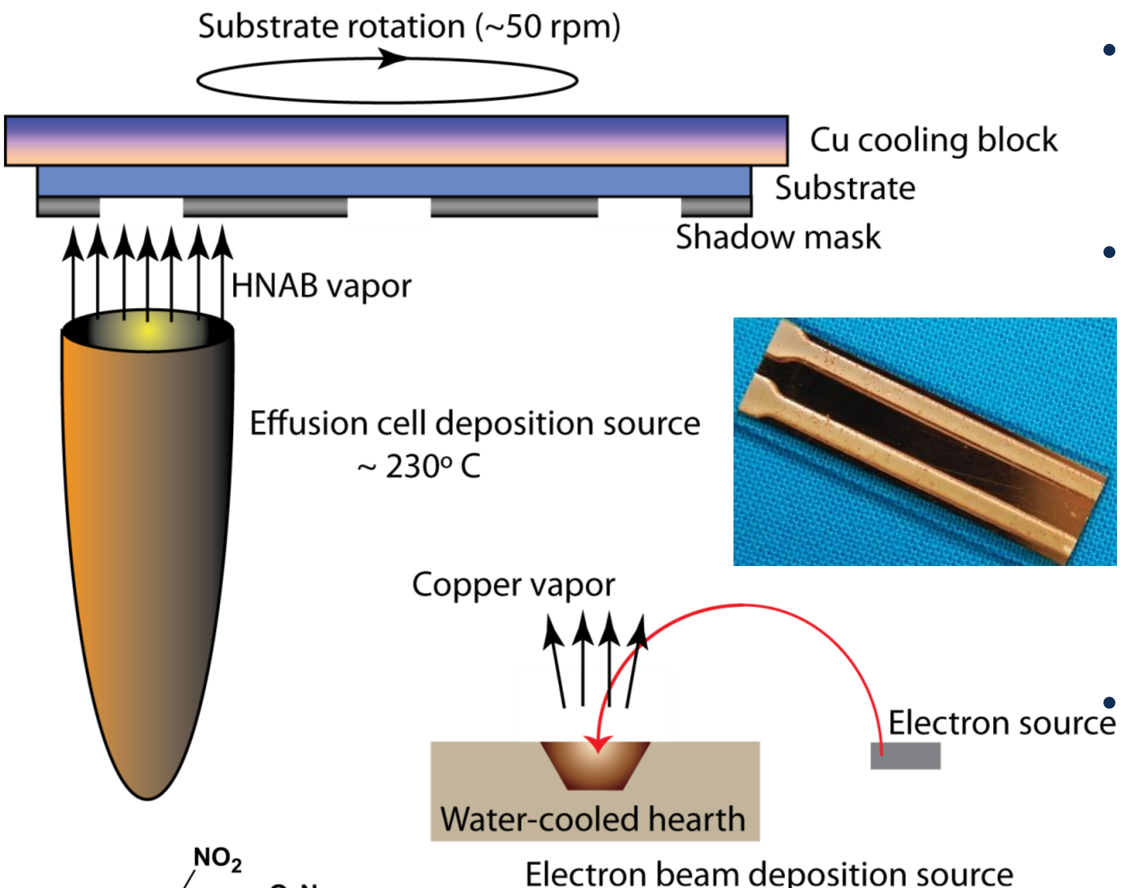
- Effects of confinement
- Physical vapor deposition
  - Microstructure of HNAB films
- Critical thickness detonation experiments
- Near-threshold anomalies
- Conclusions

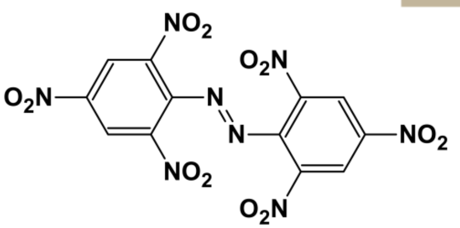
Effects of Confinement



- Confining an explosive with a dense inert material is known to affect detonation velocity and failure thickness due to increased pressures in the reaction zone
- The amount of confinement needed and the magnitude of its effect are largely unknown
- We have performed experiments to determine minimum thickness of confinement necessary to behave as though it was effectively infinite
- These data can also provide information about reaction kinetics in explosives

Physical Vapor Deposition

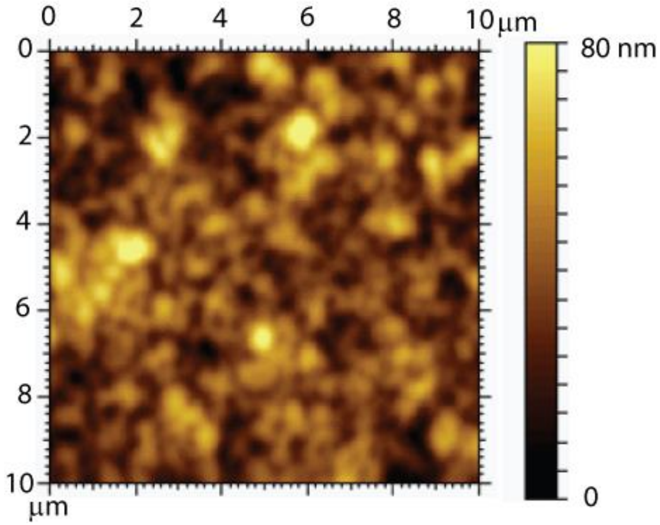




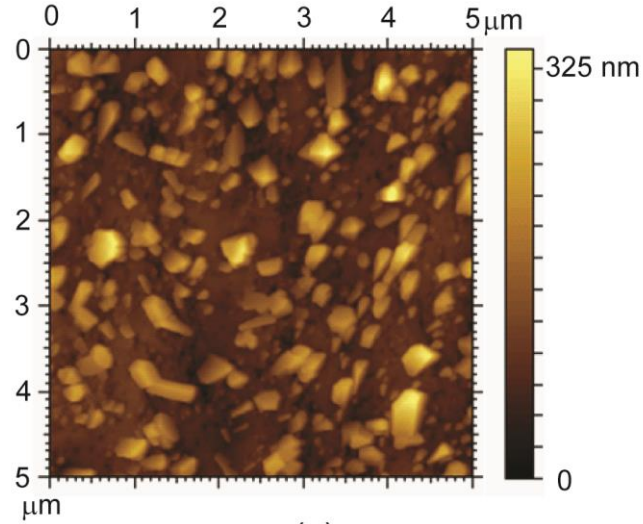
HNAB

- Use physical vapor deposition to fabricate both explosive and confinement layers
- Use HNAB and copper as a model system
  - HNAB – dense, small critical thickness, very low roughness promotes pristine interface between explosive and confinement
  - Copper – fairly high shock impedance, deposition does not decompose HNAB
- Experiments required use of thin chromium adhesion layers (few tens of nm)
  - Copper delaminated without adhesion layers
  - Chromium has a very similar shock impedance to copper, so expected to have little effect on experiments

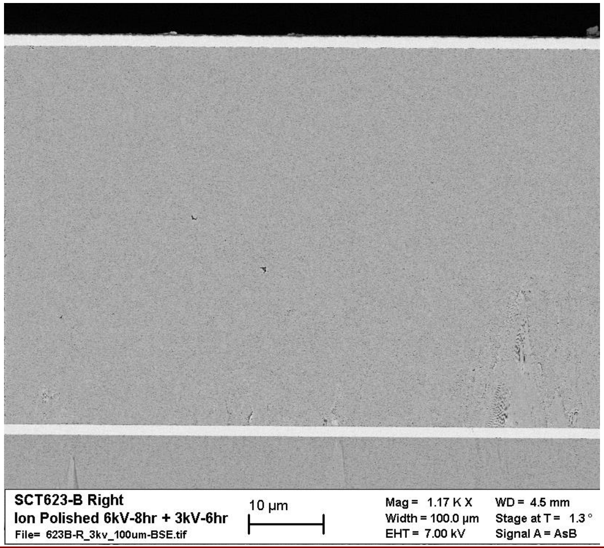
Microstructure of HNAB films



AFM image of an as-deposited amorphous HNAB film.

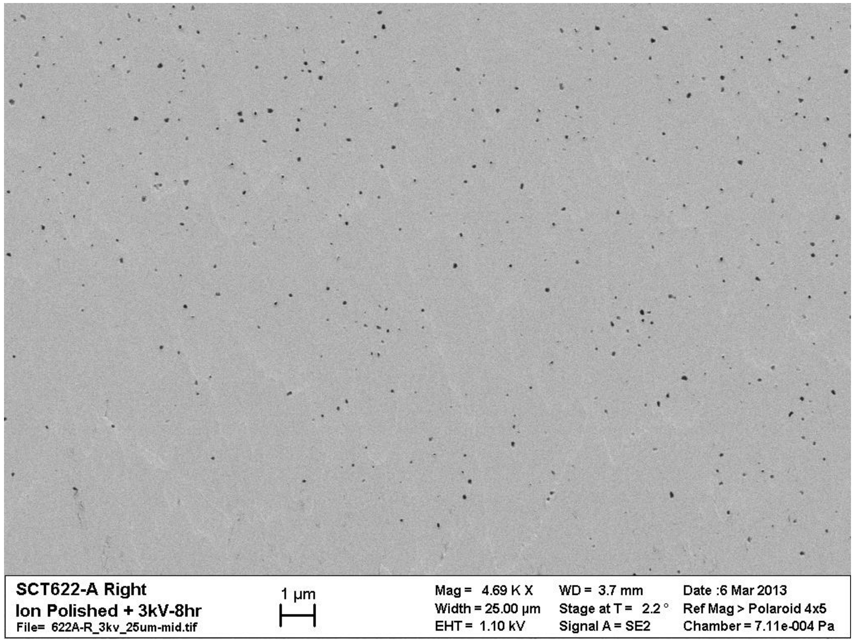


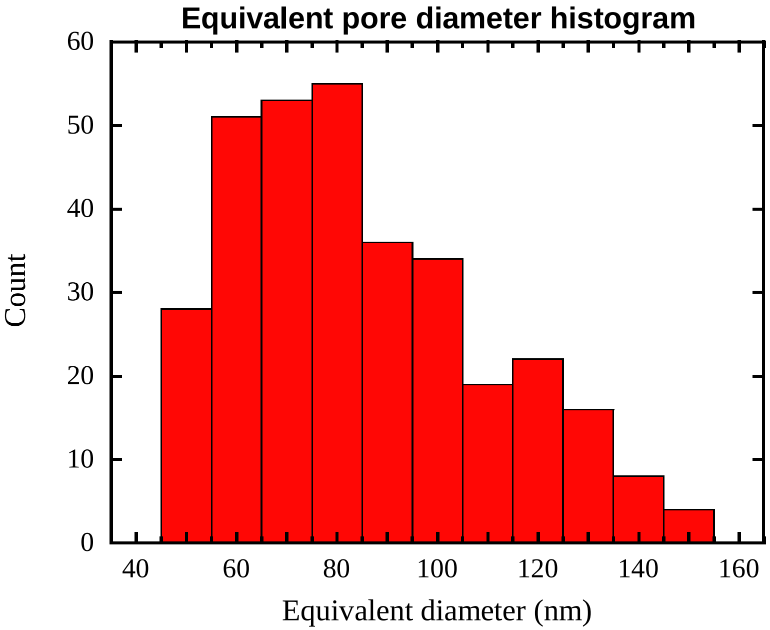
AFM image following crystallization at RT and an SEM image of a Cu/HNAB/Cu stack.



- HNAB deposits in a dense amorphous structure which crystallizes over several weeks at RT
- Surface roughness increases from ~15 nm to 50 nm during crystallization
- Grain size after crystallization ~200 nm
- Low surface roughness promotes pristine interface between HNAB and copper confinement

Microstructure Analysis

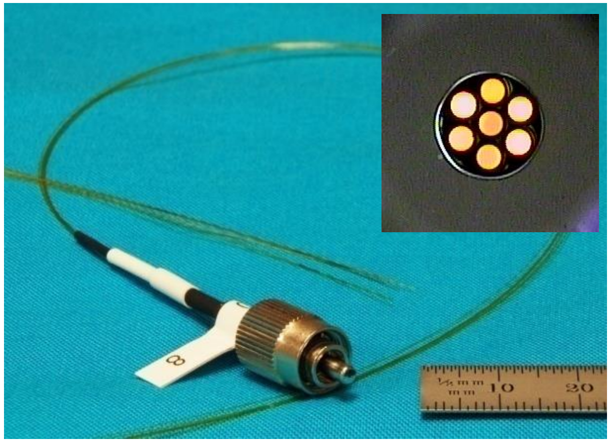




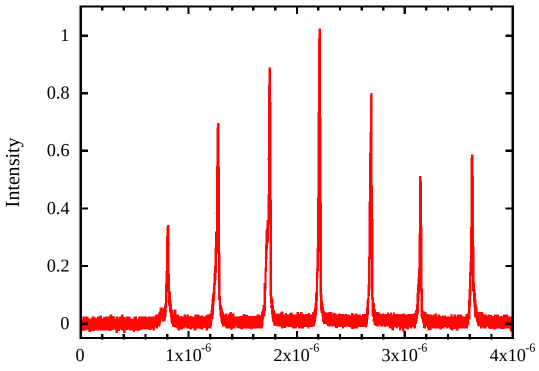
Ion-polished cross-section SEM image of an HNAB film crystallized at room temperature and the corresponding distribution of pore sizes.

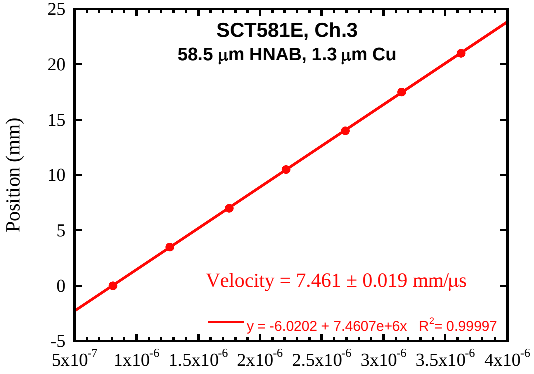
- Following crystallization at RT, HNAB films are very dense (> 99% TMD) with only a sparse array of small pores [analyzed using methods described by *Wixom et al. 2010*]
- See Tappan *et al.* – this session, 11:00 AM for more on HNAB microstructure!

Thin Film Detonation Experiments

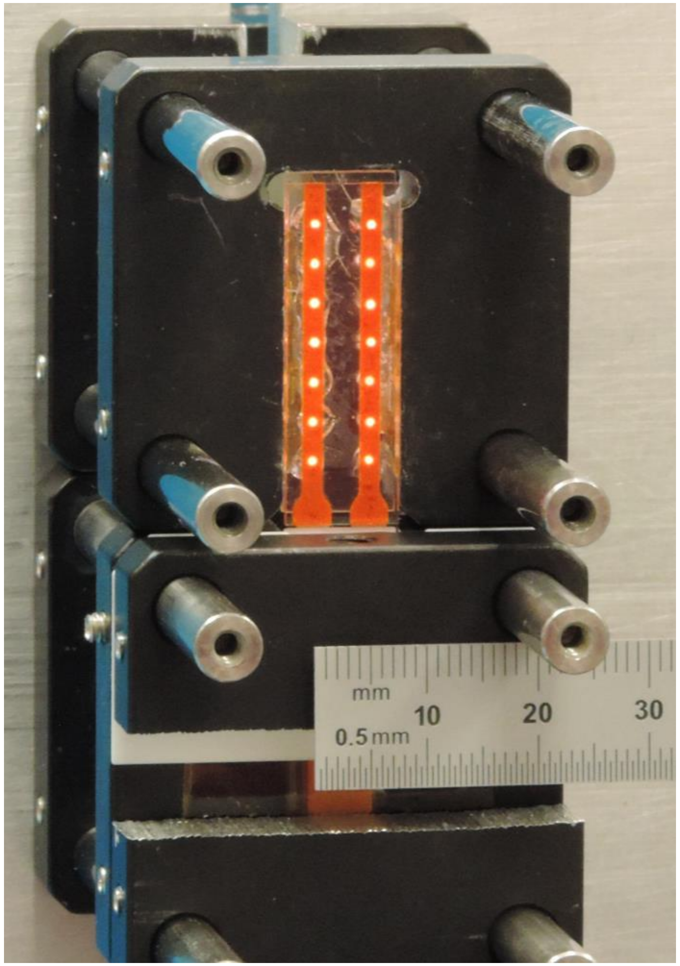


Photograph of optical fiber probe with inset showing six-around-one connector.



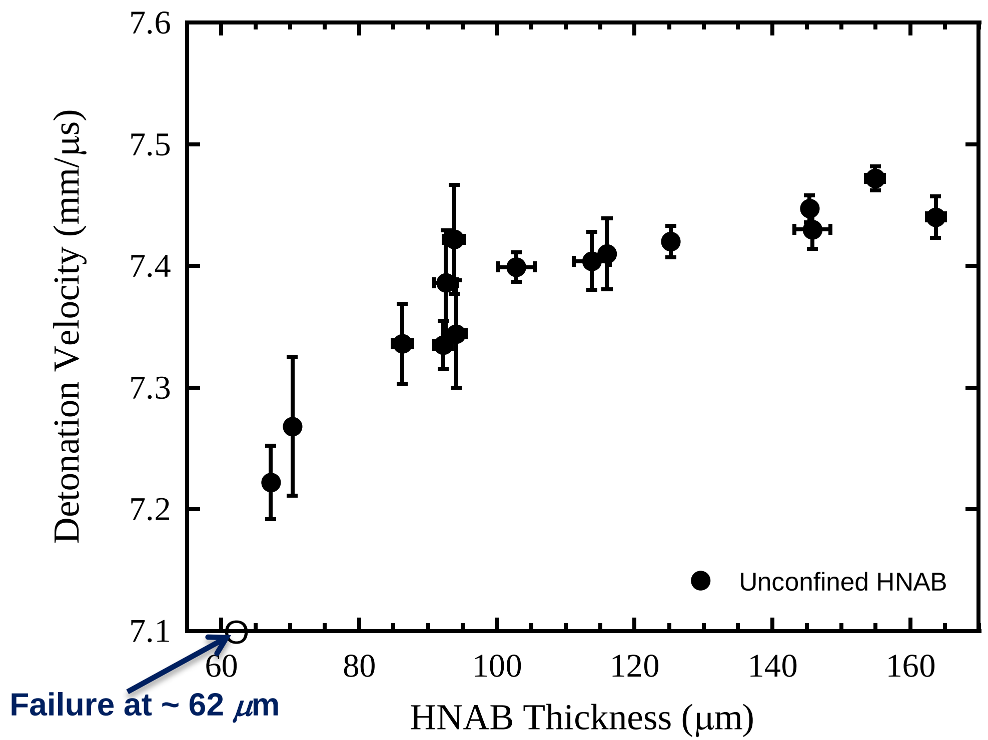


Sample oscilloscope data and resultant position vs. time plot to determine detonation velocity.



Photograph of optical fiber probe lid on deposited HNAB. Optical fibers illuminated to show position.

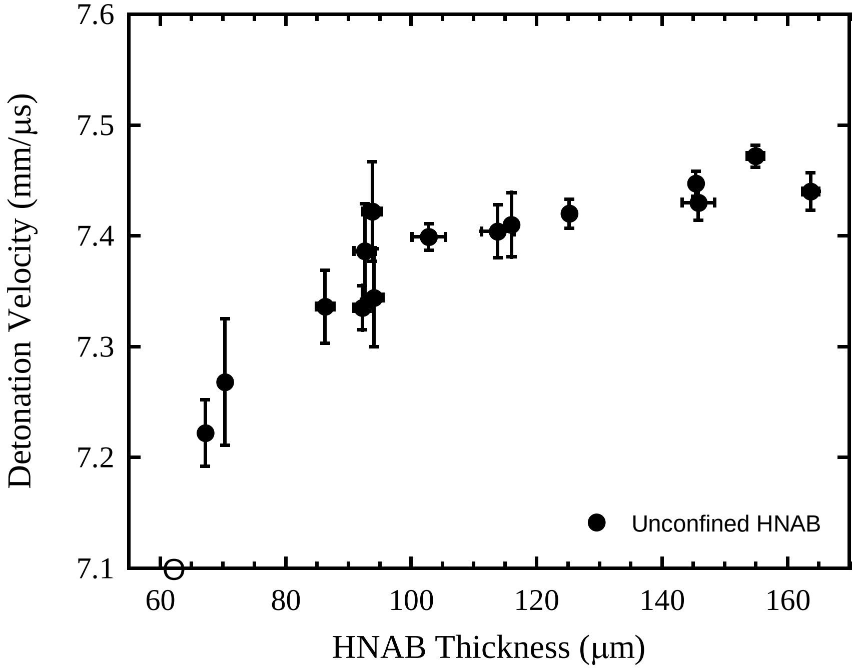
Unconfined HNAB Films



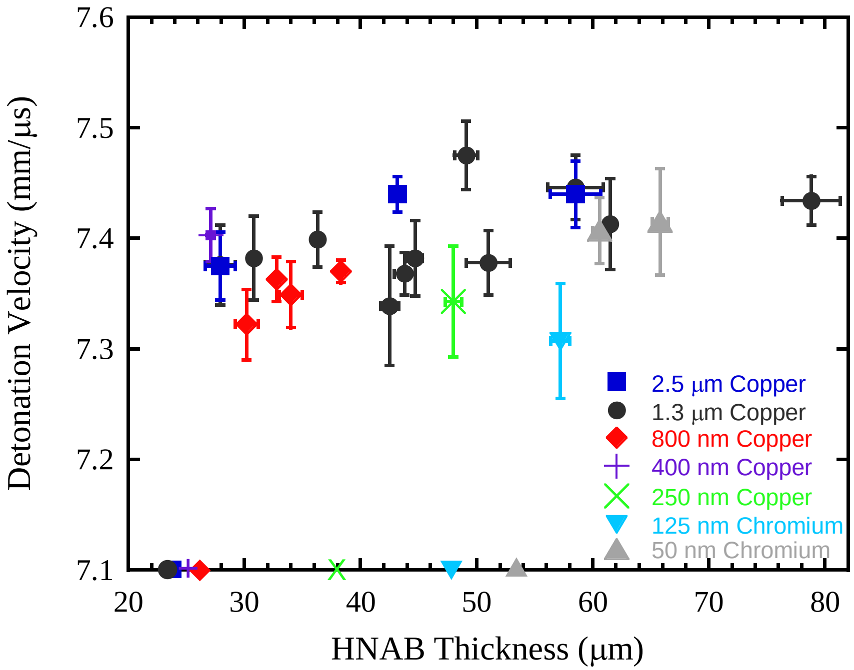
Detonation velocity vs. thickness for unconfined HNAB films.

- HNAB films are able to propagate a detonation at thicknesses greater than 65 μm
- Small change in detonation velocity when approaching failure thickness
- Detonation only observed in films consisting primarily of the HNAB-II structure

Effects of Confinement on HNAB Failure Thickness



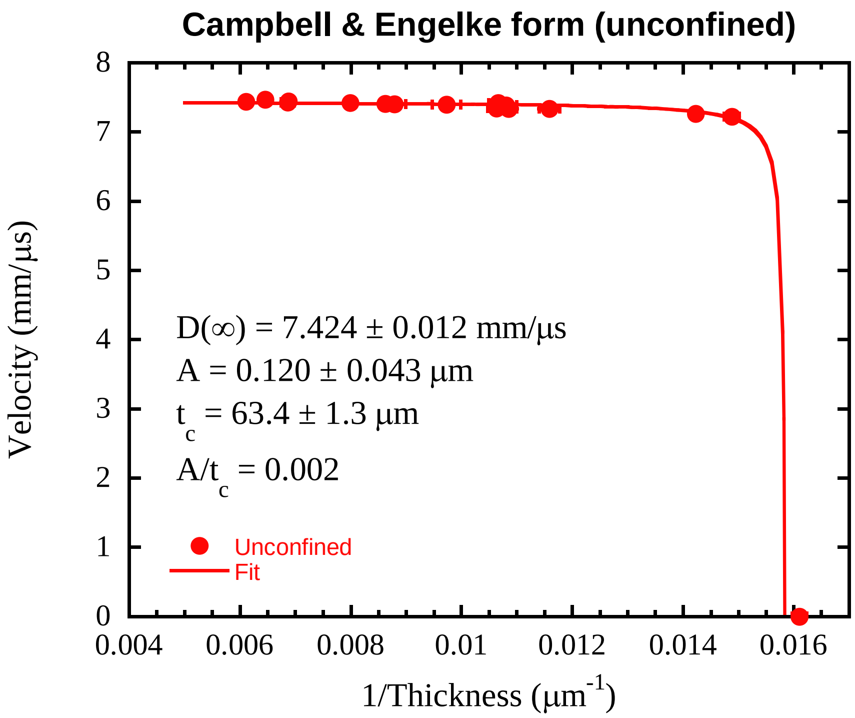
Detonation velocity vs. explosive thickness for unconfined HNAB films.

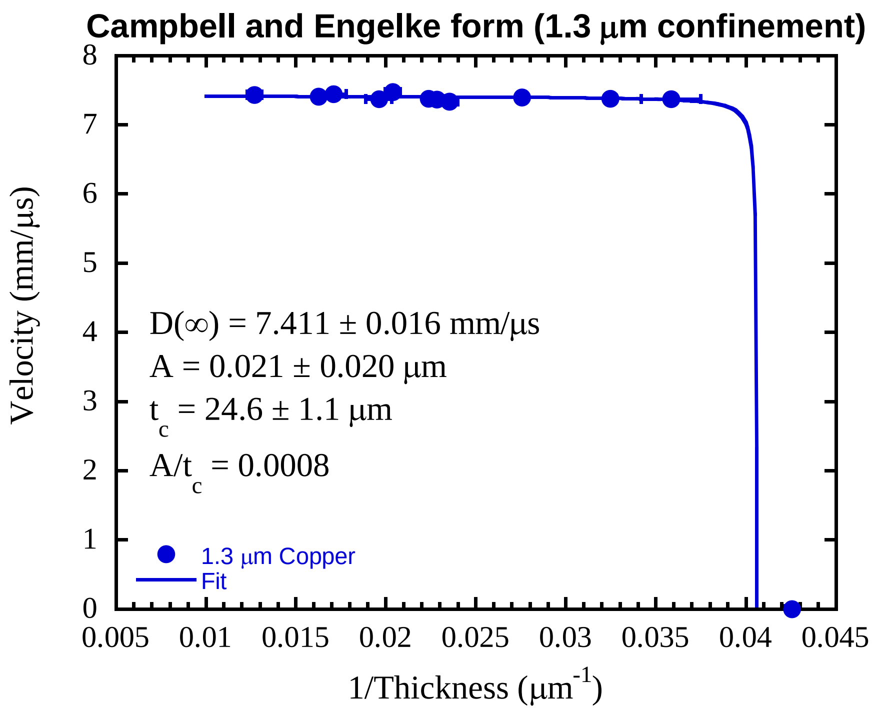


Detonation velocity vs. explosive thickness for copper confined HNAB films.

- Copper confinement decreases failure thickness from ~ 65 to 27 μm
- No difference in failure thickness observed for films with between 400 nm and 2.5 μm confinement
- Failure thickness increases significantly as confinement decreases below 400 nm
- Suggests that relevant reactions complete in less than 200 ps, reaction zone ~ 1 μm

Critical Thickness Curve Fits





- Fit to Campbell and Engelke (1976) form: $D(t) = D_\infty\left[1 - \frac{A}{t - t_c}\right]$
- Petel *et al.* (2007): *thickness* (slab) ~ *radius* (cylinder)
- t_c = critical thickness
- A = length parameter – A/t_c = measure of how quickly velocity drops off (~ 1 for many cast/pressed explosives)

Near-Threshold Detonation Anomalies

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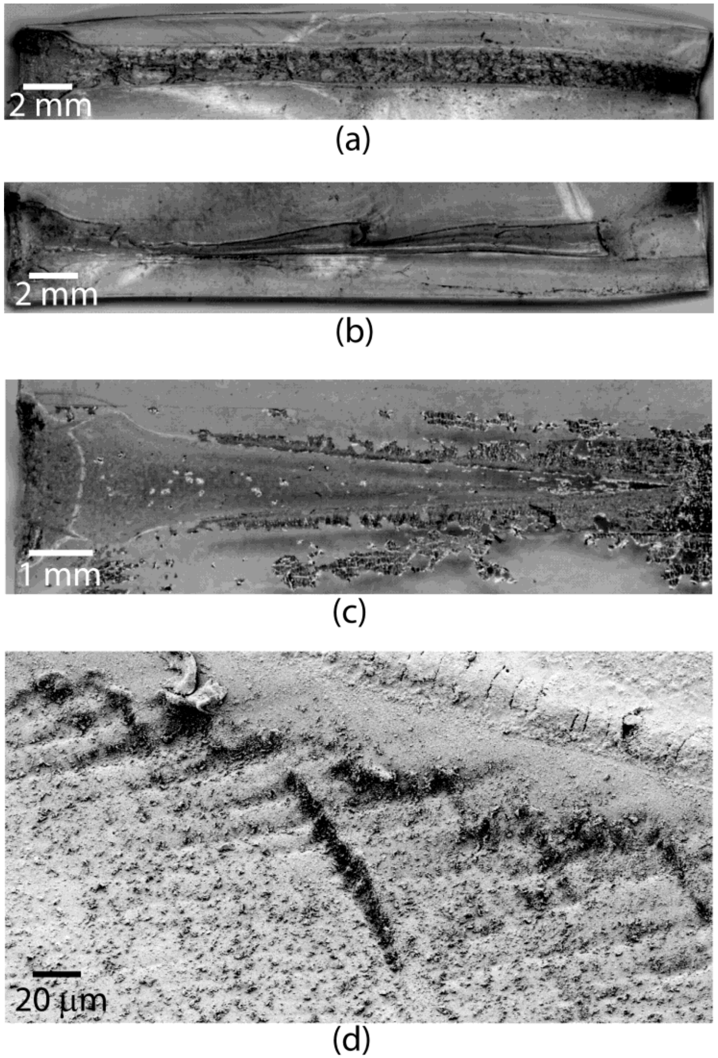

Dent tracks in polycarbonate substrates following detonation tests in HNAB films.

(a) Normal detonation dent track

(b) Partial failures occurring at defects at thicknesses slightly above t_f

(c) Detonation failure (tunneling) below t_f

(d) Cross-hatch pattern seen in dent tracks of most films in vicinity of t_f – indicates instabilities in detonation front

Conclusions

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- HNAB films form a dense amorphous structure when vapor-deposited that crystallizes over a period of several weeks at room temperature
  - ⇒ Creates a low-roughness surface that promotes pristine interfaces with confinement layers

- Adding small amounts of copper confinement decreases the failure thickness of HNAB films from ~ 65 to 27 μm, but does not affect detonation velocity of larger samples

- No difference in t_f observed with confinement thicknesses varying from 2.5 μm to 400 nm − t_f increases when confinement is thinner
  - ⇒ Suggests that relevant reactions complete in less than 200 ps and that reaction zone length ~ 1 μm

- Anomalous detonation behavior (tunneling, cross-hatch patterns) indicates instabilities in detonation front near failure conditions

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Questions?


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